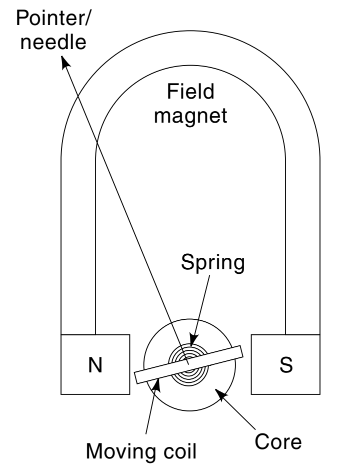


Figure 1. Basic diagram of the d'Arsonval meter movement.

MULTIMETERS

The term multimeter is used to describe many different types of instruments. Multimeters are just what the name describes, meters that can measure multiple quantities with the same instrument. The most basic multimeters measure voltage, and current both ac and dc, and more advanced digital multimeters (DMMs) measure voltage, current, resistance, frequency, and temperature, and they can trend this information. Top of the line DMMs now have waveform capture capabilities, digital storing capabilities, and printing functions. Some models can communicate with personal computers (PCs). This allows users to store and recall setups, save measurement data to disk, and perform postprocessing functions on the data. This communication feature enables the use of measurement data in documents used for reporting and verification testing.

Technicians, engineers, facilities managers, and repair technicians use multimeters to diagnose a multitude of problems with equipment and power systems. These tools are an invaluable part of any field service personnel's toolbox. Making simple continuity checks is a snap with instruments that use an audible signal to alert the user of resistance values less than 20 Ω.

This article presents a historical account of multimeters, volt-ohm meters (VOMs), and the techniques used to make measurements in electronic and electrical circuits.

HISTORY OF METER MOVEMENTS

Primitive humans were in awe of lightning. Lightning was used as a source of fire for heat and cooking. The early Greeks were the first known to question the phenomenon of lightning. Although for years the Greeks had known about the attraction of particles and the forces of magnetic substances, it wasn't until approximately 700 BC that one Greek astronomer offered an explanation. This astronomer, Thales of Miletus, suggested that magnetic substances had a soul and were alive (1).

Throughout human history in other places there have been scientists who experimented with electricity and magnetism. In 376 BC the Chinese developed the first compass using magnetism. In the late eighteenth century Benjamin Franklin demonstrated that lightning was really an electrical phenomenon. In 1796 Alessandro Volta developed the first battery. In 1820 Hans Oersted discovered the relationship between current and magnetism. Using this information, André Marie Ampère showed the relationship between current flow and magnetism. He actually proved that a current flowing through a wire acted in the same manner as a magnet. In 1827 Georg Simon Ohm discovered one of the most basic and useful principles of electrical engineering, the relationship between voltage, current, and resistance, known as Ohm's law.

In 1881 Jacques d'Arsonval developed and patented a moving coil based on Oersted's principle known as the moving-coil galvanometer (see Fig. 1). The basic principle of operation of the d'Arsonval meter movement is much like that of a permanent magnet dc motor. As current passes through the windings of the moving coil, north and south poles are set up on the coil, also known as the armature. These poles interact with the poles of the permanent magnet and cause the needle to deflect. The direction of rotation depends on the direction of current flow. Therefore the polarity of the meter movement is crucial, and the terminals on the movement are marked accordingly. The spring that is attached to the moving coil is used to retract the needle to the "zero" position after current is removed (2).

Before we begin the discussion of DMMs, we must first look at their predecessor, the volt–ohm meter, or VOM. The VOM is an analog device that is capable of measuring several different electrical quantities: voltage, current, and resistance. A majority of VOMs incorporate the use of a d'Arsonval meter movement. A simplified diagram of the d'Arsonval meter movement is shown in Fig. 1.

This type of meter responds to the average value of the current that passes through the moving coil. The amount of current passing through the meter movement is dependent on the design and calibration of the instrument. The d'Arsonval meter movement responds to current flow, not the quantity that the scale indicates. In other words, when the meter is being used to measure ohms, the scale may read 100 Ω, but the meter is actually responding to the average amount of current being passed through the moving coil.

This type of meter is rated with a full-scale deflection, usually measured in microamps, that relates the amount of current needed to make the needle move from "zero" to its maximum value. This value is important when designing a meter that incorporates the use of a d'Arsonval meter movement. Resistors placed in series with and in shunt with the meter movement allow the measurement of greater currents and voltages than is indicated by the full-scale deflection of the meter movement

The following sections discuss the use of the d'Arsonval meter movement and its uses in various types of meters. There are three basic measurements performed with VOMs and DMMs: current, voltage, and resistance. Basic design theory for each measurement is addressed.

