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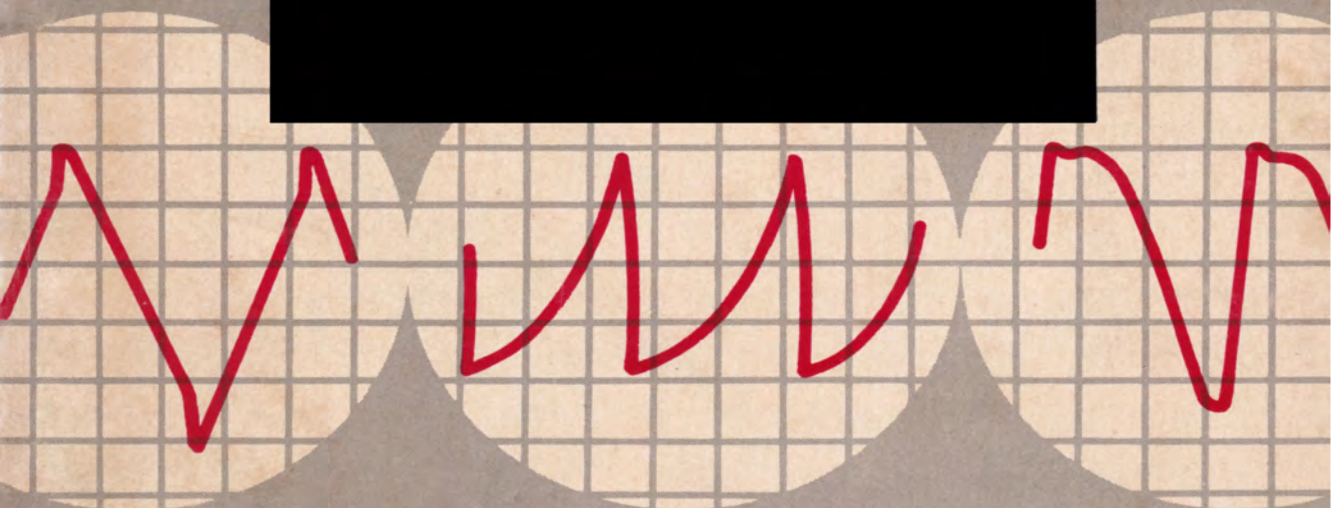
by ROBERT G. MIDDLETON



How to obtain and interpret oscilloscope waveforms encountered in all types of electronic equipment.

SCOPE WAVEFORM analysis

by ROBERT G. MIDDLETON

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SCOPE WAVEFORM ANALYSIS

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Preface

Whenever you use an oscilloscope you must be able to analyze and interpret the waveform patterns; otherwise, observations provide no information. If you are adept at pattern analysis, a scope provides much more data than any other basic electronic instrument. In the simplest cases, analysis consists merely of noting the pattern amplitude. Usually, you will be concerned with the waveshape, which may be as uncomplicated as an ideal sine or square wave. When accompanied by some type of distortion (for example, a sine wave might be clipped) it may be mixed with identifiable interference; it may display a parasitic "bulge"; it may show the effects of crossover distortion; or its contour may differ slightly from the ideal.

A square wave might display overshoot, perhaps accompanied by ringing; the top may be tilted, curved, or both; corners might be rounded; an interval of parasitic oscillation may be observed; the rise time of the square wave might be slow; the wave may be mixed with hum voltage or other spurious interference; or a reproduced square wave might be distorted due to circuit nonlinearity. Circuit response at one square-wave repetition rate is usually different from its response at some other repetition rate.

There is a vital consideration behind all waveform distortions and attenuations. Every effect has its cause and if you know how to analyze the effect, you can proceed without hesitation to its cause. There is no easy road to scope trace analysis. Proficient analysis is based on an understanding of Ohm's law, both for DC and AC circuits. In some cases recourse must also be made to Kirchhoff's law. When dealing with AC circuits, you will find that Ohm's law involves phase and frequency, as well as voltage, current, and resistance. Frequency and phase enter into the analysis when reactance is present, as in inductive or capacitive circuits.

In general, you can do better work with better tools. A "sophisticated" scope with extended bandwidth and DC response provides more information than an AC scope with limited bandwidth. Still more data is provided by advanced operating features, such as calibrated and triggered sweeps. However, this book is concerned chiefly with waveforms displayed by the better class of low-cost scopes. A scope with reasonably flat response out to 4 mc is satisfactory for most work, including the analysis of color-TV waveforms.

Patterns can be completely misleading, unless the scope is applied properly. Circuit loading will be a problem unless a low-capacitance probe is used to test medium- and high-impedance circuits. Certain classes of tests cannot be made without the use of a demodulator probe. Inasmuch as these requirements are incidental to the main topic of this book, beginners are directed to specialized texts for information on scope probes and applications.

ROBERT G. MIDDLETON

April, 1963

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CHAPTER 1

Introduction

There is an old proverb: "If you want a rabbit stew, first catch your rabbit." An electronic technician would say: "If you want to analyze a circuit waveform, first display your waveform."

Displaying waveforms is something like catching rabbits. A waveform can be an elusive will-o'-the-wisp. For example, suppose you connect a scope at the plate of the second IF amplifier in a TV receiver and nothing happens. There is a reason for the missing waveform, of course. First, there may be no signal present (a circuit defect might be stopping the signal). Second, a technical error could have been made, such as using a low-capacitance probe instead of a demodulator probe. Third, the scope controls could be adjusted incorrectly—perhaps the vertical step attenuator is set to the low end of its range. Fourth, circuit loading might have thrown the stage under test into oscillation.

When this type of difficulty occurs, carefully check each of the following possibilities:

1. Is a waveform present at a previous test point in the circuit? If so, it is a good possibility that nothing happens at the following test point because the circuit is defective between the two points.
2. Is there conclusive evidence that a signal is actually present—such as some semblance of an image on the picture-tube screen? If so, look to see whether a suitable probe is being used; as noted previously, a modulated-IF signal can be displayed only with the aid of a demodulator probe.
3. Are the scope and probe in working condition? If the scope is operating, you will see a distorted 60-cycle sine wave when you touch your finger to the scope vertical input terminal. If the demodulator probe is working, you will see a sine-wave pattern when the modulated output from an AM generator is fed via the probe to the scope.
4. Is the probe properly connected to the scope? Everyone at some time has reversed cable terminals by connecting the ground lug to the "hot" input terminal. Occasionally, a whisker from a frayed cable will short out the input terminals. In other words, look for obvious defects first, before condemning the equipment.
5. Is circuit loading causing the IF stage to "take off" and oscillate uncontrollably? This happens in a certain percentage of tests. In such a case, the dead stage comes to life when the probe is moved from a plate terminal to a grid terminal, or vice versa.

UNEXPLAINED HUM INTERFERENCE

All experienced technicians have run into hum interference that did not make sense. An example is illustrated in Fig. 1-1. In other words, circuit operation is such that high-level hum cannot be present, but for some unexplained reason a high-level hum interference appears to be present at every test point in the circuit. When this puzzler confronts you, immediately check the ground return to the scope. If you are using a coax input cable, there is a high probability that an ohmmeter check will show an open ground circuit. Or, if you are using open test leads, look to see whether the ground lead is clipped to a point on the chassis that is actually grounded. Support brackets, for

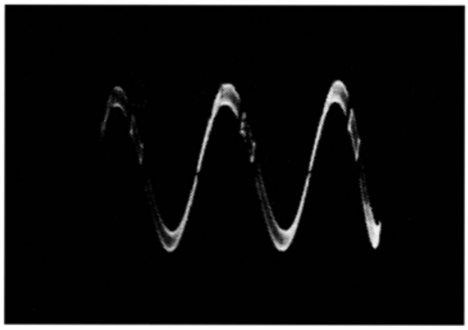


Fig. 1-1. Small signal, large hum.

example, might look like a ground connection and in fact be floating.

PULSATING PATTERN

A curious and sometimes baffling situation occurs when the scope is operated at maximum sensitivity. A pattern is displayed normally, except that the waveform flips up and down on the screen. Usually the flipping occurs at a fairly slow rate, although it may be fast enough to make the waveform appear blurred. In this case the test setup is "motorboating." There is feedback present between the power supplies of the scope and the unit under test.

In some cases, the test setup can be stabilized by turning over the power plug of the scope. However, in stubborn situations both the scope case and the chassis under test must be physically grounded. Beware of hot-chassis equipment in all cases—use a line-isolating transformer to power a hot-chassis device. Otherwise, a premature Fourth-of-July pyrotechnics display can be expected—not to mention the possibility of serious shock to the operator.

SCOPE OSCILLATES

Sooner or later, a scope operator will run into another type of puzzler caused by a scope oscillating uncontrollably. For example, you might connect a sound-IF coil across the scope vertical input terminals and be confronted by an off-screen, high-frequency pattern. This self-oscillation is more likely to occur when a preamplifier is used with a scope, but it occasionally happens when a coil is connected directly to the scope vertical input terminals. It occurs when the plate circuit of the input stage is not sufficiently isolated from the grid circuit, and a tuned-plate-tuned-grid oscillator system is established. In other words, the coil under test is operating like a grid tank, and feed-back due to interelectrode capacitance sets up self-oscillation with the plate-circuit peaking coil(s) and stray capacitances serving as a plate tank. This difficulty is most commonly encountered with preamps that do not employ a cathode-follower input stage. If it does occur, the preamp cannot be used in the particular test. A completely useful preamp must have a cathode-follower input—otherwise, it is quite likely that tests of high-Q coils in certain resonant-frequency ranges will become impossible because of self-oscillation.

HOOKED BASE LINE

Another baffling situation sometimes met in high-impedance circuit tests is a bending or hooking of the base line, usually toward the left end. In other words, a normal horizontal base line is present as long as the circuit under test has low or moderate impedance, but when you test across a high-impedance circuit the base line dips down or curves upward at the left end (Fig. 1-2). The amount of base-line distortion changes with the setting of the vertical-gain control. Distortion is in-

Fig. 1-2. Hooked base line.

creased when the impedance across the scope vertical input terminals is increased.

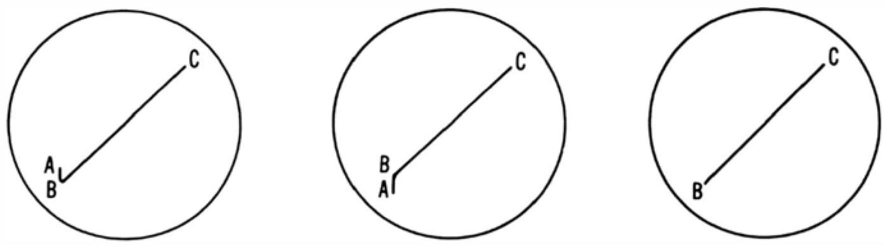
This difficulty is caused by the presence of sawtooth-deflection voltage in the vertical-input system of the scope. It sometimes develops when the front panel does not make good connection with the case. It may be caused by leaving a "floating" lead from the pulse-gate terminal near the scope vertical input terminals. In rare cases the internal shielding of the scope is insufficient to prevent the pick up of stray fields from the deflection system by the step-attenuator section.

SPURIOUS PIP ON SINE-WAVE DEFLECTION

An analogous type of distortion is sometimes observed when a scope is operated on 60-cycle sine-wave deflection, as when displaying a frequency-response curve. If you see a spurious pip on the curve or base line, it might be caused by crosstalk from the sawtooth oscillator into the vertical amplifier of the scope. Try changing the setting of the sawtooth-frequency control to see if the pip starts moving or changes its rate of movement on the pattern. If it does, the cause is clear. Scopes which have this inherent characteristic are provided with an off position for the sawtooth-frequency control—the off position must be used in such cases.

WAVEFORM CHANGES WITH STEP-ATTENUATOR SETTING

Modern scopes have frequency-compensated vertical-step attenuators. That is, the attenuator resistors are shunted by trimmer capacitors that must be adjusted to eliminate frequency discrimination. If you switch to an adjacent step and find a change in waveshape, the cause is most likely incorrect trimmer



(A) Trimmer capacity low.

(B) Trimmer capacity high.

(C) Trimmer properly adjusted.

Fig. 1-3. Trimmer-adjustment patterns.

adjustment. Usually, you will find that the associated resistor has been damaged by overload and increased in value. Hence, the resistor should be checked before the trimmer is readjusted; otherwise, you are likely to end up with an incorrect attenuation factor on the particular step.

Overload and resistor damage commonly result from applying excessive voltage to the scope vertical input terminal. Ill-advised tests in horizontal and vertical sweep circuits are generally responsible. In such cases the blocking capacitor of an AC scope will probably be punctured and require replacement. After defective components are replaced, it is quite easy to adjust attenuator trimmers correctly without the use of special equipment. Simply connect a test lead from some point in the horizontal-deflection system to the scope vertical input terminal. Adjust the sawtooth oscillator to a rate of approximately 20 kc. Then, adjust the pertinent trimmer for a straight diagonal line on the screen (Fig. 1-3).

LOW-CAPACITANCE PROBE DISTORTS WAVEFORM

You may find that the step attenuator is properly compensated in the previous test but that distortion appears when the sawtooth test voltage is fed into the scope via the low-capacitance probe. This indicates that the probe is out of adjustment. A low-C probe contains resistance and shunt capacitance in the same configuration as the step attenuator itself. Hence, if the shunt capacitance has an incorrect value, the probe will distort complex waveforms. Some probes have an adjustable trimmer capacitor—in this type set the trimmer in the same manner as previously described for a step attenuator.

If your probe has a fixed compensating capacitor, it will be necessary to replace the capacitor with another having correct value. This necessity generally arises when a general-purpose low-C probe is used with a scope to which it is not matched. However, the same problem occurs when the coax input cable of a low-C probe is replaced with a cable having a different capacitance. In any case, a low-C probe does not serve its purpose unless the time constants of both probe and scope-input system are equalized.

In a few cases you will find that a scope has considerably different input capacitance and resistance values on various steps of the vertical attenuator. Such scopes cannot be used satisfactorily with low-capacitance probes. When circuit loading is a problem due to capacitive loading by a coax input cable, the best that can be done is to use open test leads. However, open leads often cause difficulty due to stray-field pickup when high-impedance circuits are under test. Hence, professional test procedures in TV circuitry require the use of a scope which has reasonably constant input resistance and capacitance, plus a matching low-C probe.

PROBE WEAKENS SIGNAL EXCESSIVELY

Various scopes have different vertical-sensitivity ratings. When testing in low-level circuits with a low-C probe, it is desirable to have high vertical sensitivity available, or the incidental attenuation of the probe may make the pattern height inadequate. If you do not wish to replace the scope with an expensive model having considerably higher sensitivity, you may choose to use a wide-band preamp. Another possibility is to employ a simple cathode-follower probe instead of a low-capacitance probe. A few scopes provide a choice of both low-C and cathode-follower probes. For purposes of comparison, a typical cathode-follower probe causes a 20% voltage loss, while a low-C probe causes a 90% voltage loss. The cathode-follower probe also imposes less circuit loading than the low-C probe.

A low-C probe is not only less expensive, but it is also easier to adapt to ordinary scopes, because a low-C probe does not require supply voltages. Scopes designed for use with cathode-follower probes have special vertical input connectors which provide heater and plate-supply voltages to the tube in the housing of a cathode-follower probe. While you can modify any scope to accommodate a cathode-follower probe, it is not an easy job.

GETTING ACQUAINTED WITH WAVEFORMS

Beginners are well advised to make haste slowly when starting waveform analysis. It is possible to become discouraged at the outset by neglecting basic principles of scope operation. If tests are made first with an ordinary 60-cycle sine-wave input, it will not take long to "get the feel" of the scope controls. Note carefully what happens as you change each control setting. When something unexpected occurs, stop right there and ask why. For example, if you have the vertical step attenuator "wide open" and attempt to adjust pattern height by means of the continuous attenuator, the waveform may appear neatly clipped. This happens because the input cathode follower is overloaded. Hence, reduce the step-attenuator setting so that the continuous (vernier) control does not need to be set near zero.

Suppose an odd pattern which does not respond to a change in the sawtooth-oscillator control setting is displayed. Remember that the function switch must be set to the sawtooth position to obtain a conventional sine-wave display. Furthermore, the sawtooth function may not be identified as such on your particular scope—it might be called "Int Sync," "+ Sync," or possibly some other designation. In any case, the instruction book for the scope will explain the designation.

After you gain confidence in displaying 60-cycle waveforms, it is advisable to gain experience with sine waves of other frequencies from an audio oscillator. Then, square waves or pulses can be investigated. These are all simple waveforms that are not mixtures. When you "graduate" to video signals, you will find that two basic patterns are obtainable, depending on the sawtooth-frequency setting. The vertical-sync interval is visible on 30-cycle deflection, while the horizontal-sync interval is visible on 7,875-cycle deflection.

Many operators who are "at home" with waveforms displayed on sawtooth deflection feel baffled when tackling frequency-response curves displayed on 60-cycle sine-wave deflection. The latter is a more difficult situation, because horizontal deflection voltage must be properly phased. Moreover, the visible retrace must be blanked by appropriate controls. Again, the secret of success is to make haste slowly and be sure that you understand each step and the reason for it.

CHAPTER 2

Fundamental Concepts

Oscilloscope-pattern reading might seem to be one of the "occult arts;" however, it is very easy to obtain considerable information from a scope pattern even when you disregard most of the fine points. For example, the height of a waveform immediately shows its peak-to-peak voltage (on a calibrated scope), because a scope is basically a voltmeter. A few scopes indicate peak-to-peak voltages directly, but most must be previously calibrated from a source of known peak-to-peak (or DC) voltage. Calibration procedure is not covered in this book, but you may consult your scope instruction booklet or such texts as *101 Ways to Use Your Oscilloscope* and *Troubleshooting With the Oscilloscope*. Although a scope is fundamentally a voltmeter, it is a much more versatile instrument.

CAPABILITIES OF THE OSCILLOSCOPE

A scope has the ability to measure basic electrical quantities and to show the relation between two or more of these quantities. It can relate one or more of these quantities to a controlled time reference. Thus, a scope can display characteristics such as waveform, frequency, and phase in addition to various voltage values. Attenuators and amplifiers are used in a scope to displace the electron beam vertically on the cathode-ray tube screen. Simultaneously, and in step with the signal voltage, the

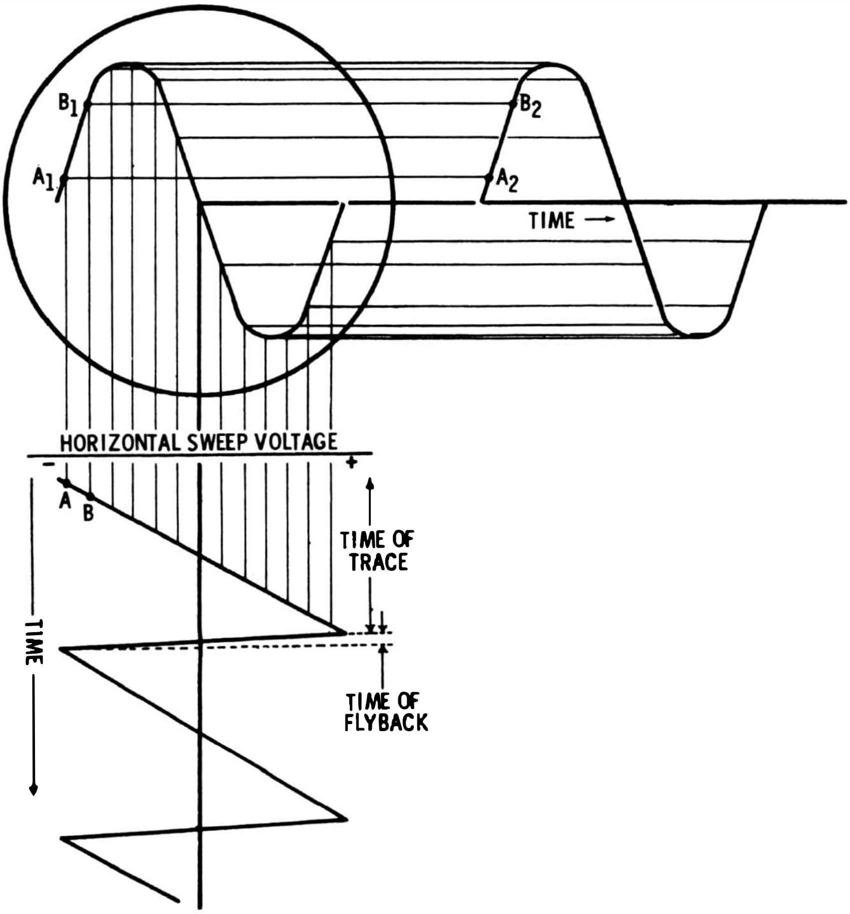


Fig. 2-1. Development of a sine-wave display using sawooth sweep.

electron beam is swept, or deflected, horizontally by a sawtooth voltage generated inside the scope. The horizontal-deflection frequency is a simple fraction, or subharmonic, of the signal frequency.

Fig. 2-1 shows how this display action occurs. Start at an instant when the sawtooth horizontal sweep voltage is close to maximum negative polarity (point A). The CRT beam at that instant will be at the left side of the screen, because the saw-tooth voltage is negative. At this same instant the sine-wave voltage applied to the scope vertical input terminal is close to zero (point A_2). Accordingly, the beam at this point has little vertical deflection, and the spot is located at point A_1 on the scope screen.

Next, the horizontal sweep voltage is less negative (point B), and the beam is at a point nearer the center of the screen. At this same instant the sine-wave voltage applied to the vertical input terminals has risen to a more positive voltage (point B_2), causing the beam to be deflected upward on the screen. Thus, the beam has moved upward and to the right and is now located at point B_1. This action continues, i.e., the beam moves horizontally toward the right side of the screen, while its vertical position follows the polarity and instantaneous voltage of the sine wave applied to the vertical input terminals. In this wave a complete waveform is traced on the screen.

BASIC ELECTRICAL QUANTITIES

An understanding of waveforms stems from recognition of the basic electrical quantities. The volt is the unit of electrical pressure. It is the force which must be applied before current will flow. Current consists of the transport of electrons, and the ampere is the unit of current flow. If 6.28×10^{18} electrons are passing a given point each second, 1 ampere of current is flowing. The ohm is the unit of resistance. It is an opposition to current flow in the same manner that friction opposes mechanical motion. If 1 volt forces a current of 1 ampere to flow through a circuit, the resistance of the circuit is 1 ohm. This is simply the statement of Ohm's law: $I = E/R$.

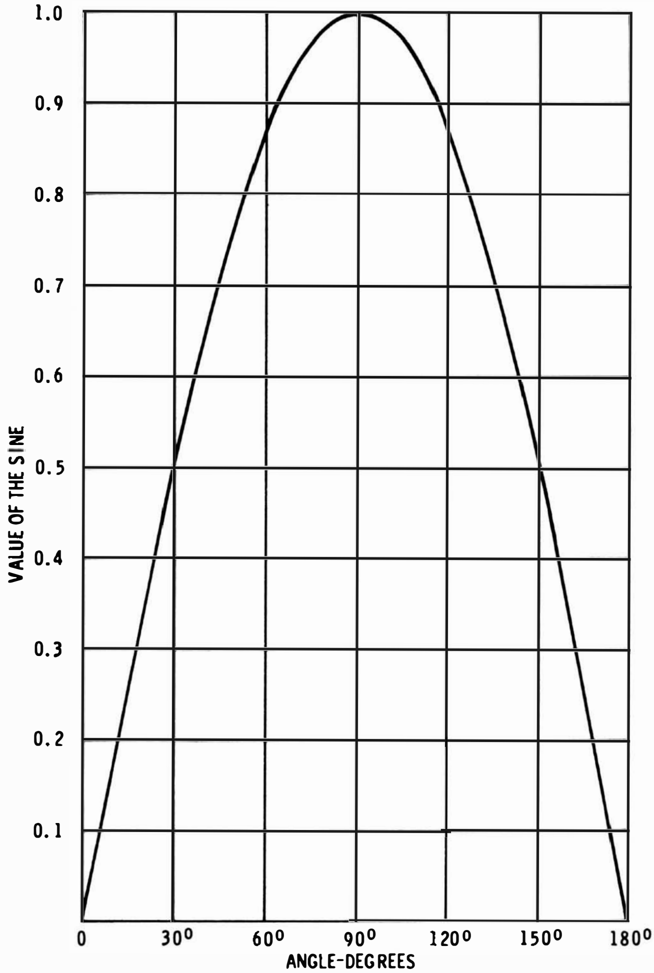
Ohm's law applies to both DC and AC circuits. In other words, voltage, current, and resistance are related in the same way in either an AC or DC circuit. However, an AC circuit often has an additional opposition to current flow that is called reactance. Thus, a capacitor has capacitive reactance, which is measured in ohms. Also, an inductor has inductive reactance, which is measured in ohms. The combination of resistance and reactance is called impedance, which is also measured in ohms. If you apply 117 volts from a 60-cycle AC line to an impedance of 117 ohms, 1 ampere of alternating current will flow. The symbol for impedance is *Z*. Ohm's law for AC is: $I = E/Z$.

WHAT IS A WAVEFORM?

Technicians who are unacquainted with oscilloscopes often ask: "Just what is a waveform?" Most waveforms are electronic graphs of AC voltages with respect to time. In other words, a waveform shows instantaneous voltage values and how the voltage rises and falls with time. Students in technical schools usually prefer to approach waveforms on the basis of graphs. For example, Fig. 2-2 shows a sine graph compared with a sine-wave display on a scope screen. In this illustration y corresponds to voltage, and x corresponds to time. If you are discussing a 60-cycle sine wave, one complete cycle occurs in 1/60 second, and one-half cycle occurs in 1/120 second.

Instantaneous voltages are evident in the Fig. 2-2A graph. The peak or crest value of the sine wave is 1 (or 100%). Observe that the sine wave has a value of 50% at 30°. If a 60-cycle sine wave is being considered, the time interval from 0° to 30° is 1/720 second, since one complete cycle, or 360°, occupies an elapsed time of 1/60 second, and 30° is 1/12 of a complete cycle. A sine wave such as that depicted in Fig. 2-2B repeats itself until the voltage is removed. In other words, the sine waveform goes through a positive excursion (or half cycle), then through a negative excursion (or half cycle), after which it repeats the positive excursion and the negative excursion. A sine wave is therefore a recurrent waveform.

The sine wave has only one frequency. In this respect it differs from many other waveforms which will be explained subsequently. The frequency of the sine wave is related to the time required to complete one full cycle. In the case of a 60-cycle sine wave, one cycle is completed in 1/60 second. In turn, 60 cycles are completed in one second, so that its frequency is stated as 60 cycles per second. The word second is often dropped, and the waveform is then said to have a frequency of 60 cycles. Nevertheless, it is always implied that the stated number of cycles occurs in one second.



(A) Graph of half cycle.

(B) Sine-wave pattern on scope screen.

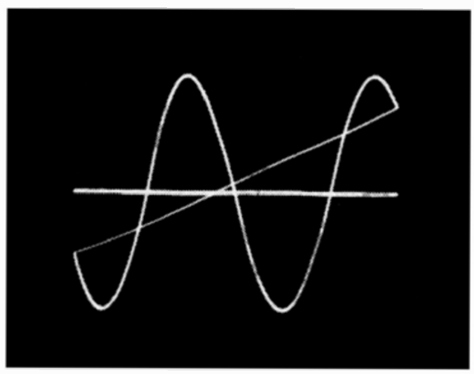


Fig. 2-2. Sine waves.

Construction of a Sine Wave

Just what is meant by the term "degrees?" Why does the complete cycle occupy 360°, and why are instantaneous voltages related to angles? These terms result from circle characteristics and sine-wave characteristics. In Fig. 2-3, the full circle contains 360° by definition. If you travel counterclockwise around the circle from zero and stop at P_1, you have gone 1/12 of the total circumference, or 30°. At point P_1 the vertical distance is half of the maximum value. In other words, the angle theta (θ) is 30° at P_1, and the related sine wave has half its peak value. Next, if you proceed to point P_2, you have gone 1/6 of the total circumference, or 60°. At P_2 the vertical distance is

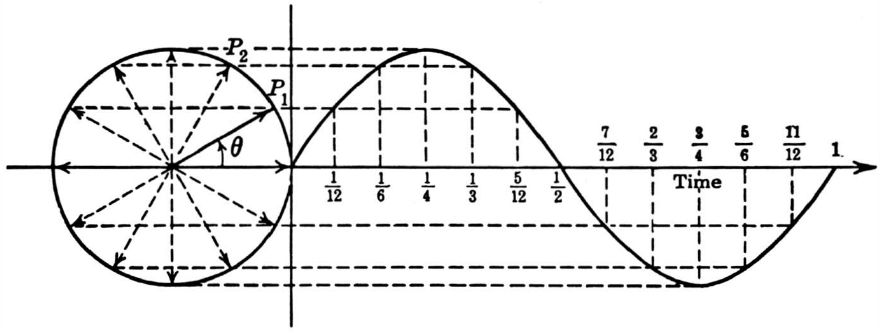


Fig. 2-3. Construction of sine wave based on angles of a circle.

about 0.866 of the maximum value. Otherwise stated, the sine of 30° is 0.5, and the sine of 60° is approximately 0.866.

The correspondence between angles and voltage amplitude should now be clear. This is a vital point, because you will eventually need to measure the phase difference between two sine-wave voltages. The phase difference is stated as an angle of separation between the two sine waves. A phase angle can also be expressed as a time difference. Hence, if one sine wave starts after another, you can state either the phase angle or the time delay between them.

At this point, it is not essential to consider details of phase measurements. What is important is that you understand what is meant by a phase angle and how the instantaneous voltages of the sine wave are tied in with the instantaneous phases of the wave. You have probably heard, for example, that the current in a capacitor leads the voltage across the capacitor by 90°. This simply means that the voltage starts 90° or 1/4 cycle after the current. The current through a pure inductance lags the voltage across the inductor by 90°, which means that the current starts 90° or 1/4 cycle after the voltage. Later it will be shown how equipment can be connected to display both voltage and current waveforms simultaneously, thereby showing on the scope the phase difference between voltage and current.

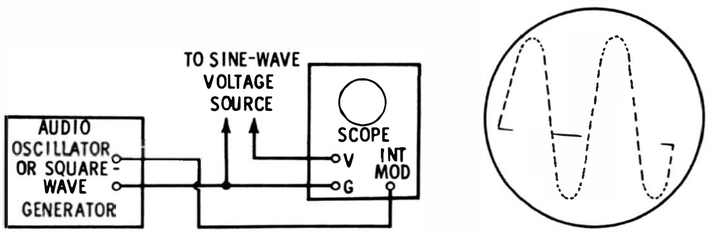
SINE-WAVE VOLTAGE SOURCES

Ordinarily 117-volt 60-cycle power sources provide a sine waveform. (In some cases this waveform may be distorted.) Another basic source of sine waves is a freely oscillating LC circuit; this is an electrical system which is analogous to a vibrating string. Audio oscillators widely used in electronics test procedures generate a sine waveform. Generally, an RC (resistance and capacitance) circuit is suitably connected to a vacuum tube to form an oscillator. Either the capacitance or the resistance, or both, are variable in order to adjust the frequency of the sine-wave source. Signal generators, also used widely in test work, generate waveforms from LC (inductance and capacitance) circuits connected to vacuum tubes in oscillator configurations. The generated frequency is varied by changing the capacitance and/or inductance values.

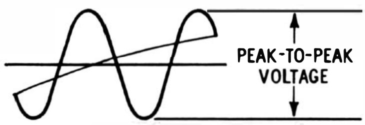
The output from an audio oscillator or a signal generator is much less than that from a 117-volt power line. An audio oscillator might have a maximum output of 10 volts, and a signal generator might have a maximum output of 1 volt. Many instruments have still less output voltage. The frequency range of an audio oscillator is typically from 20 to 20,000 cycles per second. More elaborate audio oscillators have an upper frequency limit of 100,000 cps. A typical AM (amplitude-modulated) signal generator has a frequency range from 100 kc to 50 mc. Some AM generators have a top frequency of 250 mc. Marker generators are accurately calibrated signal generators used in television service procedures. They commonly have a frequency range from about 4 mc to 250 mc and a maximum output of 0.1 volt. All such generators have one basic feature in common: their output has a sine waveform.

MARKING TIME AND INSTANTANEOUS VOLTAGES

Basic electrical quantities noted in the foregoing pages are not simply theoretical matters; quite to the contrary, each can be displayed and measured with the aid of a scope. Instantaneous voltages along a sine wave can be displayed with the arrangement depicted in Fig. 2-4A. Observe how the pattern appears as a series of dots. The dots are spaced more closely on the peaks of the sine-wave pattern than on the sides of the sine wave. Furthermore, the dots are stretched out far apart on the retrace interval. This difference is simply the result of equal time intervals between each pair of dots.



(A) Method of showing instantaneous voltages.



(B) Meaning of peak-to-peak voltage.

Fig. 2-4. Sine-wave voltages.

Note how the pattern is developed in Fig. 2-4A. The sine-wave voltage source provides the vertical deflection. This source might be from any circuit or device which generates a sine-wave voltage. Dots along the pattern are obtained by feeding an AC voltage into the intensity-modulation terminal of the scope. The action of the intensity-modulation AC voltage is to cut off the CRT beam and turn it back on at the frequency of the modulating voltage. Either an audio oscillator or a square-wave generator can be used, because the exact waveshape of the intensity-modulating voltage is not a primary consideration.

It can be seen from the time-marked pattern in Fig. 2-4A that the retrace time is quite rapid. There are 36 dots in one complete cycle of the sine-wave pattern, but there are only two dots in the retrace interval. This means that the retrace time is only 1/18 of the time taken by one cycle of the sine wave. Suppose you are intensity-modulating the sine-wave pattern with a frequency of 2,160 cps. The time from one dot to the next is accordingly 1/2,160 second. Inasmuch as there are 36 dots in one complete cycle of the pattern, the frequency of the displayed sine wave is 60 cps.

Fig. 2-4 also clarifies the distinction between instantaneous voltages and the peak-to-peak voltage of a waveform. An instantaneous voltage might be measured at any arbitrary point on the waveform of Fig. 2-4A, but the peak-to-peak voltage is measured from the positive peak to the negative peak (Fig. 2-4B). It is not anticipated that you will immediately proceed to set up equipment and measure instantaneous or peak-to-peak voltages; however, this understanding is very important to the beginner in electronics, because these are facts which you will use as a base on which to add future knowledge.

SYNCHRONIZATION

If you connect a test setup as shown in Fig. 2-4A, the first operating feature that you will observe is the necessity to set the audio oscillator critically to an exact harmonic of the pattern frequency. Unless the oscillator is carefully tuned, you will see the dots moving, or running along the pattern. The dots stand still only when the oscillator is tuned to an exact harmonic of the pattern frequency. Any drift of either input frequency makes the dots start to run on the pattern. This fact points up the necessity for synchronizing the marking frequency with the pattern frequency.

For this reason the audio oscillator is usually replaced by a shock-excited oscillator in laboratory or industrial instrumentation. Shock-excited oscillators are discussed in some detail subsequently; at this point you need merely note that a shock-excited oscillator is triggered by the sawtooth voltage of the scope. Because of this, the first dot in the pattern always starts exactly at the beginning of the waveform, no matter what the frequency of the shock-excited oscillator. To put it another way, this triggering method synchronizes the intensity-modulating voltage with the sweep waveform, which is in turn synchronized with the pattern frequency.

Triggering action is employed in all scopes to synchronize the sawtooth sweep frequency with the signal frequency in the scope vertical channel (Fig. 2-5). Otherwise stated, the sawtooth waveform maintains the same phase relation to the signal at all times. The sawtooth oscillator in most scopes is a multivibrator configuration, and a sample of the incoming signal voltage is injected into the grid circuit of the multivibrator. Thus, the multivibrator is triggered, and its oscillating frequency is locked to the signal frequency.

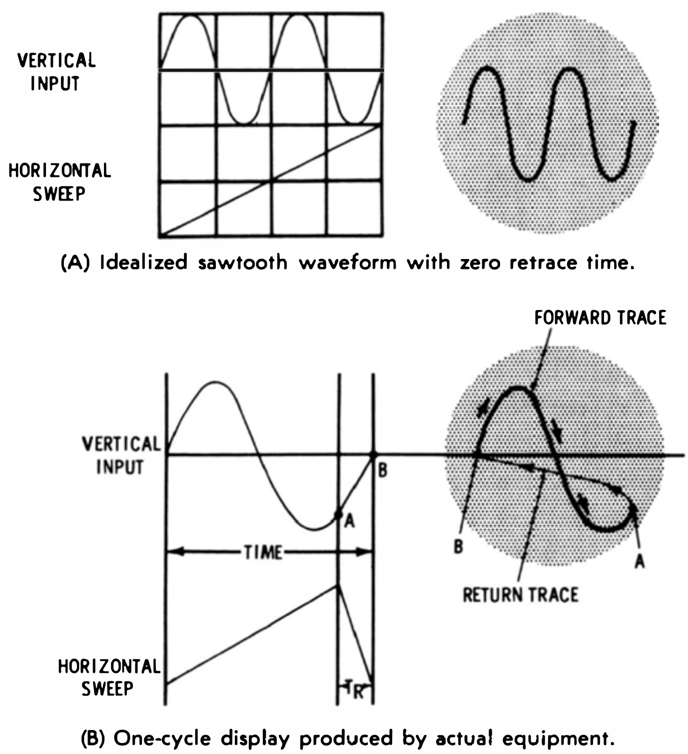


Fig. 2-5. Sawtooth waveform synchronized with sine-wave signal.

Note also in Fig. 2-5B that the time required for retrace takes a portion out of the pattern (from A to B). The retrace time T_R is made as short as practical, but it is never possible to obtain a zero retrace time. Hence, you will never be able to see the entire signal pattern if you display only one cycle of the signal. It is standard practice to set the sawtooth oscillator to one-half the signal frequency. This results in the display of one complete cycle, plus most of the following cycle. It is commonly said in such a case that two cycles of the signal waveform are being displayed, but if you observe the pattern closely, you will see that a small portion of the second cycle in the pattern is "bit off" by retrace, just as in the single-cycle display shown in Fig. 2-5B.

Observe that the pattern depicted in Fig. 2-5B is not a true sine wave. Instead, it is a distorted sine wave—the positive peak is narrower than the negative peak. Such a waveform is often described loosely as a sine wave, but it is in fact a complex waveform. Any waveform that departs from a true sine wave is a complex waveform. This means that a distorted sine wave has more than one frequency; that is, the distorted sine wave contains harmonics. These harmonics are exact multiples of the pattern repetition rate. In other words, if the distorted sine wave has a repetition rate of 60 cycles, the harmonics in the waveform have frequencies that are 120 cycles, 180 cycles, etc.

