ELECTRONIC TESTS AND MEASUREMENTS

by Robert G. Middleton

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PREFACE

Principles and practices of electronic tests are of vital concern to technicians and engineers. The individual who can make valid and accurate measurements is of great value to his organization.

A thorough grasp of the contents of this book will increase the scope and efficiency of those who are concerned with making electronic tests and measurements.

One of the primary requirements for efficient use of measuring instruments is an understanding of their basic design and operating principles. In this book, a number of discussions are included with that objective: a discussion of rms, peak, and average values as applied to AC measurements with VOM's and VTVM's; square-law response to small signals; response and loading effects of accessory probes; bridge-circuit configuration and null interpretations; the signal content of various waveforms used for testing; and other pertinent items.

A second but no less important factor for efficient measuring procedures is a thorough knowledge of the theory of the circuits being measured. A significant portion of this text deals with such topics as electronic units, resistive loads, reactive loads, linear and nonlinear loads, zener action in semiconductors, diode circuits, basic transistor circuitry, graphical analysis of load lines, differentiating and integrating circuits, negative feedback, cathode followers, phase inverters, and many others.

The experiment sections included at the end of each chapter will serve as a means of supporting and emphasizing points covered in the text and, it is hoped, will lead the reader to attempt other experiments of similar practical nature.

ROBERT G. MIDDLETON

January, 1963

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Chapter 1

Electrical and Electronic Units

The *ampere, ohm, and volt*—representing current, resistance and potential difference, respectively—are the basic units in electrical measurement. An ampere is the electrical current that is composed of 6.24×10^{18} electrons passing a given point in one second; it is also the current flow which will deposit 1.118 milligrams of silver per second in a standard *voltameter*, or coulometer, containing silver nitrate. (The voltameter is a laboratory-type electrolysis device that is a *primary standard* of current; ammeters, no matter to what accuracy they may be calibrated, are always considered *secondary* standards.)

Electromotive force (emf) is the source potential of a battery or generator. The unit of emf, or difference of potential, is the volt and is commonly defined in terms of the no-load potential across a Weston standard cell. This cell produces a 1.0183-volt emf under its specified operating conditions.

The unit of electrical quantity is the coulomb, or *amperesecond*. It is the amount of electricity that passes a given point in a circuit when one ampere of current flows for one second. Work, or energy, is required to produce this current flow; the *joule* is the basic unit of work. A joule is the amount of energy expended in moving one coulomb through a circuit across which a potential difference of one volt is applied. Power is the rate of doing work, or the rate at which energy is expended; its unit is the *watt*. When one coulomb is moved in a conductor through a potential difference of one volt for *one second*, work is being done at the rate of one watt, or one joule per second.

The unit of electrical resistance is the ohm. It is the opposition to electric current which permits one ampere to flow through a conductor when an emf of one volt is applied across its terminals. The ohm, defined in other terms, is the resistance presented by a column of pure mercury at 0°C, that weighs 14.4521 grams, measures 106.3 cm long, and is of uniform cross-section.

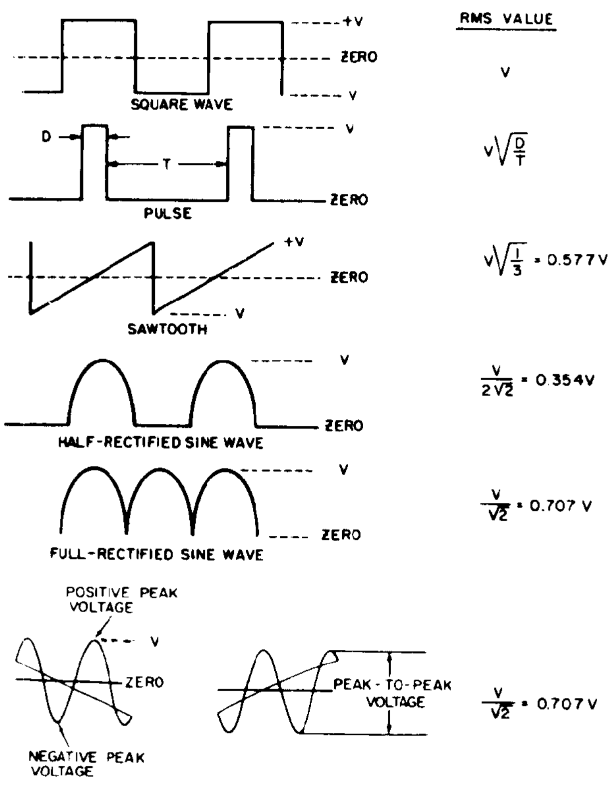


Fig. 1-1. RMS values of common waveforms.