Direct Current (dc) Meters

Perhaps the most common use for the d'Arsonval meter movement is in the dc ammeter. Figure 2 illustrates the most basic type of dc ammeter. A resistor is placed in shunt with the meter movement in order to limit the amount of current that passes through the meter movement. The value for R_{shunt} will vary depending on the desired full-scale reading of the ammeter.

Given a meter movement with a full-scale deflection of 10 mA and an internal resistance of 100 Ω, the value of R_{shunt} can be calculated as follows for an ammeter with a full-scale reading of 10 A.

The voltage drop across the meter movement at full scale would be 10 mA times 100 Ω, which gives 1.0 V. The voltage across the shunt resistor is the same as the voltage across the meter movement. The amount of current that must pass through the shunt resistor is the total full-scale reading (10 A) minus the current that passes through meter movement (10 mA). This value is 9.99 A. Therefore the value for R_{shunt} would be

$$R_{\text{shunt}} = \frac{V_{\text{shunt}}}{I_{\text{shunt}}} = \frac{1.0\ \text{V}}{9.99\ \text{A}} = 0.1001\,\Omega \tag{1}$$

The power requirements of the shunt resistors must be taken into account when designing ammeters. The physical and electrical size of the shunt resistor plays an important role in the overall physical design of the instrument. The

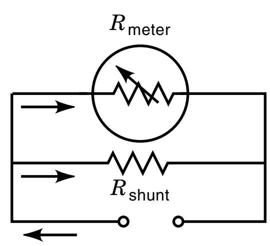


Figure 2. Schematic diagram for basic dc amp meter.

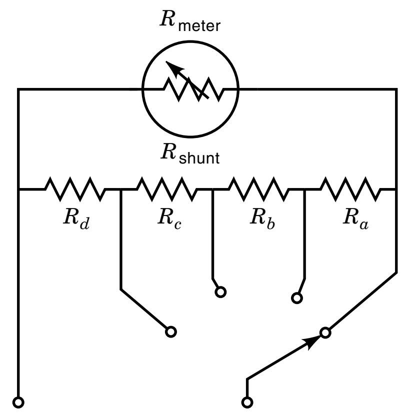


Figure 3. Schematic diagram for a multiple-range dc ammeter using the d'Arsonval meter movement and the Ayrton shunt.

power requirement for the shunt resistor in our example was found by taking I^2R to be approximately 10 W.

The previous example illustrates how the d'Arsonval meter movement was used to make an ammeter capable of measuring current from 0 A to 10 A using a meter movement with a full-scale deflection of 10 mA. It is desirable, however, to have an instrument capable of measuring various ranges of current. Figure 3 is an example of such a meter. The meter in Fig. 3 incorporates the use of the Ayrton shunt.

This type of design allows for multiple scales in one meter. The values for the shunt resistors R_a through R_d are calculated in a similar manner to the shunt for the single-range meter. The actual values for the resistors that comprise the shunt are calculated starting from the most sensitive range to the least sensitive range. In the case of the meter shown in Fig. 3, the instrument is switched to its most sensitive range. The value for the shunt resistor for that range is $R_a + R_b + R_c + R_d$. The equations will not be derived for determining the values of the individual resistors. Instead, the reader is referred to Ref. 2.

Direct Current (dc) Voltmeter

As mentioned previously, another use for the d'Arsonval meter movement is for measuring voltage. However, some modification to the meter movement is necessary to make the meter practical. If the meter movement configuration in our previous example were used as is, it would only be able to measure 1 V. By placing resistors in series with the meter movement, as opposed to in parallel as in the ammeter, the deflection of the meter movement can be made to represent voltages of various magnitudes. Figure 4 is a schematic diagram of a simple voltmeter. Proper selection of the series resistors, sometimes called multipliers, R_a, R_b, and R_c results in a three-range voltmeter as shown. Given the internal resistance (100 Ω) and full-scale deflection (10 mA) of the meter movement, the values for the series resistor can be calculated. The three ranges of the meter are 2 V, 20 V, and 200 V.