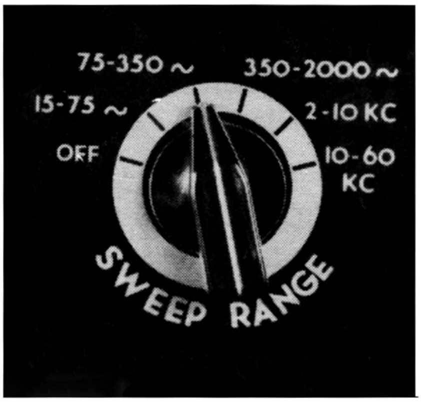
FREQUENCY VERSUS REPETITION RATE

The terms *frequency* and *repetition rate* are often used interchangeably, although strictly speaking you can speak of frequency only for a sine wave. The reason is that a complex waveform has many frequencies. You may properly state the frequencies contained in a complex wave. On the other hand, the time occupied by one complete cycle of a complex wave is properly described by the term repetition rate. The repetition rate of a complex wave is the frequency of its fundamental frequency. Thus, a distorted 60-cycle sine wave has a fundamental frequency of 60 cycles, and its repetition rate is 60 times per second. These fine points of waveform description might seem like hairsplitting; however, you will find that when highly complex waveforms are to be analyzed, the distinctive terms become vital to avoid confusion.

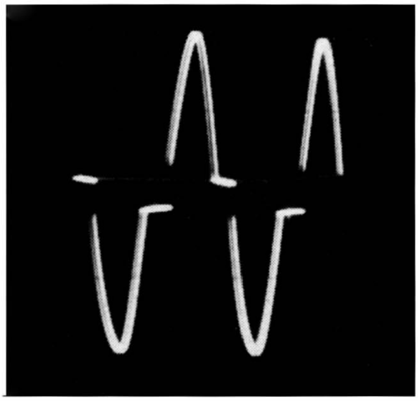
What are the harmonic frequencies in a distorted sine waveform? This depends on the way in which the wave is distorted. Some types of distortion give rise to even harmonics only (even harmonics are 2, 4, 6, etc. times the repetition rate.) Other types of distortion give rise to odd harmonics only (3, 5, 7, etc. times the repetition rate). Still other types of distortion give rise to both even and odd harmonics. Harmonic generation is an extensive subject, and details of the process are covered subsequently.

GENERAL WAVEFORM CHARACTERISTICS

The general characteristics of any waveform are apparent from a pattern. Thus, you can observe whether the waveform in question is a sine wave, square wave, sawtooth, pulse, or some combination of basic waveforms, such as peaked-sawtooth, half-sine, sine-and-pulse, narrow pulse on a wide pulse, and so on. A peaked-sawtooth waveform is typical in vertical-sweep



(A) Horizontal oscillator frequency panel control.



(B) Display showing two cycles of waveform.

Fig. 2-6. Determination of the frequency of a waveform.

circuits, a half-sine waveform (hybrid sine and square wave) is typical in half-wave rectifier circuits, sine-and-pulse waveforms are typical in sync circuits, and a narrow pulse on a wide pulse forms a horizontal sync pulse.

You can determine the approximate frequency of the waveform, because the horizontal-oscillator frequency control in the scope (Fig. 2-6A) will be set to a position which corresponds to the repetition rate of the waveform. If there is one cycle displayed on the scope screen, the repetition rate will fall within the range limits indicated. Its repetition rate can be estimated more closely by observing how far the fine-frequency control has been advanced, because the continuous control fills in between the steps of the coarse control.

Thus, if the coarse-frequency control indicates that the displayed waveform has a frequency between 150 and 700 cycles, as in Fig. 2-6A (note that there are two cycles of the waveform for every cycle of the sweep), and you observe that the fine-frequency control is set at the midpoint of its range, the pattern frequency will be about half way between 150 and 700 cycles, or 375 cycles. This 375-cycle estimation is necessarily approximate for two reasons. First, the sweep frequencies of a service scope are not calibrated to high accuracy. Second, internal synchronization is used in this example; this tends to force the sawtooth oscillator slightly higher than its indicated frequency.

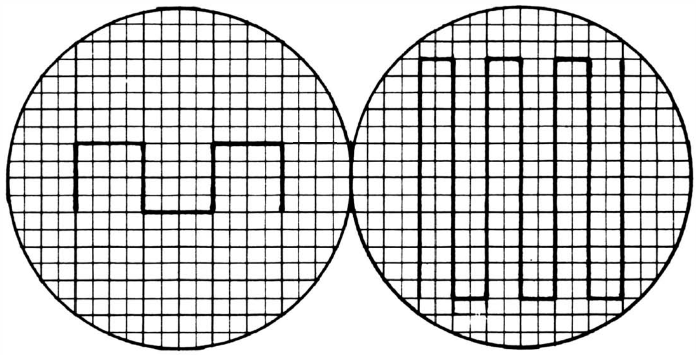
This limitation is not present in lab-type scopes, which have accurately calibrated horizontal sweeps and trigger circuitry which does not affect the sweep frequency. This book is concerned chiefly with the analysis of patterns displayed by service-type scopes; hence, suitable procedures will be explained to determine the repetition rates of waveforms with high accuracy whenever this becomes a matter of interest. In general, these procedures utilize the accuracy provided by auxiliary equipment such as audio oscillators.

PATTERN BRIGHTNESS VERSUS BEAM SPEED

Most patterns show considerable variation in brightness. Thus, in Fig. 2-6B the retrace is just barely visible, due to its comparatively high speed of travel. This is a distorted sine-wave pattern in which the beam moves very rapidly up and down the "step" intervals. The beam speed is so high through these intervals that the trace is invisible. If the scope brightness control were advanced sufficiently to make the invisible intervals apparent, the main portion of the pattern would be badly defocused; the CRT beam current would, in turn, become so high that possible damage to the tube would result. Hence, the technician must learn to "join up" a pattern when it appears to be comprised of segments.

WAVEFORM PROPORTIONS

Although an experienced technician takes waveform proportions into account as a matter of course, the neophyte is sometimes confused by changes of proportions caused by changes in settings of the scope operating controls. A common example is confusion between a square-wave and a pulse waveform. When the vertical and horizontal gain controls are adjusted to make the amplitude of the waveform approximately equal to the width occupied by one complete cycle (Fig. 2-7A), the distinction between a square wave and a pulse is apparent. When the vertical gain control is advanced and the horizontal gain control is turned back, the amplitude of the waveform is then considerably greater than the width occupied by one cycle



(A) Square wave displayed in standard proportions.

(B) Same square wave expanded vertically and compressed horizontally.

Fig. 2-7. Two displays of the same waveform.

(Fig. 2-7B). There is no question as to whether the same waveform is displayed in both cases; however, an uncritical observer may jump to the conclusion that the tall square-wave display represents a pulse waveform. This error in analysis results from a limited familiarity with waveform proportions. It is customary in theory books to show waveforms in so-called standard proportions. This custom does not imply that a waveform must appear in the same proportions on a scope screen. Actually, any waveform may appear in any proportions whatsoever in the display. Note that the so-called standard proportions can always be obtained by suitable adjustment of the vertical and horizontal gain controls, plus adjustment of the horizontal deflection rate.

Theory books often limit waveform presentation to one complete cycle, although some discussions limit the presentation to two complete cycles. Receiver service data standardizes on two-cycle presentation as in Fig. 2-6B. This is simply a function of the deflection-rate adjustment. The operator has a choice of displaying one, two, three, or an indefinite number of cycles in the screen pattern. It is disadvantageous to display only one cycle, because more or less of the waveform will then be lost on retrace. On the other hand, it is also disadvantageous to display a very large number of cycles, because the pattern becomes so cramped that it is difficult to evaluate. The best practice is to adjust the horizontal-deflection rate to display two cycles, inasmuch as all details of the waveform are then clearly apparent.

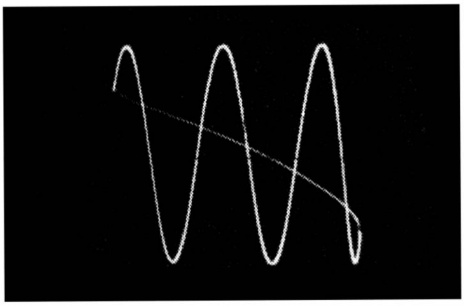
BASIC FACTS OF COMPLEX WAVEFORMS

In conventional situations the sine wave is considered to be the basic waveform. Fig. 2-8 illustrates what this means. A sine wave (Fig. 2-8A) is considered to be an electrical "atom" in the building up of complex waveforms. The complex waveform in Fig. 2-8B has a fundamental frequency, or repetition rate, which is the lowest frequency in the wave. The higher frequencies are in harmonic relation to the fundamental frequency. This simply means that the harmonics are exact integral multiples of the fundamental frequency.

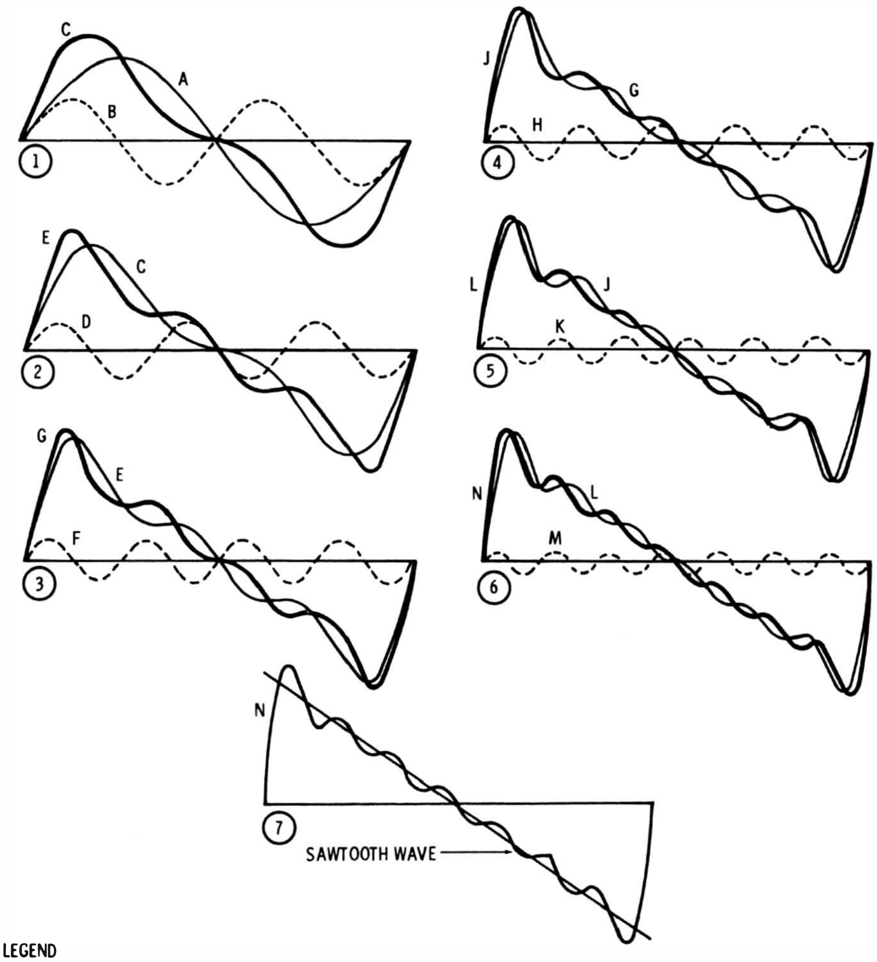
Thus, if the sawtooth wave depicted in Fig. 2-8B has a fundamental frequency of 60 cycles per second, its harmonic frequencies are 120, 180, 240, 300, etc., cycles per second. As higher and higher harmonics are included, the waveform becomes less wavy. To obtain a perfect sawtooth waveform with no waviness in its outline, an infinite number of harmonics must be added.

It must not be supposed that infinity is a number in any sense of the word. Infinity is something that is "always still more." You cannot say that a million-million-million cycles per second is an infinite frequency. An infinite frequency is always higher than any frequency that you can state. To put it another way, infinity is not a number at all; it is a concept which is outside of the class of real numbers.

Fig. 2-8 shows the synthetic approach to waveform description. In other words, any practical waveform can be considered to be composed of a series of sine waves having suitable voltages, frequencies, and phase relationships. As will be explained



(A) Basic sine wave.



LEGEND

A. FUNDAMENTAL
B. 2D HARMONIC
C. FUNDAMENTAL PLUS 2D HARMONIC
D. 3D HARMONIC
E. FUNDAMENTAL PLUS 2D AND 3D HARMONICS
F. 4TH HARMONIC
G. FUNDAMENTAL PLUS 2D, 3D AND 4TH HARMONICS
H. 5TH HARMONIC
J. FUNDAMENTAL PLUS 2D, 3D, 4TH, AND 5TH HARMONICS
K. 6TH HARMONIC
L. FUNDAMENTAL PLUS 2D, 3D, 4TH, 5TH, AND 6TH HARMONICS
M. 7TH HARMONIC
N. FUNDAMENTAL PLUS 2D, 3D, 4TH, 5TH, 6TH, AND 7TH HARMONICS

(B) Sawtooth wave composed of sine waves.

Fig. 2-8. Composition of a complex waveform.

in the next few paragraphs, waveforms are not actually produced in this way; this is merely a mathematical device for studying the waveform. In many cases this is the most convenient way to study a particular waveform, but in other cases it is much easier to consider the waveform in other ways. Some examples follow.

WAVEFORMS CONTAINING STRAIGHT LINES

A sine wave contains no straight lines. Even the "straightest" portions of the sine wave in Fig. 2-8A are curves, although they are "slow" curves. On the other hand, a true sawtooth wave consists of a succession of straight lines with no curvature whatsoever. Accordingly, it might seem surprising that a true sawtooth wave with perfectly straight lines could be built up from the sine waves that have no straight lines at all! This is possible if the sawtooth wave is regarded as containing an infinite number of sine waves.

Otherwise stated, waveforms comprised of straight lines can be built up from sine waves only with the proviso that an infinite number of harmonics is present. How can this be possible in real circuits and real scopes which never have an infinite bandwidth? As a matter of fact, it is impossible. No practical device can generate or display a perfect complex waveform, although many devices can produce an approximation that for all practical purposes is as good as the ideal waveform. As a familiar example, consider the display of a sawtooth wave on the screen of a scope—you will often observe such waveforms which contain straight lines, in spite of the fact that the scope bandwidth has an upper limit of a megacycle or two. The scope does not build up the waveform from its harmonics; it merely reproduces a waveform which has been generated by some circuit. In turn, the generating circuit does not build up the sawtooth waveform from its harmonics; it simply charges a capacitor from a DC-voltage source or a constant-current source.

Natural Laws of Growth and Decay

Fig. 2-9 shows the response of simple differentiating and integrating circuits. When a square-wave voltage is applied, the circuit action is the same as if a battery were switched first in one polarity and then in the other polarity. It is clear that resistance limits the current flow into and out of a capacitor. This current flow is exponential, because its rate of increase or decrease depends on the existing charge; that is, it depends on how nearly the capacitor voltage approaches the driving voltage. Exponential curves are natural laws of growth and decay.

Another illustration of the exponential concept in this regard follows from the fact that the curved intervals in differentiated or integrated waveforms can be straightened by an opposite curvature. In other words, one type of nonlinearity can be cancelled by the opposite type of nonlinearity to obtain a straight-line trace. This method is utilized in vertical-deflection

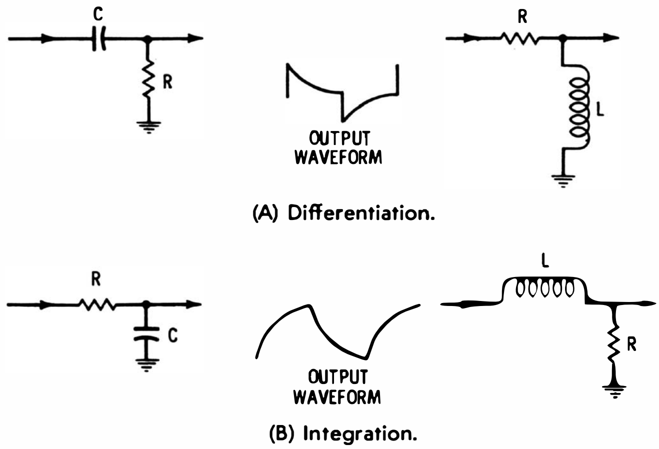
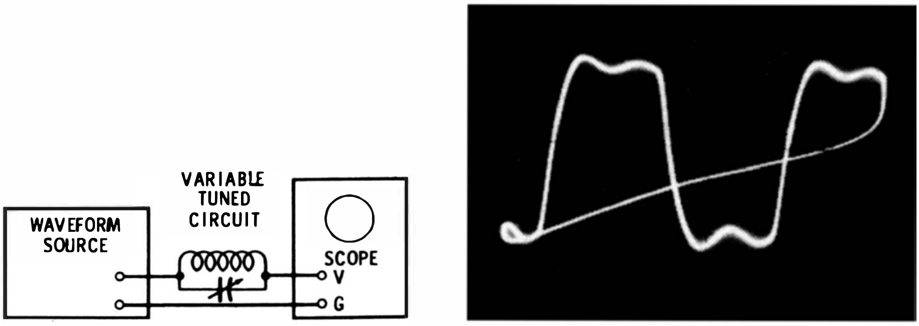


Fig. 2-9. Differentiating and integrating circuits.

circuits of TV receivers—the curvature in a generated sawtooth wave is cancelled out by a following circuit which introduces an opposite curvature. Thus, a linear sawtooth wave is obtained. Again, these are direct circuit responses, having no reference to suppositions of harmonics.

PRINCIPLES OF WAVE ANALYSIS

When the treacheries of infinity are clearly recognized, the idea of a complex wave as a combination of a fundamental plus an infinite number of harmonics can be very useful—even indispensable on occasion. The reason is that some circuits see a complex wave as if it were built up in this way.



(A) A simple waveform-analyzer arrangement.

(B) Square-wave pattern with third-harmonic ripple.

Fig. 2-10. Waveform analysis.

To quickly determine the harmonic frequencies in a complex waveform, the circuit current can be passed into a scope through a variable tuned circuit (Fig. 2-10A). As the LC circuit is tuned through a harmonic frequency, a sine-wave ripple appears in the scope pattern. This is a simple wave-analyzer arrangement.

RINGING OUT THE HARMONICS IN A WAVEFORM

Consider how a high-Q tuned circuit "rings out" the harmonics in a complex waveform. The excursions of the complex wave must necessarily sustain the ringing pattern to display a ripple in the reproduced waveform. Fig. 2-11 indicates how the ringing pattern is sustained when the high-Q circuit is tuned to the fundamental frequency of the waveform. When the square-wave voltage increases upward, the sine-wave voltage also increases upward, and vice versa.

In a commercial spectrum analyzer the arrangement depicted in Fig. 2-10A is considerably elaborated. It is common to use

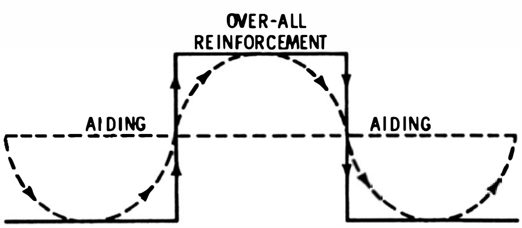


Fig. 2-11. A square wave sustains ringing at the fundamental frequency of the square wave.

superheterodyne circuitry with narrowband IF response. In some cases a quartz-crystal filter is used in the IF amplifier to obtain an extremely high Q. Thus, the effective resonant circuit is set to a constant frequency. The effect of tuning, obtained by means of a variable capacitor in Fig. 2-10A, is electronically controlled in a commercial spectrum analyzer. An FM oscillator (search frequency) is heterodyned with the waveform under analysis. As each harmonic frequency is swept through, an IF-beat output occurs. This IF-beat interval is passed by the quartz-crystal filter and appears as a pulse on the screen of the spectrum analyzer.

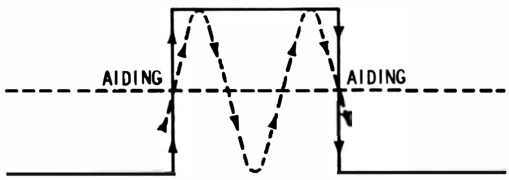


Fig. 2-12. A third-harmonic ringing oscillation is sustained in a tuned circuit by a square wave.

Reinforcement of the Third Harmonic

Fig. 2-11 shows how a ringing circuit reinforces the fundamental frequency of a square wave. As would be expected, the ringing circuit reinforces the third harmonic of the square wave (Fig. 2-12). When the square-wave voltage increases upward, the sine-wave voltage also increases upward, and vice versa. You will find that the ripple amplitude decreases as the tuned circuit is resonated at higher frequencies. This results from the fact that the higher harmonics in a square wave have lesser amplitudes (Fig. 2-13). The square wave contains odd harmonics only. Tests at higher ringing frequencies show less ringing voltage than should theoretically be present, and eventually the ringing becomes so low in amplitude that it is no longer visible. There are two chief causes for this:

1. The bandwidth of the scope may be too narrow to pass the higher ringing frequencies.
2. The applied square wave may not approximate a true square wave sufficiently.

The implications of these points will be considered next.

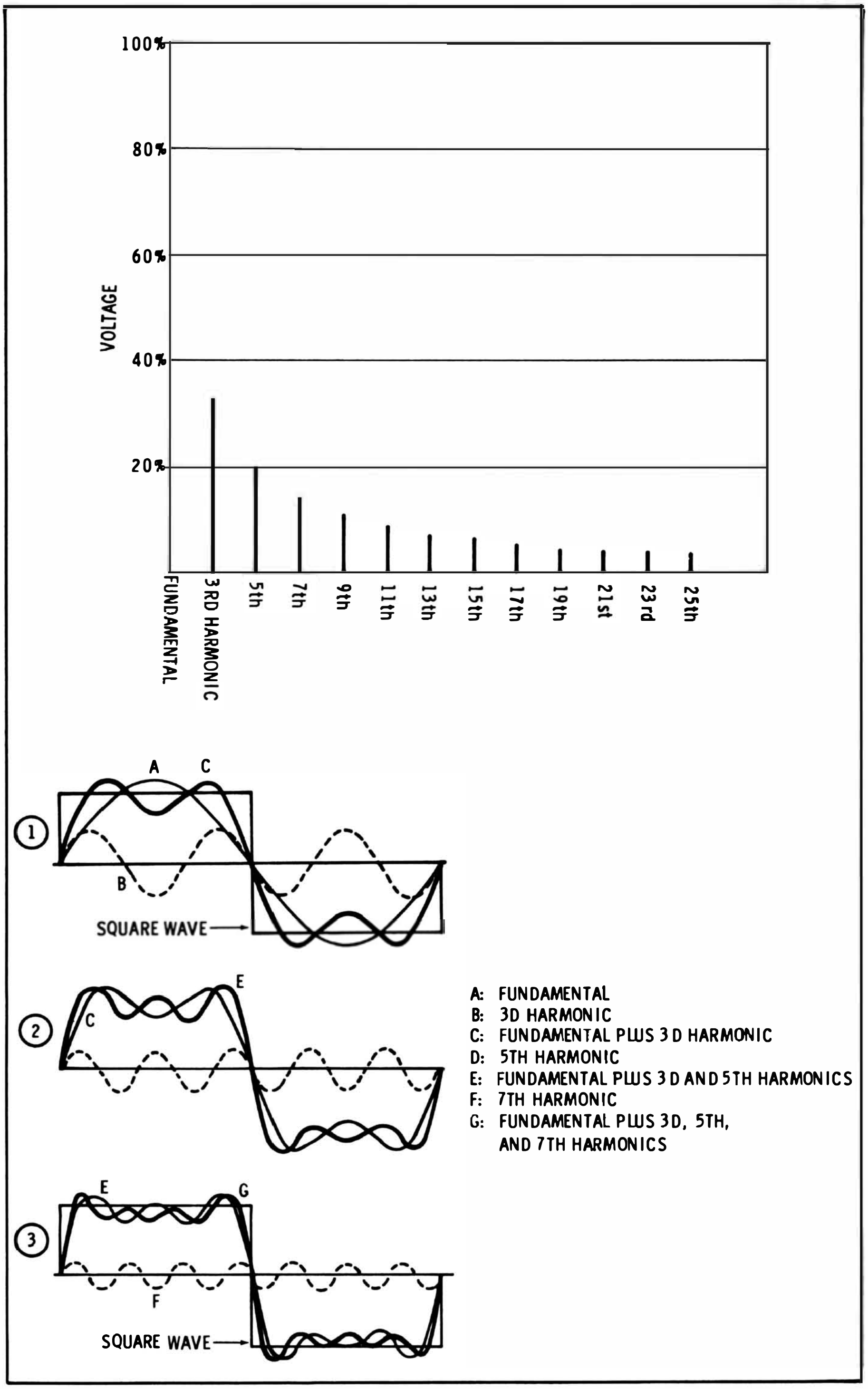


Fig. 2-13. Relative harmonic voltages in an ideal square wave.

WHAT IS RISE TIME?

In theory, a perfect square wave is built up from an infinite number of harmonics. But in practice, actual square waves have a more or less limited number of detectable harmonics. This limitation results from the finite bandwidth of square-wave generator circuits. Obviously, if a perfect square wave could be generated, the associated circuitry would require an infinite bandwidth. This is not possible. Because an infinite number of harmonics cannot be generated, practical square waves do not change from positive to negative, and vice versa, in zero time. Furthermore, the perfectly square corners predicted by theory cannot be realized in practice. Observe in Fig. 2-13 that the leading edge of a synthesized square wave becomes steeper as the number of harmonics is increased—but no finite number of harmonics will suffice to get a perpendicular leading edge. Again, in Fig. 2-13 observe that the corner of a synthesized square wave is always rounded as defined by the rounding of the highest harmonic. No finite number of harmonics will suffice to get a completely square corner.

Thus, actual square waves have a finite rise time, as depicted in Fig. 2-14. This is the time required for the voltage to rise from 10% to 90% of its total excursion. Rise time can be easily measured with a good scope having calibrated sweeps. For example, the sweep speed indicated in Fig. 2-14 is 0.5 microsecond per major division on the screen, and the rise time is 0.05 microsecond. The reason for defining rise time between the 10% and 90% points is to eliminate cornering from the rise-time measurement.

It is a basic precept that an instrument used as an indicator must have better characteristics than the unit under test. For example, if a scope is used to check the rise time of a square-wave generator output, the scope must have a faster rise time than the generator. Otherwise, the displayed rise time is that of the scope, not of the generator.

RISE TIME VERSUS FREQUENCY RESPONSE

As a rough rule of thumb, note that the rise time of a scope amplifier is equal to 1/3 the period at the high-frequency cutoff

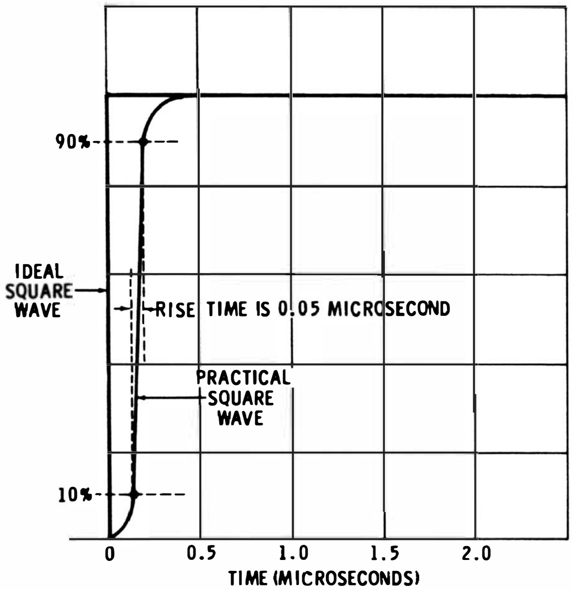


Fig. 2-14. Rise time.

point. In other words, a scope might have a pass band which cuts off at 4 mc. The cutoff point is said to occur at the point where response is 3 db down (about 30% down). Thus, if the response of a scope is 3 db down at 4 mc, the period is 0.25 microsecond at the cutoff point, since the period is the reciprocal of frequency: $T = 1/f$. Hence, in this example, the scope's rise time will be approximately 1/3 of 0.25 microsecond, or about 0.08 microsecond.

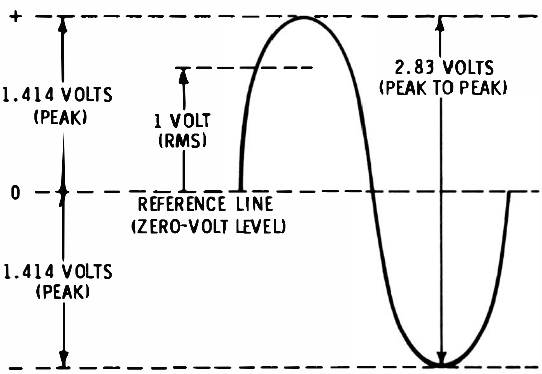
CHAPTER 3

Basic Waveform Characteristics

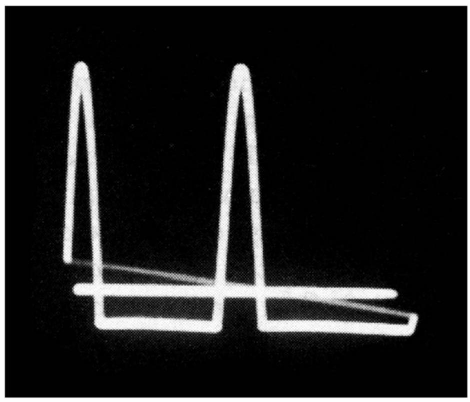
Waveforms are characterized not only by shape, frequency or frequencies, and rise time, but also by voltage and phase. The amplitude of a waveform is always of importance in test work; it is sometimes more significant than waveshape. Amplitude means the largest excursion of the wave, measured in peak-to-peak volts, amperes, or milliamperes. Since the scope can measure the voltage drop across a known value of resistance, the amplitudes of either voltage or current waveforms can be measured with a scope.

Scope patterns indicate the peak and the peak-to-peak voltages of a waveform if the scope is suitably calibrated. The relations of these voltages in a sine wave are depicted in Fig. 3-1A. Note that in a sine wave the positive-peak voltage is equal to the negative-peak voltage, the peak-to-peak voltage is equal to twice the peak voltage, and the root-mean-square (rms) voltage is equal to 0.707 of the peak voltage.

You will find that the positive-peak voltage in a complex waveform is generally different from the negative-peak voltage. This fact is illustrated in Fig. 3-1B. When no input voltage is applied to the scope, the trace rests at a certain reference level on the screen. This is the zero-volt level. When a complex waveform voltage is applied to the scope input terminals, the waveform is displayed in a certain relation to the reference (zero-volt) line, as seen in Fig. 3-1B.



(A) Sine wave.



(B) Unsymmetrical waveform.

Fig. 3-1. Peak voltage relations.

The zero-volt line divides the complex waveform into a positive half cycle and a negative half cycle. The excursion above the zero-volt line gives the negative-peak voltage. The total excursion (sum of positive- and negative-peak voltages) gives the peak-to-peak voltage of the waveform.

The positive-peak voltage is not necessarily equal to the negative-peak voltage in a complex waveform, but the area of the positive half cycle is always equal to the area of the negative half cycle. This results from the fact that there is just as much positive electricity as negative electricity in each cycle. Horizontal deflection is linear in time when sawtooth deflection is used, and electrical quantity is given by the product of voltage and time.

Otherwise stated, the positive and negative excursions of the Fig. 3-1 waveforms enclose exactly equal areas. You would judge this to be true by simple inspection. If you have a knowledge of calculus, you can integrate voltage with respect to time for a generalized complex waveform and prove this fact analytically. The scope is operating as an electronic computer in this application; it automatically performs the integrations and separates the equal areas at the zero-volt level. This is an analog-computer situation.

PEAK-TO-PEAK, RMS, AND DC VALUES

The rms voltage is 0.707 of the peak voltage only for a sine wave. Any complex waveform has a different rms value. The rms voltage of a complex waveform cannot be measured directly with a scope or with ordinary service voltmeters. What is the significance of an rms voltage? This concerns the power developed by a waveform. For example, if a soldering iron is heated from a 117-volt rms AC line, it will develop just as much heat as when powered from a 117-volt DC line. In other words, the rms voltage of a waveform relates it to a DC voltage that will produce the same amount of power in a resistor. In most situations you are concerned only with the power developed by a sine wave; hence, the rms voltages of complex waveforms are not of general interest.

Peak-to-peak voltages are of chief concern in analysis of waveforms generated by electronic circuitry. In certain situations a peak voltage is also significant. There is an important relation between peak-to-peak and DC voltage values which is encountered in working with DC scopes. Recall that a DC scope can be calibrated either from a sine-wave or a DC voltage source, as mentioned in the preceding chapter. This fact results from the equal deflections produced by a given value of either DC or peak-to-peak AC voltage. If you apply +10 volts to the vertical input terminals of a DC scope, the beam will be deflected upward by a certain amount; if you apply −10 volts, the beam will be deflected downward by the same amount. If you apply a 10-volt peak-to-peak AC input to the scope, the excursion of the beam will be the same as if 10 volts DC were applied. To put it another way, it makes no difference whether the DC scope is calibrated from a 10-volt DC source or a 10-volt peak-to-peak AC source. In either case you will step off the same number of vertical intervals.

Note that if you apply a DC input voltage to an AC scope, the beam merely flicks up (or down, depending on polarity) and promptly comes to rest at its original level. The reason for this transient action is that an AC scope utilizes an RC-coupled vertical amplifier. The coupling capacitors will not pass DC, because a DC voltage has zero frequency, and a capacitor has infinite reactance at zero frequency. Inasmuch as DC cannot be passed, why does the beam nevertheless flick up momentarily when you apply a DC voltage? This happens because the sudden application of the DC voltage is equivalent to the leading edge of a square wave. Thus, the scope responds just as if a square-wave voltage had been applied.

If you apply a DC voltage to the vertical input terminals of an AC scope then break the connection and apply the voltage once again, the beam does not respond the second time. This is because the first application charged up the input coupling capacitor, and the capacitor (if good) holds this charge. Of course, if the capacitor is leaky, the beam will flick on the second application of the DC voltage. Hence, this is a quick check which shows whether the input coupling capacitor to the AC scope is defective and may need replacement. Eventually, of course, any charged capacitor will discharge itself, because insulation resistance is never infinite. Nevertheless, the input coupling capacitor in an AC scope should hold a charge for at least 5 or 10 seconds.

RESISTANCE WAVEFORMS

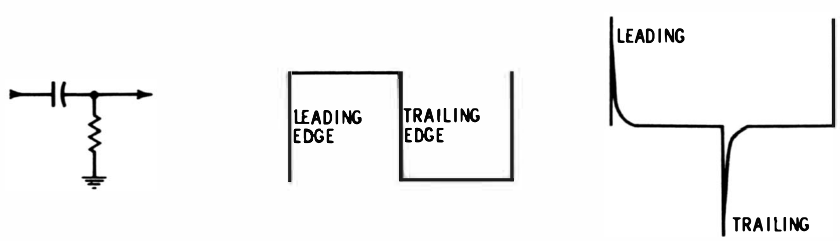
Everyone is familiar with the use of an ohmmeter to measure resistance. A scope can also be used to measure resistance. It has the advantage of high sensitivity with fast response to change in resistance. A common example of a resistance waveform is the output from a strain gauge. Wire changes its resistance when it is strained in extension or compression. Hence, if a zig-zag length of wire is bonded to an insulating sheet and cemented to some structure (such as a girder) which is subjected to varying forces, the resistance of the wire (strain gauge) changes with any bending of the structure.

If a constant current is passed through the strain gauge, and the vertical input leads of a scope are connected across the gauge terminals, the scope deflection will be proportional to resistance. The resistance variation which produces the scope waveform may be rapid or slow; it is always in step with the varying forces applied to the structure under test. If the resistance waveform has a slow variation, a DC scope is used. Resistance waveforms with rapid variation can be displayed accurately on an AC scope.

Thus, simple test setups suffice to display the three basic electrical parameters of voltage, current, and resistance. While voltage waveforms are most commonly utilized, current waveforms are often of interest also. Resistance waveforms are less common, although they are quite familiar to technicians in various branches of industrial electronics.

PRINCIPLES OF DIFFERENTIATION

Fundamentals of differentiation were mentioned in the preceding chapter. Basic principles of the differentiating action will now be explained. If a differentiating circuit has a short time constant and a square wave is applied, the peak-to-peak output voltage is twice as great as the input voltage, as indicated in Fig. 3-2. The initial spike or surge has the same peak-



(A) Differentiator circuit. (B) Input waveform. (C) Output waveform.

Fig. 3-2. Differentiator action.

to-peak voltage as the square wave, and it soon decays practically to zero. The second spike or surge is in the opposite polarity and also has the same peak-to-peak voltage as the square wave. Hence, the peak-to-peak amplitude of the output waveform in this case is double the amplitude of the input square wave.

What about the harmonics in the differentiating output? First, you will find the same harmonic frequencies present as in the square wave itself. However, the differentiating circuit weakens the low frequencies with respect to the high frequencies. Hence the relative voltages of harmonics in the differentiated output are not the same as in the input square wave.

Harmonic Amplitudes in a Differentiated Square Wave

Recall that a square wave consists of a fundamental frequency plus many odd harmonics of this fundamental frequency. When a square wave is passed through a differentiating circuit, each of its frequencies can be considered apart from all of the other frequencies. That is, you can consider the circuit action with respect to the fundamental by itself, with respect to the third harmonic by itself, and so on. Then, if you add up all the separate outputs, you will obtain the differentiated waveform.

Suppose that a differentiating circuit contains a 2700-mmf capacitor and a 1-megohm resistor. If you apply a 60-cycle square wave to the circuit, the fundamental frequency is 60 cycles. The capacitor has a reactance of about 1 megohm at 60 cycles. Hence, the fundamental is attenuated to 71% of the input level by passage through the differentiating circuit. Next, the third harmonic in the square wave has a frequency of 180 cycles. The capacitor has a reactance of about 330,000 ohms at this frequency. Hence, the third harmonic is attenuated to 94% of its input level by passage through the differentiating circuit. The fifth harmonic has a frequency of 300 cycles, and the capacitor has a reactance of 200,000 ohms at this frequency; therefore, the fifth harmonic is attenuated at 98% of its input level by passage through the differentiating circuit.

How then does it happen that although the differentiating circuit weakens all the harmonics and weakens the low-frequency voltages more than the high-frequency voltages, the end result is a waveform with twice the original amplitude? The reason is simply that the harmonics are also shifted in phase by the differentiating circuit. This phase shift is such that the peaks of all the harmonics are moved closer together during the pulse than in a square wave. As a result, the sum of the harmonic voltages at the instant of peak voltage is greater than before their phases were shifted.

