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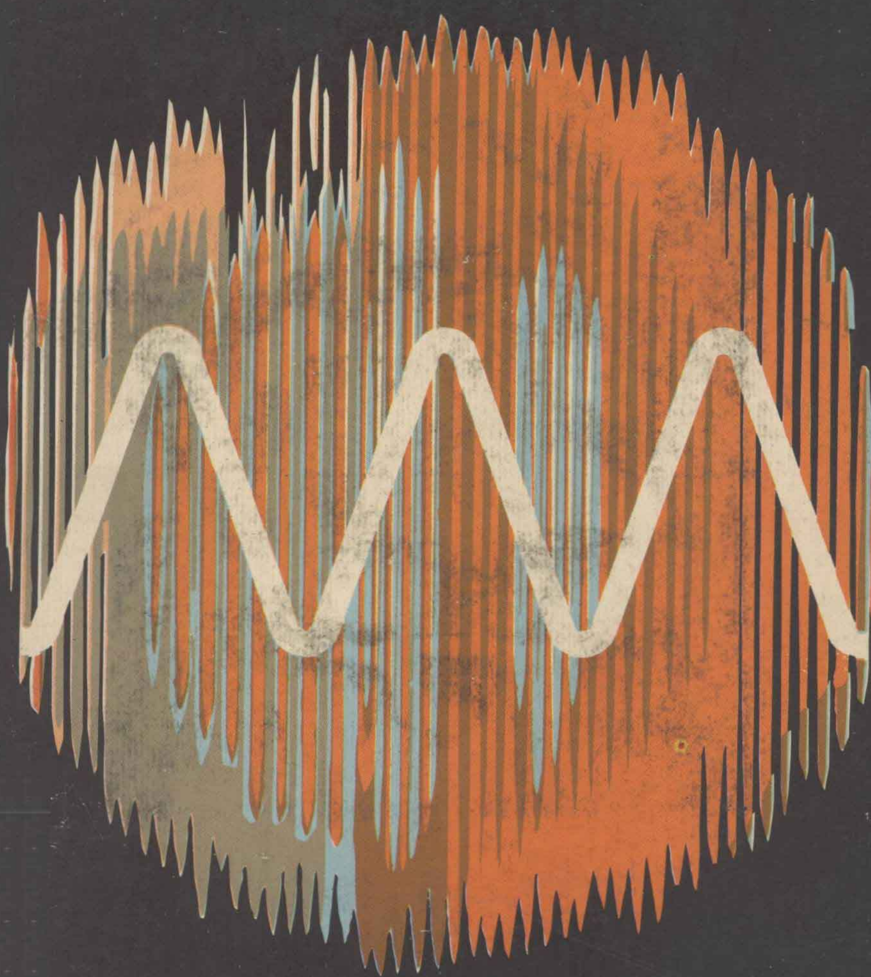
Understanding & Using the Oscilloscope

by Clayton Hallmark



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Preface

This book was written for the electronics technician who has an intermediate knowledge of troubleshooting and servicing fairly complex circuitry. We envisioned a person who uses a scope in his work but who blindly follows the scope setup instructions supplied by the manufacturer. Assuming you want and need to know much more, this book takes you behind the scenes, so to speak, and tells you **what is happening** when you turn a knob on a scope's panel, **why** you need to do certain things to obtain a proper and **valid** display, **how** poor setup resulting in a poor display can lead you down byways rather than directly to sources of circuit trouble—in other words, it is a short but intensive course in knowing what's inside your scope, how to use it properly, and how to figure out what you're looking at after you get it.

Naturally, we describe various modes, circuits to be tested, input and output results vs expectations, and so on. All this is presented in step-by-step fashion—usually with simple algebra—and every section builds logically on those preceding it.

With the knowledge you will gain (or perhaps, deeper knowledge, if you are reviewing), you will be ready to understand the sophisticated tests and scope techniques presented in full in the later chapters.