The current through the meter will be the same as the current that passes through the series resistor. Therefore, for the 2 V range, we calculate the total resistance of the meter and series resistor to be 200 Ω (2 V divided by 10 mA). The

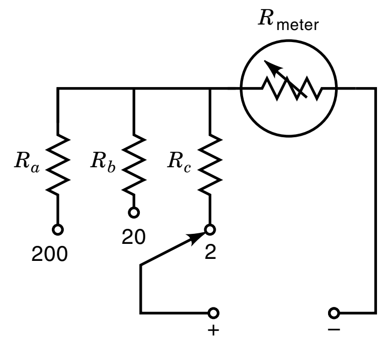


Figure 4. Schematic diagram of a multiple-voltmeter incorporating the use of a d'Arsonval meter movement.

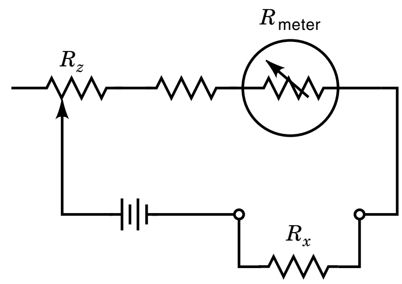


Figure 5. Schematic diagram for an ohmmeter that incorporates the use of a d'Arsonval meter movement.

value of the series resistor R_c is 100 Ω (200 Ω − 100 Ω). It follows that the values for R_b and R_a are 1900 Ω and 19,900 Ω, respectively. Another commonly used way to calculate the series resistors is to use the sensitivity of the meter movement. The sensitivity of the meter movement is the inverse of the full-scale current rating of the meter movement. To determine the resistor size, simply multiply the desired voltage range by the sensitivity of the meter movement; then subtract the value of the internal resistance of the meter. In our example, the sensitivity of the meter movement is 1 divided by 10 mA. This gives a sensitivity of 100 Ω/V. Therefore the value for R_c, the series resistor for the 2 V range, would be

$$R_c = \left[100\frac{\Omega}{\text{V}} \cdot 2\right] - 100\,\Omega = 100\,\Omega \qquad (2)$$

For the 20 V range the value for R_b would be calculated as

$$R_b = \left[100\frac{\Omega}{\text{V}} \cdot 20\right] - 100\,\Omega = 1900\,\Omega \qquad (3)$$

Values for other series resistors can be found in the same way. The only limitation on the magnitude of the measured voltage is the dielectric strength of the series resistors used in the multiplication.

When the direct current voltmeter is used to measure the voltage across a component in a given circuit, the voltmeter is in parallel with the circuit and changes the total resistance of the circuit. The resistance in the circuit is now smaller than either of the two resistances, and the voltage measured is less than the actual voltage across the test component. For this reason it is desirable to make the resistance of the voltage meter much larger than the resistance of the circuit under test. In other words, the sensitivity of the voltmeter should be high, on the order of 20 kΩ/V. Quality voltmeters typically have an input impedance of 1 MΩ or higher.

The Ohmmeter

As discussed earlier the d'Arsonval meter movement measures the amount of current that passes through its coil. Using Ohm's law, an instrument that measures resistance can be developed according to the d'Arsonval meter movement principle. Figure 5 gives the basic schematic diagram of an ohmmeter that incorporates the d'Arsonval meter movement. There is one major difference in the diagram of the ohmmeter compared with the voltmeter and ammeter—a voltage source. The ohmmeter requires a voltage source, since it is used to measure a passive element or circuit. Unlike the voltmeter and ammeter, there is no current flow in the circuit unless a source is supplied. A potentiometer or variable resistance is used to "zero" the meter. The potentiometer compensates for fluctuations in the source voltage, lead resistance, and meter resistance changes due to temperature fluctuations.

The principle of operation of the ohmmeter is basically the same as that of the voltmeter or the ammeter. That is, it relates the deflection of the needle to the quantity under test. In this case the deflection of the needle represents the resistance of the element.

Multiple-Range Ohmmeters

Figure 6 is a schematic diagram of a multiple-range ohmmeter. By using some type of switch, usually a rotary switch, different ranges on the ohmmeter can be easily selected.