BASICS OF RC CIRCUIT ANALYSIS

The foregoing review of harmonic amplitudes in a differentiated square wave gives a general picture of differentiating circuit action. Now, it will be helpful to explain the basics of the analysis. First, it was stated that the reactance of a 2,700-mmf capacitor is about 1 megohm at 60 cycles. How do you know this? You can read the answer from a reactance slide rule, or you can calculate the reactance from the relation:

$$X_C = \frac{1}{2\pi fC}$$

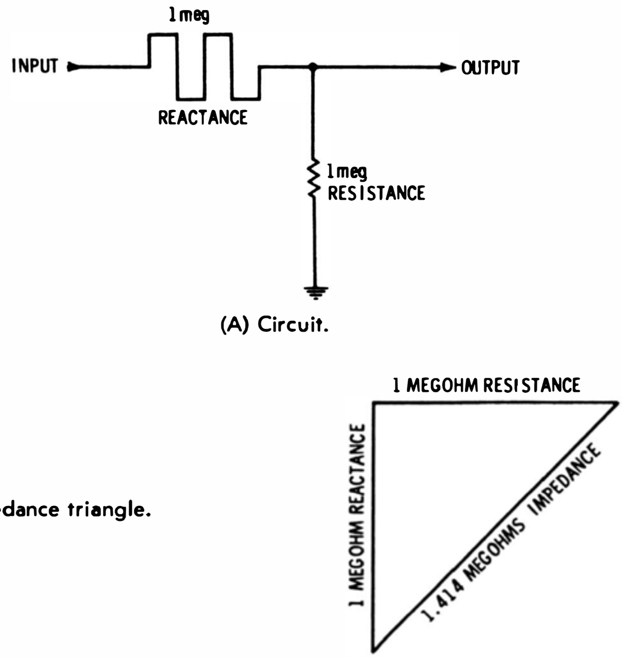
where,

X_C is the capacitive reactance in ohms,
π is 3.1416,
f is the frequency in cycles per second,
C is the capacitance in farads.

When the arithmetic is performed, the answer is found to be about 1 megohm.

Next, it was stated that the fundamental is attenuated to 71% in passing through the differentiating circuit. How do you know this? The attenuation is seen from the triangle shown in Fig. 3-3B. The triangle shows the ohms relation in an RC circuit. To remind yourself that reactive ohms add at right angles to resistive ohms, you may find it helpful to draw reactive ohms with a different symbol than resistive ohms. The input voltage is applied across the impedance, which has a value of 1.414 megohms. You do not need to make the calculation—simply scale off the impedance with a ruler. Inasmuch as the 1-megohm resistance is approximately 71% of the 1.414-megohm impedance, it follows that the voltage across the 1-megohm resistor is attenuated to 71% of the input voltage.

It is apparent from the diagram in Fig. 3-3A that a differentiating circuit acts simply as a voltage divider. The only complication is that since it is an AC voltage divider, the two different types of ohms must be combined at right angles. The RC circuit is almost, but not quite, as easy to work out as an ordinary resistive voltage divider. It is quite essential that you see the difference between DC and AC circuit response, because all waveforms are based on AC circuit response.



(A) Circuit.

(B) Impedance triangle.

Fig. 3-3. Impedance relationship in an RC circuit.

The circuit response to the third harmonic is determined in the same way as has been described for the fundamental. The only difference is that the third harmonic has three times as high a frequency as the fundamental so that the capacitive reactance is only 1/3 as great, or 330,000 ohms. In turn, the ohms triangle has different proportions, and the third harmonic is attenuated to 94% by the differentiating circuit. It is by no means implied that you will need to make this graphical analysis when you are called on to analyze differentiating action in a circuit. On the other hand, it is vital that you understand why the circuit weakens the low frequencies with respect to the high frequencies.

Understanding Phase Shift

The maximum phase shift that can be theoretically obtained in a differentiating circuit is 90°. The reason for this limit is that the current leads the voltage by 90° in a pure capacitance. In a differentiating circuit the current into the capacitor causes a voltage drop across the circuit resistance. Inasmuch as voltage and current are in phase in a resistance, the voltage output from a differentiating circuit has the same phase as the current. If the capacitive reactance is very large compared with the resistance in the circuit, the output voltage will be shifted almost 90° in phase. On the other hand, if the capacitive reactance is very small, the output voltage will have practically the same phase as the input voltage.

Beginners occasionally have difficulty in understanding why current and voltage are 90° out of phase in a capacitor. Understanding of this relation is easy when the capacitor is recognized as an electrical storage device. A capacitor can be compared with a tank of compressed air—the more air pressure you apply to the tank, the more air you force into the tank. Similarly, if you apply more voltage to a capacitor, you will force more electrical charge into the capacitor. The capacitor exerts an opposition to the incoming current, just as a tank of compressed air exerts a back pressure against the air that you are forcing into it.

If you open a valve in a tank of compressed air, the air flows out; similarly, if you connect a wire across a charged capacitor, its electric charge flows out. If you increase the voltage across a capacitor, electricity is being stored in the capacitor as long as the voltage is increasing; if you decrease the voltage across a capacitor, the stored energy flows out of the capacitor. If you increase the voltage across a capacitor quickly, electricity flows into the capacitor quickly; if you increase the voltage across a capacitor slowly, electricity flows into the capacitor slowly.

Common-Sense Analysis

Suppose you decrease the voltage across the capacitor quickly—the stored charge then flows out quickly. But if you decrease the voltage across the capacitor slowly, the stored charge flows out slowly. These basic facts are obvious. Now refer to Fig. 3-4. As the voltage E starts to rise from zero, it increases rapidly. Hence, current flow into the capacitor is rapid. On the other hand, as E approaches the 90° point, the voltage levels off and ceases to increase at its peak. In turn, no more current flows into the capacitor at the peak-voltage point—the

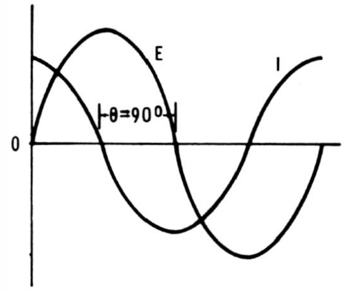


Fig. 3-4. Phase relationship in pure capacitance.

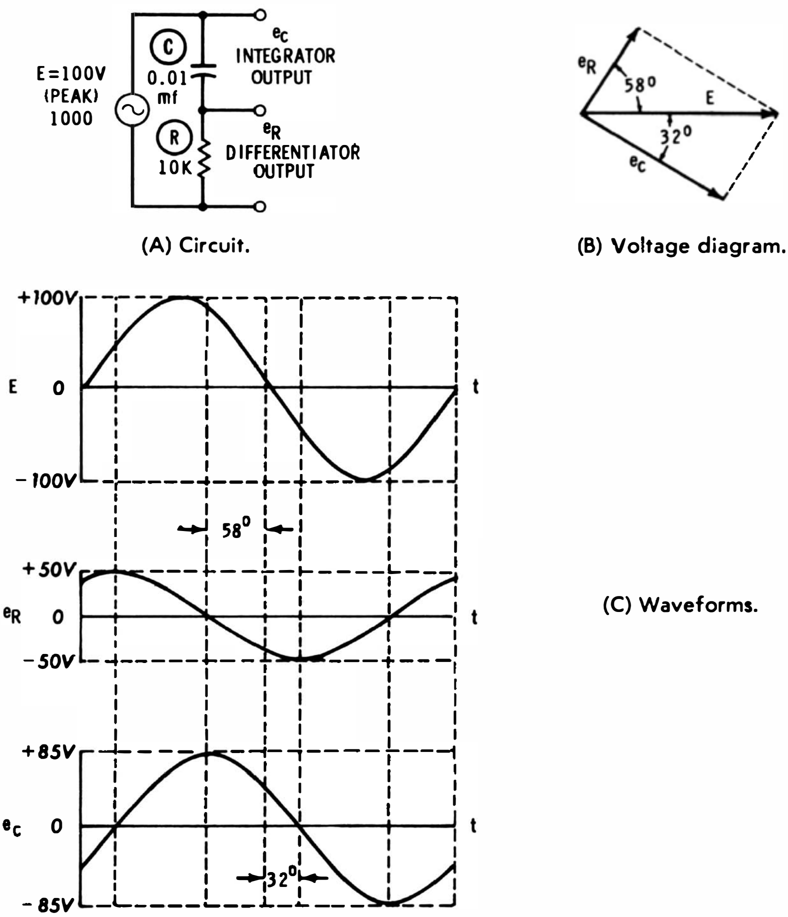
current flow has dropped to zero at this point. This is the same as saying that the current flow is zero when the voltage is maximum. The same common-sense analysis can be applied to the interval from 90° to 180°, during which time current is flowing out of the capacitor. To summarize, it is clear that the current flow must be 90° out of phase with the voltage across a capacitor.

Resistance and Capacitance in Series

It is interesting to consider the phase relation between current and voltage when capacitance and resistance are connected in series (as in a differentiating or integrating circuit). Fig. 3-5 shows this situation. If you take the output from across the resistor, the circuit is called a differentiating circuit; if you take the output from across the capacitor, it is called an integrating circuit. In either case the phase difference between the input voltage and the current is obviously the same. Again, a sine-wave voltage is applied to the circuit for a common-sense analysis of phase.

The same general principle previously explained for a pure capacitance applies in this case. Current flows into the capacitor when the voltage is increased; conversely, current flows out of the capacitor when the voltage is decreased. If the voltage is increasing rapidly, the current flow increases rapidly, and vice versa. However, there is a difference in circuit action caused by the series resistance. The resistance slows down the rate at which the capacitor can be charged or discharged.

This simply means that the current flow tends to lag behind the voltage. To put it another way, voltage E is increasing most



(A) Circuit.

(B) Voltage diagram.

(C) Waveforms.

Fig. 3-5. RC circuit relationships.

rapidly as it rises from zero, but the peak current flow is now delayed somewhat due to the opposition of the resistance. For the values given in Fig. 3-5, the peak of current flow does not occur until 32° after the voltage starts its rapid rise. Likewise, current flow does not fall to zero until 32° after the voltage has passed its peak and is no longer increasing. The resistance reduces the rate of outflow of current from the capacitor, just as it reduces the rate of inflow of current into the capacitor.

Phases in RC Series Circuits

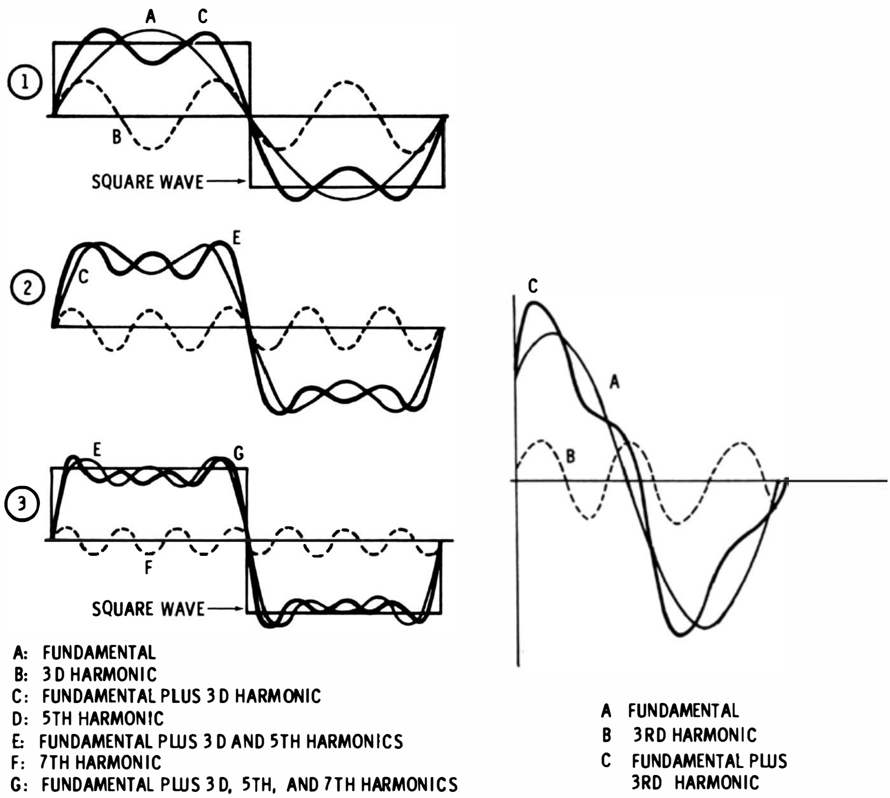
As just explained, current flow does not lead the voltage by 90° in an RC series circuit. Instead, the current flow leads by less than 90°. For the particular values used in Fig. 3-5, the current lead is 58°. It is evident that if you choose a very large value of resistance, the current lead will become very small and approach 0° as a limit. From another point of view the reactance of the capacitor becomes negligible when you make the resistance extremely large—effectively, the circuit tends to look like a pure resistance to the source voltage.

On the other hand, when you make the series resistance extremely small, its value becomes negligible with respect to the reactance of the capacitor. If the resistance is so small that it can be practically disregarded, the circuit looks like a pure capacitance to the voltage source. Thus, the output voltage from the circuit can be made to differ in phase from the input voltage over the range from practically zero to 90°. This is the fundamental principle of simple phase-shifting circuits which are widely used in both service and industrial equipment.

Phase Shift With Square Wave Applied

With these simple facts in mind it is easy to see why the various harmonics are shifted in phase by different amounts when a square wave is applied to an RC series circuit. Each harmonic has a different frequency, which means that the capacitor has a different reactance for each harmonic. Returning to the former example of a 2700-mmf capacitor connected in series with a 1-megohm resistor, recall that the capacitor has a reactance of about 1 megohm at 60 cycles, a reactance of 0.33 megohm at 180 cycles, and a reactance of 0.2 megohm at 300 cycles. The phase angle between output and input is large when the frequency is low (60 cycles); but the phase angle between output and input is small when the frequency is high (300 cycles).

Knowing that low frequencies will be shifted in phase more than high frequencies by a differentiating circuit, you are now in a good position to recognize that the peaks of the harmonics in a square wave are all shifted by the circuit action, as is evident from Fig. 3-6. In both of the diagrams the fundamental is taken as the reference. Consider the effect of differentiation on the phase of the third harmonic. In the square wave (Fig. 3-6A) the third harmonic has a negative peak which subtracts from the positive peak of the fundamental, thereby making the resultant waveform flatter than a sine wave. On the



(A) Square wave. (B) Pulse.

Fig. 3-6. Harmonic phase relationships.

other hand, in the pulse (Fig. 3-6B), the third harmonic has a positive peak which adds to the positive peak of the fundamental, thereby making the resultant waveform more pointed than a sine wave.

You can form a pulse from the same harmonics as are present in a square wave. To do so, you need merely shift the phase of each harmonic so that all positive peaks occur at the same instant. A differentiating circuit has this general action. To see why this is so, first observe the relative harmonic phases in the square wave (Fig. 3-6A). Note that all harmonics start in phase with the fundamental of a square wave. In other words, each harmonic starts rising from zero voltage at the start of the square wave.

This is no longer the case after the square wave has passed through a typical differentiating circuit; the fundamental is shifted 45° from its original position, the third harmonic is shifted 18° from its original position, and the fifth harmonic is shifted 11° from its original position. What this means with regard to the peaks of the waveforms is shown in Fig. 3-6. In the square wave the fundamental and the third harmonic have opposing positive and negative peaks. On the other hand, in the differentiated wave the fundamental and third harmonic have essentially aiding peaks. If you plot the shift of the fifth harmonic, you will see that it too will aid the fundamental peak in the differentiated wave.

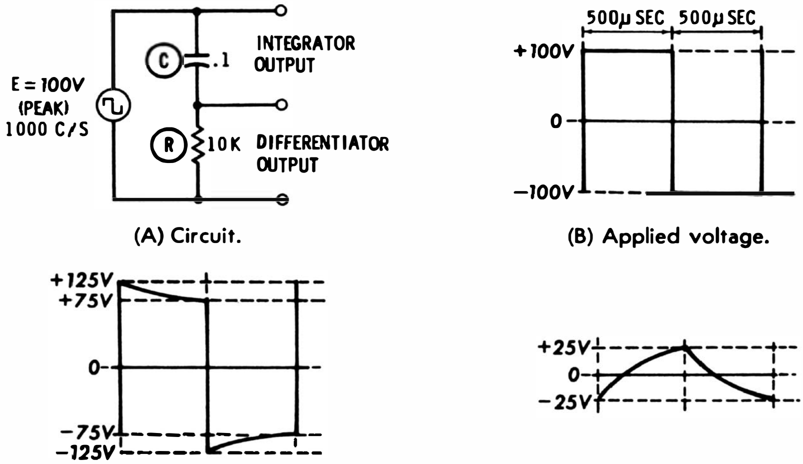
Sharpness of Differentiated Wave

As you know, the output from a differentiating circuit with a very short time constant is a sharp spike. On the other hand, the output from a differentiating circuit with a long time constant is a much broader pulse. In terms of harmonic phase shift, the short time constant brings the peaks of the harmonics into a highly aiding position, but a long time constant brings the peaks of the harmonics into only a partially aiding position.

It is not anticipated that you will need to go through this analytical procedure when you are evaluating the action of a differentiating circuit. However, it is important to understand what is happening in the circuit from a qualitative standpoint. Unless you recognize the circuit actions which underly waveforms, you will be baffled and fail in attempts to analyze practical situations. If you understand why a certain type of waveform appears on the scope screen, you are then in a position to recognize the circuit action behind the waveform. This circuit action may be normal or abnormal, depending on the particular circumstances. If the waveform is abnormal, your ability to analyze the pattern will guide you to the circuit defect that is causing the abnormal waveform.

KIRCHHOFF'S LAW

Kirchhoff's law applies to all circuits. This law states that the sum of all the voltages around a complete circuit is zero. Observe how this applies to Fig. 3-7. The generator applies 100 peak volts to the 0.1-mfd capacitor and 10-K resistor in series. Since a negative charge of 25 volts remains on the capacitor from the preceding cycle, the total voltage across the resistor



(A) Circuit.

(B) Applied voltage.

(C) Resistor voltage.

(D) Capacitor voltage.

Fig. 3-7. RC differentiator and integrator action on a square wave.

at the start of the positive half cycle is 125 volts. The sum of the capacitor and resistor drops is 100 volts. This 100 volts opposes the 100 volts of the generator, and the sum of the voltages around the circuit is equal to zero.

Going from peak voltages to instantaneous values, you will find that at every instant the sum of the voltages around the circuit is equal to zero. This is the consequence of the basic characteristics which were shown in Fig. 2-9; Curve B is simply curve A turned upside down. It is an illustrative statement of Kirchhoff's law.

If it seems strange that the voltage drop across the resistor is 25 volts greater than the source voltage, refer to Fig. 3-2. This situation illustrates a short time constant in which the output peak-to-peak voltage is actually twice as great as the input peak-to-peak voltage. Note in Fig. 3-7 that the output voltage decays 25 volts between the leading and trailing edges. The input leading edge still changes 200 volts every time. Hence, the output voltage consists of the difference between the input voltage and the decay voltage. For the example shown in Fig. 3-7, this circuit action makes the peak output voltage 25 volts greater than the peak input voltage.

VOLTAGE AND CURRENT WAVEFORMS

From the previous development it is clear that a waveform may depict either voltage or current. In Fig. 3-7 the integrator output is a voltage waveform; the scope displays the voltage across the capacitor. On the other hand, the differentiator output is a current waveform; the scope displays the current through the resistor. Of course, the scope senses the voltage drop across the resistor while it is displaying the charging-current flow into the capacitor.

How is the current measured? Let us suppose that the scope is calibrated for 25 peak-to-peak volts per vertical interval. The differentiator output is taken across a 10-K resistor. By Ohm's law, the scope calibration then becomes 2.5 milliamperes peak-to-peak per vertical interval. If the differentiator output deflects the beam 10 squares, the peak-to-peak charging current is 25 milliamperes.

DIFFERENTIATION AND INTEGRATION OF SINE WAVES

It is sometimes stated that a sine wave cannot be differentiated or integrated. This is true insofar as waveshape is concerned—the output waveform is always the same as the input waveform. Nevertheless, this assertion neglects considerations of phase. If a sine wave flows in a differentiating circuit, the output voltage leads the source voltage. Or, if a sine wave flows in an integrating circuit, the output voltage lags the source voltage.

These facts follow from the principles which have been noted previously—a capacitor draws a leading current with respect to the source voltage. The output in a differentiating circuit is taken across the resistance; hence, the output voltage is proportional to current flow and leads the source voltage. This fact sometimes causes confusion for the beginner, because he often will ask: "How can a current exist in the circuit before voltage is applied?" This question confuses the steady state which is assumed for sine-wave drive, as contrasted with the transient state which exists for a brief period after the voltage is first applied. This interesting point will be discussed later in this chapter.

Now, however, to continue with the sine-wave relations in an RC circuit, the integration of a sine wave results in an output voltage which lags the source voltage. This fact is easily understood by returning to Fig. 3-5, the full implications of which might have escaped you the first time around. When you combine the resistive and reactive ohms in the circuit, each side of the impedance triangle which you draw indicates the phase of its associated voltage. These lines are shown in Fig. 3-5B as arrows all starting from the origin, so that the phase relations are clearly apparent. Here, the voltage across the resistor (e_R), is leading the source voltage (E) by 58°. The voltage across the capacitor (e_C) is lagging the source voltage (E) by 32°. Inasmuch as these phase relations are established by the resistive and reactive ohms which are present in this circuit configuration, it is clear that the output voltage from an integrating circuit must lag the source voltage by an amount determined by the circuit design.

TRANSIENT AND STEADY STATES OF SINE WAVES

A distinction must usually be made between the transient and the steady state. That is, if you switch a sine-wave voltage suddenly into an RC circuit, the steady-state conditions do not exist at the instant that current starts to flow. But the voltages soon settle down to their steady-state relationships. How long is the transient interval? This depends on the time constant of the circuit. If the time constant is long, it takes more time for the circuit to reach equilibrium with the resistor voltage leading the capacitor voltage by 90°.

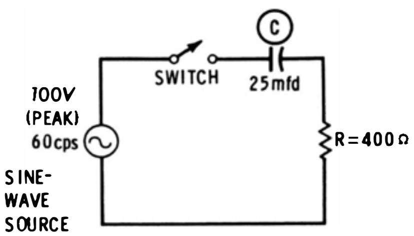
A specific situation is depicted in Fig. 3-8. Let the voltage across the capacitor be called e_c. Then, by application of Kirchhoff's law (which is not carried out here but may be consulted in textbooks):

$$e_c = \frac{-E}{Z\omega C}\cos(\omega t + \phi) + \frac{E\epsilon^{\frac{-t}{RC}}}{Z\omega C}\cos\phi$$

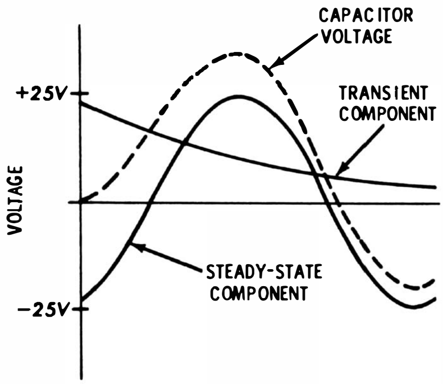
where,

E is the peak applied voltage,
ω is 2π times the frequency in cycles per second,
Z is the circuit impedance,
ϕ is the angle whose cotangent is ωRC,
R is the resistance in ohms,
C is the capacitance in farads,
ϵ is 2.718.

In the expression for e_c, the first term is the steady-state voltage, while the second term is the transient voltage. Eventually, of course, the transient term decays to zero, leaving only the steady-state term. When the switch is first closed, the two terms subtract from each other, because one is positive and the other is negative.



(A) Circuit.



(B) Waveforms.

Fig. 3-8. Transient response of series RC circuit.

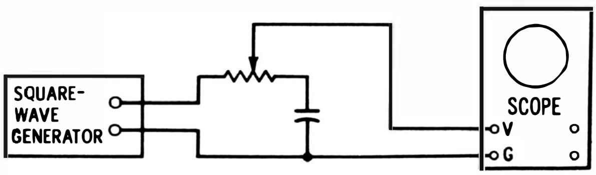
The graph of this equation for the circuit values in Fig. 3-8A is shown in Fig. 3-8B. (The values were chosen to make the transient voltage easily recognizable.) Note that the resultant voltage waveform is the algebraic sum of the steady-state and transient components.

It can be seen from a close study of the equation that the relation between the steady-state and transient components in any given case depends on the values of R and C. In this illustration it was assumed that the switch was closed at the start of the cycle of the applied voltage. If the switch is closed at any other time, the resultant waveform is further altered.

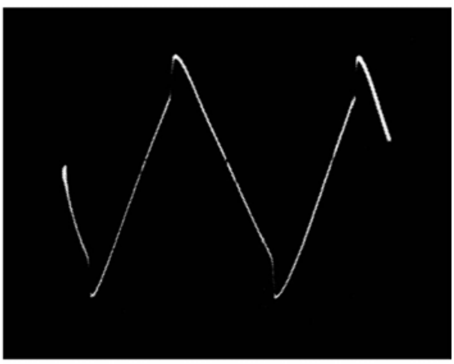
ELIMINATION OF THE TRANSIENT INTERVAL

It is clear that the current cannot lead the voltage at the instant of switching in the foregoing example, because there is as yet no current established in the circuit to lead the voltage. Hence, it might be supposed impossible to devise a switching circuit which could establish the steady state instantaneously. However, this supposition would be false. Consider an electronic switch which can be set to close at any point you choose along the source waveform. Then, a setting will be found which will establish the steady state instantaneously, with no distortion at all from a transient interval.

What is this critical instant for switching which eliminates the transient and establishes the steady state at the outset? This instant corresponds to the phase of the source for which the capacitor voltage will be zero in the steady state. In other words, switching must occur at a phase which normally exists for zero stored energy in the capacitor. The critical phase, in



(A) Circuit configuration.



(B) Typical waveform.

Fig. 3-9. Combined integrator and differentiator.

turn, is determined by the time-constant of the RC circuit. At the critical instant, the source voltage is somewhere between its zero and peak values.

Just as it is possible to time an electronic switch so that an AC voltage can be introduced into an RC circuit without transient distortion, it is also possible to time the switch so that the AC voltage can be turned on without distortion in an RL circuit. Of course the timing must be different in this case.

COMBINED DIFFERENTIATION AND INTEGRATION

Some circuits, such as in Fig. 3-9A, operate as simultaneous differentiators and integrators. The output waveform is taken across the capacitor and part of the resistor. The combination waveform can have a wide variety of shapes, depending on how much of the differentiated voltage is introduced, and also on the time-constant of the circuit. A typical output waveform is shown in Fig. 3-9B.

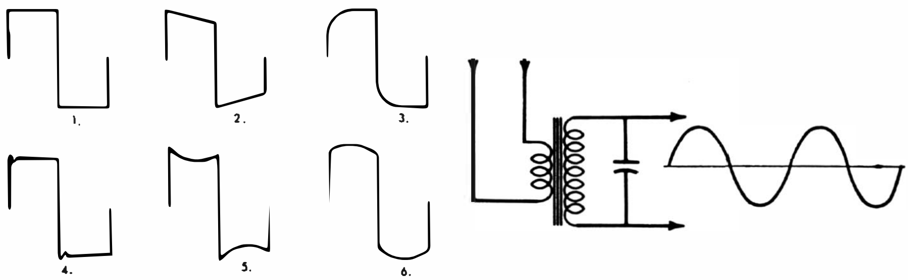
CHAPTER 4

Waveshaping Principles and Analyses

As the term indicates, waveshaping techniques are concerned with changing one waveform into another. Television receivers and transmitters, radar equipment, industrial-electronic control devices, and electronic computers are examples of the application of these techniques. You will find an extensive array of circuit actions employed in waveshaping processes. Differentiation, integration, clipping, clamping, resonance, rectification, timing, mixing, counting, amplifying, and heterodyning are all used. These circuit actions are not covered in detail in these pages, but interested readers may refer to specialized texts such as the *Basic Electronics* series.

WAVESHAPING WITH RESONANT CIRCUITS

Fig. 4-1 illustrates how a tuned circuit shapes a complex waveform into a sine wave. If you apply each of the waveforms of Fig. 4-1A individually to the tuned transformer (Fig. 4-1B), the secondary output is a sine wave in each case. Maximum output amplitude is obtained when the waveshaping circuit is resonant to the fundamental frequency of the input waveform. However, a sine-wave output of less amplitude results when the circuit is tuned to any odd harmonic of the input waveform. A small sine-wave output is also obtained by tuning to the ringing frequency of waveform 4 in Fig. 4-1A.



(A) Input waveforms. (B) Circuit and output waveform.

Fig. 4-1. Waveshaping with resonant circuit.

In passing it is instructive to note the chief characteristics of these input waveforms. Thus, 1 depicts an ideal square wave. The tilt along the top and bottom of 2 results from phase shift of the harmonics in the reference square wave—in other words, all the harmonic voltages in 2 have the same amplitudes as in 1. Diagonal corner rounding in 3 is the result of high-frequency attenuation and phase shift. The overshoot and ringing in 4 is caused by LC elements in the source, such as inadequately damped peaking coils in a video amplifier. Curvature in the top and bottom of waveform 5 is the result of low-frequency attenuation—the small amount of tilt results from harmonic phase shift. The opposite curvature displayed in 6 is the result of high-frequency attenuation with negligible phase shifts.

The tuned secondary circuit in Fig. 4-1B must have a high Q to provide an undistorted sine-wave output. Therefore, its frequency response is sharp, so that only one frequency is transferred from primary to secondary. The symbol Q refers to the quality factor of the resonant circuit; $Q = X_L/R$ in most practical situations. X_L is the number of inductive ohms at the resonant frequency of operation, and R is the AC resistance of the coil. The effect of the capacitor on Q value is commonly neglected, because nearly all the circuit losses are imposed by the inductor.

A generalized configuration is depicted in Fig. 4-1, but you will probably be interested in a specific application also. Refer to Fig. 4-2; here a quartz crystal is used to develop a 3.58-mc CW signal from a complete color signal in a color-TV receiver. The complete color signal contains 3.58-mc bursts which follow each horizontal-sync pulse. Thus, the 3.58-mc signal has an interrupted and recurrent characteristic. It is desired to shape this succession of bursts into a continuous sine wave.

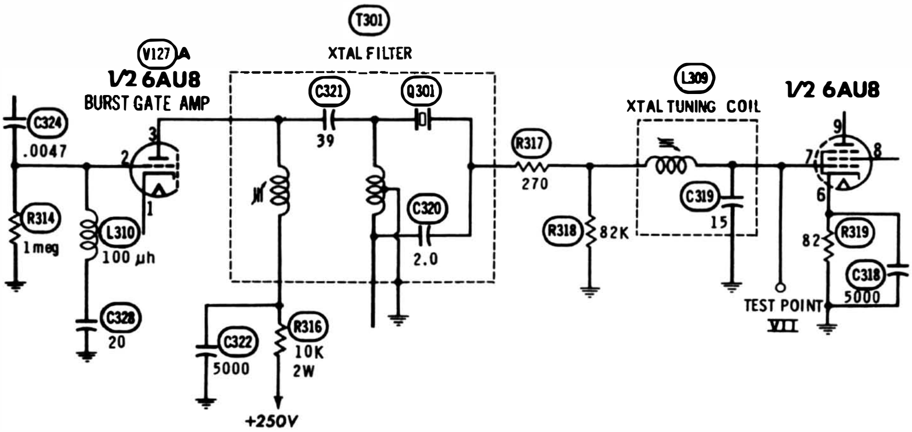


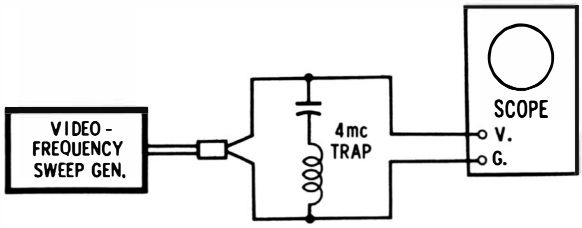
Fig. 4-2. Application of ringing circuit in color-TV receiver.

The required waveshaping action is obtained through the use of a quartz crystal as a resonant circuit having a very high Q. It is called a filter, because it separates, or filters out, the 3.58-mc burst frequency from any other frequencies which might be present. An adjustable coil is provided in series with the crystal so that its resonant frequency can be adjusted exactly to that of the burst. In addition, correct adjustment of the slug provides an output phase which is exactly the same as the transmitted burst phase.

Although the input to the crystal filter is an interrupted series of bursts, the output is essentially a continuous sine wave. This characteristic results from the very high Q of the crystal. It can be shown that when Q is high, a large energy storage takes place—between the incoming bursts, output is sustained by this large reservoir of stored energy in the crystal. The configuration is also called a crystal-ringing circuit. When an incoming burst energizes the crystal, it vibrates much as a bell does when it is struck. Of course, this mechanical vibration is very rapid; it occurs 3,580,000 times a second.

SCOPE FREQUENCY RESPONSE

Since a color burst has a 3.58-mc frequency, it cannot be viewed with a scope unless wide-band response is provided.



(A) Test setup.

(B) Scope display.

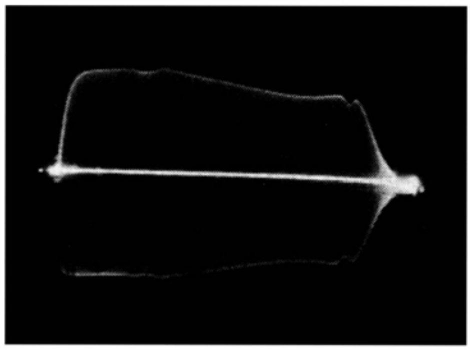


Fig. 4-3. Frequency response of scope vertical amplifier.

Scopes used to check waveshapers such as shown in Fig. 4-2 should have a reasonably uniform response out to 4 mc. Note in passing that you can easily check the frequency response of a scope with a video-frequency sweep generator, as shown in Fig. 4-3A. This is an FM generator which provides an output varying periodically from about 100 kc to 5 mc.

Note also the 4-mc series-resonant trap in Fig. 4-3A. As the FM voltage sweeps through the 4-mc point, the trap absorbs a small amount of energy from the circuit and produces a dip in the wave envelope near the right end. This is called an absorption marker and is itself a waveshaping operation from one point of view. Its specific purpose, however, is to identify accurately the 4-mc point on the envelope of the waveform.

TIME MARKERS FROM RINGING CIRCUIT

Ringing-circuit waveshapers are also found in laboratory equipment and radar indicators. However, the purpose of waveshaping is somewhat different in these instances. For example, it has been previously mentioned that instantaneous voltages on a waveform can be marked by intensity-modulating a scope from a voltage of known frequency. This is basically a time-marker technique. This technique is used in radar equipment for range estimation and measurement. A dominant characteristic of such waveshapers is synchronization with the displayed signal.

A resonant circuit contained in a shock-excited oscillator configuration provides generation of the desired marking frequency plus synchronization with the signal repetition rate. A circuit in which the plate current of a switching tube flows through the inductor of a tank circuit is commonly used to produce a damped train of oscillations which is initiated by tube cutoff. A typical system is illustrated in Fig. 4-4. A negative-going square pulse drives the grid of V1 below cut-off at the instant that the sweep starts, thus causing L1 and C2 to ring. Sharp, well defined marker pulses are produced by feeding the output from the tank circuit through the remaining circuitry shown in Fig. 4-4.

The damped wave trains are clipped and amplified by V2 so that its plate output is an approximation to a square wave. Resistor R2, in series with the grid, limits the grid current so that the ringing circuit remains lightly loaded. This prevents the damped sine wave from decaying too rapidly for proper utilization. The cathode bias developed across R3 and C3 prevents the grid from going extremely positive, which also assists in minimizing grid-current flow. A low plate voltage is used to provide good clipping action. The output from V2 is coupled to the grid of V3, which is an overdriven amplifier and produces a good approximation to a square wave at its plate.

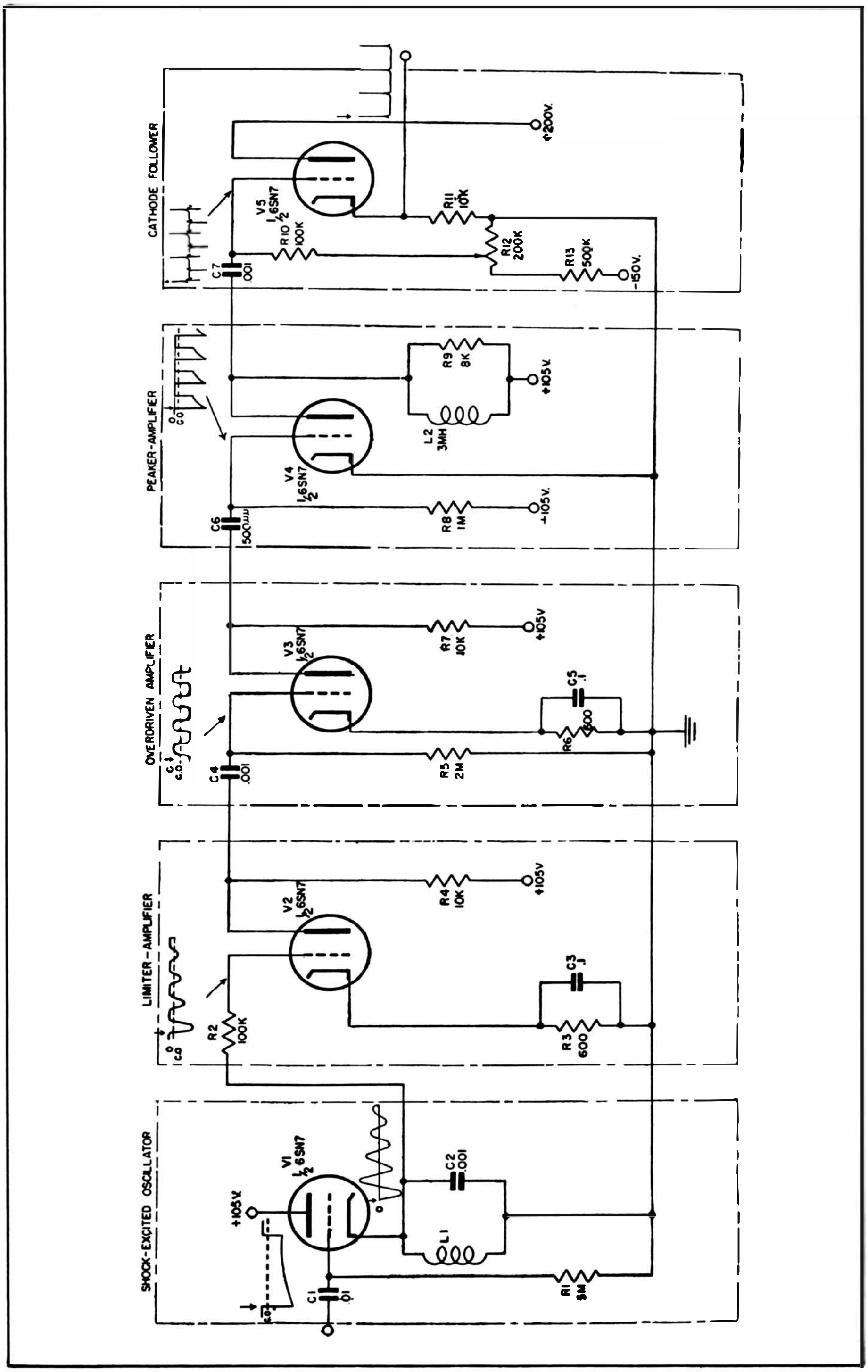


Fig. 4-4. Waveshaper for producing timing pulses synchronized with drive signal.