Clayton L. Hallmark

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Chapter 1

Functional Basics

An oscilloscope is a measuring instrument capable of measuring a wide variety of rapidly changing electrical phenomena, even phenomena occurring only once and lasting for a fraction of a millionth of a second.

The oscilloscope graphs changes in voltage with time. The amplitude, or strength, of the voltage is graphed along a vertical axis, and the length of time graphed along a horizontal axis. Because the graph of a voltage often takes the form of a wave, the graph is often called a **waveform.**

The ordinary moving-coil type of meter commonly used to measure ac and dc is somewhat limited in usefulness, since it only indicates a **value** of voltage or current. In the case of ac voltages and currents, for example, it gives the effective, or dc equivalent value, but no indication of the waveform. Since the waveform has a definite effect on the meter reading, the meter reading is accurate only if the waveform is the same as the meter is calibrated for. This means the meter reading is accurate only if the voltage or current being measured has the same waveform as power-line voltage and current. However, many of the voltages and currents in electronic equipment do not have this waveform, and an oscilloscope is required for their measurement.

By the same token, a simple meter becomes quite useless in the case of a pulsating dc consisting of an ac voltage superimposed, or riding, on a dc voltage. Such voltages are common in electronics, and their measurement also requires an oscilloscope.

Often it is impossible to tell whether or not a circuit is operating properly by merely checking the values of the voltages and currents in the circuit, even when they can be

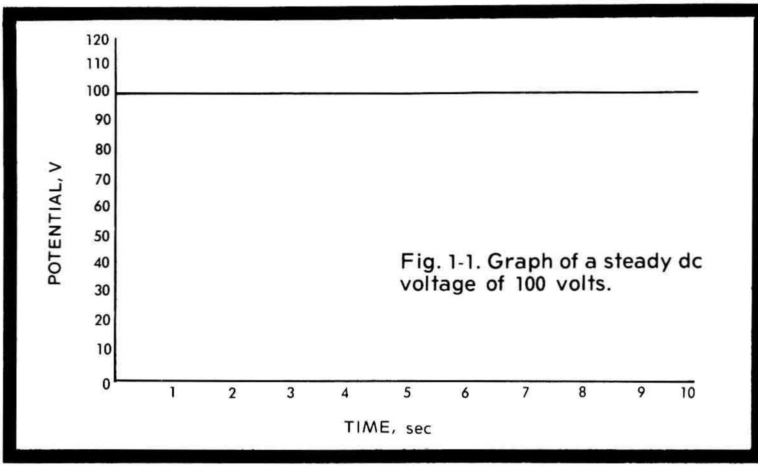

Fig. 1-1. Graph of a steady dc voltage of 100 volts.

accurately measured by a meter. Many circuits will not operate properly unless the ac voltages or the pulses involved have the correct **waveform**. For example, when the sound coming from a speaker is distorted, it is because the audio waveform has been changed in some circuit. The ac signal may have the proper amplitude (strength) and frequency, but it does not have the desired waveform. This intolerable defect would not be indicated by a voltmeter, but it would be indicated by an oscilloscope.

The use of the oscilloscope in waveform observation is only a small part of what it is capable of doing. The oscilloscope is the most useful and versatile of all electronic test instruments. It can measure voltage, current, time, gain, frequency, phase, hum, ripple, etc. But it is useful only if you understand it and it's versatile only if you really know how to use it. When you have finished this book, you **will** understand and really know how to use the oscilloscope. In order to more fully understand the usefulness of the oscilloscope for measuring ac voltages, we shall review the principles of ac and dc.