The Multimeter. The multimeter was developed because scientists, engineers, technicians, and electricians needed to make different types of measurements. The multimeter is simply a meter that is made up of several of the meters pre-

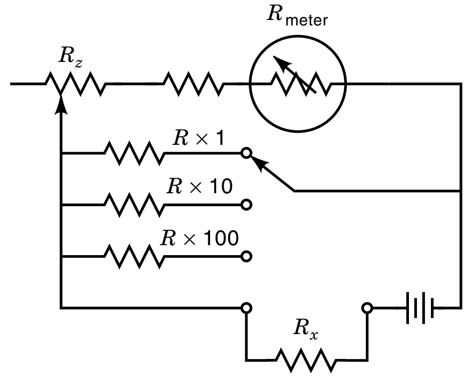


Figure 6. Schematic diagram for a multiple-range ohmmeter that incorporates the d'Arsonval meter movement.

Figure 7. Photograph of the Fluke 803 differential dc–ac voltmeter. Reproduced with permission from Fluke Corporation.

viously discussed. Multimeters typically measure dc volts and amperes, ac volts, and dc resistance. Each of these meters uses the same basic d'Arsonval meter movement for its operation, and therefore it is reasonable to assume that one instrument, using the same meter movement, can measure several quantities. Multimeters come in various shapes and sizes with different functions and accuracy. Figure 7 illustrates a differential, laboratory grade multimeter used for measuring both ac and dc quantities.

Up to this point we have discussed the use of the d'Arsonval meter movement with dc voltage and current readings. The d'Arsonval meter movement can also be used for ac measurements. The following sections address the issues of concern in using a d'Arsonval meter movement for ac measurements.

Alternating Current (ac) Meters

Measuring ac quantities can be more difficult than measuring dc quantities. With dc, the value of the voltage or current under test remains constant with time. However, with ac, the value of the voltage or current changes with time. Since the d'Arsonval meter movement responds to the average value of a signal, meter manufacturers are faced with a design dilemma. For dc, the average value of the signal is equal to the rms or effective value. For ac, the average value of the signal is equal to zero (assuming that only one frequency is present and that the negative and positive half-cycles are equal).

The rms value of a signal is the value that causes the same heating effect in a circuit element as a dc signal. The rms value of a signal, or the effective value of the signal, is found by squaring the signal, then computing the average value or the mean, and then taking the square root of the result (6).

Manufacturers have developed different methods for dealing with ac quantities when using the d'Arsonval meter movement. For example, two such methods are half-wave and full-wave rectification. Figure 8 illustrates a sinusoid, its half-wave rectified signal, and its full-wave rectified signal.

Half-Wave Rectification. When a diode is placed in series with the meter movement, the ac signal seen by the meter movement is half-wave rectified. This produces an ac signal with an average value of 0.318 times the peak value of the signal. By this principle, the scale on the meter itself can be calibrated to read correctly for a purely sinusoidal signal.

If the same meter movement and circuit is used as in Fig. 4, the sensitivity of the meter would be approximately 45% of the dc voltmeter's sensitivity. Therefore a new circuit is developed so that the full-scale deflection of the meter is obtained when a 2 V, 20 V, or 200 V rms ac signal is applied.

Full-Wave Rectification. By using full-wave rectification, the sensitivity of the ac voltmeter can be improved to 90% of the dc voltmeter. The average value of a full-wave rectified ac signal is twice the value (0.636 times) of a half-wave rectified signal.

Both half-wave and full-wave rectification techniques are only valid for pure sinusoidal waveforms. For nonsinusoidal signals, ac voltmeters employing half-wave or full-wave rectification will give erroneous readings. These types of signals will be addressed later in the article.

There are other types of meter movements that are used for both ac and dc measurements:

- Electrodynamometer movements
- Iron-vane meter movements
- Thermocouple meter movements

However, these types of meter movements will not be discussed here. The reader is directed to Ref. 2 for further read-

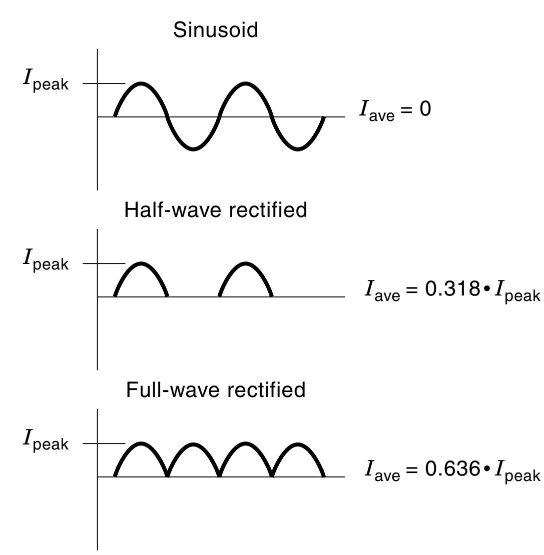


Figure 8. Illustration of the average value for three ac signals.