The peaker-amplifier tube (V4) has as its plate load inductor (L2) shunted by resistor R9. This inductor resonates with its distributed capacitance at a frequency of approximately 2 mc. When the tube is cut off by the negative-going square wave, the coil is shock-excited into oscillation. However, the shunt resistance damps the oscillation almost completely before one cycle is completed so that a positive pulse of approximately 0.25 microsecond duration is produced. When the grid swings positive, a negative pulse of smaller amplitude appears at the plate. This negative pulse has no significance, since the following tube is biased below cutoff so that only positive pulses can produce an output.

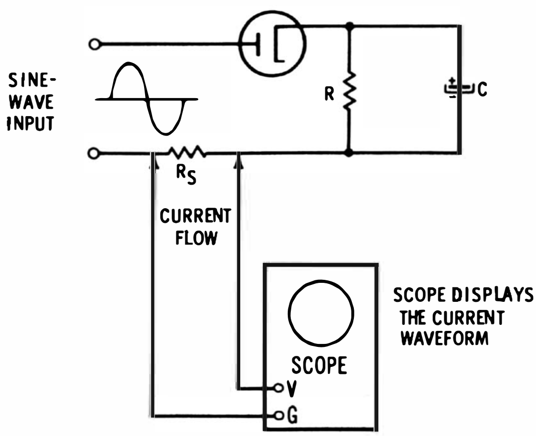
Note that the grid of V4 is returned to a positive potential, rather than to ground, in order to insure high conduction in the tube just before the grid swings negative. The large resistor (R8) in the grid circuit limits the grid current to a low value. From the pulse generator the shaped waveform is fed to a cathode follower which is biased below cutoff. By adjusting this bias so that the positive peaks raise the grid above cutoff by the desired amount, the amplitude of the marker pulse can be controlled. Thus, the end result of the waveshaping process is to generate a series of sharp and accurately timed pulses which are always locked in with the repetition rate of the deflection voltage.

WAVESHAPING WITH RC CIRCUITRY

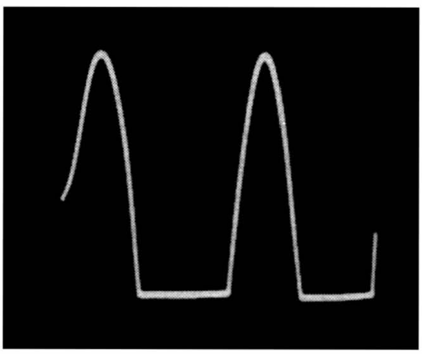
It is apparent that RC circuits can be used for a wide variety of waveshaping functions. For example, an RC configuration can be used to change a peaked-sawtooth wave into a pulse-type wave. This method is commonly used to produce a vertical-retrace blanking pulse in TV-receiver circuitry. The peaked sawtooth is unsuitable for blanking, inasmuch as it would cause severe picture shading from top to bottom of the screen. On the other hand, the pulse-type waveform has an essentially flat top which causes negligible picture shading.

Differentiating and integrating circuits only produce approximations to mathematical differentials and integrals. If the resistance is very small, the circuit action is more nearly in accord with the mathematical ideal. In theory the result of differentiating a true square wave is to produce a series of pulses that are infinitesimal in width and infinite in amplitude. The ideal situation is approached if you utilize a very small series resistance—the voltage drop across the resistor becomes a very narrow pulse. Again, in theory the result of integrating these pulses is to form a square wave; the first suddenly charges the capacitor to a certain voltage which is held until the next pulse arrives. This next pulse has an opposite polarity which suddenly brings the capacitor voltage once more to zero—thus a square wave is formed. It can be seen that differentiation and integration are opposite operations.

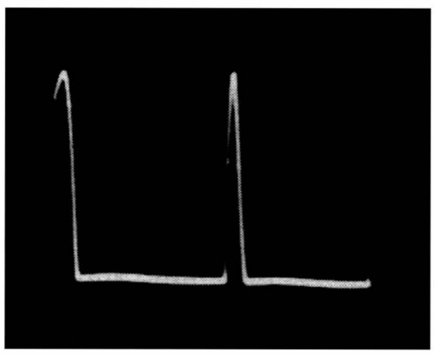
The waveforms in Fig. 4-5 result from application of a sine-wave voltage to a circuit containing nonlinear resistance such as a rectifier. When the load contains capacitance, as in Fig. 4-5,



(A) Circuit.



(B) Waveform with small capacitance.



(C) Waveform with large capacitance.

Fig. 4-5. Current waveforms in a half-wave rectifier with RC load.

the diode is back-biased, and current flow occupies less than a half cycle. Since a complete cycle occupies 360°, a half cycle occupies 180°, and the current waveforms in Fig. 4-5 occupy a progressively smaller number of degrees. Accordingly, such waveforms are described in terms of their conduction angle.

Capacitor C charges in proportion to the time-constant of the load and places a positive bias on the cathode of the diode. The higher the bias voltage, the smaller is the conduction angle. This bias consists of a DC component and an AC component. The DC component can be measured with a DC voltmeter or with a DC scope. Superimposed on this DC component is the AC ripple voltage (Fig. 4-6). The ripple waveform in this circuit is a semisawtooth. It rises to a peak with the current peak; the diode is then cut off by back bias, and the capacitor charge decays through R to form the semisawtooth wave.

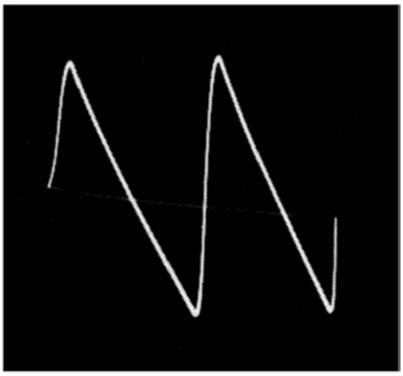


Fig. 4-6. Ripple-voltage waveform in half-wave rectifier with RC load.

Note in Fig. 4-5 that the current waveforms are both shown at the same amplitude. This is done because the conduction angle is being emphasized. However, as the conduction angle is decreased, the amplitude of the current waveform becomes less. In turn, the amplitude of the voltage waveform becomes lower as the value of *C* is increased. This is simply another way of saying that the amplitude of the ripple voltage decreases when you make the filter capacitor larger. If the filter capacitance or resistance R were infinite, the time constant would also be infinite and the ripple voltage would be zero. Likewise, the current-conduction angle in Fig. 4-5 would be zero, and the amplitude of the current waveform would be zero.

If you utilize a dual-trace scope, both the current waveform and the voltage waveform can be displayed simultaneously on the screen. Or, if you use an electronic switch, both current and voltage waveforms can be displayed simultaneously on the screen of an ordinary scope. Dual-trace presentation is very useful during circuit development, because the overall result of a circuit change can be observed without making connection changes or employing more than one scope. Dual-trace patterns are also advantageous in certain circumstances because the phase relation between any two chosen waveforms is displayed on the screen.

Note that a single-trace display does not show the relative phase of a waveform unless external sync is used. This lack of phase information on the internal-sync function results from the lack of a reference trigger or sync voltage. On the other hand, when external sync is used, the sawtooth oscillator in the scope is triggered independently of the waveform which is passing through the vertical amplifier. Likewise, when an electronic switch is used, the two waveforms are alternately sampled so that phase information is presented.

WAVESHAPING BY NONLINEAR RESISTANCE

The varying conduction angles illustrated in Fig. 4-5 result from the time constant of the RC load circuit. In addition, the rectifier is an essential component in the waveshaping circuit. A rectifier is a special case of nonlinear resistance—it is a form of resistance in which current will flow in one direction only; current flow is blocked in the reverse direction. Other forms of nonlinear resistance used in waveshaping circuits conduct current in either direction, but the current flow is disproportional to voltage. In other words, the resistance value depends on the instantaneous current value.

A practical example of waveshaping makes use of the nonlinear resistance characteristic inherent in a semiconductor diode. The resistance of a diode varies with current; it is basically a logarithmic relation, and the exact characteristic can be controlled by employing a suitable value of fixed resistance in the circuit. Two semiconductor diodes can be connected in opposite shunt polarity, so that a symmetrical waveshaping action is obtained on both positive and negative half cycles of the signal.

Logarithmic waveshapers are used because the output from the waveshaper can be made proportional to decibels—you will recall that db are a logarithmic unit of output. Inasmuch as ear response is proportional to decibels (rather than volts or watts), it is clearly advantageous to use a db waveshaper when analyzing audio signals. Then, the deflection on the scope screen is directly proportional to audibility. Eye response is also proportional to db; hence, engineers sometimes evaluate receiver response curves with the aid of a logarithmic waveshaper. The height at any point on the response curve is then proportional to the effective contrast of the picture which will be reproduced.

The effect of logarithmic waveshaping on a sine wave is to compress the peaks of the waveform. The output from a logarithmic waveshaper at first rises almost as fast as the input signal; then, the output becomes less as the input signal continues to rise. At high input amplitude, the output increases very slowly. In theory, the input voltage would have to be infinite to completely level off the output; however, in practice the dynamic range of the tubes and semiconductor diodes restricts the db range which you can accommodate with a logarithmic waveshaper.

LINEARIZING WAVESHAPERS

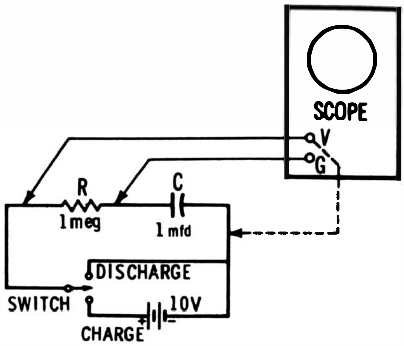
Just as a controlled nonlinear output is desired in some waveshaping arrangements, you will find many applications in which a waveshaper is used to linearize a curved waveform. A common example is the linearization of a sawtooth waveform which is distorted in that the rising portion is concave or convex. The fundamental response of an RC circuit is exponential. The most common problem is to shape an exponential curve into a linear trace. When a capacitor is charged through a series resistor, a semi-sawtooth voltage waveform is produced across the capacitor. To improve the sawtooth linearity, various auxiliary waveshaping circuits may be employed. The choice in a particular application is based on considerations of economy, reliability, and accommodation to normal tolerances. For example, if the waveshaping network contains a tube, potentiometers must often be used in place of fixed resistors to compensate for tolerances on replacement tubes. A potentiometer is much more expensive than a fixed resistor, but it is the most economical solution to the problem.

Compensating controls in waveshaping networks can often be eliminated by utilizing a large amount of negative feedback. However, the output voltage is greatly reduced, and added amplification is required to bring up the output level. This is a comparatively costly solution. The sawtooth linearity can be improved by utilizing a high value of source voltage to charge the capacitor—only the initial portion of the exponential is then passed into the output circuit (Fig. 4-7). This reduces the curvature in the waveform. Note that with the 10-volt battery, the excursion from 0 to 6 volts on the A curve is considerably nonlinear. If a 20-volt battery is used, you will obtain 6 volts output at the 30% point on the curve, and the excursion from 0 to 6 volts is then fairly linear.

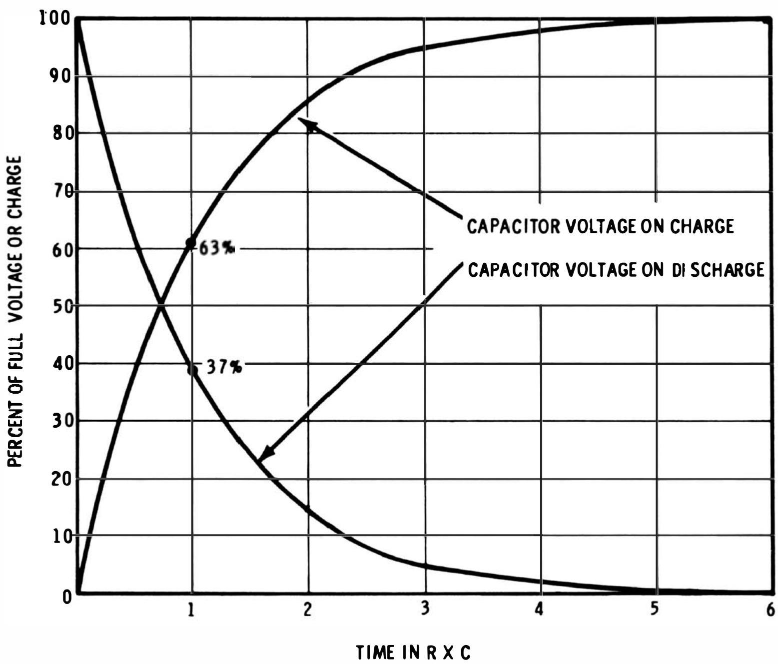
If the charging voltage is indefinitely increased, the sawtooth rise can be made as nearly linear as desired. However, this is not always the most economical solution, because the cost of high-voltage power supplies and the associated component parts is often excessive compared with other means of corrective waveshaping. You can use a comparatively low supply voltage and still obtain an essentially linear rise if you replace the charging resistor with a pentode vacuum tube—a pentode is a good approximation to a constant-current device. But a tube is so much more expensive than a resistor or potentiometer that other approaches will generally be preferred.

Compensatory Distortion

In many cases the initial waveshaper will be supplemented by a network or device which introduces a compensating distortion. An example is depicted in Fig. 4-8. Here, *R* and *C* form an integrating network which shapes the square wave into a semi-pyramid wave. The rising and falling portions are curved. The integrator is followed by the RC divider network R1C1, R2C2. When C1 is adjusted so that the time constant R1C1 equals the time constant R2C2, no compensating distortion is introduced—the output waveform is simply attenuated. However, if C1 is decreased, the output waveform can be linearized, as shown for the compensated case. If C1 is further decreased,



(A) Circuit.



(B) Curves.

Fig. 4-7. Capacitor charging and discharging.

the curvature of the input waveform is reversed, due to overcompensation.

The required value of C1 for correct compensation depends on the repetition rate of the square-wave generator. If the operating frequency is changed, C1 must be readjusted. The values of R1 and R2 should be comparatively high—1 or 2 megohms are generally suitable values. If R1 is equal to R2, the attenuation of the compensating network will be about 50%.

The value of C2 should be chosen to give a suitable control range, but C2 is always considerably smaller than C. The value of R is selected to give a fair approximation to a pyramid wave so that excessive compensation will not be required. It is evident that the impedance of the integrator is much lower than the impedance of the compensating network.

Since the output impedance of the compensating network is comparatively high, it will not function properly with heavy loading. A scope has high impedance; hence, it does not load the circuit objectionably. Likewise, you can drive any amplifier with high input impedance without upsetting the compensating network. Note that this compensating network is basically the same configuration as used in a step attenuator for a scope. The difference is that a compensating network is adjusted to introduce a controlled amount of distortion, while the step attenuator in a scope is adjusted for distortionless output.

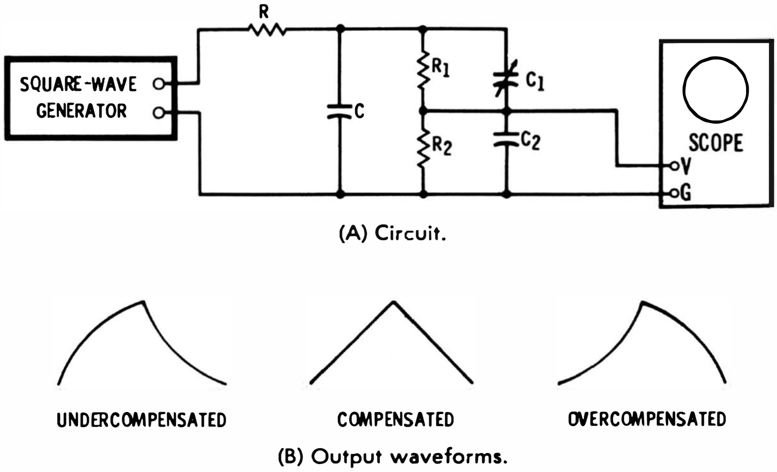


Fig. 4-8. Example of compensatory distortion.

Compensating Tube Characteristic

When an amplifier follows the waveshaper, it is economical to introduce the compensating distortion by operating the amplifier tube on a nonlinear portion of its characteristic. Thereby, the attenuation inherent in the voltage-divider configuration of Fig. 4-8 is avoided. Note the sawtooth waveform shown in Fig. 4-9.

The waveshape can be linearized in the subsequent amplifier stage, as shown in Fig. 4-10. The tube is operated in class AB by suitable adjustment of cathode bias, with the result that the transfer characteristic is curved. This curvature compensates for the curvature of the input waveform so that the amplifier produces a linear sawtooth output (Fig. 4-10B). It is evident that the gain of the amplifier is reduced when the cathode bias is increased (curvature of the transfer characteristic increased),

Fig. 4-9. Nonlinear sawtooth waveform.

so that the linearity control incidentally affects the output amplitude. Adjustment must be made at another point in the system to compensate for this.

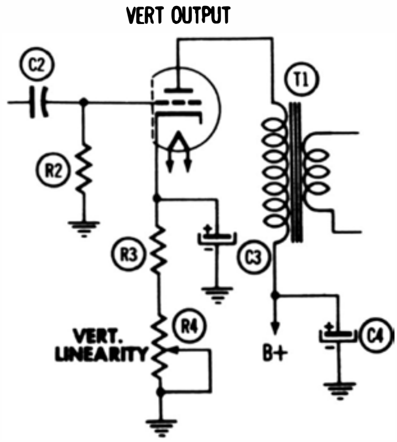
WAVESHAPING FOR IMPEDANCE LOAD

The sawtooth waveform depicted in Fig. 4-10 is suitable only for driving a sawtooth current through a resistive load (Fig. 4-11A). When a sawtooth voltage is applied across an inductance, the current waveform is not a sawtooth. To obtain a sawtooth current through an inductance, a rectangular type of voltage waveform must be applied (Fig. 4-11B). In the case of the horizontal-deflection coils in a yoke, the load can be considered as practically a pure inductance; hence, a rectangular voltage is applied to the horizontal-deflection coils. As a result, a sawtooth current flows and generates a sawtooth variation of the magnetic field. The beam is deflected horizontally in the cathode-ray tube by this varying magnetic field.

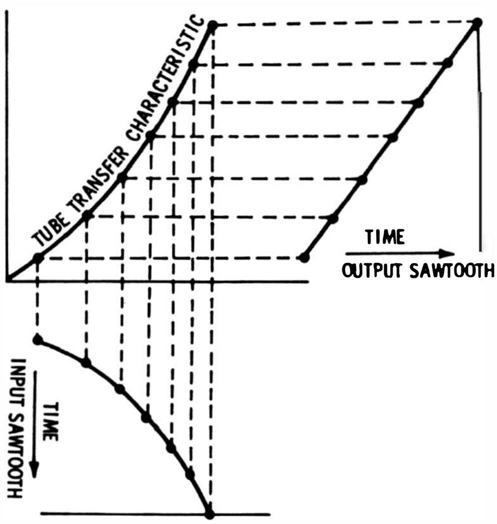
The vertical deflection coils in a yoke contain both inductance and resistance. Hence, neither a sawtooth voltage nor a rectangular voltage across the vertical coils can produce a sawtooth current flow. Instead, the driving voltage must consist of a sawtooth wave plus a rectangular wave. When you add sawtooth and rectangular waveforms, the sum is a peaked-sawtooth waveform (Fig. 4-11C). The sawtooth component produces a sawtooth current flow through the resistance of the coils, while the square component produces a sawtooth current through the inductance of the coils. The total current flow through the coils is accordingly a sawtooth waveform.

Peaked-Sawtooth Waveshaper

To produce a peaked-sawtooth voltage wave, a peaking resistor is connected in series with the sawtooth capacitor, as



(A) Circuit.



(B) Graphical analysis.

Fig. 4-10. Effect of compensating tube characteristic in a TV-receiver deflection circuit.

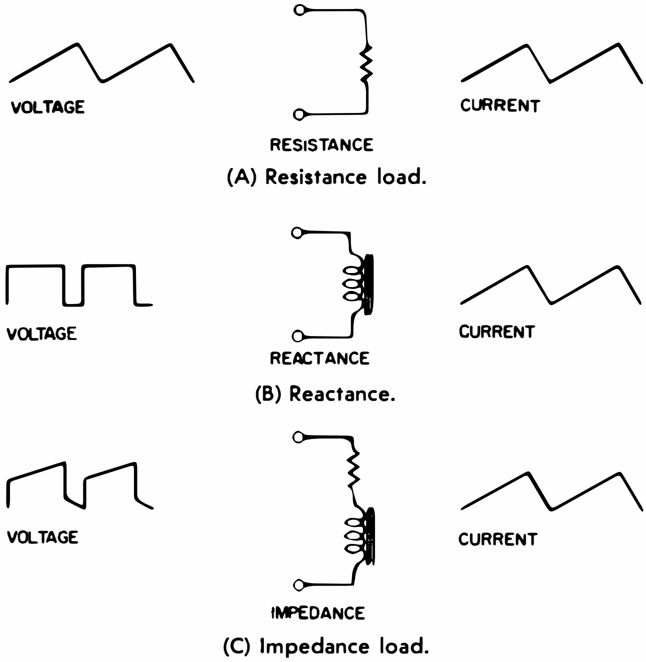


Fig. 4-11. Voltage waveforms needed to produce a sawtooth current.

shown in Fig. 4-12. Here is how it works: suppose that the sawtooth capacitor C1 is charged to the positive peak of the output waveform. The tube then conducts briefly (for the fly-back interval), and during conduction the plate is practically shorted to ground, because the plate resistance falls to a very low value when the tube conducts heavily. Accordingly, the sawtooth capacitor discharges quickly. However, C1 is unable to fully discharge during the rapid flyback interval, because R2 restricts the electron flow.

The tube is cut off following the flyback interval, leaving the residual charge on C1, which appears in the output waveform as the peaking pulse. The B+ voltage then recharges C1

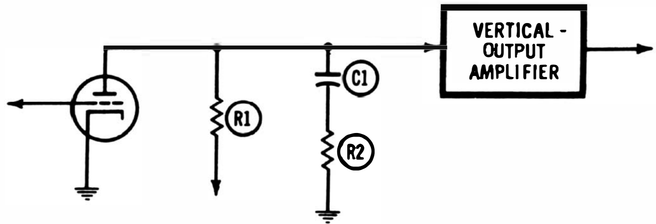
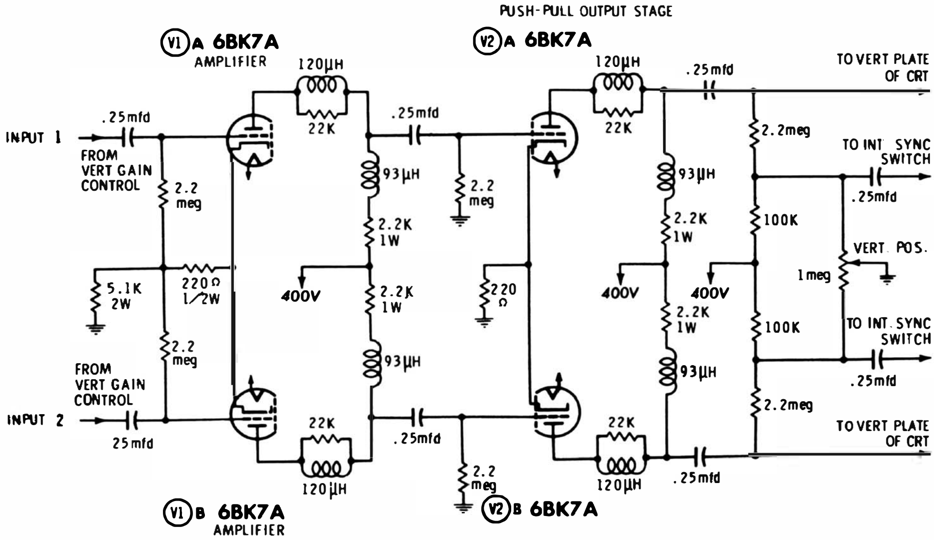


Fig. 4-12. Circuit for producing a peaked-sawtooth waveform.

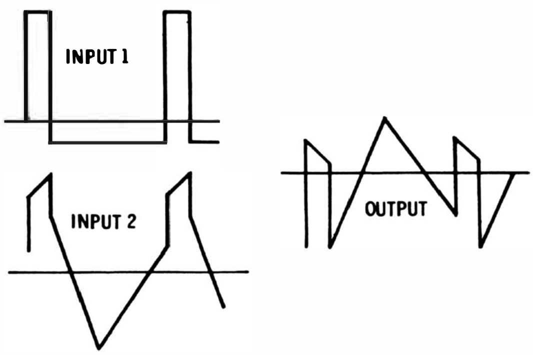
through R1 and R2. This produces the sloping portion of the peaked sawtooth waveform. The value of R2 depends on the ratio of inductance to resistance in the vertical deflection coils. The larger the L/R ratio, the larger is the peaking pulse required, and in turn the greater is the resistance required for R2.

DIFFERENTIAL MIXER

The differential mixer is a waveshaping configuration commonly used in laboratory-type oscilloscopes. Such scopes are said to have push-pull input, differential input, or double-ended input. A typical configuration is shown in Fig. 4-13. It is



(A) Circuit.



(B) Typical waveforms.

Fig. 4-13. Differential mixer.

basically a push-pull amplifier which drives the vertical deflection plates in a cathode-ray tube. It is evident that if a positive voltage is applied to V1A, the CRT beam will be deflected in an opposite direction than if a positive voltage is applied to V1B.

Suppose that equal positive voltages are applied from each gain control. The two voltages balance out in the amplifier, and no beam deflection occurs. Otherwise stated, input voltages of the same polarity subtract. On the other hand, input voltages of opposite polarity add. Thus, if you apply 1 positive volt to V1A, for example, the beam might be deflected upward 1 inch. If at the same time you apply 1 negative volt to V1B, the beam will be deflected upward 2 inches. Next, suppose you apply 1 negative volt to V1A; the beam will be deflected downward 1 inch. If you then apply 1 positive volt to V1B, the beam will be deflected downward 2 inches.

It is evident that the differential mixer is basically an analog computer arrangement which produces the difference between two input signal voltages. In order to do so, the two gain controls must be identical; this follows from the requirement that two equal input voltages of the same polarity must produce an output of zero. The input system is actually a three-terminal arrangement, because there are two input channels and a ground reference. However, unless you encounter circulating ground currents, you can neglect the ground reference. In other words, either Input 1 or Input 2 can be used as a conventional ground lead in single-ended operation. For double-ended operation, Inputs 1 and 2 are applied at two "hot" points in the circuit under test.

An example of double-ended operation is the display of the voltage waveform across a coupling capacitor. Both ends of a coupling capacitor are hot. In many cases, the signal voltage is the same at both ends of a coupling capacitor, and in this situation there will be no vertical deflection on the scope screen. But if a coupling capacitor has a comparatively small value, there is a different signal voltage at each end of the capacitor, and the difference between them is the voltage across the capacitor. A double-ended scope displays this difference signal.

In sync circuitry, for example, a coupling capacitor may be connected between two active circuits, each of which generates a different waveform. The waveform found at each end of the capacitor is quite different. An illustrative example is depicted in Fig. 4-13B. Note how the output waveform is the difference between the two input waveforms. The output waveform is displayed on the scope screen. It shows the voltage drop across the coupling capacitor.

Another practical example of differential mixing concerns the suppression of common-mode hum. When a scope has long input leads, such as half a mile to a missile-launching site, a single-ended monitor scope may display so much hum voltage that the pattern is useless. However, if a push-pull signal is utilized and fed into a differential-input scope, the hum voltage does not appear on the screen. The reason is that the input leads pick up hum voltage in the same phase—accordingly, the hum voltages on the input leads cancel out. On the other hand, the desired signal flows in the leads with opposite phases, so that the push-pull signals add in producing the scope-deflection voltage.

WAVESHAPERS IN RADAR TIMERS

A radar timer establishes the pulse-repetition rate of the system and synchronizes the response of the other components. The most obvious synchronizing action is that of causing the CRT deflection to start at the same instant that a pulse of RF energy is radiated. The block diagram shown in Fig. 4-14 shows the method used in the timer to produce the trigger pulse. The master oscillator in this system generates an 800-cycle sine-wave voltage. The sine wave is passed through a limiter stage to produce a waveshape which is approximately square. An overdriven amplifier is utilized to make the sides of the square wave more nearly vertical. In this way a sharp pulse

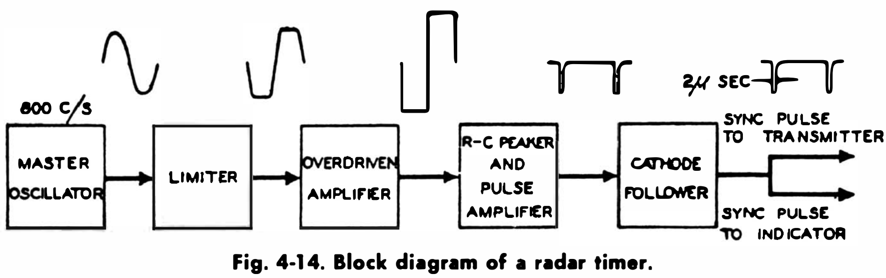


Fig. 4-14. Block diagram of a radar timer.

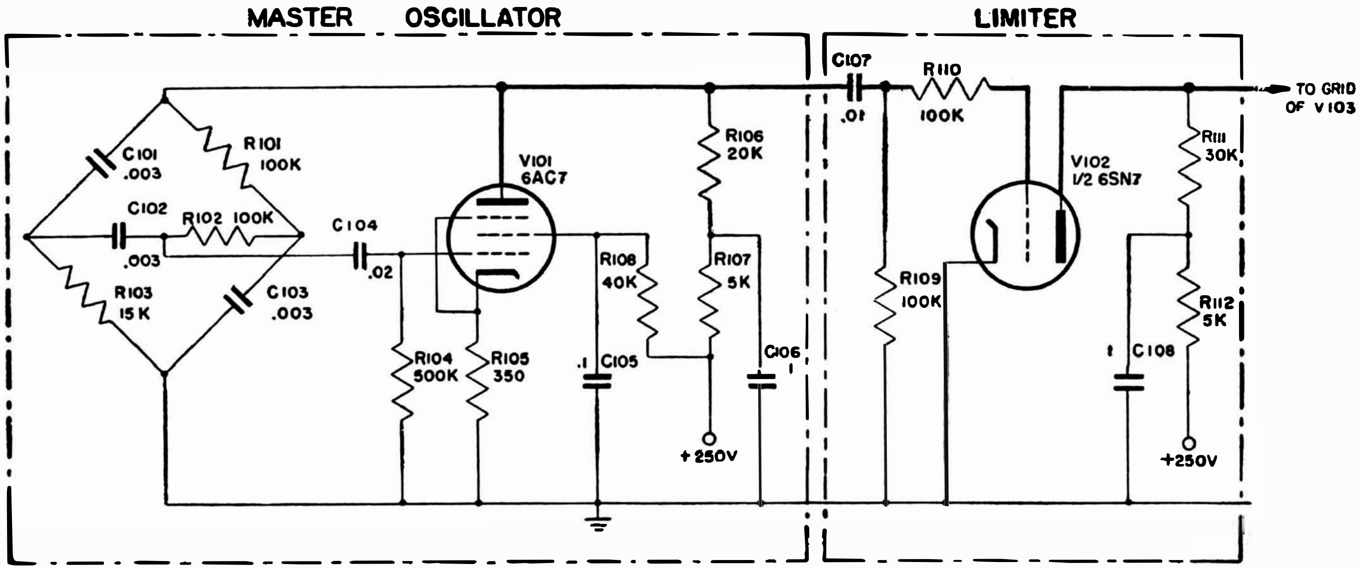
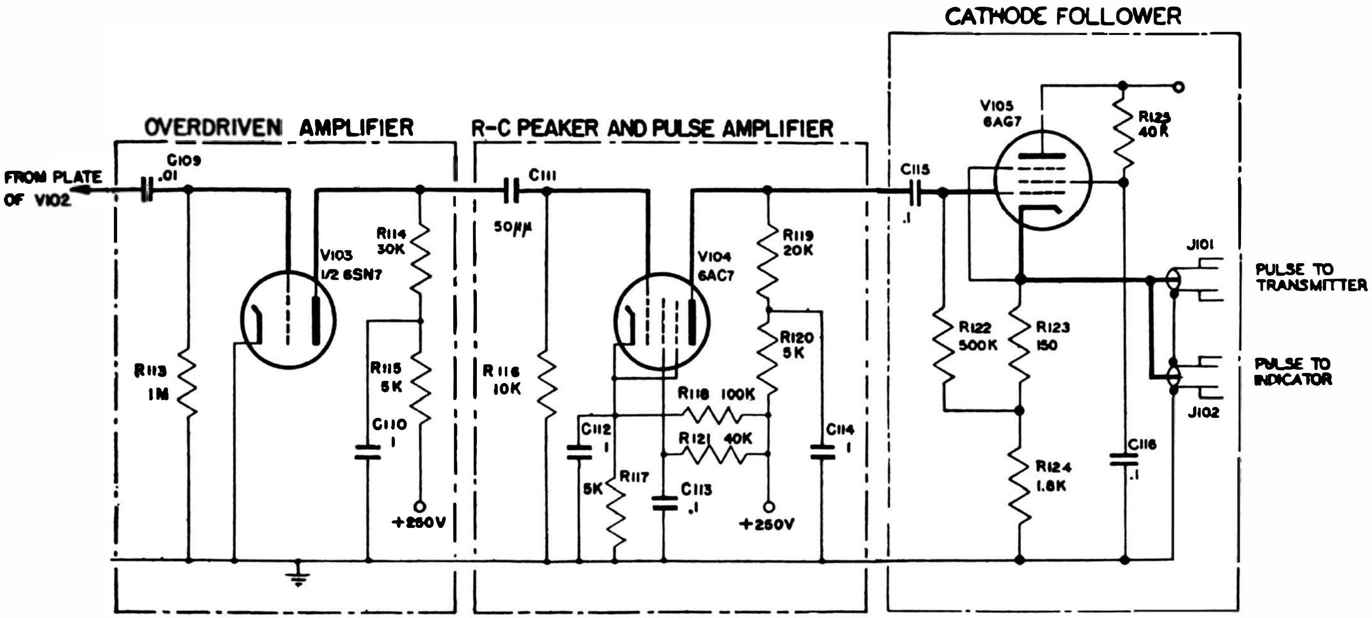


Fig. 4-15. Circuit

of pulse timer.



of approximately 2 microseconds duration with a well-defined leading edge can be derived from the RC peaker which follows the overdriven amplifier. The positive pulse of the peaker output is selected and amplified. This pulse is used to trigger the transmitter and to synchronize the start of the CRT deflection. A circuit diagram of the timer is shown in Fig. 4-15. The circuit employed to control the repetition rate is a phase-shift oscillator. Its output is a sine wave having good frequency stability that produces a trace free from jitter.

Master Oscillator

Oscillation is obtained by coupling the plate of V101 back to the grid through an RC bridge network. This network reduces the signal from plate to ground by an amount equal to the gain of the tube and produces a 180° phase shift only at 800 cycles. A negative feedback voltage, which is essentially constant for all frequencies, is developed across the unbypassed cathode resistor R105. This feedback maintains a sine-wave output at the plate of V101. The combination of a phase shift other than 180° with the negative-feedback voltage reduces the tendency of the system to oscillate at any frequency except 800 cycles. Component values in the feedback network determine the frequency at which oscillation occurs, while the resistance of R105 determines the amplitude of oscillation. The output voltage is developed across plate-load resistor R106.

R107 and C106 in the plate circuit act as a filter to prevent feedback through the power supply. The low reactance of C106 at the oscillator frequency effectively short-circuits the AC voltage which tends to appear at the junction of R106 and R107. This prevents interference with other circuits which are energized by the same power supply. Capacitor C106 can be considered as a battery, because the voltage between its terminals cannot change until charge has been added or removed. Since the resistance in the circuit prevents any instantaneous change, the voltage across the capacitor is held practically constant.

Limiter

The first step in producing trigger pulses from the sine-wave voltage is to convert the sine-wave voltage into a square wave.

To make this conversion, the amplitude of both the positive and negative excursions of the sine wave must be limited. Zero fixed bias is utilized by the limiter, but signal-developed bias is generated by grid-current flow. Coupling capacitor C107 is charged during the positive swing of the applied voltage due to current flow through resistor R109 in parallel with the series combination of R110 and the internal grid resistance of V102. During the negative swing, the charge which has accumulated on C107 leaks off through R109. Since the resistance for discharge is greater than the resistance for charge, a residual charge is accumulated on C107, which is effectively a negative bias between the grid and cathode of V102.

Signal-developed grid bias produced by grid-current flow reduces the effectiveness of the applied sine-wave voltage in driving the grid positive. This bias represents the average about which the sinusoidal variation takes place. Fig. 4-16 shows the average grid-leak bias as a negative voltage relative to ground, with the sine wave superimposed on it. When the grid is driven positive, series resistor R110 still further limits the effective signal, because of the voltage drop across the resistor due to grid-current flow. This limiting is illustrated

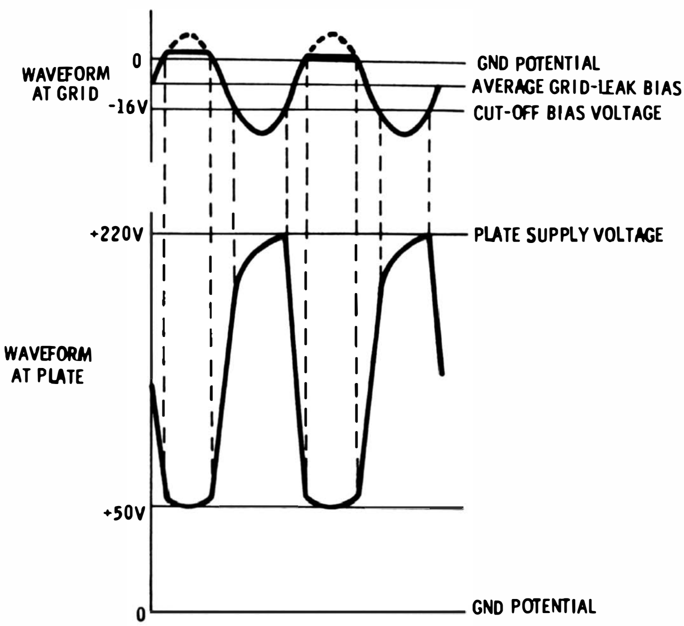


Fig. 4-16. Waveforms in limiter circuit.

in Fig. 4-16 by the reduction of the positive peak in the sine wave.