AC VALUES AND EFFECTS

Electronic circuits ordinarily operate with nonsinusoidal (complex) voltages and currents, which are ordinarily measured in (rms) values. An rms current (or voltage) corresponds to the direct current, or voltage, which will produce the same heat energy in a load. Typical complex waveforms with their rms values are depicted in Fig. 1-1. A familiar example is a 117-volt AC line. It has a sine waveform at 117-volts rms and generates the same amount of light and heat energy in a lamp as 117-volts DC. Note the full-rectified sine wave in Fig. 1-1; its rms value is the same as that of the pure sine wave. The half-rectified sine wave has an rms value equal to one-half that of the unrectified sine wave.

Average and Rms Values

All AC waveforms have an average value of zero. This means that if the waveform were applied to a DC meter, the resultant reading would be zero. A simple example of average value is the AC pulse shown in Fig. 1-2 which

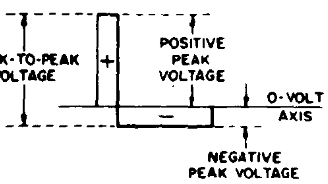


Fig. 1-2. Pulse voltage and current waveforms.

contains as much positive electricity as negative electricity. Since electrical quantity (coulombs) is equal to current multiplied by time, the positive area of the pulse is equal to its negative area. Furthermore, according to Ohm's Law, current is proportional to voltage; hence, voltage and current waveforms are the same in a resistive load.

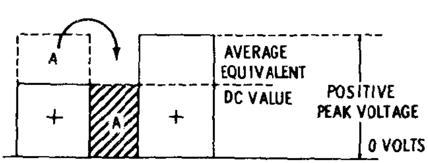


Fig. 1-3. Meaning of average value.

The meaning of average value is shown in Fig. 1-3, where area A fills in the space between the cycles of the square wave to produce an equivalent study DC value. A VOM responds to the average value of a rectified waveform (which is not zero). In other words, a meter movement does not indicate power, but rather indicates current. The shaded area above the dotted line in the sine wave of Fig. 1-4 is equal to the shaded area below. As before, the upper area fills in the empty space to give a steady average value. It is easy to see this exact relation in the rectangular rectified waveform of Fig. 1-3, but not as easy to see in the curved waveform shown in Fig. 1-4. (The 0.636

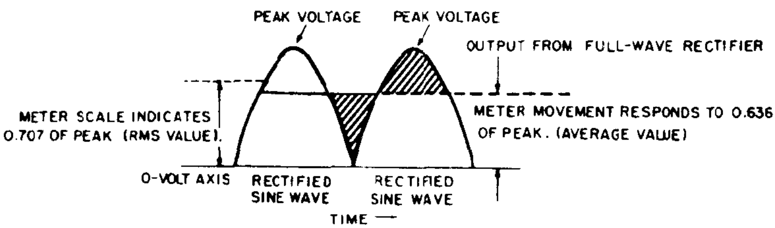


Fig. 1-4. Current waveform through meter movement in a full-wave instrument.

average value is determined by use of integral calculus; interested readers are referred to any standard text on that branch of mathematics.) Inasmuch as a meter movement *responds* to the average value of a rectified waveform but the scale *indicates* the rms value of a sine wave, it is clear that a VOM reading will be high when energized by DC voltage on its AC voltage function. Thus, if you apply 1-volt DC to a full-wave AC voltmeter (VOM), the pointer will indicate 1.11 volts.

This value of 1.11 simply expresses the ratio of the rms value to the average value of a full-rectified sine wave, or:

$$1.11 = \frac{0.707}{0.636}$$

Next, consider an older type of VOM that uses a half-wave instrument rectifier. In this case, the average value of meter current for a (half-rectified) sine wave is 0.318 of peak.