Figure 9. Example ac voltmeter incorporating full-wave rectification technique. Photo by Bill Dabbs.

ing on these meter movements. Figure 9 is a picture of an ac voltmeter that incorporates the full-wave rectification technique.

DIGITAL MULTIMETERS—ELECTRONIC METERS

With the development of the semiconductor in the 1950s came a new breed of instrumentation, the digital multimeter (DMM). Semiconductor technology has advanced greatly since the 1950s and has allowed the development of smaller, more accurate meters. Today's DMMs measure the same quantities as their predecessors, the analog meters. Similar to the analog meters, the DMM can be used to measure many quantities including:

- ac voltage and current
- dc voltage and current
- dc resistance
- Frequency
- Diode characteristics
- Minimum, average, and maximum values
- Capacitance

Manufacturers have developed small pocket multimeters that incorporate basic measurement functions like voltage, current, and resistance. Figure 10 is an example of a small pocket multimeter that measures voltage, both ac and dc, calculates dc resistance, and has an audible indication of continuity for resistance under 20 Ω. Other multifunction DMMs are also available. Any quantity can be measured with a DMM provided that the proper transducer is used. Quantities like temperature, vibration, and pressure are easily measured with a DMM and a transducer. The transducer is used to convert the mechanical quantity into either a voltage or a current. The developed voltage or current is measured by the DMM, and the result is displayed. Using the ratio between the mechanical quantity and the electrical quantity, the actual quantity can be calculated. Several meter manufacturers offer instruments with transducers scaled in such a way that when the DMM displays volts they are directly proportional to the quantity being tested. In other words, 158 mV may be equivalent to 158°F. An example of a popular high-quality DMM is illustrated in Fig. 11.

Theory of Operation

Most digital meters function in a similar way. The signal under test is reduced to an appropriate level for the circuit that will be measuring the signal. This is normally accomplished by using a voltage divider network much like the ones in analog meters. However, once the signal has been transformed, the similarities between analog meters and digital meters end. Digital meters incorporate a digitizer, or analog-to-digital converter (ADC). The function of the ADC is to change the analog signal into a digital word. Many DMMs incorporate the use of a $3\frac{1}{2}$ digit ADC.

Number of Digits

Most DMMs have a digit or value associated with them. This value is the number of digits that can be displayed. A $3\frac{1}{2}$ digit display can display values from 0 to 1999. Similarly a $4\frac{1}{2}$ digit display can display numbers ranging from 0 to 19,999. This value serves another purpose, apart from indicating the number of digits a meter can display. The number of digits also gives an indication as to the number of "counts" that an instrument uses. A $3\frac{1}{2}$ digit instrument has 1999 counts, and a $4\frac{1}{2}$ digit instrument has 19,999 counts. The count is the highest number that can be displayed on the instrument. Figure 12 is a typical $4\frac{1}{2}$ digit display.

DMM Resolution

The resolution of DMMs is typically given in the specification sheet of the instrument. The resolution of an instrument is the smallest change in a measured value to which the instrument will respond. For an analog instrument, the resolution is one-minor scale division. For digital instruments, the digitizer or ADC determines the reso-

Figure 10. Example of a typical pocket DMM. Photo by Bill Dabbs.

Figure 11. Photograph of the Fluke 87 III true rms multimeter. Reproduced with Permission from Fluke Corporation.

lution. The range that is selected on the instrument determines the resolution in measured units. An example of this calculation follows.

This example calculates the resolution of a $3\frac{1}{2}$ digit DMM. The instrument for this example is a $3\frac{1}{2}$ digit, 2000 count DMM on the 200 V range:

$$\text{Resolution} = \frac{\text{Range}}{\text{Count}} = \frac{200\,\text{V}}{2000\ \text{counts}} = 0.1\,\text{V} \tag{4}$$

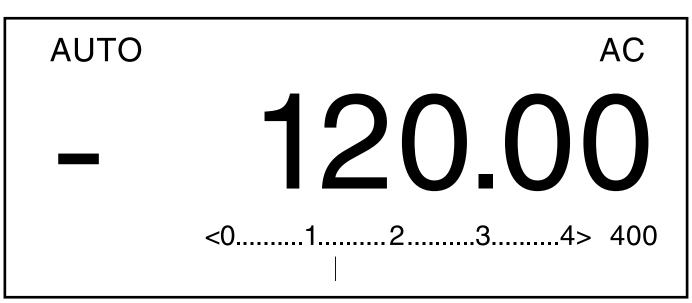


Figure 12. Typical $4\frac{1}{2}$ digit display for a DMM.