V102 reproduces the limited grid signal as an approximate square wave. The positive half cycles of the applied sine wave increase the plate current and reduce the plate voltage to a low value. The least positive portion of the plate waveform corresponds to the period of grid-current flow and is flattened by grid limiting. As the grid signal swings negative, plate current is reduced, and finally ceases to flow when the combination of signal and bias reaches the cut-off value. The plate voltage rises toward the supply voltage during this time. Since the input circuit of V103 is connected to the plate-load resistor through coupling capacitor C109, charging current flows in R111, which prevents the plate voltage from rising instantaneously.

Overdriven Amplifier

Although the sine-wave voltage is approximately squared by the limiter, the sides of the square wave are not as vertical as required for the production of a sharp trigger pulse. Therefore the square wave produced by the limiter tube is applied to an overdriven amplifier in order to steepen the sides of the waveform (Fig. 4-17). The output from the limiter stage is a voltage of large amplitude. The plate current of V103 is cut off early in the negative alternation and is driven to a maximum early in the positive alternation. In addition, the grid current which is drawn during the positive half cycle of the applied voltage charges C109 through the relatively low cathode-to-grid resistance of V103. Consequently, the coupling capacitor is charged to an average voltage which acts as a high negative bias for the grid of V103.

The only bias present in the grid circuit of V103 is due to grid-current flow. Distortion in the plate waveform of V102 is caused by the charging and discharging of C109. As the grid signal of V103 starts to swing positive, it is ineffective until at time t_1 it drives the grid above cut-off. At time t_2, when the grid signal drives the grid to zero bias, grid current flows which limits the signal until t_3. The grid is then swung negative, reaching cutoff at t_4. Development of the plate waveform follows from the drop in voltage produced by current flow through

R114. Because tube conduction takes place entirely in the positive half cycle of grid signal, the negative portion of the plate signal is narrower than the positive portion.

RC Peaker and Pulse Amplifier

Output from V103 is applied to an RC peaker circuit. The important feature of the peaker is its ability to charge and discharge completely in the available time between signal alter-

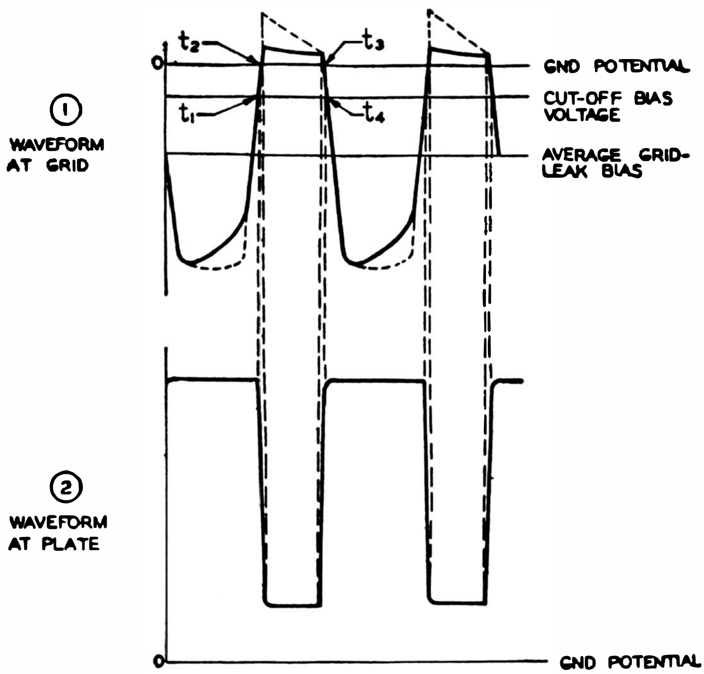


Fig. 4-17. Waveforms in overdriven amplifier circuit.

nations. The plate voltage can accordingly rise to the supply voltage only after the peaker circuit is charged. Leading edges of both positive and negative portions of the waveform are slightly rounded because of the short time utilized for charge and discharge. In order to produce a sharp pulse from the square-wave output of the overdriven amplifier, the time-constant of the coupling circuit to the following stage is made very short. Because this time-constant is so short, C111 charges and discharges completely, and the average bias produced is negligible. The grid may therefore be considered to be at ground potential. Note that the time-constant of the coupling

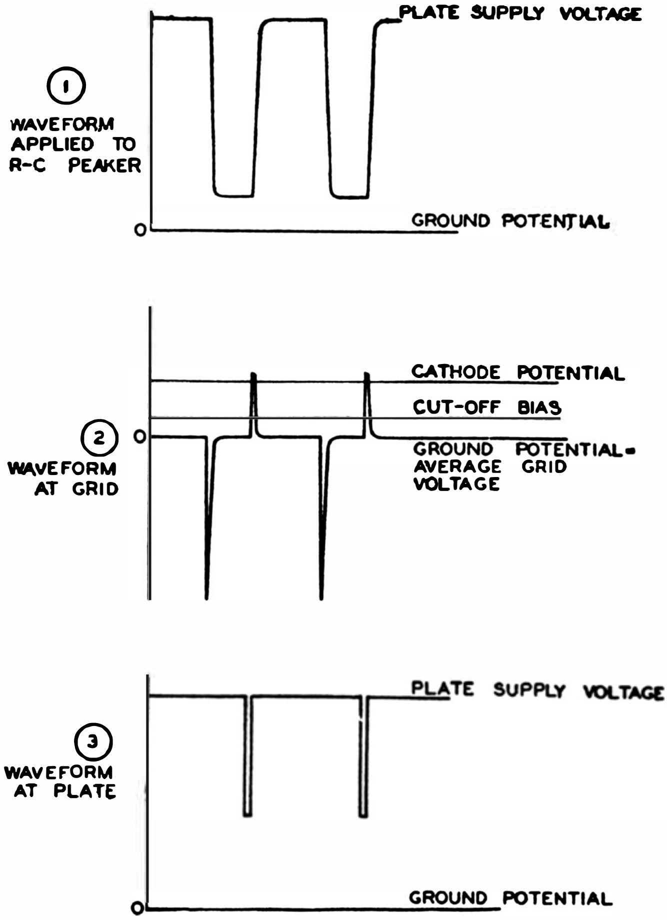


Fig. 4-18. Waveforms in RC peaker and pulse amplifier.

circuit is approximately 2 microseconds for a negative voltage swing at the grid of V104 and less than 2 microseconds for a positive swing at the grid, because the low cathode-to-grid resistance shunts R116 when grid current is drawn.

When the voltage applied to the coupling capacitor rises sharply (Fig. 4-18), a charge is quickly developed on C111. The voltage at the grid of the tube follows the charging current, rising almost instantly to its maximum value, and dropping back to zero quickly. In the same way, when the applied signal voltage swings negative, the grid is driven below ground potential, but it returns to ground quickly because C111 discharges rapidly. A series of sharp positive and negative pulses accordingly develops at the grid.

In order to eliminate the negative pulses at the input to the pulse amplifier, the tube is biased beyond cut-off. Cut-off for a 6AC7 tube with a 250-volt plate supply is approximately −6 volts. A bias of nearly 12 volts is supplied by raising the cathode potential of V104 by means of the voltage divider R117 and R118. Using this bias, the tube does not conduct until the grid is raised to a potential of +6 volts relative to ground. Both the negative pulses and the broad lower portions of the positive pulses are lost because of the bias on the tube. The portion of the grid signal which tends to drive the grid more positive than the cathode is limited because of the flow of grid current. The peaks of the positive pulses tend to drive the grid of V104 positive relative to the cathode, and accordingly cause a large current to flow in the tube for the duration of the pulse. This large current flow produces a large drop of voltage at the plate of the tube, so that the output is a high amplitude negative-going pulse with a duration of approximately 2 microseconds.

Cathode Follower

In most systems of this type, the trigger pulses are conducted to the transmitter and to the CRT via coaxial cables. Cable characteristic impedances range from 50 to 150 ohms. To prevent reflections in a cable, the terminating impedance should be as nearly equal to the characteristic impedance as is practical. A cathode follower is used as a low-impedance source to feed the output pulse from the timer to the coaxial cable.

Since the trigger pulse is negative-going, it is desirable to have the cathode follower normally conduct a heavy current so that a pulse of large amplitude can be developed across the cathode resistors. The bias on V105 (Fig. 4-15) is the voltage developed across R123 by the plate current of the tube flowing through this resistor. The characteristic curves for a 6AG7 tube show that a plate current of 24 milliamperes flows in this circuit configuration. The voltage developed across R124 does not affect the bias on the tube, since it raises both the cathode and grid above ground potential.

Until the negative pulse is applied to the grid of V105, the cathode is 47 volts positive with respect to ground ($1{,}950 \times 0.024 = 47$ volts). Since the output from the pulse amplifier is more than sufficient to cut off the cathode follower, a negative-going pulse of 47 volts is produced across R123 and R124 when V105 is cut off by the applied signal. The negative pulse output from the cathode follower is fed into the coaxial lines which connect to J101 and J102.

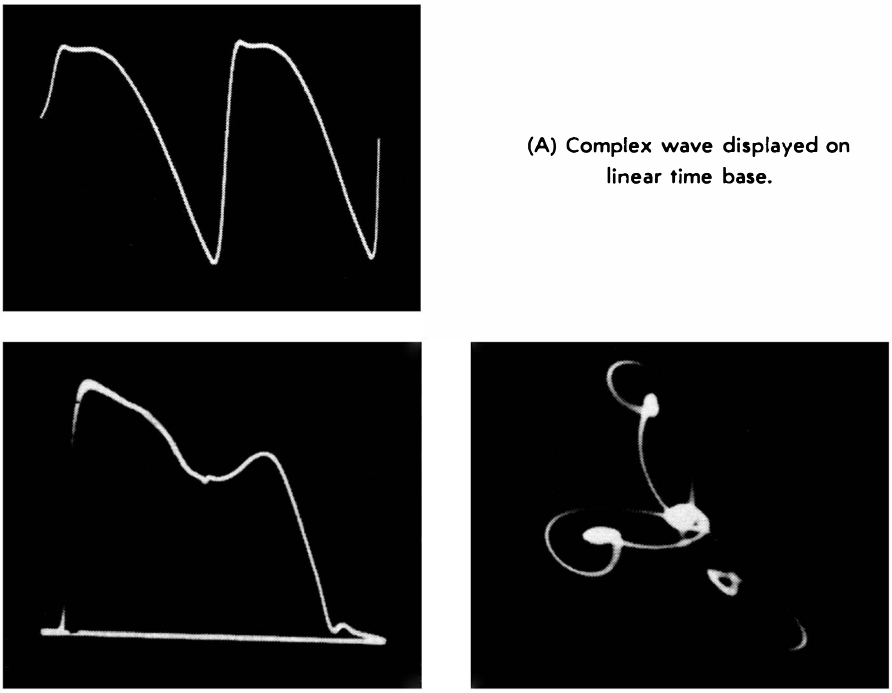
CHAPTER 5

Waveform Types and Aspects

You will encounter numerous types of waveforms in electronic circuits. Three basic types are the complex waveform, frequency-response curve, and cyclogram (Fig. 5-1). The complex waveform is usually displayed on a linear time base (sawtooth deflection); the frequency-response curve is usually displayed on 60-cycle sine-wave deflection; the cyclogram is displayed as the resultant of two different signal voltages, each deflected with respect to the other. Sawtooth deflection is most commonly used to display complex waveforms, because it displays the waveform voltage as a linear function of time. This is the meaning of the term *linear time base.*

A frequency-response curve displays output voltage versus frequency; that is, the horizontal deflection is proportional to frequency. Note carefully that horizontal deflection is not proportional to time in this type of display. The fact that 60-cycle sinewave deflection is commonly used is incidental to the frequency display; economic considerations in the design of FM generators dictate the use of power-frequency deviation of the output frequency. When the scope horizontal deflection is at the same 60-cycle sine-wave rate, deflection is proportional to frequency deviation.

A cyclogram contains the information of two waveforms; one waveform voltage is applied to the vertical input terminals, and



(A) Complex wave displayed on linear time base.

(B) Frequency response curve.

(C) Cyclogram.

Fig. 5-1. Basic types of waveform display.

the other to the horizontal input terminals of the scope. Thus, horizontal deflection is proportional to signal voltage—not to time or frequency. Most cyclograms are displayed from waveforms having the same repetition rate; thus, the current waveform in a circuit might be displayed against the voltage waveform. In this case a particular type of cyclogram results which is sometimes called a power pattern (Fig. 5-2). The pattern shows the phase relation between current and voltage from which the power factor (cos θ) can be read.

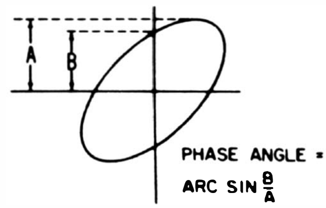


Fig. 5-2. Determination of power factor from a cyclogram.

ASPECT OF A WAVEFORM

A waveform displayed on a linear time base might appear right side up, or upside down. The aspect merely depends on the number of stages in the vertical amplifier of the scope—each stage inverts the waveform. Most scopes produce an upward deflection for a positive-going input voltage, although this is not true of all scopes. A linear time base always displays a pattern with time increasing toward the right. Hence, if current and voltage are displayed with an electronic switch, you can observe whether the current leads or lags the voltage (Fig. 5-3). It makes no difference whether the current and voltage waveforms are displayed right side up or upside down as long as both are displayed in the same aspect.

As the name indicates, an electronic switch is a vacuum-tube device which operates automatically. It rapidly samples the two source voltages back-and-forth, with the result that an ordinary scope becomes effectively a dual-trace scope. An electronic

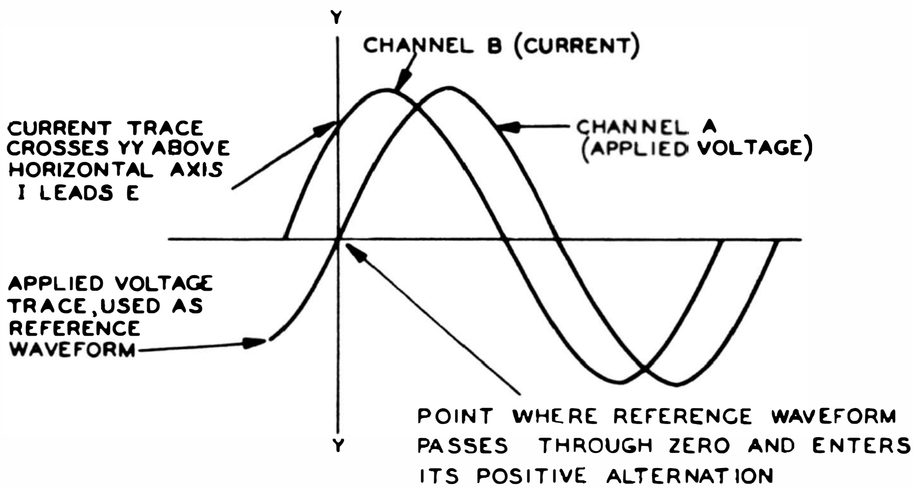


Fig. 5-3. Representation of phase difference displayed on linear sweep by means of an electronic switch.

switch usually operates at a considerably higher frequency than the sawtooth oscillator in the scope, and the switch need not be synchronized with the sawtooth oscillator. In case the switch should be synchronized with the sawtooth oscillator, the two traces appear broken up into dots in accordance with the sampling rate. When the switch is unsynchronized however, the dots appear at arbitrary points along the pattern on successive sweeps, with the result that the display blends into an apparently continuous pattern.

Aspects of Frequency-Response Curves

Frequency-response curves may be displayed either right side up or upside down and either left to right or right to left. Whether a response curve is inverted with reference to a published waveform depends not only on the number of stages in the scope vertical amplifier, but also on the polarity of the detector output. The detector might be a video detector in a TV receiver, or it might be a semiconductor diode in a demodulator probe. Whether a response curve is displayed with frequency increasing from left to right or right to left depends on the number of stages in the horizontal amplifier (Fig. 5-4). Most scopes provide a beam deflection from left to right when

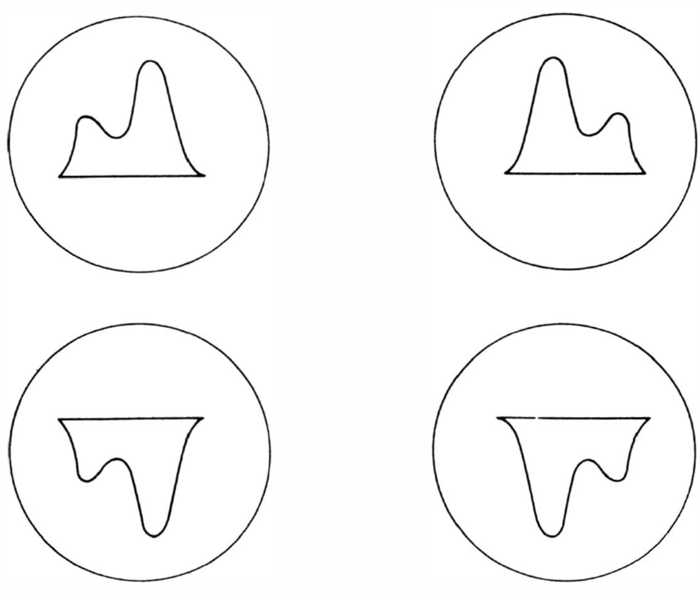


Fig. 5-4. Frequency-response curve shown in four different aspects.

a positive-going voltage is applied, but a few recently manufactured scopes are designed in such a manner that the beam deflects from right to left when a positive-going voltage is applied to the horizontal input terminal.

A few scopes provide a vertical polarity-reversing switch. In such scopes, you can turn the pattern upside down when desired by merely throwing the reversing switch. Most scopes have no control of vertical aspect, however. A few sweep generators provide a control to reverse the pattern from right to left, but most generators do not. Inasmuch as these features are usually absent, you must become familiar with the various aspects of frequency-response curves so that you can analyze the patterns regardless of aspect.

Distinction Between Lissajous Figures and Cyclograms

The basic distinction between a Lissajous figure and a cyclogram is that the former is produced by sine waves, while the latter is produced by complex waves. While this waveform classification is useful, there is actually no clear-cut dividing line between the two types of waveforms. This fact is evident from the photo shown in Fig. 5-5A; although the pattern has the essential characteristics of a Lissajous figure, it is a cyclogram in the strict sense. The input sine waves to the scope are not pure in this example, with the result that the pattern is a distorted Lissajous figure. A sine wave that is not ideal is a complex wave; hence, the photo in Fig. 5-5A actually falls in the class of cyclograms.

It should be noted that no sine waveform displayed on a scope screen is ideal, and that if sufficiently sensitive tests were made, a sine wave which appears to be perfect would be found to have at least a small trace of distortion. No audio oscillator supplies a 100% perfect waveform, regardless of its quality. Likewise, there is no such thing as a completely distortionless audio amplifier. In practice, however, if a waveform appears to be perfect, you can proceed with analysis on the assumption that no distortion is present, and your conclusions will be valid within the limitations of the particular test procedure. This is merely another way of saying that although nothing is perfect in actual practice, analytical methods must be based on various ideal assumptions.

Cyclogram Aspects

Whether a cyclogram appears right side up or upside down and whether it is displayed left to right or right to left depends on the number of stages in the scope vertical amplifier and the number of stages in the horizontal amplifier. Cyclograms, such as Lissajous figures used to determine frequency ratios (Fig. 5-5B), display various aspects, depending on the phase relation of the two input voltages. In any case the information concerning frequency ratios is the same.

When Lissajous figures are displayed, the two frequency sources are seldom synchronized. In general, one source is being calibrated against another. No generator has absolute frequency stability, with the result that each of the input frequencies tends to drift more or less. This causes a moving aspect in the pattern as the two sources pull apart and come together alternately in phase. In Fig. 5-5B, the effect of this movement is seen in the four different patterns. In case the sources are synchronized, the pattern is stationary on the screen, and its aspect depends only on the fixed phase difference between the two sources.

The aspect of the pattern indicates this phase angle. Thus, the Lissajous figure serves not only to measure the ratio of two frequencies, but also to measure the phase difference between them. The information concerning phase given in the Fig. 5-5B patterns is an extension of the single-frequency method shown in Fig. 5-2. For example, the initial phase difference in (1) of Fig. 5-5B is 0°, while the initial phase difference in (3) is 90°. You will generally employ Lissajous pat-

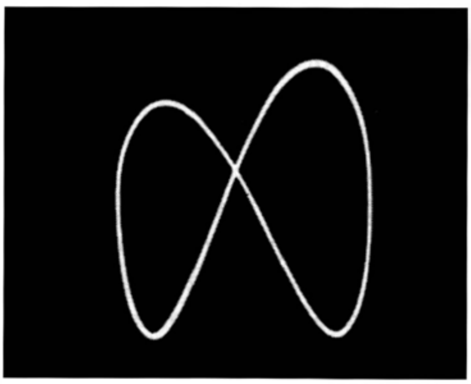


Fig. 5-5A. Photograph of typical scope trace of Lissajous figure.

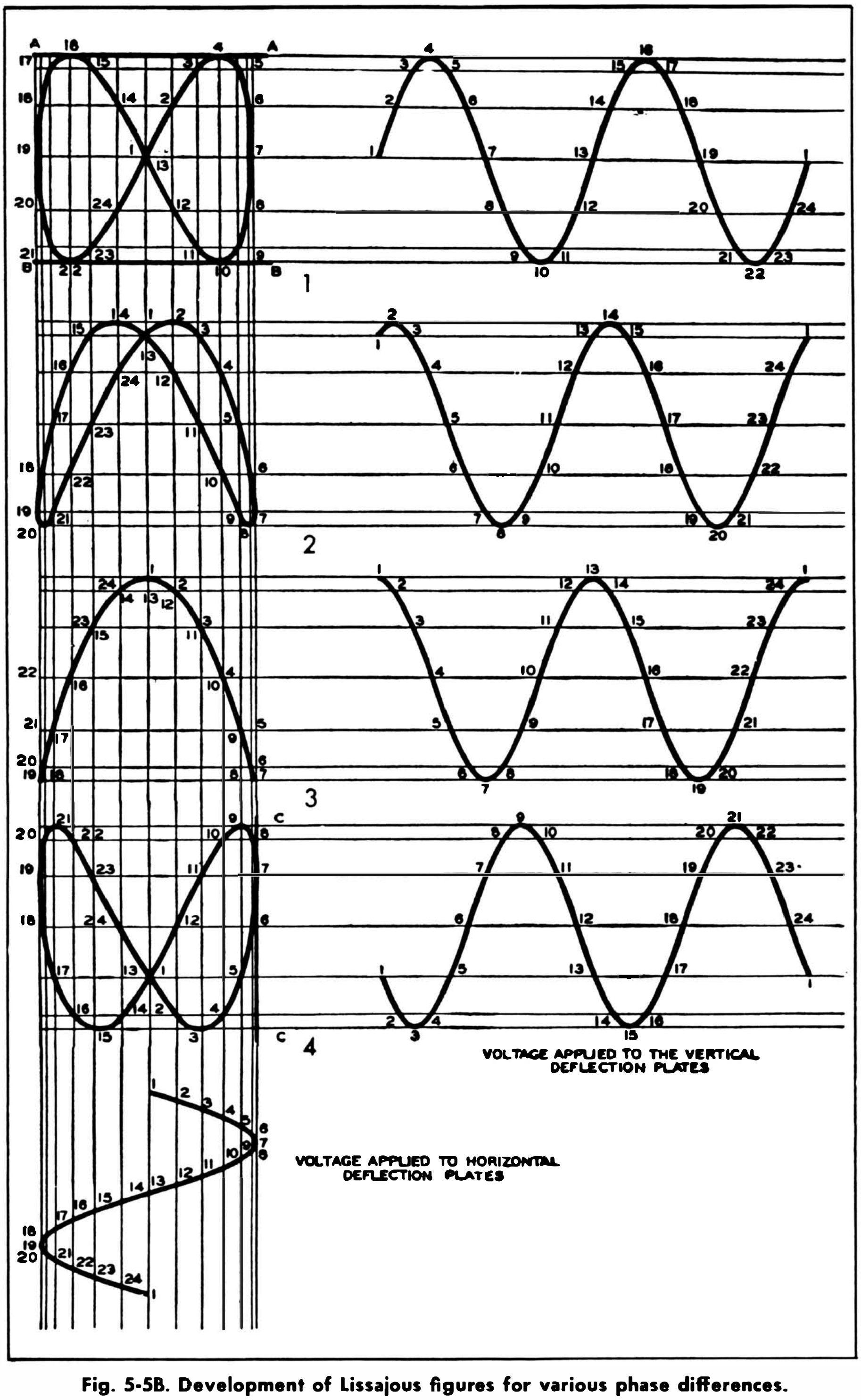


Fig. 5-5B. Development of Lissajous figures for various phase differences.

terns to measure frequency ratios, although it is apparent that phase differences can also be measured when the sources are synchronized, as when displaying voltage versus current from the same circuit.

MEANING OF POWER FACTOR

Recall that when reactance is present in a circuit, the current is out of phase with the voltage. Then there are three power values present. One is the *apparent power*, or volt-amperes—it is given by the product of the rms voltage times the rms current. This is the largest of the three power values. Another is the *real power*, which does useful work—it is given by the product of the apparent power times the power factor. The power factor, cos θ, is equal to the resistance divided by the impedance. The third power value is the *reactive power*, which does no useful work; reactive power merely surges back and forth in the circuit and does not appear as load power. Reactive power is given by the product of the apparent power times sin θ—the value of sin θ is equal to the reactance divided by the impedance.

Note that the three power values combine in a right triangle, just as the three types of ohms (resistance, reactance, and impedance) combine in a right triangle. To clarify the meaning of the various types of power, it is helpful to consider three extreme examples. First, consider an amplifier which delivers power to a 600-ohm resistor—all of the output energy from the amplifier does work in heating the resistor. Next suppose you disconnect the resistor from the amplifier and replace it with a capacitor which has a reactance of 600 ohms at the operating frequency. Now, all of the energy merely surges in and out of the capacitor and does no work. Finally, if you connect a resistor and capacitor in series so that they present an impedance of 600 ohms to the amplifier output, the current flow through the resistor does work, but the current flow through the capacitor does no work.

Waveform of Amplifier With Impedance Load

When an amplifier drives an output transformer, the load is theoretically a pure resistance. However, in practice the transformer primary usually presents inductance as well as resistance to the amplifier output terminals. In turn, the plate current of the output tube lags the plate voltage, and there is reactive power as well as real power present in the output circuit. The load line is not straight but follows an elliptical path of operation on the family of tube plate characteristics.

The waveform of such a load impedance can easily be analyzed with a scope. A small resistor is connected in series with the primary of the output transformer. The voltage drop across this resistor is proportional to the output current flow. Connect the vertical input leads of the scope across the resistor, and connect the horizontal input leads of the scope across the primary of the output transformer. When the amplifier under test is driven by an audio oscillator, either a diagonal line or an ellipse will be displayed on the scope screen. If a line is observed, the output transformer and speaker present a purely resistive load; if an ellipse is displayed, the load is an impedance consisting of both resistance and reactance.

The proportions of the ellipse give the power factor, which is equal to the ratio of resistance to impedance. A change in operating frequency results in a change of power factor. Hence, the frequency at which the power factor is measured should be specified. This simple test makes it possible to compare the quality of one transformer-speaker system against another. The most desirable system is one which gives the highest power factor over the widest frequency range. When the power factor is high, the output efficiency is also high. Moreover, less distortion can be expected when the power factor is high, because the path of operation does not dip down so far into the nonlinear region of the plate characteristics.

It is evident that a Lissajous figure which represents an impedance waveform is developed from synchronized sources; the current in the circuit is always in synchronism with the voltage, although there may be a phase difference between current and voltage. If the current waveform is different from the voltage waveform, as will be the case when the tube is operated over a nonlinear region of its plate resistance, the ellipse will be distorted accordingly. Nevertheless, the harmonics are synchronized with the fundamental, and the pattern is stationary on the screen.

MIXED WAVEFORMS

Many of the waveforms which are analyzed in the course of electronic circuit testing are of the mixed variety. For example, if hum voltage is present in a video signal, the pattern is a mixed waveform. Complex waveforms are not mixed waveforms, although they contain harmonics. The difference between a mixed waveform and a complex wave can be stated as a difference between inexact frequency relations and exact frequency relations. Consider, for example, a square wave which contains a fundamental, third harmonic, fifth harmonic, and so on. The square wave is a complex waveform because the frequency relations between the fundamental and its harmonics are absolutely exact. In other words, the third harmonic is exactly 3 times the fundamental frequency, and never 3.0001 or 2.9999.

On the other hand, a video signal is a mixed waveform; its components are complex waveforms. Recall that horizontal-sync pulses have a repetition rate of 15,750 cycles per second and vertical-sync pulses have a repetition rate of 60 cycles per second. These are nominal repetition rates, which are held to close tolerances. Nevertheless, the horizontal pulse timing can vary slightly in one direction, while the vertical pulse timing may vary slightly in the other direction. Clearly, the horizontal-sync pulses do not have a true harmonic relation to the vertical-sync pulses. Hence, the sync-pulse train is a mixed waveform.

The question may be asked why the relative timing of the horizontal- and vertical-sync pulses is not absolutely precise. The answer is that the two types of pulses are developed by separate counter (trigger) circuits. There is always more or less jitter in a counter chain, even though it might be held to a very small amount. The result of residual jitter is that the horizontal-sync pulses cannot be an absolutely exact harmonic of the vertical-sync pulses. Fig. 5-6 illustrates a comparatively bad case of the "jitters." You will often see these extreme examples when adjusting the counter circuits in a pattern generator with the aid of a scope. When objectionable jitter is observed, a control is usually incorrectly set near the end of its lock-in range. If this is not the cause, there is a defect in the counter circuitry.

Fig. 5-6. Jitter in a 15,750-cps signal.

Counter-Circuit Waveforms

Counter circuits are used in a wide variety of modern electronic equipment, such as pattern generators, color-bar generators, and synchronizing circuits in oscilloscopes. Sophisticated equipment, such as radar systems and electronic computers, make extensive use of counter circuits. Frequency standards employed in commercial transmitting and laboratory research installations contain chains of multivibrators which are locked in synchronism by counter action.

A typical counter-circuit waveform is shown in Fig. 5-7. This, of course, is a mixed waveform. The pattern represents the outputs from two or more locked oscillators, each of which triggers the next. Each individual oscillator generates a complex waveform.

The chief item of interest in such mixed waveforms is the number of triggers that appear in the lower-frequency interval of the wave. This characteristic indicates whether the counting action is correct. In a counter chain in which you are counting down from say, 31,500 cycles to 60 cycles, the final output waveform represents the outputs from several locked

Fig. 5-7. Typical counter-circuit waveform.

oscillators, each of which is triggered by the preceding oscillator in the chain. If any one of the oscillators is counting incorrectly, the evidence is seen in the corresponding waveform. In case of doubt, refer to the instrument instruction book—in most cases the manufacturer illustrates the correct counter waveforms for the particular instrument.

When a circuit counts incorrectly, the troubleshooter must determine where the defect is located in the counter chain. The waveforms are observed step-by-step through the system and the counter action is evaluated, as previously described. When you replace tubes in a simple device such as a color-bar generator, tube tolerances will often throw the counter action into an incorrect mode of operation. The output pattern appears scrambled. When this happens, refer to the instruction book for the instrument; it will specify successive test points for checking the counter waveforms. The maintenance control in each stage is then adjusted to obtain the specified counter waveform. This can be a baffling procedure if a scope is not employed; if you have a chain of six counters in a color-bar generator and do not make progressive scope tests, you can waste a vast amount of time in aimless control adjustment—it is not apparent from the output pattern whether one or more stages is counting incorrectly, nor does the output pattern indicate which stage or stages may be at fault.

Mixed Waveforms in Color-TV Circuits

Another important example of a mixed waveform is the color video signal (Fig. 5-8). Here, a 3.579545-mc sine wave is switched into the black-and-white video signal at suitable intervals. The color burst appears on the back porch of the horizontal sync pulse, and the burst phase is not controlled with respect to the repetition rate of the sync tip; hence, the burst appears blurry if the scope is synchronized with respect to the sync tip. However, if you utilize the subcarrier-oscillator output for external synchronization of the scope, the burst phase then appears fixed on the screen—the burst can be expanded as desired, and a sine-wave pattern is displayed.

An expanded burst can be displayed either with a sweep magnifier or a triggered-sweep function in a scope. A sweep magnifier is somewhat limited in the amount of expansion which it provides (5 times is typical), but it is easier to use. The waveform is first displayed on the screen in the conventional manner, and the magnifier is then switched on. The magnifier-positioning control is then adjusted to bring the desired interval of the expanded waveform to the center of the screen.

Adjustment of triggered-sweep controls is somewhat more complicated. Trigger amplitude, slope, and stability must be suitably adjusted. However, the deflection rate can then be set to any desired value, and a very large expansion obtained.

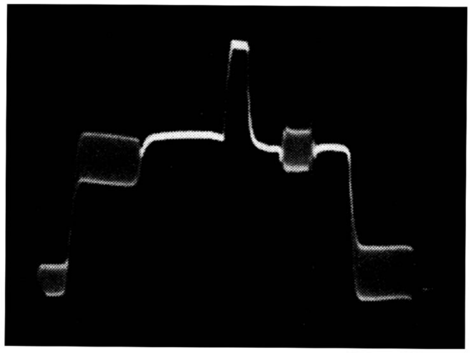


Fig. 5-8. TV signal with color burst.

When triggered sweep is used, flexibility is provided by a sweep-delay control; horizontal deflection can be started at any chosen time after the trigger pulse arrives. This gives a positioning action which is similar to the magnifier-positioning function noted previously. Sweep delay is applicable only to repetitive waveforms.

NONRECURRENT TRANSIENT WAVEFORMS

There is a special case of both mixed and complex waveforms called nonrecurrent transients. This type of waveform is exemplified by the starting surge to a power supply in a TV receiver. When the receiver is turned on, there is a sudden inrush of current after which the current rapidly settles down to its steady state. This surge waveform does not recur, of course, until the switch is turned off and then on again. Nonrecurrent transients cannot be displayed satisfactorily on ordinary scopes unless triggered sweep is provided. An additional facility is also required for completely satisfactory display.

When a waveform is not repetitive, but is a nonrecurrent transient, a delay line is utilized in the vertical amplifier. This delay is comparatively short, and its purpose is to provide time for the sweep to get started before the transient signal arrives at the cathode-ray tube. If a delay line is not used, part or all of the leading edge in the pattern will be lost. Since the delay line must operate at the full bandwidth of the vertical amplifier without introducing frequency distortion or phase shift, requirements are stringent and much technical ingenuity has been directed to the development of high-performance delay lines.

FREQUENCY INDICATION

Note the frequency marker on the response curve illustrated in Fig. 5-9. This is a mixed waveform—the output from a marker generator is mixed with the output from an FM generator to produce the complete waveform. Here, the mixture

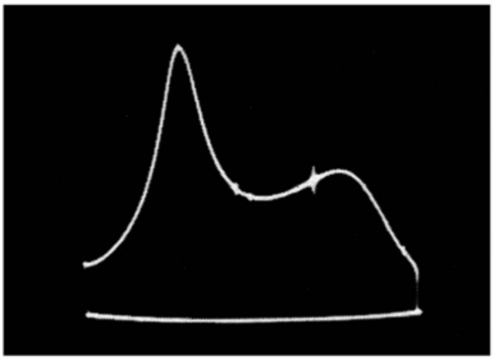


Fig. 5-9. Photograph of marked frequency-response curve.

provides the unique function of measuring frequency along the horizontal excursion of the waveform.

By suitable observation of the marker interval it can readily be seen that the marked curve is a mixed waveform. If you reduce the sweep width to a low value and readjust the center frequency of the sweep generator to keep the marker in the center of the screen, you can expand the marker horizontally as much as desired. Then, if you advance the vertical gain control of the scope, the amplitude of the marker is increased. Now, the details of the marking waveform become clearly apparent. You will see that the marker does not stand still, but instead writhes in its position on the curve. This is a consequence of mixing the outputs from two separate generators to produce the marker pattern. Inasmuch as the marker does not have an absolutely fixed relation to the sweep signal, the pattern is a mixed waveform.

ASPECT CONTROL

Some aspects of a waveform are under the control of the operator, while others are not. Thus, if a sweep-frequency waveform is not centered on the base line (Fig. 5-10), the center-frequency control of the FM generator can be adjusted as required. Compare this waveform with the response curve illustrated in Fig. 5-9; in the latter display both sides of the response curve are clipped (the waveform is centered on the base line). If the sweep-width control of the FM generator has been advanced to maximum, then the aspect of the waveform is not under the control of the operator. However, this should not be assumed to imply that the off-screen portions of the response

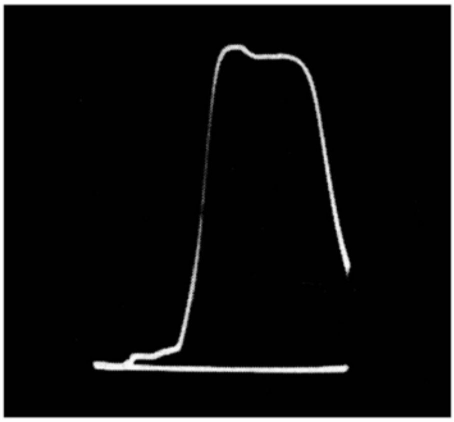


Fig. 5-10. Response curve not centered.

curve in Fig. 5-9 cannot be made visible; all that is required is to turn the center-frequency control sufficiently in the appropriate direction. Thus, if the curve in Fig. 5-10 is moved sufficiently far to the left, the off-screen portion on the right will become visible. It is often impossible to display an RF response curve completely, because the bandwidth is comparatively great and the deviation of conventional FM generators is somewhat limited. However, a few generators are designed to sweep all the low VHF channels simultaneously, or all the high VHF channels simultaneously. This type of generator is utilized in checking TV distribution amplifiers and wide-band boosters.

Another aspect of waveform display which often confuses the beginner is shown in Fig. 5-11. Here, the left portion of the pattern is cramped. This compression does not indicate a fault in the circuit under test; instead, it stems from a defect in the scope. It is an example of nonlinear horizontal deflection—otherwise stated, the progression of the trace from left to right is not uniform in time; the beam moves more slowly at the left end than at the right.