Again, the scale is calibrated to read rms values of a sine wave so that if 1-volt DC is applied, the pointer will indicate 2.22 volts. This value of 2.22 is the ratio of the rms to the average value, or:

$$2.22 = \frac{0.707}{0.318}$$

Rectifier Action

An example of a half-wave instrument-rectifier configuration that is used chiefly with copper-oxide units is shown in Fig. 1-5. Although two rectifiers are used, only the series

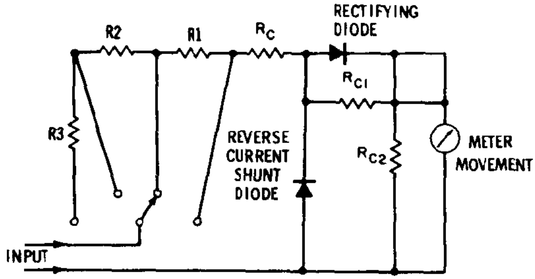
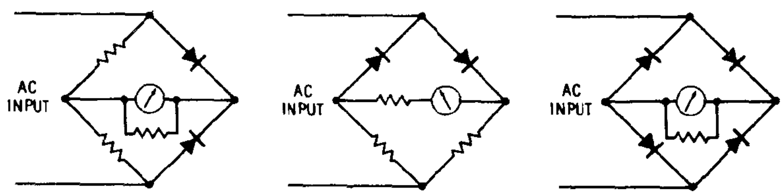


Fig. 1-5. AC voltmeter with half-wave rectifier.

rectifier feeds current to the meter movement. The shunt rectifier merely reduces the back voltage across the series rectifier, improving the indication accuracy. Multiplier resistors R1, R2, and R3 provide the various voltage ranges for the instrument. R_c, R_{c_1}, and R_{c_2} are calibrating resistors which are adjusted at the factory. Often, when instrument rectifiers are replaced, the calibrating resistors require adjustment for best indication accuracy.



(A) Opposed half-bridge. (B) Series half-bridge. (C) Full bridge.

Fig. 1-6. Full-wave instrument rectifiers.

Full-wave instrument rectifiers are commonly used in one of the three configurations illustrated in Fig. 1-6. The half bridges (Fig. 1-6A and B) provide full-wave rectification but are less efficient electrically than the full bridge (Fig. 1-6C). Both the half bridges have a response which causes the pointer to read 1.11 of the DC voltage value applied to the VOM on its AC-voltage function. While copper-oxide rectifiers are most often used in the half-wave circuits, germanium diodes are generally used in full-wave bridges.

Sine and Cosine Values

Sine values are essential to electronic tests and measurements. Although reference can be made to a table of sines

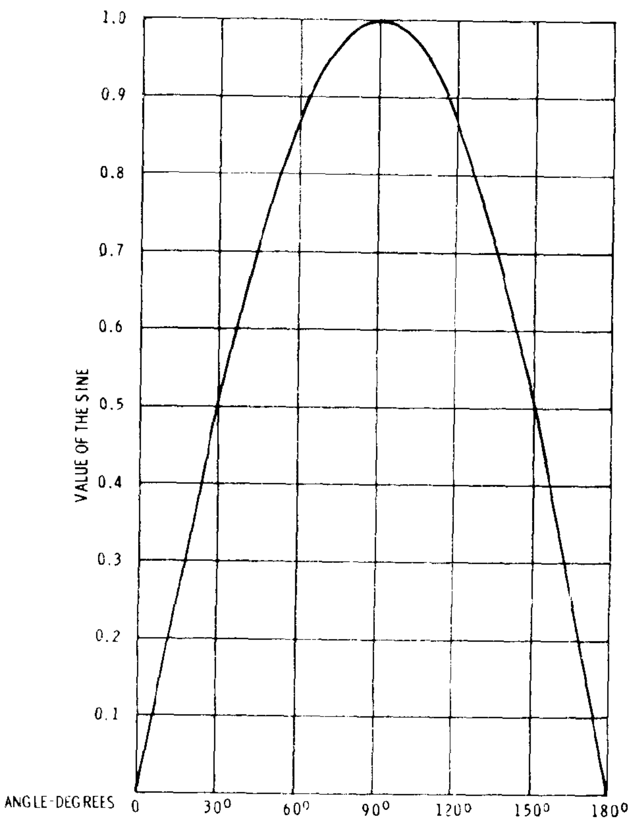


Fig. 1-7. Sine curve.