AC AND DC

Direct current (dc) is current that flows in one direction only. Its amplitude, or strength, may vary but not its polarity,

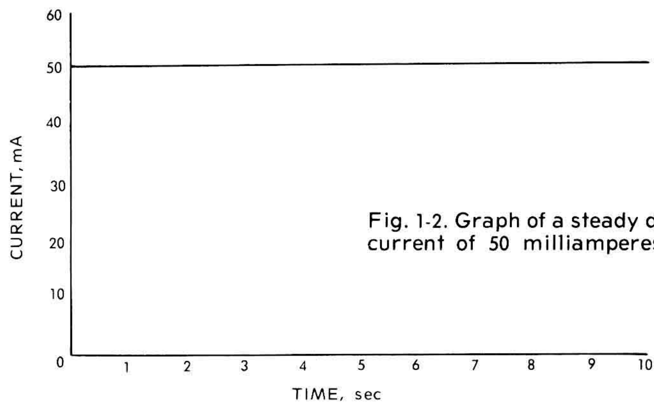

Fig. 1-2. Graph of a steady dc current of 50 milliamperes.

or direction. A source of dc, such as a battery or a dc power supply, can supply different amounts of current, depending on the power rating of the dc source and the resistance of the load connected across the source. If the resistance of the load should increase, for example, the current will decrease. Its direction, however, will always be the same, from the negative source terminal to the positive one. The direction will be the same for any length of time.

The graph of a steady dc potential of 100 volts appears in Fig. 1-1. Notice that time is marked off along the horizontal axis of the graph and that voltage is marked off along the vertical axis. A graph of the output current of a constant-current source delivering 50 mA is shown in Fig. 1-2. Again time is measured horizontally, and current is measured vertically. For both illustrations, the value of voltage or current is the same over the entire 10 second period. The value would in fact be the same for any length of time, unless some change were made in the source or the load. In both cases, it is sufficient to measure the value of voltage or current only once and be able to accurately state the value, not only at the time of measurement, but for all times.

Ac is another story altogether. It is constantly changing both in amplitude and polarity. A single measurement at a particular instant in time will not suffice to tell the amplitude for any other instant, only for the instant it is made.

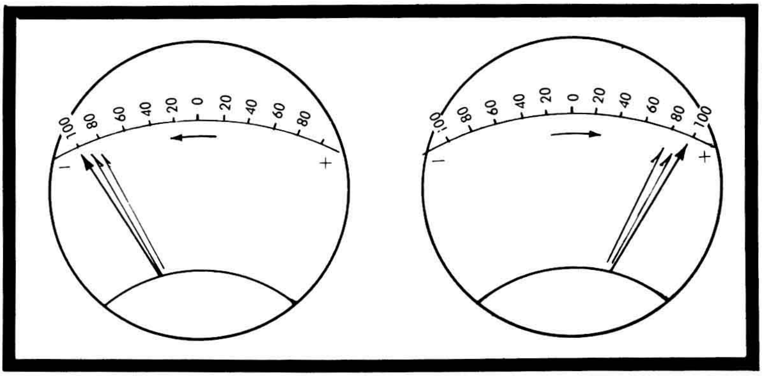

Fig. 1-3. Change is characteristic of an ac voltage.

The manner in which ac reverses polarity is regular and periodic. A 60 Hz voltage (or current), for example, increases from zero to a maximum in the positive direction, falls back to zero, continues down to a negative maximum and returns to zero again, 60 times a second. If we were to use a zero-center ac voltmeter to measure the 60 Hz voltage (Fig. 1-3), the needle would swing from center to the left, back through zero to the right, and back to zero again, 60 times per second. Of course, no meter exists whose needle can deflect so rapidly. Even if it did, the needle would move so fast that the human eye could not follow it. Thus, it is impossible to tell the direction much less the value of an ac voltage at any particular instant, using a meter.

Fig. 1-4 shows graphically the way an ac voltage varies with time. The horizontal line represents **elapsed time**. As time passes, from starting time A to time C, the voltage rises from 0 volts at A to 100 volts at B, and then falls back to zero. It then increases again, but this time in the opposite direction, until it reaches −100 volts at D. Finally it returns to 0 volts at point E. This completes one cycle. From point E to point I the cycle repeats itself. Using an oscilloscope, it is a simple matter to observe these variations we have been talking about, but using a meter it would be impossible.