Scanning nonlinearity can result from low supply voltage or a component defect in the sawtooth-oscillator circuit. Sometimes merely replacing a tube will clear up the distortion. If the sawtooth oscillator is functioning properly (this can be checked with another scope), the source of nonlinear scanning will be

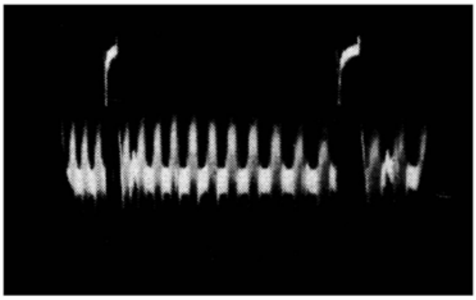


Fig. 5-11. Waveform compressed at left side.

found in the horizontal amplifier. Low supply voltages and leaky coupling capacitors are common causes of this symptom. When the supply voltage is low, the amplifier tubes tend to saturate on the peak of drive, and the bias may also shift to an unfavorable operating point. A leaky coupling capacitor permits positive voltage to bleed into the control-grid circuit, thus upsetting the normal grid-cathode bias.

It must not be supposed that nonlinear deflection always appears as shown in Fig. 5-11. In some scopes, depending on the nature of the defect, the pattern can appear compressed at the right. When push-pull amplifiers in a horizontal amplifier are incorrectly biased, the pattern can appear compressed in the center region. This latter type of distortion is often called crossover distortion. In another type of aspect distortion, the center portion of the pattern is displayed normally, but the waveform is cramped at both ends. This symptom results from low supply voltage to a push-pull amplifier, while the operating points of the tubes remain correct.

ONE SCOPE CHECKS ANOTHER

Beginners are frequently baffled when a scope develops defects; however, it is often easy to run down the trouble in a defective scope by testing it with another scope. Simply trace the waveforms through the areas which fall under suspicion. Thus, if the symptom happens to be deflection nonlinearity, trace the sawtooth wave from its origin in the sawtooth-oscillator section through the amplifier stages to the deflection plates of the cathode-ray tube. Suppose that the sawtooth exhibits nonlinearity at the output of the sawtooth oscillator—the trouble will be found in this section. A capacitor might be leaky, a resistor may have changed in value, or a capacitor may have lost a substantial amount of its capacitance—sometimes a capacitor will open completely.

If you find that the sawtooth-oscillator output is linear, the trouble will be found in one of the subsequent amplifier stages. When you come to the stage which first exhibits nonlinearity, check out the components in that stage. Capacitors can be tested on a capacitor checker or by substitution; bias and supply voltages can be measured with a voltmeter; resistors can be checked with an ohmmeter. In any case, remember that tubes are the most likely cause of faulty operation. From a statistical standpoint, capacitors are the next most likely culprits, followed by resistors.

When distortion is present in the vertical amplifier of a scope, you can localize the defect in the same manner by signal tracing with another scope. Apply any convenient AC signal to the vertical input terminals. Then follow the waveform from the vertical input terminals stage by stage to the deflection plates of the CRT. When you come to the first display of distortion in the waveform, the trouble will be found in that stage. Note that you can compare the waveform amplitudes at the input and output of a stage to measure the stage gain. In this manner, a low-gain symptom can also be localized.

MODULATION CYCLOGRAM ASPECTS

Another type of waveform is obtained when a modulated waveform is applied to the vertical input terminals of a scope, and the modulating waveform is applied to the horizontal input terminals. This is called a trapezoidal display (Fig. 5-12). The photo shows the modulated waveform as it appears on conventional sawtooth sweep. When it is converted to a trapezoidal pattern, it becomes easy to read the modulation percentage. The formula for percentage modulation is:

$$\%\ \text{Mod} = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100$$

where,

E_{max} is the total vertical deflection at the large end of the pattern,

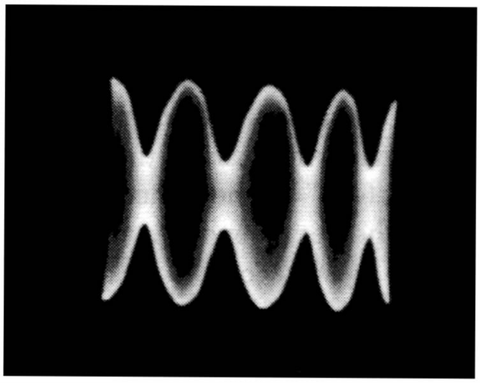
E_{min} is the total vertical deflection at the small end of the pattern.

100% modulation occurs when the trapezoid comes to a point. If the pattern "tails off" into a horizontal line, overmodulation is present. Overmodulation is undesirable, because tone distortion occurs and sideband "splatter" is generated. These cause interference on other channels. Trapezoidal patterns also show whether modulation is symmetrical—thus the example of 50% modulation in Fig. 5-12 depicts unsymmetrical modulation, while the example of 90% modulation is symmetrical. Unsymmetrical modulation results from incorrect adjustments in the modulating circuitry of the transmitter.

When making a trapezoid read-out, the audio channel must be energized from a steady source, such as an audio oscillator. The instrument need not have good waveform, since this does not affect the shape of the trapezoidal pattern. It is only necessary that the percentage modulation be maintained constant while the readout is made. Most scopes have vertical amplifiers with limited bandwidth, and the modulated RF signal must be coupled directly to the vertical deflection plates in the cathode-ray tube. Details of such procedures are explained in specialized texts such as *101 ways to Use Your Ham Test Equipment.*

The audio input to the scope horizontal amplifier must have the same phase as the envelope of the modulated-RF signal, or the trapzoidal patterns will overlap on trace and retrace, giving a confused double-image presentation. It is easy to phase the modulated-RF signal satisfactorily if a small loop is used to pick up the RF energy from the final tank in the transmitter.

(A) Modulated signal displayed with linear sweep.



0% modulation. 50% modulation.

(B) Trapezoidal patterns for various modulation percentages.

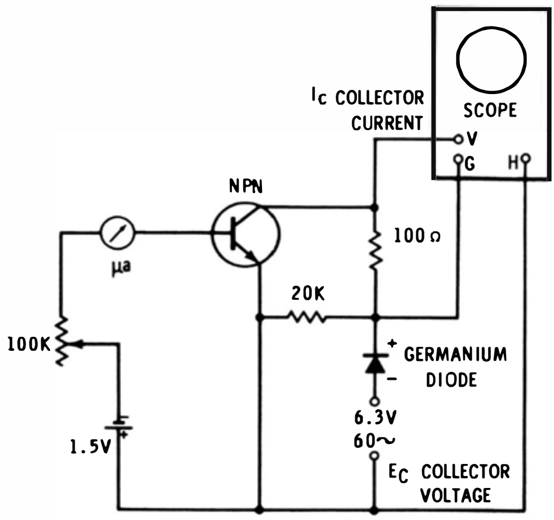
Fig. 5-12. Trapezoidal display.

By turning the loop and varying its distance from the tank coil, you can select a signal input of both correct phase and amplitude.

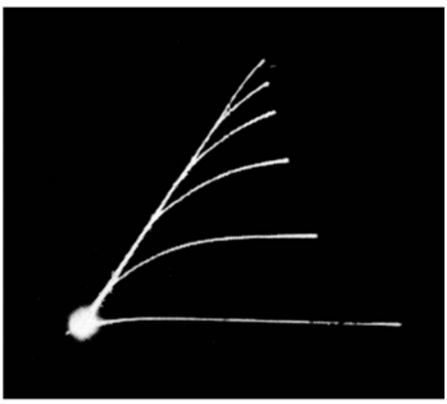
TRANSISTOR CHARACTERISTICS

Still another type of pattern is obtained as shown in Fig. 5-13 in which a scope is used to display transistor characteristics. Collector voltage is displayed along the horizontal axis, while collector current is displayed along the vertical axis. Base current is the running parameter. With the arrangement shown in Fig. 5-13A only one characteristic is displayed at a time. The base current must be changed to display the succeeding curve. The photo is a multiple exposure.

You can display the entire family of collector characteristics by driving the base of the transistor from a staircase generator. The "steps" of the generator output need not be synchronized with the rectifier output in the collector circuit. It is essential to use a DC scope in this application, because the origin will shift otherwise, offering a confusing pattern. The display in Fig. 5-13B shows the *saturation region* of the transistor, because the applied collector voltage is comparatively low. If more voltage is used, the curves are extended accordingly.



(A) Circuit.



(B) Scope display.

Fig. 5-13. Display of transistor characteristics.

Note that the 20K resistor in Fig. 5-13A is employed to stabilize the output from the germanium-diode rectifier, so that the origin is sharply defined.

In tests of this type it is advantageous to utilize a scope which has differential input. Differential input balances out common-mode hum which is sometimes a problem because of circulating ground currents in the test setup. Circulating ground currents stem from capacitive coupling between primary and secondary windings of the power transformers in the scope and the 6.3-volt supply to the collector circuit. However, if the power transformers contain electrostatic shields, a single-ended scope can be used without encountering difficulty from circulating ground currents.

TUBE CHARACTERISTICS

Vacuum-tube characteristics are displayed in the same general manner as transistor characteristics. Thus, the plate family is developed as a pattern on the scope screen. A staircase generator permits the grid voltage to be varied as the running parameter in any chosen number of steps. The staircase drive voltage should be limited to negative values to avoid possible damage to the tube under test due to grid-current flow. However, this does not mean that tube characteristics cannot be checked for positive grid voltages. If the grid drive signal is a narrow pulse, the grid dissipation can be reduced below the rated limit. Since a scope shows current and voltage values as readily for a narrow pulse as for a step voltage, you can check out a tube completely.

Sophisticated scopes are designed to accommodate plug-in vertical and horizontal units for displaying the plate family of a vacuum tube, the collector family of a transistor, and characteristics of various semiconductor diodes, including tunnel and zener diodes. The test units can be adjusted for any desired voltage and current ranges, so that the device under test is not operated out of limits. Other plug-in units provide display of transistor switching characteristics, so that their suitability may be determined for application in high-speed computers. A scope used to display the switching characteristics of a tunnel diode must have a large bandwidth—up to 1000 mc. An oscilloscope with 1,000-mc bandwidth does not use conventional vertical amplifier circuitry. Instead, it uses a sampling function, which is analogous to heterodyne action. To put it another way, the input waveform is converted by sampling action to a similar waveform with a much lower repetition rate. Note that a sampling-type oscilloscope can be used to display recurrent waveforms only. Nonrepetitive transients cannot be displayed.

HUM IN WAVEFORMS

The presence of hum voltage in a waveform changes its appearance in certain characteristic ways. Fig. 5-14 illustrates how 60-cycle hum voltage thickens a trace when the repetition rate of the waveform is much higher than 60 cycles. The hum voltage beats with the waveform, but the beat rate is so fast that it exceeds the persistence of vision; hence, the waveform displays no movement; it simply appears blurred. On the other hand, when the repetition rate of a waveform is near the 60-cycle hum frequency, the beating becomes evident—the waveform writhes about its average position.

Fig. 5-14. Sawtooth pattern with 60-cycle hum.

If the waveform under observation has a 60-cycle repetition rate, the pattern is stationary; however, the 60-cycle hum changes the shape of the waveform. It is for this reason that a 50-cycle or 70-cycle square-wave test is better than a 60-cycle square-wave test—if hum voltage is present, the reproduced square wave will writhe. Thus, the operator does not run the risk of confusing hum voltage with amplitude distortion. The same observation applies at integral multiples of 60 cycles; it is better to make a square-wave test at 130 cycles, for example, than at 120 cycles.

In some cases, hum voltage can affect the triggering level of the sawtooth oscillator in the scope, as illustrated in Fig. 5-15. In this case, the end of the pattern appears as if it were a section of a tube. Careful adjustment of the sync-amplitude control will usually square up the end of the pattern. This effect is similar to the appearance of a TV image when the vertical-output tube is energized by 60-cycle hum voltage—the picture appears to be rolled up on a tube.

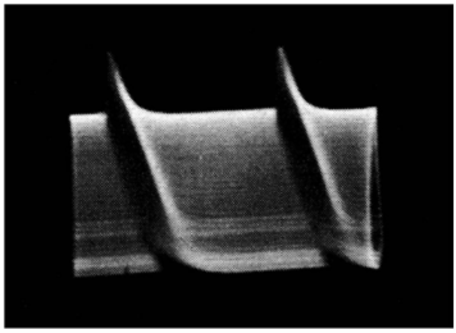


Fig. 5-15. Scope pattern showing effect of hum on triggering level.

Hum in Scope Circuitry

In the foregoing situations the hum source is in the circuit under test or in the test setup—not in the scope itself. It is possible for defective tubes or filter capacitors in the scope to produce hum interference or distortion in the display. The nature of the symptom depends on the type of defect which has occurred; for example, heater-cathode leakage in the cathode-follower input stage of a vertical amplifier produces a 60-cycle sine-wave pattern on the scope screen which is unaffected by short-circuiting the vertical-input terminals. On the other hand, heater-cathode leakage in a well balanced push-pull stage produces little or no deflection; nevertheless, since the cathode-grid bias is varying at a 60-cycle rate, the dynamic range of the stage is reduced, and you will be unable to obtain full-screen deflection without clipping of the displayed waveform.

When heater-cathode leakage is present in a sawtooth-oscillator tube, it becomes difficult to lock low-frequency waveforms, because the oscillator is self-locked on the power frequency. At higher frequencies, waveforms can be synchronized, but the pattern oscillates horizontally at a 60-cycle rate. If heater-cathode leakage occurs in a sync-amplifier tube, the locking symptoms are much the same as noted for the sawtooth-oscillator tube. However, you can distinguish between the two conditions, because the hum symptom disappears when the sync-amplitude control is turned down if the trouble stems from the sync-amplifier tube.

In case the high-voltage filter capacitor becomes open or loses a substantial proportion of its capacitance, intensity modulation of the trace appears. At low levels the trace is broken up into successive bright and dim intervals at a 60-cycle rate. At higher intensity levels the bright intervals become defocused and mushroom. Defective filter capacitors in the low-voltage power supply produce a variety of pattern distortions which depend on the circuitry of the particular scope—the various decoupling circuits have different time-constants, so that the supply voltages of some stages and sections are better filtered than others.

Beginners should not be misled by the appearance of hum when the scope is operated with its case removed; the case usually serves an important shielding function and prevents stray external fields from entering the scope high-impedance circuitry. Another word of caution—because of the heavy filtering required in the 60-cycle high-voltage power supply, there is a possibility of fatal shock. Hence, never operate a scope with its case removed unless it becomes necessary to troubleshoot the circuitry. *Never touch the circuitry until after the high-voltage filter capacitors have been completely discharged.*

The high-voltage circuitry in a scope is tricky, because a negative high-voltage supply is almost always employed. This means that the heater, cathode, and control grid of the cathode-ray tube are at high potential. Beginners tend to assume that the heater and cathode circuitry can be worked "hot" as in a television receiver, not realizing that the circuit configuration is different in a scope. Remember that the grim reaper makes no allowance for ignorance.

Pictures in Video Waveforms

Still another waveform aspect resulting from 60-cycle hum voltage is the appearance of picture information in a video waveform (Fig. 5-16). This can result when hum voltage becomes mixed with the video signal either in the circuit under test or in the vertical amplifier of the scope itself. It is the result of the vertical deflection of the normal pattern by the hum voltage.

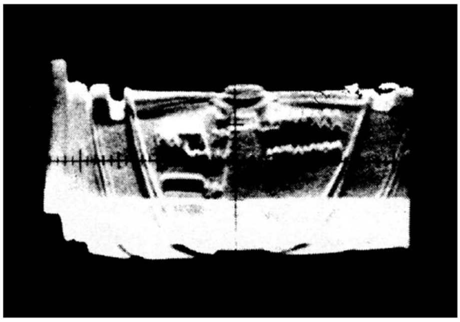


Fig. 5-16. Picture information caused by hum in video waveform.

COLOR WAVEFORM ASPECTS

It is disconcerting to the newcomer in color TV to look in vain for the color burst. The old-timer, on the other hand, proceeds to make systematic tests to track down the bug or bugs.

In case no burst is displayed in the station transmission (Fig. 5-17A), remember that technical difficulties or propagation vagaries could be attenuating the burst below visible amplitude. To eliminate this possibility, check the chassis with signal from a color-bar generator. Fig. 5-17C shows a typical waveform provided by a generator. If this substitution does not correct the situation, the next logical step is to check the generator.

Check the Color-Bar Generator

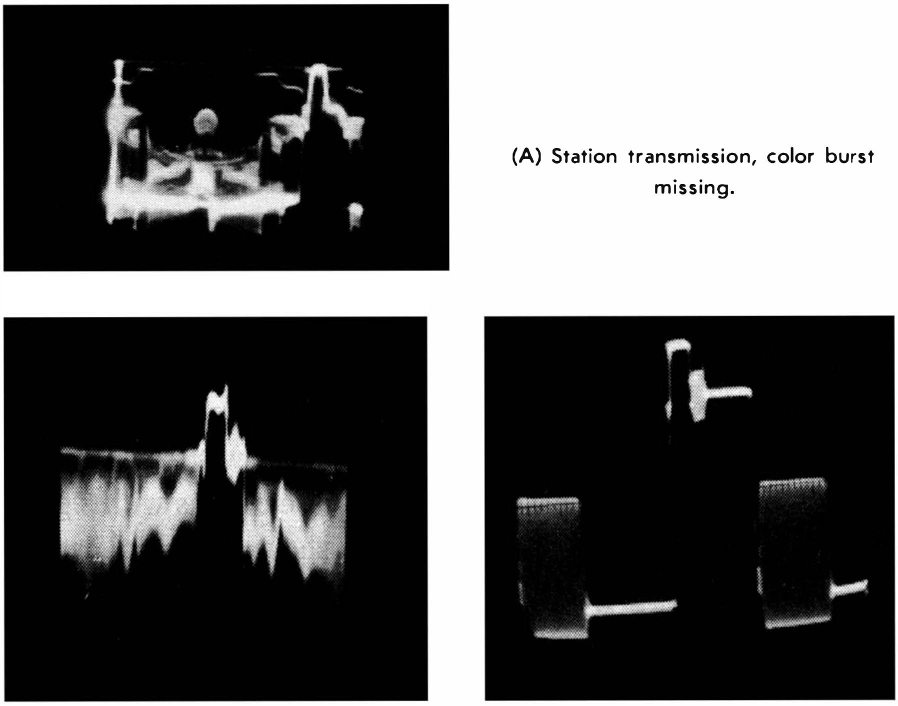
Nearly all color-bar generators have a video output terminal provided. When the video signal is fed to the vertical input terminals of a wide-band scope, you should see a waveform, such as in Fig. 5-17C. The color burst normally has the same peak-to-peak voltage as the horizontal-sync pulse. A burst-amplitude control is provided to adjust the burst voltage.

If, when the burst-amplitude control is turned to maximum, the burst voltage still appears too low, do not jump to the conclusion that the color-bar generator is defective. The difficulty could equally well be an inadequate or defective scope.

Check the Scope

The vertical amplifier should have a flat response through 3.58 mc. To determine this point, apply the output from a video-frequency sweep generator to the vertical input terminals. The test result is easy to judge if you use a 4-mc absorption marker. This may be a built-in feature of the sweep generator, or you may have to use an external marker box.

A typical test display was shown in Fig. 4-3B. The notch near



(A) Station transmission, color burst missing.

(B) Station transmission with normal color burst.

(C) Color-bar generator signal with normal burst display.

Fig. 5-17. Color TV waveforms.

the right end of the pattern is a 4-mc absorption marker. Note that the response at burst frequency is down about 20%, or 2 db. This is a usable frequency response, although it does have the undesirable action of attenuating all chroma voltages 20% in color-TV tests. If a scope has 100% response at the color-burst frequency (3.58 mc), no interpretation of chroma waveforms is required—what you see is really there.

The foregoing test result does not signify that you should immediately go into the scope to bring up the high-frequency response. While it is true that the burst frequency appears 2 db down in the pattern, the scope itself could be flat through the burst frequency. It is possible that the high-frequency attenuation is in the sweep generator.

Check the Sweep Generator

To confirm or eliminate this possibility, feed the output from the sweep generator through a demodulator probe to the vertical input terminals. In case a flat characteristic is displayed (Fig. 4-18), the high-frequency loss is occurring in the scope.

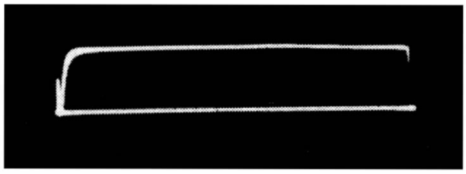


Fig. 5-18. Scope display showing flat output from video sweep generator.

But on the other hand, if the characteristic shows a 2-db attenuation at 3.58 mc, the scope actually has a flat frequency response through the color-burst frequency.

To summarize: waveform aspects are not always what they seem to be, because a false assumption might have been made concerning the characteristics of associated instruments. Since you can make definitive cross-checks with basic instruments, it is a simple procedure to run down the source of unexpected waveform aspects.

CHAPTER 6

Waveform Measurements

Some waveform measurements are obvious; for example, since a scope is basically a voltmeter, vertical deflection is directly proportional to peak-to-peak voltage. Since the voltage across a resistor is proportional to current, vertical deflection is directly proportional to peak-to-peak current when the waveform is taken across a resistor in a circuit. On the other hand, measurement units that are not proportional to vertical deflection are not entirely obvious. Decibel measurements are a case in point.

HOW TO MEASURE DB WITH A SCOPE

It is often necessary to identify various db points on a frequency-response curve. If the bandwidth of a TV-IF curve is defined as the frequency interval between the −6 db points on the curve, this simply refers to the points half way down from the peak of the curve to the base line. A trap response might be specified as -20 db down, which means a point 90% down on the response curve.

Decibels can be defined in terms of vertical deflection in this manner because the scope is connected across the same load for all db masurements taken on any one curve. It makes no difference what the load may be because the difference between db readings across any fixed load is a true measurement that

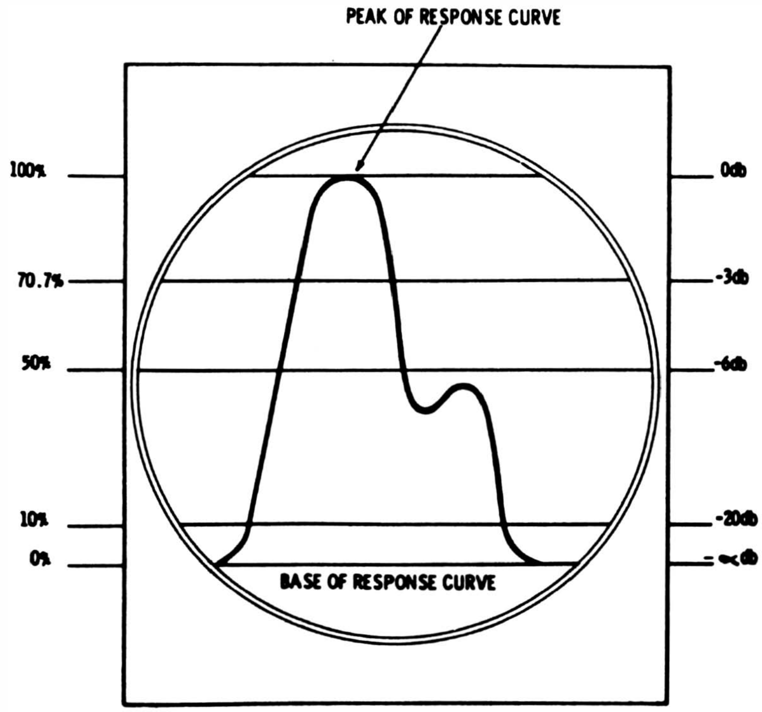


Fig. 6-1. Correlation of db response and percentage response.

requires no conversion. The derivation of this relation is not of present importance, but its availability permits the construction of direct-reading db graticules for scopes (Fig. 6-1). A db graticule is employed only in specialized applications which require a long series of db measurements. Usually an ordinary graticule is used, and reference is made to a table of voltage ratios versus db values when db readings are being made.

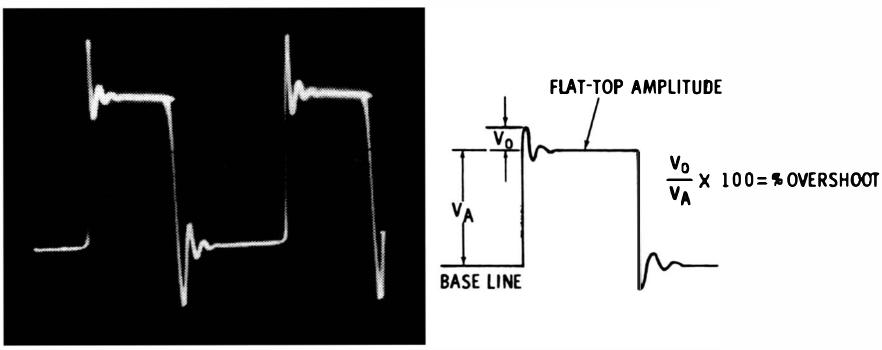
Dual db Scales

On IF and RF frequency-response curves, measurement is always made in terms of db loss. In other words, the peak of the curve is taken as the reference point (0 db), and all measured db values are negative. When evaluating the response of an audio amplifier, it is customary to take the gain at 1,000 cycles as the 0-db reference point; the gain at other frequencies may be either greater or less than 0 db. Hence, graticules employed in this type of test are provided with two db scales, one of which is calibrated in db gain and the other in db loss. In specifying the total variation of an audio-frequency response curve, the maximum and minimum values are read, for example, ±3 db, or +2 and −4 db. The practice of analyzing frequency-response curves in terms of db loss and db gain with respect to a mid-band 0-db reference extends to wide-band amplifiers, such as TV-distribution amplifiers.

PERCENTAGE OVERSHOOT

Amplifiers are often rated for overshoot at a specified square-wave frequency. For example, an amplifier might be rated for less than 10% overshoot when driven by a 10-kc square wave. The meaning of percentage overshoot is shown in Fig. 6-2B. In this example, overshoot is followed by ringing—this is often the case, although overshoot occasionally occurs without subsequent ringing. In Fig. 6-2A overshoot occurs on the trailing edge as well as on the leading edge. The trailing overshoot may have the same percentage as the leading overshoot or a different value. In some cases, overshoot occurs only on one edge.

An amplifier may develop overshoot without ringing on the leading edge or overshoot on the trailing edge. Both positive



(A) Scope display. (B) Calculation of percentage overshoot.

Fig. 6-2. Overshoot and ringing.

and negative peaks may exhibit tilt. An overshoot may terminate quickly or gradually; in the limit, the overshoot becomes a tilt. Intermediate situations can be characterized as either a prolonged overshoot or as tilt with curvature. Percentage tilt is measured in the same manner as percentage overshoot.

Amplifier square-wave responses often show a combination of characterisics, such as overshoot with ringing, overshoot with tilt, or overshoot with ringing and tilt. When overshoot is tolerated, it is the price paid for faster rise time. In other words, most amplifiers provide decreased rise time if a reasonable percentage of overshoot is permitted. If residual inductance is present in the amplifier circuitry, the overshoot is usually accompanied by ringing. Whether ringing is brief or prolonged depends on the Q of the associated inductive circuit. This fact is put to use to measure the Q of the coil. If you measure the ringing frequency, you can also find the inductance and the AC resistance of the coil under test.

HARMONICS AND RINGING FREQUENCY

In most cases the ringing frequency has no relation to the fundamental or harmonic frequencies of the distorted square wave. Hence, when it is desired to measure the ringing frequency, this procedure may be carried out without regard to the square-wave repetition rate. To measure a ringing frequency, first adjust the scope controls so that the ringing interval occupies an appreciable portion of the screen area. This gives ample excursion of the ringing waveform so that it can be effectively analyzed. Then, note the number of horizontal squares occupied by one cycle of the ringing waveform. This number of squares is used for reference in the final step of the procedure. Disconnect the scope from the source of the ringing waveform and feed the output from an audio oscillator into the scope. Without changing the settings of the scope controls, adjust the audio-oscillator tuning control until the number of horizontal squares observed previously is occupied by one cycle. The reading of the dial on the oscillator then gives the ringing frequency. Note that ringing intervals are often encountered when any complex waveform is applied to the input of an amplifier.

Whether a complex waveform contains odd harmonics only, even harmonics only, or both odd and even harmonics can be seen from the mathematical expression for the waveform. Thus, a square wave can be expressed by the equation:

$$e = \frac{4E}{\pi} (\cos \omega t - \tfrac{1}{3} \cos 3\, \omega t + \tfrac{1}{5} \cos 5\, \omega t - \tfrac{1}{7} \cos \omega t\ .\ .\ .)$$

where,

e is the instantaneous voltage,
E is the peak voltage,
ω is 6.28 times the fundamental frequency.

This is called the cosine expression of a square wave. Any desired number of cosine terms can be added to the equation. A cosine wave has the same shape as a sine wave, but it differs 90° in phase. A minus sign in the expression means that the harmonic is 180° different in phase from the same harmonic with the plus sign.

It is obvious that the frequencies in a square wave are related according to factors of 1, 3, 5, 7, 9, 11, etc. Hence, a square wave contains odd harmonics only. The ringing frequency in Fig. 6-2 is a new and arbitrary frequency which is added to the harmonic frequencies contained in the reference square wave. The ringing frequency can be filtered out by a harmonic analyzer, just as a harmonic of the reference square wave can be filtered out.

Output of Full-Wave Rectifier

Compare the expression for a square wave with that for the output from a full-wave rectifier; the succession of half-sine waves from a full-wave rectifier is described by the expression:

$$e = \frac{2E}{\pi} (1 + \tfrac{2}{3} \cos 2\omega t - \tfrac{2}{15} \cos 4\, \omega t + \tfrac{2}{35} \cos 6\, \omega t - \ldots .)$$

where,

e is the instantaneous voltage,
E is the peak voltage,
ω is 6.28 times the fundamental frequency.

The frequencies are related according to factors of 2, 4, 6, 8, etc.; the wave contains even harmonics only. Compare the foregoing expressions with that for a sawtooth wave:

$$e = \frac{2E}{\pi} (\sin \omega t - \tfrac{1}{2} \sin 2\omega t + \tfrac{1}{3} \sin 3\,\omega t - \tfrac{1}{4} \sin 4\,\omega t \ldots)$$

where,

e is the instantaneous voltage,
E is the peak voltage,
ω is 6.28 times the fundamental frequency.

The frequencies in a sawtooth wave are related according to factors of 1, 2, 3, 4, etc. Accordingly, a sawtooth wave contains both even and odd harmonics. Any expression of sines can be converted to cosines, or vice versa, but, of course, the harmonic relations described are the same.

Pulse With Infinitesimal Width

When you differentiate or integrate a waveform, the frequencies of the harmonics are unchanged; however, their amplitudes and phases are changed. Suppose an ideal pulse is integrated and a square wave is obtained. This shows that a pulse contains the same frequencies as a square wave. Next, suppose that the square wave is integrated; a pyramid (back-to-back sawtooth) wave results, and it is evident that the same harmonic frequencies are present. If this wave is integrated, a parabolic wave is obtained, and the same harmonic frequencies are present.

An ideal impulse wave contains odd harmonics only, and each harmonic has the same amplitude. Integration weakens the higher harmonic amplitudes so that the third harmonic in the resulting square wave has $\frac{1}{3}$ the amplitude of the fundamental, the fifth harmonic has $\frac{1}{5}$ the amplitude of the fundamental, etc. If you integrate the square wave to form a pyramid wave, the higher harmonic amplitudes are weakened still more. The expression for a pyramid wave is:

$$e = \frac{8E}{\pi^2} (\cos \omega t + \tfrac{1}{9} \cos 3\,\omega t + \tfrac{1}{25} \cos 5\,\omega t + \ldots.)$$

where,

e is the instantaneous voltage,
E is the peak voltage,
ω is 6.28 times the fundamental frequency.

When you integrate the pyramid wave to obtain a parabolic wave, the harmonics decrease in amplitude still more rapidly. The succession of parabolic waves looks very much like a sine wave, and indeed, if an infinite number of integrations is carried out, you would arrive at a pure sine wave having the frequency of the fundamental, since all harmonic amplitudes would ultimately become zero.

Note that you can go backward from a parabolic wave and by successive differentiations arrive at an impulse wave. In this case each differentiation brings up the amplitude of the higher harmonics.

When a waveform is expressed mathematically, it is said that the analytic solution has been obtained. In a sense, then, a scope is an analog computer.

Q VALUE OF A COIL

A distinction must be made between two different types of Q values for a coil. The basic value is the Q of the coil in isolation, i.e., when it is not loaded by associated circuitry. The other value of Q is lower for the same coil. It is obtained when the coil is loaded by various circuit components to which it may be connected, such as in an amplifier. Ringing patterns provide a convenient means of measuring the Q of an isolated coil. When you connect the coil to the input terminals of a scope, the coil is isolated for all practical purposes because the input impedance of a scope is very high. The stray capacitance that is present will resonate with the coil at some frequency.

A pulse voltage is injected into the coil by very loose coupling. For example, some scopes have a front-panel terminal which supplies a pulse voltage; connect a lead to the pulse terminal and place the open end of the lead near the coil. This provides very loose capacitive coupling. Now, a damped sine wave should appear on the scope screen (Fig. 6-3). Note the points indicated at a and b in Fig. 6-3. At b, the amplitude of the damped sine wave has decreased to 37% of its amplitude at a. In other words, if there are 16 squares of vertical deflection at a, there are 6 squares at b. The significance of the 37% value is that it shows the time constant of the ringing coil. The Q of the coil is given by the formula:

$$Q = \pi n$$

where,

π is 3.1416,

n is the number of peaks between a and b.

Q in this example is approximately 22.

If you know what the Q value of a coil should be, you can make a ringing test to check the Q value. Shorted turns, for example, reduce the normal Q value. This is merely a simple comparison test, and additional waveform observations must be made to obtain a more complete evaluation of the coil. These are discussed subsequently, but now, consider how you would measure the Q of a coil which is connected in a resonant circuit.

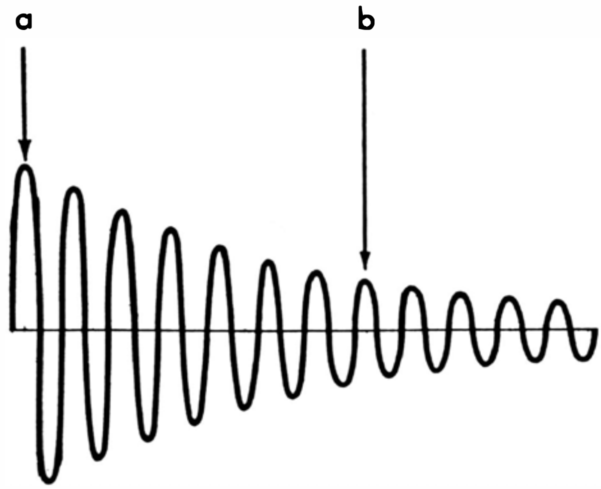


Fig. 6-3. Determination of Q from ringing waveform.

It is most convenient to determine the Q of the loaded coil by evaluating the frequency-response curve for the stage (Fig. 6-4). This is done by noting the frequencies at the −3 db points on the curve. The −3 db points occur at 70.7% of peak amplitude—they are often called the half-power points. The Q of the loaded coil is then given by the formula:

$$Q = \frac{f_r}{f_2 - f_1}$$

where,

f_r is the center frequency,

f_1 and f_2 are the frequencies at the −3 db points.

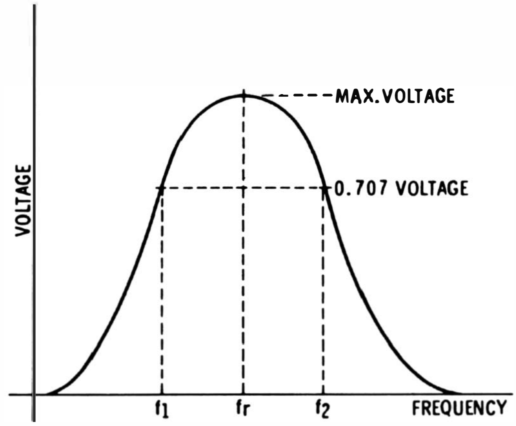


Fig. 6-4. Determination of Q from frequency response curve.

Ringing Frequency

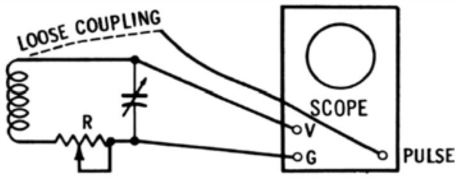
The value of Q means little unless you specify the frequency at which it was measured. This lack of meaning results from the fact that the Q value changes with frequency. In Fig. 6-3 you would relate the Q value to the ringing frequency. How do you measure the ringing frequency? If the scope has calibrated horizontal sweeps, you can read the frequency from the ringing pattern. However, most scopes do not have calibrated sweeps, and an audio oscillator is required. Connect the output from the audio oscillator in place of the coil and adjust the frequency until the pattern shows the same number of peaks between a and b as before. The dial of the audio oscillator then indicates the ringing frequency.

AC RESISTANCE

Beginners sometimes suppose that the AC resistance of a coil is the same as its DC resistance. This is not necessarily true. At low frequencies, such as 60 cycles, the AC and DC resistances are practically the same for most coils. On the other hand, at higher frequencies, such as 1 mc, the AC resistance will always be higher—often very much higher—than the DC resistance. It is easy to measure the AC resistance of a coil at its ringing frequency. Merely connect a potentiometer in series between the coil and a tuning capacitor (Fig. 6-5). The tuning capacitor may be adjusted for any desired ringing frequency within its range.

The potentiometer is used to determine the AC resistance of the coil. To do this, note that the ringing waveform becomes more highly damped and dies out faster when the value of R (Fig. 6-5) is increased. Referring to Fig. 6-4, the ringing waveform falls to 37% of its initial amplitude after 7 peaks. If you adjust the potentiometer so that the waveform falls to 37% of its initial amplitude after 3½ peaks, the resistance of the potentiometer is equal to the AC resistance of the coil. You can measure the potentiometer resistance with an ohmmeter.

Fig. 6-5. Method of determining AC resistance of a coil.



The value of AC resistance changes with the ringing frequency; hence, a measured value of AC resistance should be stated with respect to the frequency at which it was measured. In general, the higher the ringing frequency, the higher is the AC resistance. In this respect, Q values and AC resistance values are both functions of frequency—other things being equal, Q doubles when the frequency is doubled. However, other things are seldom equal, because the AC resistance varies with frequency in a more or less unpredictable way. Inasmuch as Q depends on both frequency and AC resistance, it is evident that a Q measurement at one frequency does not justify a prediction of its value at some other frequency.