(in any trigonometry book), it is probably easiest to read the value from a curve similar to that shown in Fig. 1-7. The curve can also be used to find the angle corresponding to a given sine; e.g., the angle is 30° when the sine is 0.5. (Or, the arc-sin of 0.5 is 30°.) There is also a need for the value of a cosine, the curve of which is shown in Fig. 1-8. The value of a tangent can be found from the simple relationship:

$$\tan = \frac{\sin}{\cos}$$

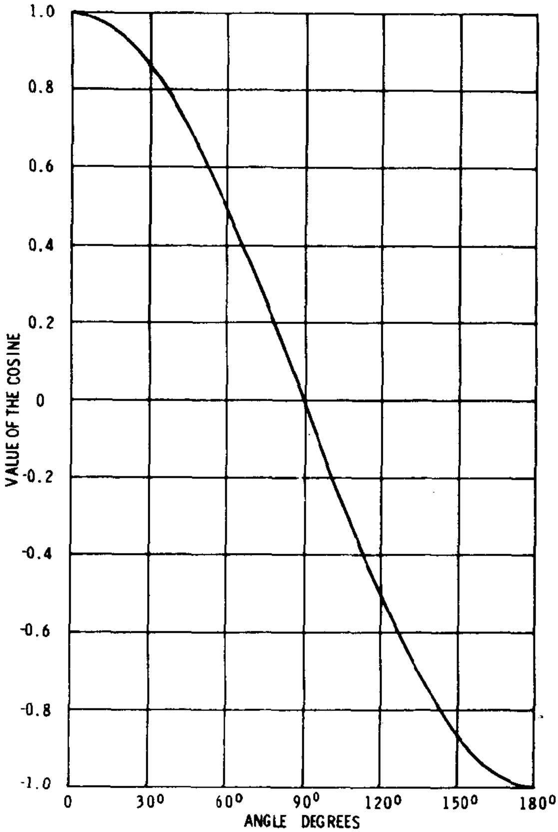


Fig. 1-8. Cosine curve.

The sine is positive for angles from 0 to 180° and negative from 180° to 360°. The cosine is positive from 0° to 90° and negative from 90° to 180°—it is 90° out of phase with the sine.

POWER AND CURRENT UTILIZATION

It has been stated that a meter movement is a current utilization device, while a lamp is a power utilization device. The distinction is basically simple—power (P) is proportional to current (I) squared. If you double the current in a circuit, the power is increased by a factor of 4. Take a practical example: a 1-volt pulse across a 1-ohm load produces a peak power of 1 watt; a 2-volt pulse across the same load results in a peak power of 4 watts.

Because ideal pulses are rectangular, it is easy to calculate their equivalent DC value with respect to power. An example is seen in Fig. 1-9. Here, a 2-volt pulse, which

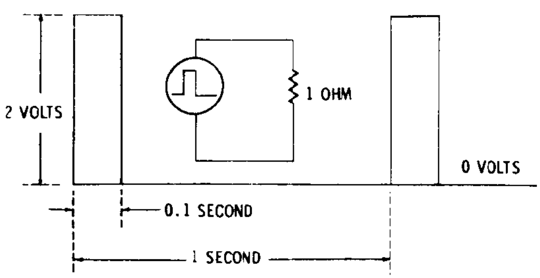


Fig. 1-9. A 0.4 watt-second pulse.

has a width of 0.1 second, recurs each second and causes current to flow through a 1-ohm load. The peak power in the load is E^2/R, or 4 watts, and has a duration of 0.1 second. Hence, its value on a time scale is 0.4 watt-second. Since this is equivalent to a peak power of 0.4 watt with a 1-second duration, the average power in the load is evidently 0.4-watt over 1 second, sustained by the recurring pulse and continuously present in the load. The DC voltage which will also develop 0.4 watt continuously in the 1-ohm load is expressed as:

$$E_{DC} = \frac{\sqrt{.4}}{1} = \sqrt{.4} = .632 \text{ volt}$$