The voltage at any instant, at A or B in Fig. 1-4, for example, is called an **instantaneous** voltage. Ac meters do not respond to instantaneous voltages. They indicate instead a

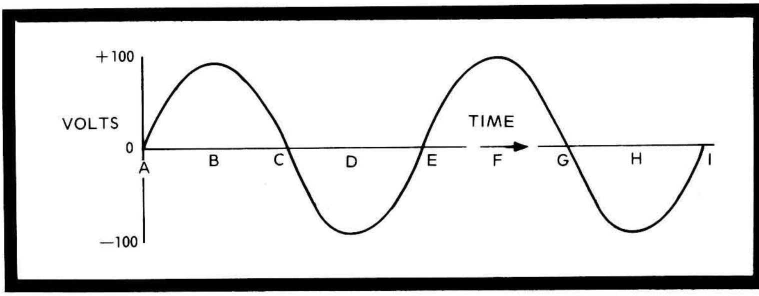

Fig. 1-4. One cycle of an ac voltage, as it actually appears in time.

sort of mean value—an rms, or effective value—which tells how large a battery would be required to supply the same amount of **power**. This is important, but it says little about the nature of the **variation** of an ac voltage. Only the oscilloscope can show the ac as it changes at each and every instant of its cycle.

Because ac cycles resemble waves when shown on a graph (or on an oscilloscope), they are often referred to as waves, and their graphical representations as waveforms.

FREQUENCY AND PERIOD

In the light bulbs, electrical appliances, and electrical machines in homes, offices, and factories around the country, the ac supplied by power companies is reversing itself in direction of flow 120 times per second. This means that the current is alternating directions 120 times per second, or, in other words, is operating at 120 alternations a second. Since a cycle consists of two alternations, the current is completing 60 cycles per second. This is its **frequency**, 60 cycles per second, or in modern terminology, 60 hertz (Hz). Frequency is defined as the number of complete cycles that occur during one second of time.

The period of time required for the completion of one cycle of a given ac current, the time between A and E in Fig. 1-4, is the **period** of the current or voltage, thus, a current that has a frequency of 10 Hz (goes through 10 cycles each second) has a period of one-tenth second. Similarly, a current that has a frequency of 60 Hz has a period one-sixtieth second. In general, the period of a wave may be expressed as

$$\text{period} = \frac{1}{\text{frequency}}$$

By transposition, the formula for frequency becomes

$$\text{frequency} = \frac{1}{\text{period}}$$

In both formulas, period is expressed in seconds, and frequency in hertz.

HARMONICS

The integral (whole number) multiples of any given frequency are known as **harmonics** of that frequency. The original frequency is called the **fundamental**. Thus, if we start out with 100 HHz, **that** is the fundamental; and its harmonics are 200 Hz, 300 Hz, 400 Hz, 500 Hz, etc. The harmonics are numbered according to which multiple of the fundamental they represent. Thus the second harmonic of 100 Hz is 200 Hz, and the third harmonic is 300 Hz, etc. By this reasoning, 100 Hz could be called the first harmonic, but usually it isn't; instead, we speak of the fundamental. Just because the first harmonic is rarely spoken of, don't forget that it exists. And don't make the mistake of confusing the first harmonic with the second harmonic, which is actually twice the first harmonic, or fundamental. That is a common mistake.

The harmonics of a frequency are referred to as **even** or **odd harmonics**, according to whether they are even or odd multiples of the fundamental. Thus, 300 Hz, 500 Hz, 700 Hz, etc., are odd harmonics of 100 Hz. Similarly, 200 Hz, 400 Hz, 600 Hz, etc. are even harmonics of 100 Hz.

The significance of harmonics in the study of waveforms is that various waveforms are made up of different harmonics of the basic waveform, which we will discuss next.