Inductance

If you have measured the ringing frequency and the Q and AC resistance at this frequency, the inductance of the coil can be determined by the formula:

$$L = \frac{RQ}{2\pi f}$$

where,

L is the inductance in henrys,
Q is the quality factor at frequency f,
f is the ringing frequency in cycles per second,
π is 3.1416.

The henry, of course, is a large unit of inductance, and most of the coils commonly used in electronic circuits have inductances in the millihenry (0.001 henry) range. If you express f in kilocycles, then L is given in millihenrys in the foregoing formula.

The inductance of an air-core coil is practically constant at any frequency of operation. On the other hand, a permeability-tuned coil may have quite different inductance values at different frequencies; this change in inductance stems from different characteristics of the powdered core material at various frequencies. Note that the inductance of coils with laminated iron cores, such as output transformers, will have less inductance when the current flow is heavy. This results from partial saturation of the iron. Thus, plate-current flow through the primary of an output transformer reduces its effective inductance.

UNTUNED TRANSFORMER

Untuned transformers, such as flyback transformers, exhibit highly complex ringing waveforms in some cases. A typical pattern is shown in Fig. 6-6. Although a transformer is regarded

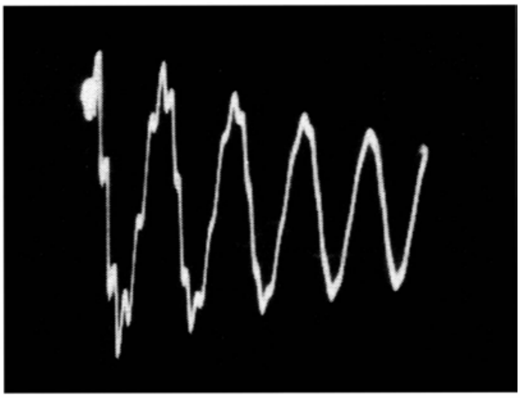


Fig. 6-6. Ringing waveform of a transformer winding.

as untuned in the sense that tuning capacitors are not connected across the windings, capacitance is nevertheless present. There is distributed capacitance between layers of the windings, with the result that the windings have self-resonant frequencies. The various windings are also coupled rather tightly by the ferrite core so that a complex electrical system results. Because the situation is so involved, ringing tests are usually made on a comparative basis only.

When a flyback transformer is connected into a horizontal-output circuit, the tendency to ring on forward scan is less than for an isolated transformer. The primary is loaded by the horizontal-output tube. At the end of the forward scan, the horizontal-output tube is suddenly cut off, and the flyback transformer, with its associated yoke circuit, rings strongly for one-half cycle. At the end of a half cycle, the damper tube conducts and heavily loads the secondary. In theory, no residual ringing would occur, but due to leakage reactances in the flyback transformer, more or less spurious ringing ensues. Thus, when you observe the screen-grid waveform, you often see evidence of spurious ringing (Fig. 6-7).

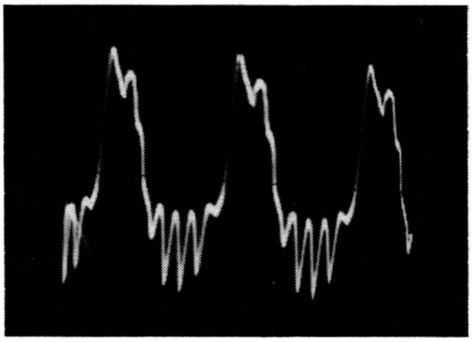


Fig. 6-7. Screen voltage waveform of a horizontal-output tube.

LEAKAGE REACTANCE

When primary and secondary are wound on the same core and coupled as tightly as possible (as in an output transformer), there is no leakage reactance present, at least in theory. In other words, if the secondary terminals are short-circuited, it would be expected that the short would be reflected back to the primary terminals, and that the primary input impedance would be zero. In practice, the short circuit is less than 100% reflected to the primary, and you will observe more or less ringing when a pulse shock-excites the primary. There is a small amount of uncoupled inductance present, which is tuned to the ringing frequency by distributed capacitance. The residual ringing is said to be caused by the leakage reactance, which resonates with the stray capacitance.

Uncoupled inductance stems from stray magnetic field flux. In other words, most of the flux set up by the primary threads through the secondary, but a small amount of flux fails to do so, escaping via air paths. Well designed output transformers have a very small amount of leakage reactance. On the other hand, a tuned IF transformer has a very high value of leakage inductance. The looser the coupling between primary and secondary, the greater is the amount of leakage inductance that exists.

DELAY TIME

In checking out delay lines and various special-purpose electronic devices, it becomes necessary to measure delay time. This is an input-output relationship and is defined as the elapsed

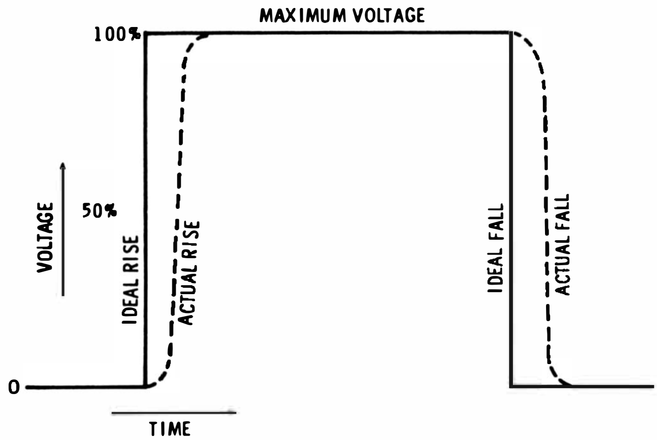


Fig. 6-8. Waveform showing 50% point.

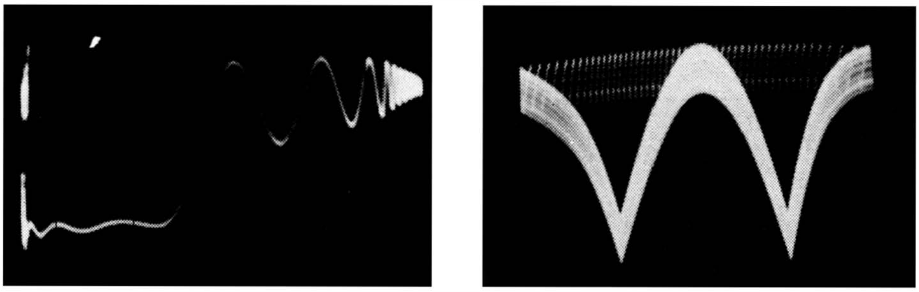
time from the 50% point on the input waveform to the 50% point on the output waveform (Fig. 6-8). To make this measurement, you must know how much elapsed time is represented by each horizontal interval along the graticule. It is not always necessary to use a sophisticated scope with calibrated horizontal sweeps; an ordinary scope can easily be calibrated for this purpose.

For example, you can connect the output from a signal generator to the vertical input terminals of the scope and tune the generator to 1 mc. Then, adjust the scope controls so that the sine-wave pattern crosses each horizontal interval. Each successive horizontal division then represents an elapsed time of

0.5 microsecond. To measure delay time use the external-sync function of the scope—for example, a lead can be connected from the external-sync terminal of the scope to the output of the device under test. Observe the input waveform first, and note its 50% point on the graticule; next observe the output waveform and note its 50% point. The separation of the 50% points gives an indication of the delay time.

USE OF EXPANDED DISPLAY

Various of the foregoing tests may be made on expanded sweep or triggered sweep, which can provide improved readability at high frequencies. Sweep magnifiers in lower-priced scopes do not always have a linear display; an example of poor linearity is shown in Fig. 6-9. A triggered-sweep function al-



(A) Display with sweep magnifier. (B) Expansion of detail on retrace.

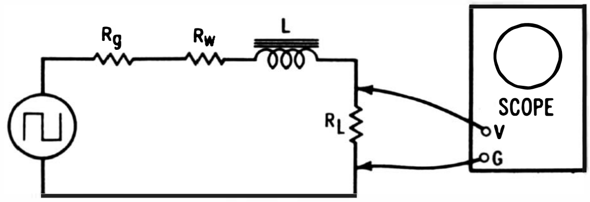
Fig. 6-9. Waveform expansion.

ways provides as good linearity as free-running sawtooth sweep and may be preferred for this reason. You can display a ringing waveform as readily on triggered sweep as on conventional horizontal free-running deflection.

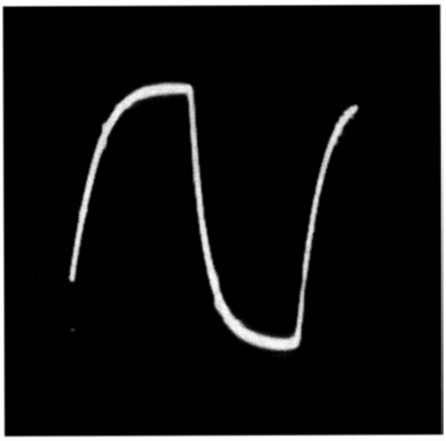
Scopes which do not have retrace blanking display a visible retrace, as shown in Fig. 6-9B. Since retrace is much faster than the forward trace, waveform detail is expanded on retrace. This is the only possibility of waveform expansion on a simple scope, and it is sometimes helpful. However, a certain amount of skill is required to display the desired portion of the waveform on the retrace interval. Among the control considerations are employment of positive, negative, or external sync with close adjustment of the sync-amplitude and horizontal-frequency controls.

WAVEFORMS FOR LARGE INDUCTANCES

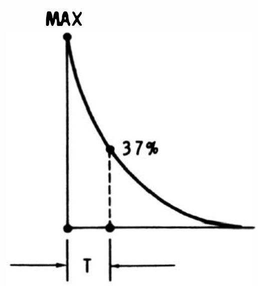
Large inductances often have a low Q and will not ring when shock-excited; however, if ringing does occur, the damping is so rapid that satisfactory measurements cannot be made. Otherwise stated, the winding resistance is so high, and the distributed capacitance is so large (natural resonant frequency so low), that the inductor is in the vicinity of or past critical damping; hence, other methods than ringing tests must be used



(A) Circuit.



(B) Waveform display.



(C) Determination of T.

Fig. 6-10. Square-wave measurement of inductance.

to determine the inductance value. A square-wave test is convenient. An integrating circuit is used (Fig. 6-10). The square-wave generator is set to any convenient frequency which is low enough to produce a decay to practically zero (the end of each excursion is practically horizontal).

The inductance (L) in henrys is determined from the formula:

$$L = R_T T$$

where,

L is the inductance in henrys,
T is the decay time in seconds,
R_T is the sum of R_g, R_w, and R_L,
R_g is the internal resistance of the generator in ohms,
R_w is the winding resistance of ohms,
R_L is the load resistance in ohms.

Some generators have a rated output resistance, but if yours does not, it is easy to measure the output resistance (internal resistance). Simply connect a potentiometer across the generator output terminals and check the square-wave amplitude with a scope. When the output voltage drops to one-half the open-circuit value, the potentiometer resistance is equal to the generator internal resistance. At low frequencies, such as 100 cycles, R_w is practically the same as the DC resistance. Hence, measure R_w with an ohmmeter.

To measure T, note that this is the time for the waveform to fall from its maximum value to 37% of maximum. This is why the operating frequency should be chosen to obtain a flat top and bottom on the waveform—the pattern shows the level at which the waveform decays to zero. Locate the point 37% up on the decay curve by counting squares of vertical deflection. Suppose you are operating the square-wave generator at 100 cycles. Then, the time for one complete cycle is 0.01 second. If there are 10 horizontal squares included in one complete cycle, each square will represent 0.001 second. Merely count the horizontal squares from the start (maximum point) of the decay curve to the point where it has fallen to 37% of maximum. Multiplying the number of squares by 0.001 gives the value of T.

The distributed capacitance of the inductor does not introduce appreciable error as long as the square-wave frequency is comparatively low. When the frequency is too high, you will not observe a waveform such as shown in Fig. 6-10, but instead a broken type of waveform will appear due to introduction of differentiation by the distributed capacitance. Therefore, always use a square wave frequency which gives a true integrated waveform. Note that the value of R_L is not critical, and any value in the range of a few thousand ohms is satisfactory.

VIEWING TOTAL HARMONIC DISTORTION

When an amplifier distorts a sine wave, the output consists of the original sine wave plus the harmonics which have been generated. A scope connected at the output of the amplifier (Fig. 6-11A) shows the combined fundamental and harmonics (Fig. 6-11B). The amplifier has distorted the input sine wave and made it unsymmetrical—the positive peak is broader than the negative peak. If the fundamenal is filtered out (Fig. 6-11C), the scope then displays the total harmonic distortion alone (Fig. 6-11D).

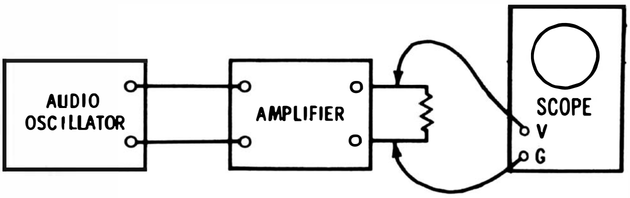
From the preceding discussion it would be anticipated that even harmonics have been generated by the amplifier. Fig. 6-11D shows that this is so; when the fundamental is filtered out by the harmonic-distortion meter, a double-frequency complex wave is displayed. This double-frequency characteristic shows that second-harmonic distortion is prominent. Of course, there are other harmonics present also, because the output from the harmonic-distortion meter is a complex wave and not a simple sine wave. The meter reads the percentage of total harmonic distortion.

Note that the output from the harmonic-distortion meter gives waveshape and frequency information only—it does not necessarily indicate either the polarity nor the phase of the total-harmonic-distortion waveform. Likewise, the relative amplitudes of the two waveforms in Fig. 6-11 are not given directly in this type of test—the test setup would have to be calibrated in order to measure the comparative amplitude of the distortion products. However, this is seldom necessary, because a related amplitude value is given by the reading of the harmonic-distortion meter.

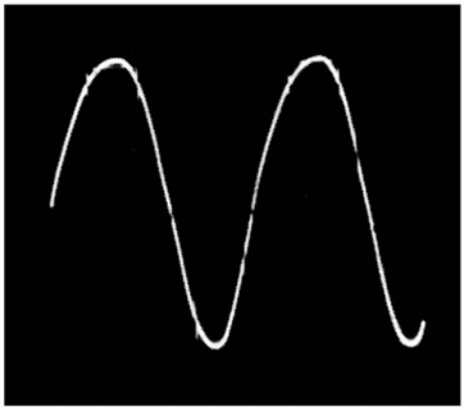
MEASUREMENT OF DC COMPONENT

Whenever a waveform is passed through nonlinear resistance, it develops a DC component. An extreme example is a sine wave passed through a rectifier. A waveform across a cathode-bias resistor "rides on" the DC bias voltage. The waveform at the base of a transistor "rides on" the base-emitter DC voltage. This mixture of AC and DC voltages is displayed by a

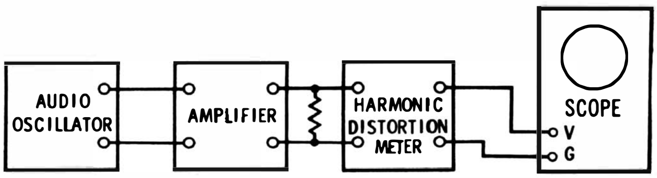
DC scope, as shown in Fig. 6-12A. Note that the sine wave is centered on the DC component. Since DC voltage is measured in the same units as peak-to-peak voltage, the DC component is determined by counting squares of vertical deflection.



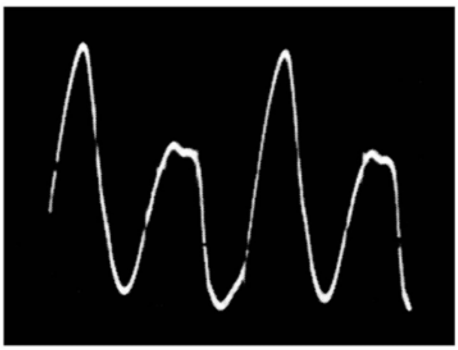
(A) Scope connected to amplifier output.



(B) Waveform at amplifier output.



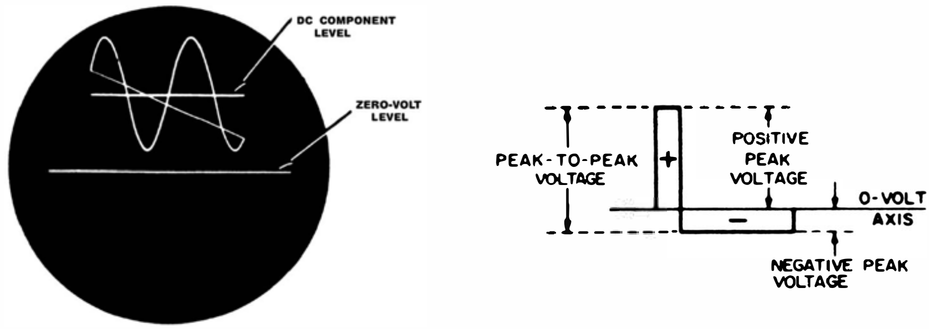
(C) Test setup to separate total harmonic distortion.



(D) Waveform of separated distortion components.

Fig. 6-11. Display of total harmonic distortion on a scope.

For example, if a scope is calibrated for a sensitivity of 1 volt peak-to-peak per square of vertical deflection, and the DC component level is located 10 squares above the base line, the value of the DC component is 10 volts. This is a comparatively simple example. The DC component level is readily apparent in Fig. 6-12A because a sine wave has a symmetrical form—in other words, the DC component level cuts half-way down the sine wave and divides it into equal positive and negative excursions.



(A) Sine wave superimposed on DC component.

(B) Determination of DC-component level of complex waveform.

Fig. 6-12. Waveforms with DC components.

If you proceed to measure the DC component in a complex waveform, the DC component level may not be obvious. In such a case, first switch the scope to its AC function and note how the complex wave is placed above and below the 0-volt axis. The waveform will be divided into equal areas. This division for a pulse wave is depicted in Fig. 6-12B. Next, switch the scope to its DC function—the waveform will rise on the screen (or fall if the DC component is negative). Now, note the separation between the former 0-volt level and the actual 0-volt level on the screen; this separation is a measure of the DC component. In other words, you do not have to guess where the DC component level cuts the waveform—a preliminary check on the scope AC function will give you this information.

Output From Demodulator Probe

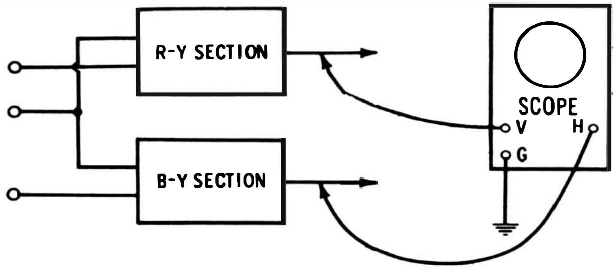
There is always a DC component present in the output from a demodulator probe, because the probe contains a rectifier diode. The DC component provides convenient measurement of percentage modulation. For example, if you wish to measure the percentage modulation in the output signal from an AM generator, simply pass the signal through a demodulator probe into a DC scope. The demodulated envelope will then ride above the zero-volt level as in Fig. 6-12A. If the negative peaks touch the zero-volt level, the signal is 100% modulated. Overmodulation shows up as a clipping of the negative peaks.

Standard modulation for an AM generator is 30%. In this case the negative peaks dip 30% down from the DC component level toward the zero-volt level. You will find that the modulation percentage for an AM generator is not necessarily constant on different bands, nor even at different settings on the same band. Likewise, the modulation envelope is not always a true sine wave and in some cases changes shape considerably from one band setting to another. Hence, it is useful to have a quick check available for modulation percentage and waveshape. Note that the waveform might appear below the zero-volt level, depending on the polarity of the diode in the demodulator probe.

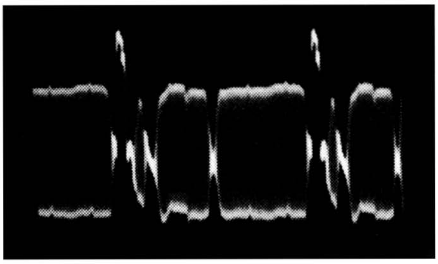
CHROMA PHASE MEASUREMENT

Various types of waveforms are utilized to check and measure chroma-demodulator phases. The cyclogram (vectorgram) display shown in Fig. 6-13C is one type. To obtain the cyclogram pattern, the output from the R—Y section is connected to the vertical input terminals of the scope, and the output from the B—Y section is connected to the horizontal-input terminals. The color receiver is energized by a chroma signal from a color-bar generator comprising sync-and-burst, R—Y, and B—Y signals, as seen in the video-detector output waveform in Fig. 6-13B.

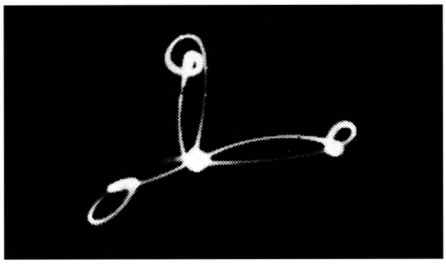
The cyclogram shows the phases of burst, R—Y, and B—Y after the chroma signal has been processed through the chroma demodulators. Note in the cyclogram pattern that the R—Y vector extends vertically, the B—Y vector extends horizontally to the right, and the burst vector extends horizontally to the left. The cyclogram shows a noticeable phase error, which can be corrected by suitable circuit adjustment. Proper phasing of the subcarrier voltages into the chroma demodulators brings



(A) Test setup.



(B) Waveform of video-detector output.



(C) Demodulator phase cyclogram.

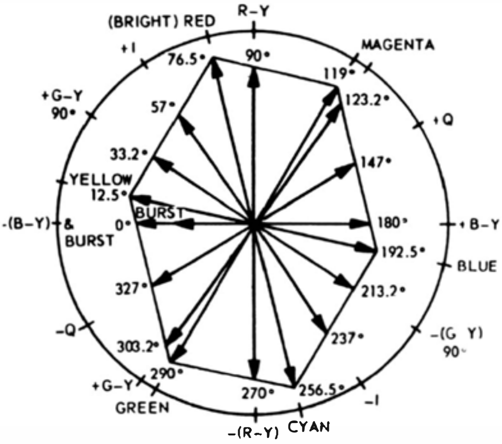
Fig. 6-13. Display of chroma phase information.

the B—Y and burst vectors into the same horizontal line, with the R—Y vector extending upward at right angles. Note also that the vectors in the cyclogram (Fig. 6-13C) are not straight lines, as they would be in theory; instead, there is a progression of noticeable loops. The looping is caused by residual phase errors in the chroma circuitry and is normal for commercial receiver circuitry.

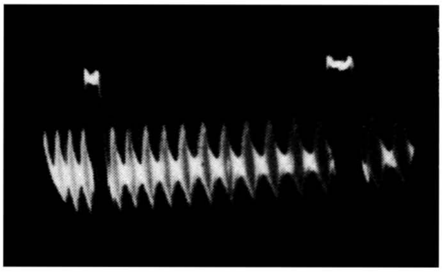
A more complete check of chroma demodulation phasing can be obtained by applying a complete color-bar signal to the receiver. A six-cornered cyclogram results in this case, showing the demodulated phases of the primary and complementary colors. However, the basic phasing data is given by the R—Y/B—Y test. A complete sequence of chroma phases is depicted in Fig. 6-14A.

PHASE CHECKS WITH KEYED-RAINBOW SIGNAL

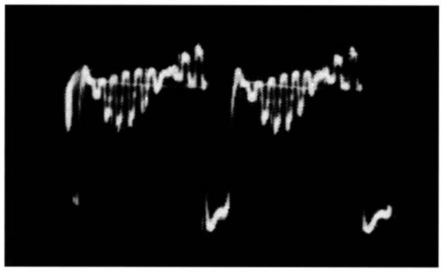
Phase tests and measurements in chroma circuits can also be made with a keyed-rainbow signal. The output from a keyed-rainbow generator is illustrated in Fig. 6-14B. Note that 11 "bursts" appear between consecutive horizontal-sync pulses, in 30° intervals. The color burst follows the sync pulse, then



(A) Sequence of chroma phases.



(B) Keyed-rainbow generator output.



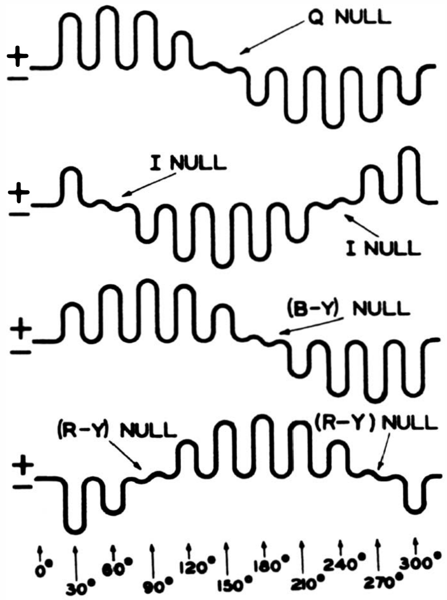
(C) Output from chroma demodulator.

Fig. 6-14. Phase determination with a keyed-rainbow signal.

$G-Y\angle 90^\circ$, I, R−Y, −(G−Y), Q, B−Y, $-G-Y\angle 90^\circ$, −I, −(R−Y), and G−Y. The −Q phase does not appear in a keyed-rainbow signal, being "lost" on the flyback interval.

When a keyed-rainbow signal is applied to a color receiver and a scope connected at the output of a chroma demodulator, the waveform rises to a maximum and falls to nulls, as illustrated in Fig. 6-14C. The null point(s) is sharply defined, and hence is used to check demodulator phase. Chroma demodulators are quadrature detectors, which means that an R−Y demodulator normally nulls on a B−Y signal, and that a B−Y demodulator nulls on an R−Y signal. A G−Y demodulator normally nulls on a $G-Y\angle 90^\circ$ signal. Similarly, an I demodulator normally nulls on a Q signal, and a Q demodulator nulls on an I signal.

Note that the 30° intervals in a keyed-rainbow signal do not all correspond exactly to the various chroma phases. Thus,



(A) I-demodulator output.

(B) Q-demodulator output.

(C) (R—Y)-demodulator output.

(D) (B—Y)-demodulator output.

Fig. 6-15. Phase nulls for four types of chroma demodulators.

R—Y and Q are actually 33° apart in phase instead of 30°; B—Y and Q are actually 33° apart, instead of 30°. However, the 3° phase discrepancy is not serious in practical work, and a keyed-rainbow generator is less costly than an NTSC type generator which is held to close phase tolerances.

Correct phase nulls for four types of chroma demodulators are depicted in Fig. 6-15. A comparison of these waveforms with the diagram in Fig. 6-14A shows that a null normally occurs in a quadrature relation to the reference phase.

Note that a null is obtained from a B—Y demodulator on both R—Y and —(R—Y) phases. Likewise, a null is obtained from a Q demodulator on both I and —I phases. In other words, a phase null is independent of signal polarity. The peak excursions of chroma demodulator waveforms, however, are developed in accordance with signal polarity—thus, an I demodulator output waveform passes first through a positive peak excursion when a rainbow signal is applied, then passes through a null at the Q phase, and then passes through another negative peak excursion. Otherwise stated, the keyed-rainbow signal progresses clockwise in the diagram of Fig. 6-14A, starting at the burst phase and finally returning to the burst phase.

CHAPTER 7

Waveform Distortion Analysis

Waveforms contain information which requires more or less interpretation. This requirement has been touched on in previous chapters. Distortion is encountered in a vast number of forms, and each type of distortion has a cause. If you recognize the reason for a particular type of distortion, you can proceed with confidence to correct the defect that is indicated.

REACTANCE VERSUS FREQUENCY

One of the simplest types of distorted waveform reproduction is observed when the vertical input leads to a scope are open-circuited. The floating input lead picks up 60-cycle hum voltage from stray fields. The 60-cycle "sine-wave" display is also distorted (Fig. 7-1), due to exaggeration of harmonics (attenuation of low frequencies) with respect to the source waveform in the 60-cycle line.

An open test lead is capacitively coupled to the power wiring in the wall and at the bench. This capacitance is small; hence, stray-field sources are high-impedance sources. Since a scope has high input impedance, it can display the voltage from a high-impedance source. Because the source is capacitively coupled to the open test lead, the coupling is reactive and its ohmic value decreases with increasing frequency. A 60-cycle stray field is basically a 60-cycle sine wave, but it almost

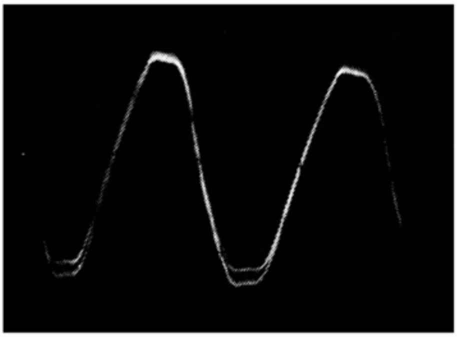


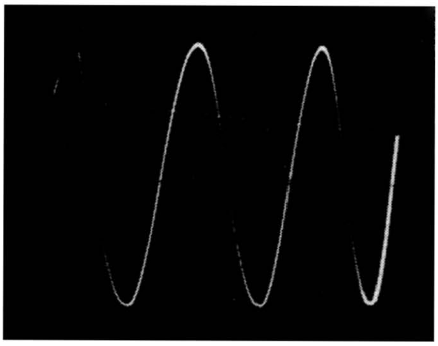
Fig. 7-1. Scope waveform with vertical input lead open-circuited.

always contains harmonics—principally odd harmonics due to the small nonlinearity of transformer cores. Thus, the 60-cycle stray field contains frequencies of 180 cycles, 300 cycles, and so on. The higher harmonics are coupled more strongly to the open test lead and are emphasized in the stray-field pattern. This is the reason that the waveform in Fig. 7-1 departs significantly from a sinusoidal shape and appears flattened on the peaks. The "fuzz" in the waveform is due to antenna action of the open test lead, which picked up the carrier of a local AM broadcast station. The "fuzz" is broader at the bottom of the waveform than at the top because the service-type scope exhibited amplitude nonlinearity.

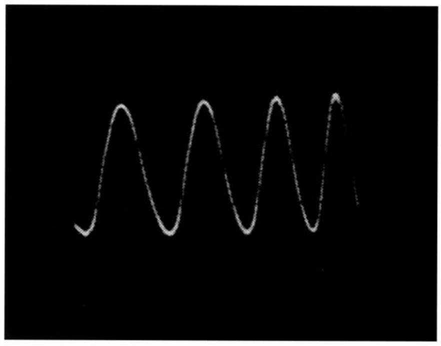
Part of the distortion in the Fig. 7-1 waveform originated in the scope. Two other types of distortion which may be produced by a scope are shown in Fig. 7-2. When a 60-cycle waveform is intensity-modulated at a 60-cycle rate, one-half of each cycle has a high intensity, while the other half has a low intensity. This intensity modulation results from incomplete filtering of the high-voltage power supply. Another common type of distortion produced by a scope is horizontal compression due to nonlinear sawtooth deflection. An experienced operator learns to distinguish between distortion arising in the scope itself and distortion caused by defects in the circuit under test.

STRAY-FIELD PICKUP CONSIDERATIONS

Beginners sometimes complain about stray-field pickup as if it were a design defect in a scope. Any instrument with high input impedance responds to stray fields. Thus, a VTVM responds to stray fields when it is set on its low-voltage ranges and the input cable is open-circuited. Waveform distortion due



(A) Intensity modulation of beam.



(B) Horizontal compression.

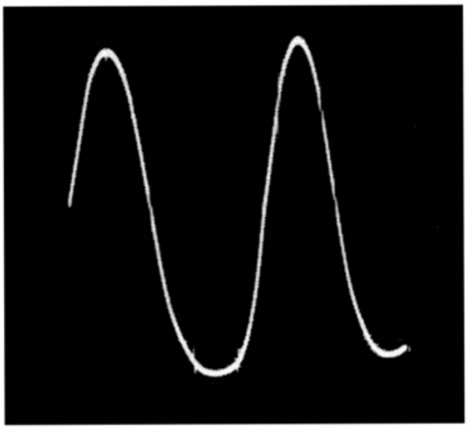
Fig. 7-2. Two types of waveform distortion.

to stray-field pickup is avoided by using a shielded input cable to the scope. Open test leads are suitable only for testing in low-impedance circuits. If a scope has exposed vertical input terminals, you may note stray-field distortion even when a shielded input cable is used, particularly if you bring your hand near the vertical input terminal while adjusting the scope controls. For this reason it is preferable to use a coaxial connector instead of exposed binding posts for the vertical input terminals.

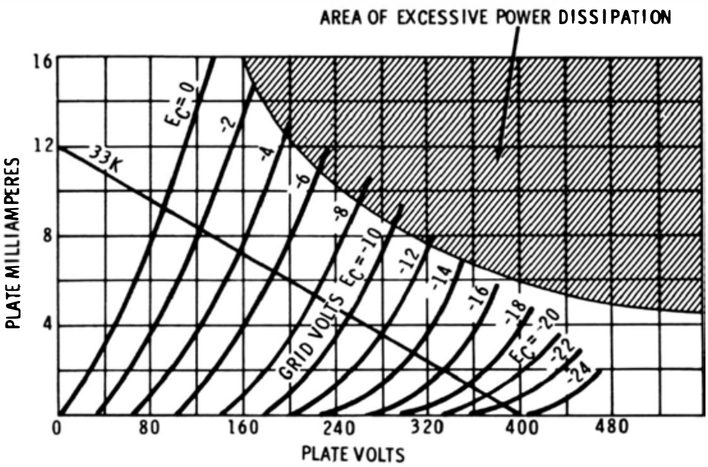
WAVEFORM DISTORTION DUE TO NONUNIFORM TUBE CHARACTERISTICS

Vertical compression (Fig. 7-3) sometimes occurs in the scope, but it is more often due to a defect in the circuit under test. An audio amplifier, for example, always starts to exhibit vertical compression when driven near the limit of its dynamic range. The reason is seen from the chart of plate characteristics in Fig. 7-3. When the grid is driven strongly negative, the characteristics become more closely spaced; this results in diminishing output. Again, when the grid is driven positive, the grid input impedance becomes very low, and the source may not be able to supply the grid-current demand. Therefore, the drive voltage falls, and the output diminishes. It is evident that negative peaks, positive peaks, or both may be compressed or clipped, depending on the operating conditions of the tube and the amount of drive voltage applied.

The area of excessive plate dissipation is shown in Fig. 7-3. Since the load line is below the "forbidden area," it might be



(A) Waveform on scope screen.



(B) Tube characteristic curves.

Fig. 7-3. Distortion due to nonlinear amplifier-tube operation.

supposed that the tube could not be damaged by overdrive. It is true that overdrive cannot cause rated plate dissipation of the tube to be exceeded. However, when the grid is driven positive, it starts to dissipate power and may become red hot. Grid dissipation must be considered in addition to plate dissipation, and if positive grid drive is substantial, the tube can be damaged.

Distortion vs. Operating Point

It can be seen from Fig. 7-3 that the grid bias might be chosen to place the operating point anywhere along the load line. Thus, the operating point might be placed at −4 volts or at −18 volts. A common method of setting the operating point is to use a cathode resistor of the proper value for the desired operating point. For the tube depicted in Fig. 7-3, a bias of about −10 volts will permit the maximum dynamic range with minimum distortion.

If the bias is set at −4 volts, it is evident that the tube will go into grid-current distortion first as the drive voltage is increased. On the other hand, if the bias is set at −18 volts, the tube will go into cutoff distortion first as the drive voltage is increased. When a tube must be operated over a large dynamic range, it is necessary to choose a midrange bias point which will cause the tube to enter grid-current distortion and cutoff distortion simultaneously at high values of drive. This might not necessarily be the operating point for minimum harmonic distortion at moderate drive.

When grid-current distortion occurs, it first appears as compression of the positive peak in the grid voltage. As the grid-current distortion increases, compression changes to clipping—this may be a horizontal clipping or a diagonal clipping (Fig. 7-4). Whether the clipping is horizontal or diagonal depends on the grid-coupling circuit time constant, component values, and the frequency of the drive signal. Remember when checking waveforms in an amplifier stage that the waveform is reversed in polarity from grid to plate. Note that when cutoff distortion occurs, waveform clipping is horizontal—the plate simply stops conducting and no further voltage change occurs until the drive signal passes through its peak excursion.

This is not to say you might not observe apparent diagonal clipping due to cut-off distortion, especially when checking low-frequency operation. Some scopes will distort a 60-cycle square wave, for example, and the clipped peak of a 60-cycle sine wave is processed in the scope like a 60-cycle square wave. This is another situation in which distortion arising in the scope might be incorrectly charged to the amplifier under test. A DC scope avoids this possibility of confusion in low-frequency tests; however, it is seldom possible to use a DC scope directly at the plate of a tube, because the plate-supply voltage throws the beam off the screen. Instead, a large blocking capacitor must be used in series with the vertical lead to the DC scope. A value of 0.5 mfd or even larger may be required to completely eliminate tilt in low-frequency tests.

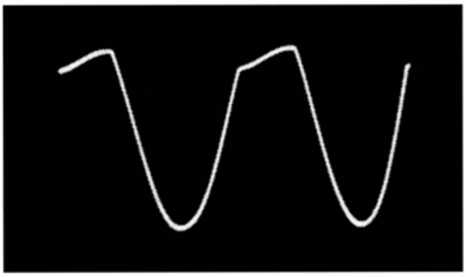


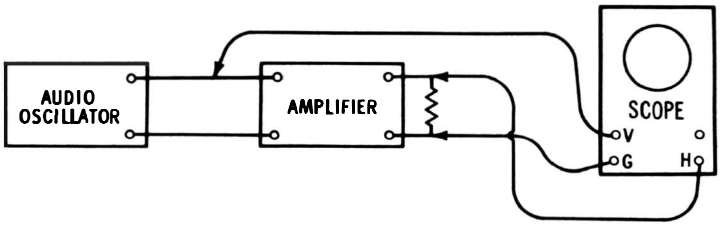
Fig. 7-4. Waveform produced by severe clipping in grid circuit.

EVALUATING SMALL AMOUNTS OF DISTORTION

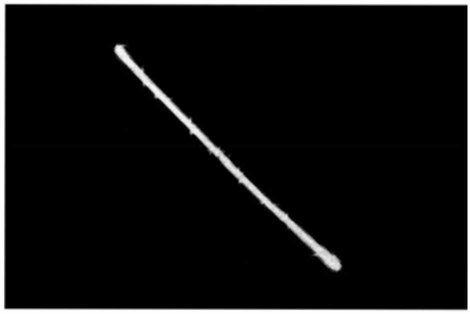
You cannot observe 5% distortion in a sine wave, and even 10% harmonic distortion may be evident only to the eye of a trained operator. Hence, a linear time base is not very useful for evaluation of small amounts of distortion; a cyclogram evaluation is preferred. A cyclogram is obtained as shown in Fig. 7-5A. A small amount of amplitude distortion is present in Fig. 7-5B, as evidenced by the slight departure of the trace from a straight line. Here again, it is necessary to distinguish between distortion originating in the amplifier under test and distortion that might occur in the scope itself. In case of doubt, remove the amplifier from the test setup and check the scope directly for amplitude linearity.

Amplitude Linearity Check

To check a scope directly for amplitude linearity simply connect the "hot" output lead from an audio oscillator to both the vertical and horizontal input terminals of the scope. Connect the ground terminal of the scope to the ground terminal of the



(A) Test setup.



(B) Scope cyclogram showing small amount of distortion.

Fig. 7-5. Method of checking amplifier for distortion.

audio oscillator. A perfectly straight diagonal line should appear on the scope screen—if it does, the scope amplifiers are linear. On the other hand, if a curved line is displayed, the scope amplifiers are nonlinear. While it is possible to make allowances for scope nonlinearity in analyzing waveforms, this is difficult at best; it is preferable to use a scope which has good amplitude linearity.

In case the scope itself is not entirely linear, note the departure from linearity in the cyclogram when the scope is tested directly. Then, when you proceed to test an audio amplifier, observe whether the same departure from linearity is displayed —if so, the amplifier under test is linear. On the other hand, if the pattern is different from the reference pattern, the amplifier is nonlinear. Amplifier nonlinearity could improve the reference pattern in particular circumstances—the essential point is that any *departure* from the reference pattern indicates amplifier nonlinearity.

TRANSIENT DISTORTION

Transient distortion may originate in the circuit under test or in the scope itself. Fig. 7-6 illustrates severe ringing of a chroma waveform. In most cases this type of distortion results from an excessively high and sharp peak in the IF- or video-amplifier response. However, it can also result from the use of a scope preamplifier which has a steeply rising high-frequency response. A preamplifier with this characteristic is sometimes employed to compensate for falling high-frequency response in a scope. Thus, if a scope has flat response out to only 1 or 2 mc, an attempt is sometimes made to obtain an over-all characteristic that is flat through 3.58 mc by utilizing a preamp with a steeply rising high-frequency response.

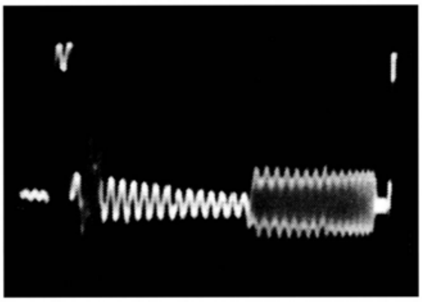


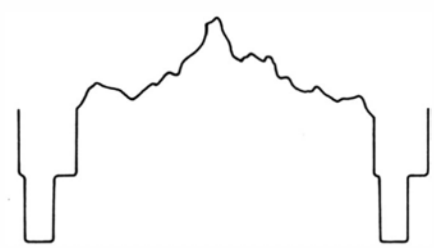
Fig. 7-6. Severe ringing in a chroma waveform display.

When the required compensation is not extreme, this expedient is satisfactory. On the other hand, when the required compensation is quite substantial, transient distortion is produced. The amount of high-frequency rise which can be tolerated depends on the rise time of the signals to be processed. If a signal has a comparatively slow rise, transient distortion will not appear; if the signal has a fast rise time, transient distortion develops in any amplifier which has a rising high-frequency response. Square-wave generators, for example, usually have a much faster rise time than color-bar generators.

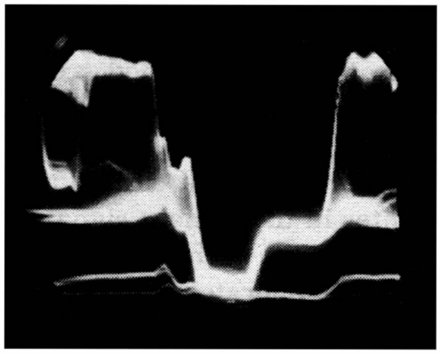
Distortion Due to Phase Shift

Even if each stage in a scope vertical amplifier has a flat frequency response, the amplifier will ring on steep wavefronts if the frequency response drops off suddenly instead of gradually. For example, a scope might have each stage adjusted for flat frequency response to 4 mc, after which the response takes a sudden "nose dive." This sharp cutoff characteristic will cause the scope to produce transient distortion of square waves with fast rise times. The reason for this difficulty is that the phase characteristic of an amplifier becomes highly nonlinear through a sharp cutoff region. A nonlinear phase characteristic will cause the higher harmonics in a square wave to ring, much as an upward-sloping frequency response will do.

To obtain a reasonably linear phase characteristic through the cut-off region of an amplifier, it is necessary to make the frequency response taper off gradually. This taper is controlled by the peaking-coil circuitry in the amplifier. Series peaking alone develops a gradually tapered frequency response. On the other hand, series and shunt peaking together produce a comparatively sharp cut-off, although the high-frequency response is extended. Hence, scopes which are employed to display steep wavefronts employ series peaking only —in turn, one or two additional stages are required in the vertical amplifier to obtain the desired sensitivity.



(A) An idealized horizontal sync-pulse waveshape.



(B) Typical sync-pulse waveform from video detector.

Fig. 7-7. Comparison of theoretical and practical waveforms.

WAVEFORM DETERIORATION

When a waveform is processed through successive circuits, progressive deterioration is inescapable. The technician's task is to distinguish between tolerable and abnormal waveform deterioration. Beginners who are schooled in theory alone sometimes expect to observe theoretically correct waveforms in electronic circuits. However, substantial departures from theory may be tolerable and satisfactory from the standpoint of practical operation. Fig. 7-7 illustrates these practical considerations of tolerance for a sync-pulse waveform. Not only does the practical waveform display slope and tilt, but it is also mixed with residual AC voltages from the receiver circuits.

More significant than the niceties of waveshape in this case is the relative amplitude of the sync tip to the complete video-signal excursion. The sync tip normally comprises 25% of the peak-to-peak signal voltage. Suppose, however, that overload in the IF amplifier compresses the sync tip to 10% of the peak-to-peak signal voltage. This is a serious distortion from a practical viewpoint, because the output from the sync separator will be attenuated. In turn, horizontal sync action will be unstable or completely lost. Accordingly, the relative amplitude of a waveform can be more important than its exact waveshape in some instances.

Reference Video Waveform

Note that amplitude observations of sync are made with respect to the total excursion of the video signal, which in turn changes greatly from time to time. Unless peak whites are present in the scanned scene, the peak-to-peak voltage of the complete video signal is less than maximum. Furthermore, due to lack of close tolerances on some transmissions, the sync tip may not appear at correct amplitude even when there are peak whites in the camera signal. Hence, it is better to use a pattern generator in such analyses—making certain, of course, that the pattern generator is in proper adjustment.

WAVEFORM CONTAMINATION

A certain amount of contamination by noise and residual AC voltages must be expected in most waveforms; however, the contamination must not be excessive. Your guide in this area consists of the key waveforms published in receiver service data—these are photographs of operating waveforms in a normal chassis. Thus, if you observe an abnormal amount of hum interference, for example, in an otherwise normal waveform a circuit defect is indicated. The hum interference could be due to a defective filter capacitor in the power supply or a tube that has developed heater-cathode leakage.

In the case of hum interference in a waveform, you will often find it helpful to evaluate the hum frequency. If you find it is 60-cycle hum, the most likely cause is heater-cathode leakage in a tube. But if you find it is 120-cycle hum, the most likely cause is inadequate power-supply filtering. To distinguish between the two cases, observe the video signal at a 60-cycle (or 30-cycle) deflection rate. Vertical-sync pulses occur at 60-cycle intervals; thus, it is easy to see whether the sync pulses are riding on a 60-cycle voltage or on a 120-cycle voltage.

Fig. 7-8 shows a typical example of 60-cycle hum voltage in a video signal. Note how the horizontal sync pulses "ride" on the hum voltage. The hum voltage is not a pure sine wave—it consists of a 60-cycle fundamental with considerable even-harmonic content. The reason for this particular waveshape is that

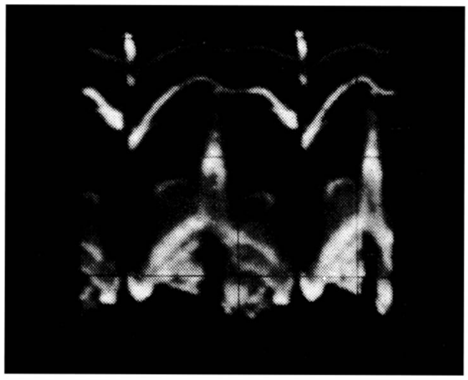


Fig. 7-8. Video signal with 60-cycle hum.

the hum voltage is a ripple waveform from a half-wave power supply. On the other hand, when hum voltage stems from heater-cathode leakage, it has a fairly good sine waveshape, unless the tube operates in class B, such as a heterodyne mixer or video-detector tube. Thus, hum voltage in a video waveform must be evaluated with respect to the circuitry utilized in the power supply and in the affected sections of the receiver.

Hum Modulation of Video Signal

Observe also in Fig. 7-8 that the hum voltage modulates the amplitude of the horizontal sync pulses. To put it another way, the sync pulses are comparatively low in the center of the camera signal (where the hum voltage rises to its crest), and comparatively high near the vertical-sync interval where the hum voltage falls to its minimum value. This hum modulation is the result of changing plate and screen voltages (and also cathode bias), due to the rise and fall of the ripple voltage. To put it another way, the gain of the affected stages varies with the amplitude of the hum voltage.

The same symptom is observed if there is hum voltage present in the AGC section—the bias level on the RF and IF stages rises and falls with amplitude of the hum voltage. In turn, the video signal becomes modulated at the hum frequency. In case of doubt as to the source of hum modulation, you can clamp the AGC line with battery bias or by means of a bias box. The possibility of hum modulation from the AGC section is thereby eliminated, which helps to identify the section where modulation is occurring. If the hum modulation persists when the AGC line is clamped, trace the distorted signal back through the signal channel to find where it first appears.

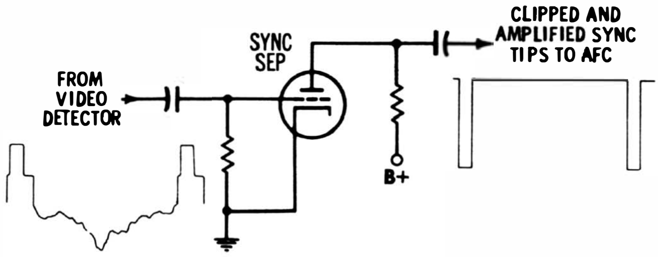
Horizontal-Sync Attenuation

Another aspect to be considered in the waveform of Fig. 7-8 is the depression of the horizontal-sync level below the vertical-sync level. This means that there is a high-frequency attenuation present (horizontal sync pulses occur 15,750 times per second, while vertical sync pulses occur 60 times per second). Do not jump to the conclusion, however, that the high-frequency attenuation is necessarily being caused by a circuit defect—the scope may be loading the circuit and impairing its high-frequency response. A low-capacitance probe must be used instead of a direct cable in video circuitry to avoid this difficulty. Even when a low-C probe is utilized, the normal action of peaking coils may be disturbed. Hence, for a definite test, apply the low-C probe at a low-impedance point in the video amplifier, such as across the contrast control.

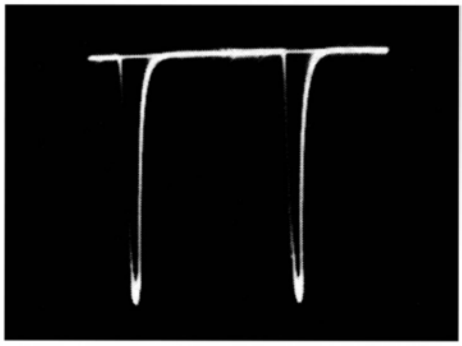
SYNC SEPARATION

Another discrepancy between theory and practice is illustrated for a sync separator in Fig. 7-9. In theory the output from a sync separator consists of ideally rectangular pulses, but in practice the output has a characteristic spike shape. The reason for this departure is that the incoming sync tips have sloping sides, as previously explained. Furthermore, the tube does not have an ideally sharp cutoff characteristic, which tends to broaden the base of the output. The applied sync tips drive the grid into current flow, and hence the grid operates with a signal-developed bias. Previous discussion has pointed out how grid-current limiting tends to round the top of a pulse, even if the applied waveform has a perfectly flat top—the grid-resistance characteristic is non-linear.

This is another example of a situation in which the shape of the output waveform is of almost no concern; the important



(A) Ideal operation.



(B) Actual output waveform.

Fig. 7-9. Sync-separator waveforms.

consideration is whether the amplitude of the output pulses is normal. On the other hand, if you observe spurious AC in the output waveform, there is a defect present which causes an incorrect clipping level, and the spurious components can disturb or completely upset normal AFC action. Fig. 7-10 shows a typical waveform which contains objectionable interference, due to an incorrect clipping level.

You will find variations in tolerances of interference, depending on individual receiver designs—some AFC systems are more tolerant of residual video than others. The important point is to check the receiver service data in each case to determine whether the interference level is a matter for concern. Otherwise, a false evaluation could be made which would lead to a waste of time in looking for a defect in the wrong place.

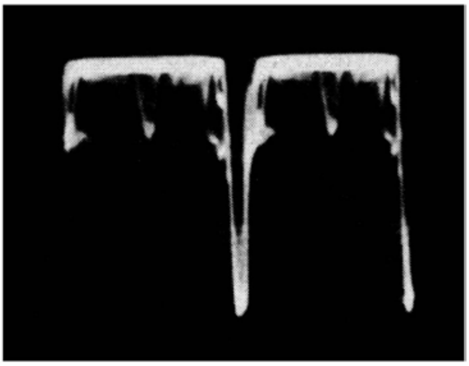


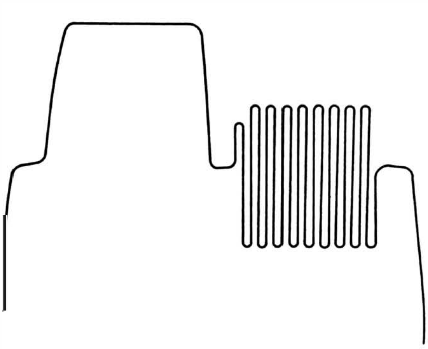
Fig. 7-10. Output from a sync separator when clipping level is incorrect.

COLOR-BURST WAVEFORM

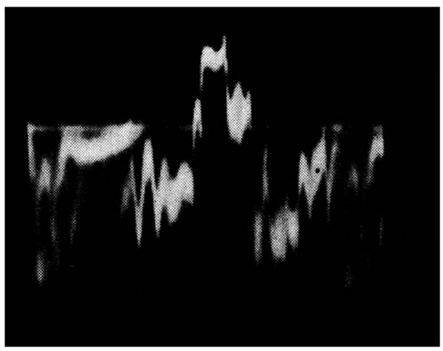
Another interesting example of a discrepancy between theory and practice is shown in Fig. 7-11. Beginners who are familiar with theory only might expect to see a clearly defined and squared-off color burst at the output of the video detector. Actually, the burst almost always has a slow rise and fall, as seen in the photo. Furthermore, the structure of the burst is seldom apparent on a service-type scope, because the 3.58-mc sine wave is mixed with various interference components, and because it is difficult to synchronize the scope with the burst frequency.

WHEN WAVESHAPE IS IMPORTANT

It must not be assumed from the foregoing examples that waveform amplitude is always a dominant consideration over wave shape. Quite to the contrary, you will encounter many



(A) Theoretically ideal color-burst waveform.



(B) Typical signal at output of video detector.

Fig. 7-11. Color-burst waveform.

practical situations in which waveshape is the chief point of concern, and amplitude is incidental. Recall that when an amplifier is tested for amplitude distortion, only the shape of the pattern comes in for critical examination—the pattern amplitude is beside the point. A case in point is shown in Fig. 7-12. This is the grid waveform of a burst-amplifier tube when the color receiver is energized by a keyed-rainbow signal.

Circuit action here is the chroma counterpart of the sync-separator principle which was illustrated in Fig. 7-9. In other words, the sync separator in a receiver picks out the sync tips from the video signal, while the burst amplifier in a color receiver picks out the burst from the complete chroma signal. Burst separation is accomplished by operating the burst-amplifier tube beyond cutoff, except for the brief horizontal-flyback interval, during which time the tube is driven into conduction. A suitably timed pulse from the horizontal-sweep system is applied to the cathode of the burst-amplifier tube to make it conduct during flyback.

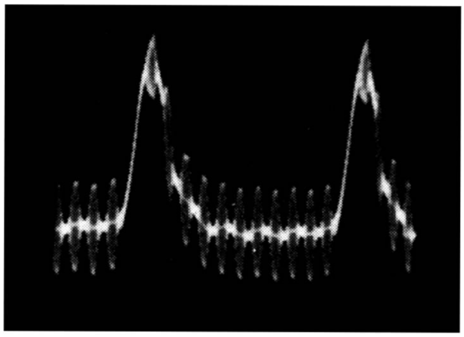


Fig. 7-12. Input to burst amplifier.

Thus, the grid waveform shown in Fig. 7-12 displays the complete chroma signal riding on the cathode-keying waveform. As the keying waveform rises to its peak, the tube comes out of cutoff. The burst signal rides on top of the keying peak, and the burst is separated from the chroma signal and amplified in the plate circuit of the burst amplifier. It is clear that the burst must be seated on top of the keying pulse, and this is the point of first concern when tracking down the cause of poor color sync or complete loss of color sync. Otherwise stated, if the timing of the keying pulse is incorrect, it is beside the point to make any amplitude checks until after correct timing is restored.

Note in passing that incorrect timing can result from defective capacitors in the keyer circuit, resistors which may have increased considerably in value, or leakage from the keyer winding to the core in the flyback transformer. AFC trouble can also cause poor timing in some receivers, because when the horizontal oscillator is pulling strongly, the keyer pulse can be delayed or advanced, as the case may be. Note also that the series of bursts which appear along the pattern in Fig. 7-12 are arbitrary and result from the use of a keyed-rainbow generator in the timing test. If you use an NTSC generator, for example, the bursts will not appear, but instead you will observe a series of chroma bars—usually six bars, although some generators supply only one bar at a time. However, the color-burst display on top of the keying pulse is always the same, regardless of the signal source utilized.

Shape of Response Curve

Another important example of a situation in which waveshape is of central concern, while amplitude is incidental is shown in Fig. 7-13. This is the IF-response curve of a color receiver. In this particular design, the 3.58-mc chroma subcarrier and its sidebands are passed through the IF strip on the flat top of the frequency-response curve. Alignment is quite critical in this case. If the bandwidth of the response curve is too narrow, the color signal falls on the side of the curve, and some of the chroma sidebands may even be lost along the baseline, where the output is zero.

When this happens, the color signal is weakened and distorted. Color reproduction is poor, and if the bandwidth is abnormally narrow, color sync is also lost. Thus, variations in

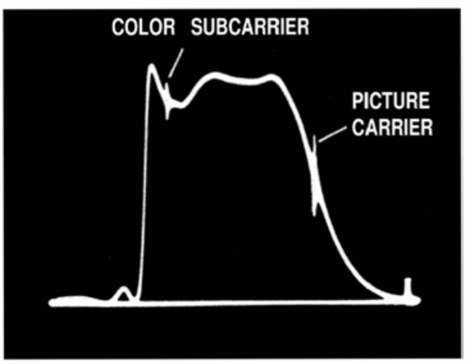


Fig. 7-13. IF-response curve of color-TV receiver.

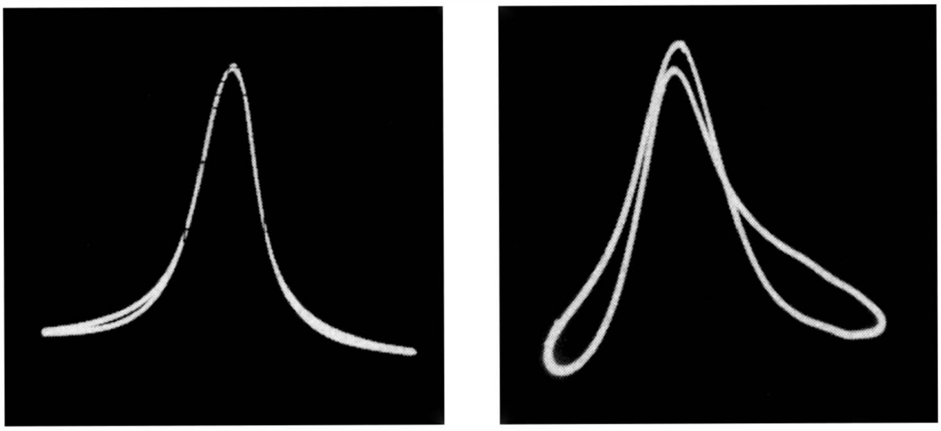
response-curve shape which would be of minor concern in black-and-white receivers assume great importance in this type of color receiver. This is not to say that IF alignment is equally critical in all color receivers—many utilize vestigial chroma-sideband response, in which the chroma signal falls on the side of the response curve by design. While the IF adjustments are somewhat less critical in this type of receiver, it is nevertheless necessary to make certain that the 3.58-mc subcarrier is not attenuated more than 6 db. Otherwise, the available gain in the subsequent chroma circuitry will be inadequate to obtain satisfactory color intensity.

When vestigial chroma-sideband response is employed, alignment of the following bandpass-amplifier section becomes somewhat critical, because a suitably tilted top must be provided by the response curve to compensate for the slope in the chroma region of the IF curve. If this complementary waveshape is not observed, the chroma sidebands become distorted, which in turn deteriorates the color reproduction. In any case, your safe guide to correct waveshapes is the service data for this particular receiver.

Phase Distortion

Phase distortion must sometimes be evaluated in frequency-response curves, as well as in square-wave patterns. An example is shown in Fig. 7-14. Fig. 7-14A shows a response curve in which trace and retrace layover is good. On the other hand, Fig. 7-14B shows very poor layover due to phase distortion in the test setup. When you see a situation of this sort, it is pointless to blank out the retrace or to convert it to a zero-volt base line, because the phase distortion is changing the shape of the curve and will lead to false conclusions. The source of the phase distortion must be localized and eliminated.

A common cause of this difficulty is shunting of excessive capacitance across the scope vertical input terminals. Another possibility is the use of an excessively large isolating resistance in series with the vertical input lead of the scope. Technicians commonly employ an isolating resistor and/or a shunt capacitor across the scope input terminals to sharpen the marker indication and suppress interference on the response curve. As long as the time-constant of the combination is not excessive, neg-



(A) Negligible phase distortion. (B) Severe phase distortion.

Fig. 7-14. Frequency-response displays.

ligible phase distortion is introduced. However, too long a time-constant leads to the difficulty illustrated in Fig. 7-14. Rarely, a defect in the sweep generator produces similar pattern distortion.

BANDWIDTH VERSUS SYNC-PULSE REPRODUCTION

Sync-pulse waveforms and amplitudes become changed when the circuit bandwidth is subnormal. The amplitude change is best observed with 30-cycle scope deflection, as was illustrated in Fig. 7-8. Waveshape change can be observed with 7,875-cycle deflection, as shown in Fig. 7-15. As the circuit bandwidth is made narrower, the sync pulses become more extensively integrated, or "feathered". It is possible to be misled, however, unless you energize the receiver from a test-pattern generator which has close-tolerance sync. The reason for this requirement

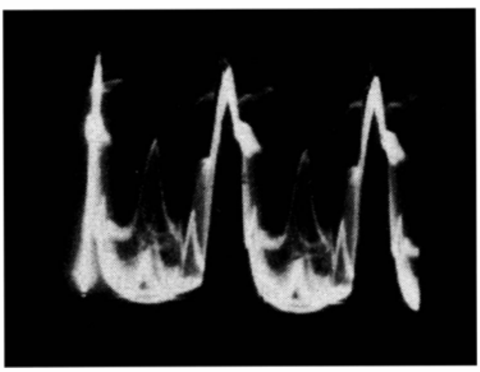


Fig. 7-15. Effect of narrow IF bandpass on sync-pulse waveform.

is that station-signal sync is often deteriorated to some extent. Network programs in particular often have substandard sync.

However, if you use a good-quality pattern generator, the sync pulses have a fast rise and flat tops. Thus, the sync pulses provide the facility of a square-wave test in evaluating the circuit action. While the evaluation is limited to 15,750-cycle pulse response, it will nevertheless be quite informative, provided that you are using a good pattern generator. Subnormal bandpass always reduces picture quality—the first question which arises is whether the narrow bandpass stems from the IF amplifier or video amplifier; inasmuch as tuner response curves are usually quite broad, the trouble will usually be localized in either the IF amplifier or the video amplifier.

For example, if you find a video waveform such as shown in Fig. 7-15 at the output of the video amplifier, transfer the low-C probe back to the video-detector output. If you find a normal video signal at the detector, the trouble is in the video amplifier. On the other hand, if the same distortion appears at the detector, the trouble is in the IF amplifier. Suppose that your pattern generator does not have fast-rise and flat-topped sync pulses—then evaluation of pulse shape is beside the point. However, you can approach the problem from another viewpoint, by making the generator supply sharp pulses. All that is necessary is to insert a white-dot slide instead of a test-pattern slide into the generator. Then the scanner automatically generates sharp pulses which are well suited for bandwidth evaluation.

Distortion of the pulses by narrow-bandwidth circuits can be evaluated on the basis of amplitude. Although the pulses are broadened when they pass through a narrow-band circuit, this effect is much less apparent than the reduction in amplitude. Thus, at the output of the generator, the sync tips will normally have 25% of the total waveform amplitude. If you check at the output of the video amplifier and find that the sync tips now have a different amplitude, it is evident that the signal has passed through a circuit with subnormal bandwidth. Transfer the low-C probe back to the video-detector output. This will immediately show you whether the trouble is in the IF amplifier or the video amplifier. Of course, you will encounter chassis in which both the IF amplifier and video amplifier have subnormal bandwidths. In such case, the pulse amplitude is reduced by passage through the IF amplifier and further reduced by passage through the video amplifier.

White-dot Signal Generator

It is apparent that a test-pattern generator with a white-dot slide is of great utility in practical test work. Not only does it provide a steady and controllable signal, but the availability of a white-dot slide provides the facility of a high-performance square-wave generator. Why do we not use an ordinary test-pattern signal when localizing narrow bandwidth in a chassis? It is true that a test-pattern signal contains high-frequency video information, but the high-frequency data in a test-pattern signal tends to be obscured by low-frequency data, whereas in a dot signal the high-frequency components are clearly in evidence. Although an experienced operator can work with the high-frequency components in a test-pattern signal, the beginner is better advised to utilize a dot signal in this type of test work.

COLOR-BAR SIGNAL IN BLACK-AND-WHITE TESTS

If you have a color-bar generator available, the color signal provides the equivalent facility of a dot signal for localization of narrow bandwidth. For example, consider the signal illustrated in Fig. 7-16. This is a mixed waveform with fundamental frequencies of 15,750 cycles and 3.58 mc. A black-and-white receiver in good operating condition has substantial response at 3.58 mc. This signal was applied to a high-quality black-and-white receiver, and the 3.58-mc component was attenuated about 10% at the video-detector output. This is quite acceptable performance. Suppose you should find that the color bars were attenuated to 50% of their normal amplitude in this test—it is then indicated that the IF amplifier is in need of realignment.

This check can be repeated at the video-amplifier output to determine whether high-frequency attenuation is occurring in this section of the receiver. In most cases, poor high-frequency response in the video amplifier will be tracked down to load resistors which have increased in value. Remember that the video-detector load resistor is a part of the video-amplifier

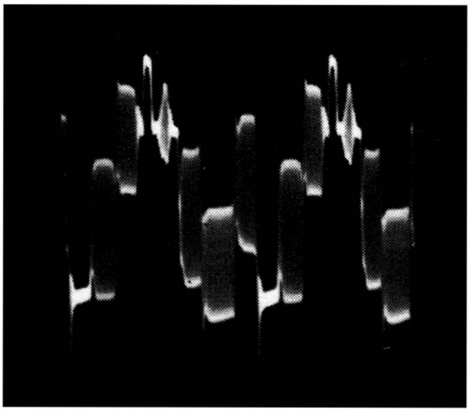


Fig. 7-16. Color-bar signal at output of video detector.

system. If it increases in value, high video frequencies will be attenuated. If the load resistors have correct values, the next most likely culprit is an off-value or defective peaking coil. Peaking-coil values are rather critical—a point which is usually overlooked by beginners.

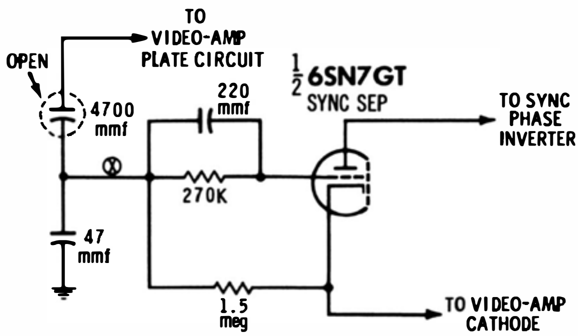
It should be unnecessary to point out that the resistance of a peaking coil has no necessary relation to its inductance. The critical parameter of a peaking coil is its inductance, and this cannot be measured with an ohmmeter. Unless you have an impedance bridge available, a suspected peaking coil should be checked by substitution. Always refer to the receiver service data for specifications of correct replacements. In case poor high-frequency response is not due to defective peaking coils, check out the decoupling circuits in the video amplifier.

PEAK-TO-PEAK VOLTAGES VERSUS DC VOLTAGES

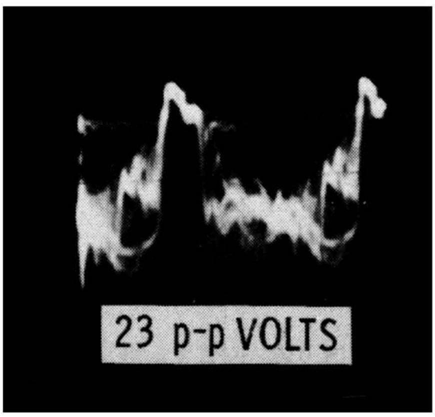
There is no necessary relation between the DC voltage and peak-to-peak voltage in an electronic circuit. It is perhaps surprising to the beginner to find that a peak-to-peak voltage may be less than, equal to, or greater than the DC voltage at the test point. For example, the plate-supply voltage to a horizontal output tube might be 420 volts DC. But the peak-to-peak voltage of the plate waveform might be 6,000 volts. Where does this extra voltage come from? It stems from the stored energy in the cores of the flyback transformer and yoke. When the horizontal output tube is suddenly cut off, a counter-emf, or kickback, voltage is generated which greatly exceeds the DC operating voltage.

TROUBLESHOOTING BY WAVEFORM ASPECT

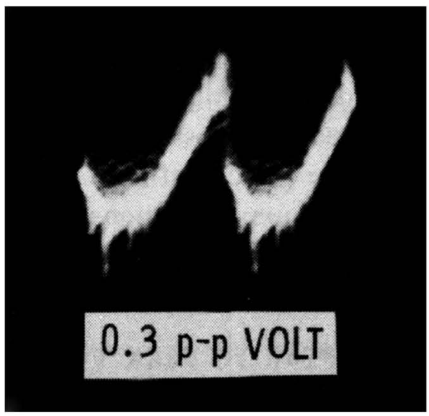
Most troubleshooting procedures involve changed waveform aspects, although amplitudes are also important. An example is illustrated in Fig. 7-17. The initial symptom is loss of horizontal sync. DC voltage and resistance measurements in this situation



(A) Circuit.



(B) Normal waveform observed at point X.



(C) Waveform with coupling capacitor open.

Fig. 7-17. Use of waveforms to locate circuit defect.

do not help to pinpoint the defective component (an open coupling capacitor). However, when the video signal is traced through the sync circuitry, a different waveform is observed on either side of the 4700-mmf coupling capacitor. In normal operation, there would be practically no change of waveform across the capacitor. The amplitude of the distorted waveform on the output side of the capacitor is also very low.

Thus, the waveform analysis points directly to an open capacitor. It might be supposed that no signal at all would be found on the output side of the capacitor. However, a small transfer does take place because of stray capacitances. Moreover, when the coupling capacitor is open, the grid network of the sync-separator tube becomes a high-impedance circuit. In turn, the grid circuitry picks up a substantial amount of stray-field voltage, which contributes to the 0.3-volt p-p waveform which is observed. In other words, the abnormal waveform is not merely a sharply-differentiated and attenuated version of the normal waveform, but also contains stray-field components.

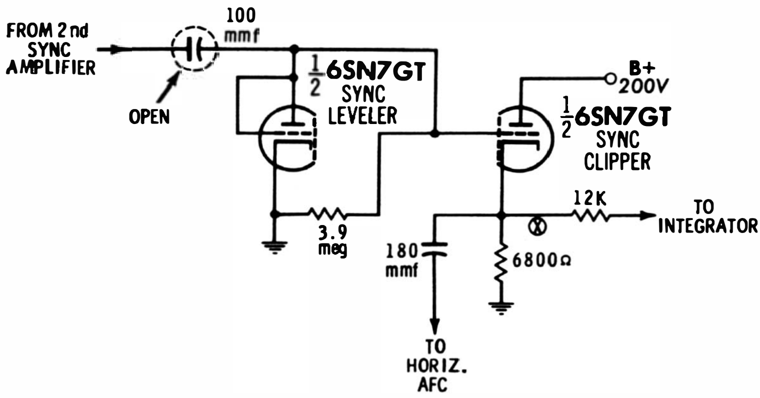
Waveform analysis is the only practical way to localize open capacitors in many cases, because there is often no significant DC voltage or resistance change. Accordingly, without waveform information there is no way to localize the trouble area.

INTERFERENCE PICKUP VERSUS CIRCUIT IMPEDANCE

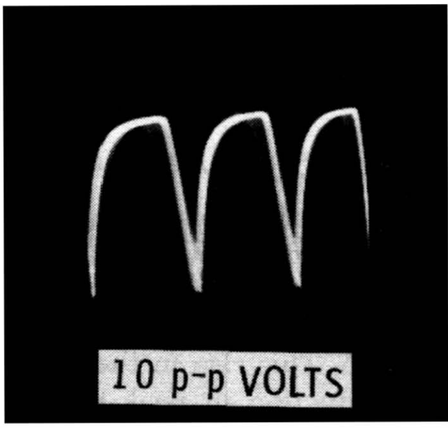
One of the more sophisticated aspects of distortion analysis concerns waveform change due to impedance variation. An example is illustrated in Fig. 7-18. Note how the interference level at the cathode of the clipper increases enormously when the 100-mmf coupling capacitor is open. This rise in the interference level is accompanied by a reduction in peak-to-peak voltage. If you analyze the distorted waveform, you will deduce immediately that the 100-mmf coupling capacitor must be open, because the interference can only stem from the grid circuit—stray fields can induce appreciable voltage in high-impedance circuits only.

It is not always recognized that the value of a coupling capacitor can determine the input impedance of a grid circuit. However, this is easily understood if the coupling capacitor is regarded as a bypass capacitor. This is so because the output of a sync-amplifier has only moderate impedance. Thus, with respect to the high-resistance grid return (3.9-megohms), the 100-mmf coupling capacitor can be regarded as grounded at its input end. So far as stray pickup is concerned, the grid input impedance is equal to the reactance of the coupling capacitor.

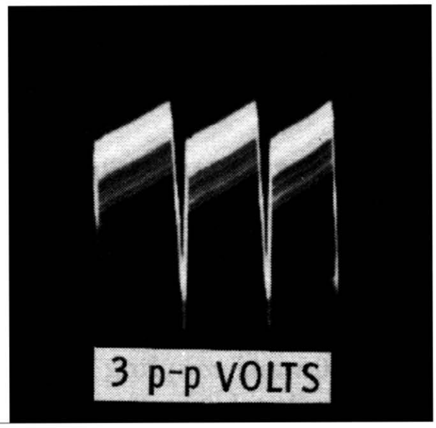
When the coupling capacitor is open, the input impedance of the grid circuit becomes 3.9 megohms, and the stray fields will



(A) Circuit.



(B) Normal waveform at point X.



(C) Waveform with open capacitor.

Fig. 7-18. Change of waveform due to change in impedance.

induce more interference voltage in the grid circuit. The result is a very large increase in the interference level. The abnormal waveform does not consist entirely of interference voltages, but a small amount of stripped sync is also passed because an "open" capacitor still has a small residual capacitance.

Thus, the trouble waveform in Fig. 7-18, which has a baffling structure to the inexperienced operator, tells its story of impedance variation and induced stray-field voltage to the technician who has learned how to analyze distorted waveforms. This knowledge is founded on an understanding of basic electronics and circuit action. In summary, you must understand circuit theory in order to read out the information displayed in an unusual waveform.

SCOPE WAVEFORM analysis

by ROBERT G. MIDDLETON

The oscilloscope is an indispensable tool for analyzing electronic circuit operation. The full value of the scope can only be realized, however, if the operator is able to properly analyze and interpret the waveforms he obtains on the scope screen. Analysis of waveforms requires an understanding of the fundamentals of scope operation, as well as a knowledge of the nature of the waveforms themselves and of the circuits in which they are found.

Providing complete coverage of the subject, the content of this book begins with a general introduction to the subject of scope waveform displays, and fundamental concepts of waveforms and circuits. Subsequent chapters discuss in more detail basic waveform characteristics, waveshaping principles and analyses, waveform types and aspects, waveform measurements, and waveform distortion analysis. These chapters describe the characteristics of waveforms, circuits for producing them, the way they are displayed by the scope, and how waveforms give indications of the nature of circuit defects.

Concentrating heavily on the practical aspects of obtaining and analyzing electronic circuit waveforms, this volume is a reference handbook of value to all electronic technicians and engineers.

ABOUT THE AUTHOR

Bob Middleton is one of the few full-time professional free-lance technical writers in the electronics field. His many books have proven invaluable to technicians and engineers because they are based on his own practical experience. His home workshop is filled with a wide variety of test instruments, receivers, and other equipment which he uses to develop faster and easier ways to diagnose electronic equipment troubles.

Other SAMS books by Mr. Middleton include: nine volumes of his famous **101 Ways to Use Test Equipment** series, four volumes of **101 Key Troubleshooting Waveforms, TV Tube Symptoms and Troubles, Using the Oscilloscope in Industrial Electronics, Solving TV Tough-Dogs, Bench Servicing Made Easy, Troubleshooting With the Oscilloscope, Troubleshooting With the VOM & VTVM, Electronic Tests and Measurements, Test Equipment Circuit Manual, Practical TV Tuner Repairs,** and **Elements of Transistor Technology.**

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