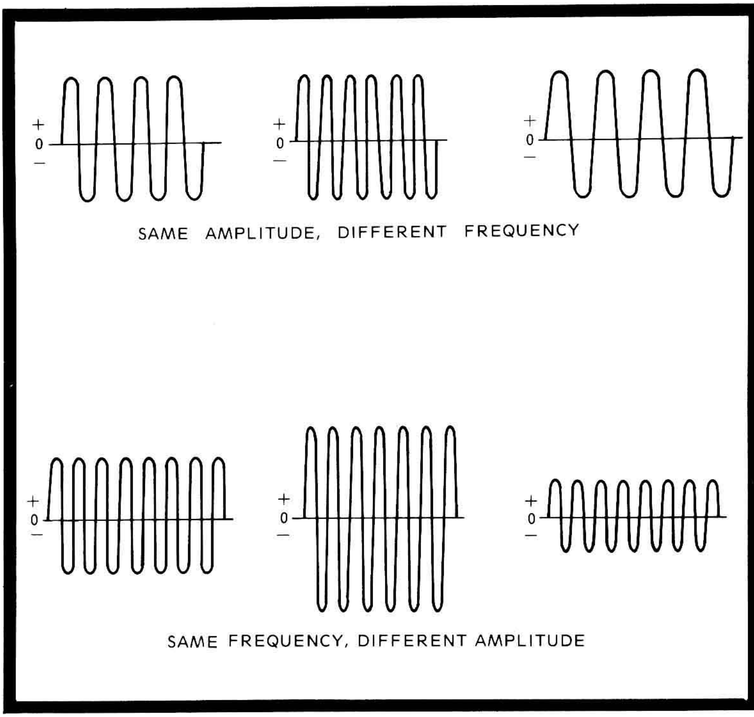

Fig. 1-5. All of the above waves are different, but all are sine waves.

THE SINE WAVE

The most common ac waveform is the sine wave, shown in Figs. 1-4 and 1-5. This waveform is typical of power-line ac and of the output of most af and rf signal generators.

All of the waves in Fig. 1-5 are different, but all are sine waves nonetheless. They all have certain characteristics that distinguish sine waves. All of the curves rise smoothly from zero amplitude to peak amplitude and decline smoothly back to zero amplitude, alternately in the positive and negative directions. Also, the amplitude of each curve changes fastest when its amplitude is zero, and changes slowest when its amplitude is maximum. Fig. 1-6 illustrates this. Notice that at point A in Fig. 1-6 the amplitude of the sine curve is nearly zero. It is, however, increasing with time. If it continued to increase at the same rate as it does at A, the curve would

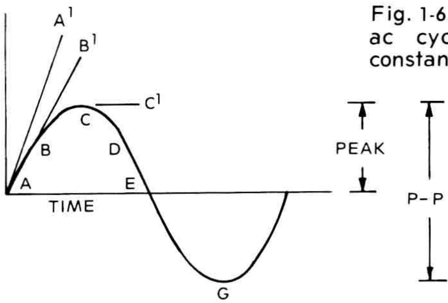

Fig. 1-6. The rate at which an ac cycle varies is itself constantly changing.

follow the line drawn from A to A', instead of following the sine curve as shown. Notice that the rate of change in amplitude continues to decrease from the rate at A, until at C the rate of change (but not the amplitude) becomes zero. That is, if the curve followed the line from C to C' it wouldn't change at all in amplitude. Its rate of change would be zero. Thus, the amplitude (height) of a sine wave changes at its fastest rate when the amplitude is zero, and at its slowest rate when the amplitude is at its positive or negative peak.

The **peak value** of the ac wave, the value at points C and G in Fig. 1-6, is equal to 1.414 times the rms value, which would be measured by an ac voltmeter. The **peak-to-peak value**, the vertical distance between points C and G in Fig. 1-6, is twice the peak value, or 2.828 times the rms value. Both the peak value and the peak-to-peak (p-p) value of a sine wave can be determined with an ordinary ac voltmeter. The peak and p-p values of other waveforms must generally be determined with an oscilloscope.

Another important point about sine waves is that they are considered basic. They are the standard by which other waves are judged. Other waves are considered as combinations of sine waves. The sawtooth, square wave, and trapezoidal waves we will look at soon are each considered to be a different combination of many sine waves of different amplitude and frequency.

The selection of the sine wave as the basic wave was not arbitrary. There is much precedent for it in nature. In electronics too, there is good reason to consider the sine wave

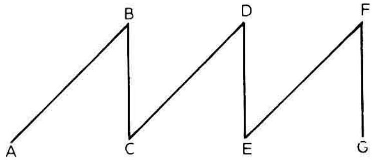

Fig. 1-7. Sawtooth waveform.

basic. It is the only waveform that will retain its shape after passing through a network containing capacitors or inductors. Other waveforms are distorted by such networks.

THE SAWTOOTH WAVE

The sawtooth wave is possibly the second most important waveform. This wave, named for its resemblance to the teeth on a saw, is widely used in oscilloscopes and other measuring instruments, as well as in television. The ideal sawtooth has a linear (straight-line) rise, as shown by the lines AB, CD, and EF in Fig. 1-7. It also has a quick, abrupt decline, as shown by the lines BC, DE, and FG. Like most ideals, the ideal sawtooth is not quite realized in practice. The rise is not perfectly linear nor the drop perfectly abrupt.

The sawtooth is used in oscilloscopes and televisions to sweep a luminous dot across the crt screen, creating a display or picture.

THE SQUARE WAVE

The so-called square wave is usually rectangular as in Fig. 1-8, rather than square. This wave is distinguished by its

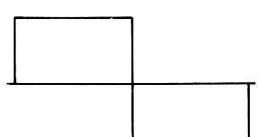

Fig. 1-8. Square wave.

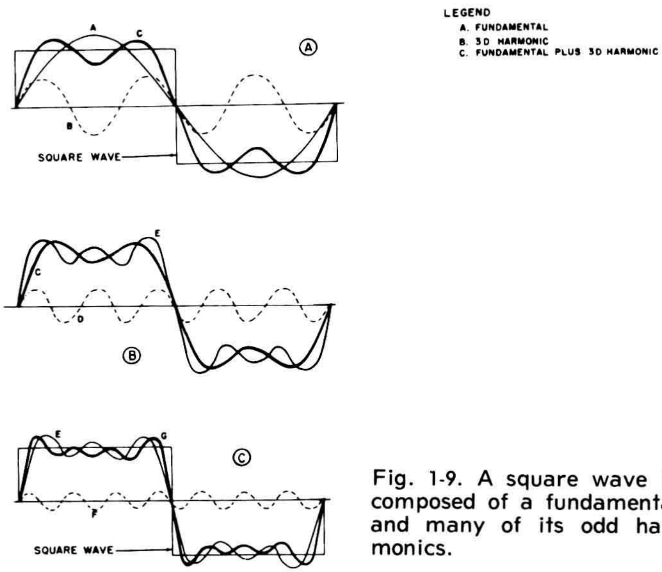

Fig. 1-9. A square wave is composed of a fundamental and many of its odd harmonics.

steep sides, which indicate an almost instantaneous rise and fall. It is also distinguished by a flat top.

Even though it looks simple, this wave is actually made up of a large number of sine-wave harmonics. Fig. 1-9 shows how the square wave is built up from a fundamental sine wave and its odd harmonics. Note that as more odd harmonics are added, the composite wave gets nearer and nearer to its ideal shape. A good square wave has many harmonics and is thus useful for testing the response of equipment to a wide range of frequencies. We will show you how square-wave testing is accomplished, later in this book.

The square wave has assumed tremendous importance in recent years due to the phenomenal growth of the computer industry and of digital electronics in general. The multivibrator, a basic circuit used in computers and other digital equipment, is basically a square-wave generator. Multivibrators are, by the way, also used in oscilloscopes.