If the number of counts for this instrument were 20,000, the resolution of the instrument on the 200 V scale would then be 0.01 V.

Sensitivity

Sensitivity of an instrument is the smallest level to which the instrument can respond. This value is usually specified by the least detectable change on the lowest range. For an analog instrument on the 1 V scale with 100 divisions, the sensitivity would be 0.01 V (10 mV). For a digital instrument with $4\frac{1}{2}$ digits on the lowest range of 200 mV, the sensitivity would be 0.01 mV. An example follows.

The instrument is an analog meter with 100 divisions on the scale. The lowest range on the instrument is the 1 V scale. Therefore the sensitivity of the instrument can be calculated as

$$S = \frac{1\,\text{V full scale}}{100\ \text{divisions}} = 0.01\,\text{V} = 10\ \text{mV} \tag{5}$$

To determine the sensitivity of a digital meter, we need to know the number of counts used and the range at which the instrument is set. For our example, suppose we have a 20,000 count DMM that is set to the 200 V range. The sensitivity or maximum resolution on the 200 V range would be 0.01 V. The equation used to determine the sensitivity is

$$S = \frac{\text{DMM range}}{\text{Number of counts}} = \frac{200\,\text{V}}{20,000\ \text{counts}} = 0.01\,\text{V} = 10\,\text{mV} \tag{6}$$

Accuracy and Uncertainty

Accuracy and uncertainty are complementary terms. An accuracy of 99.9% has an uncertainty of 0.1%. Accuracy is a measure of “closeness” to a known or given value. If an instrument has an accuracy of 1%, this means that the measurement will be within plus or minus 1%. Accuracy is given in two ways.

- Percent of full scale
- Percent of reading

There can be quite a difference between these two methods of determining accuracy. The following example illustrates the difference.

Given an instrument with a full-scale reading of 200 V and an accuracy of 1% of the full-scale value. The accuracy is ±1% of the 200 V, or 2 V. A reading of 100 V could actually be 102 V or 98 V. This produces an error of 2%. A reading of 10 V could actually be 12 or 8 V. This produces an error of 20%.

An instrument with an accuracy of ±1% of the reading produces drastically different results than a meter with an accuracy of ±1% of the full-scale value. Measuring the same 100 V would result in a reading between 99 V and 101 V. This is an error of 1%. A reading of 10 V could actually be between 9.9 V and 10.1 V. This also is an error of 1%.

The accuracy depends on temperature and other environmental conditions. Manufacturers often state accuracy in typical values, not the worst case values.

Voltage

Ac, dc, rms. The most important factor to consider when selecting and using a DMM is the method of calculation used in the meter. All of the commonly used meters are calibrated to give an rms value for the measured signal. A number of different methods are used to calculate the rms value. The three most common methods are

- Peak method
- Averaging method
- True rms method

Peak Method. A peak-detecting DMM uses a peak detection circuit to determine the peak of the signal. The circuitry in the meter determines the peak value and divides the result by 1.414 (square root of 2) to obtain the rms value. The rms value of a pure sinusoidal signal is related to the peak value by a factor of 1.414. This is also known as the crest factor of a signal.

Average Responding. An average-responding meter determines the average value of a rectified signal, as does the d'Arsonval meter movement. For a clean sinusoidal signal, the average value is related to the rms value by the constant, $k = 1.11$. This value is used to scale all waveforms measured. As with the d'Arsonval meter movement, the average value of a sinusoid is 0.636 times the peak value. Therefore the rms value of the rectified signal can be found by multiplying the average value $(0.636 \times \text{peak}) \times 1.11$.

True rms. The rms value of a signal is a measure of the heating which will result if the voltage is impressed across a resistive load. One method of detecting the true rms value is to actually use a thermal detector to measure a heating value. Modern digital meters calculate the rms value by squaring the signal on a sample by sample basis, averaging over a period, and then taking the square root of the result. Figure 13 illustrates a good-quality true rms DMM.

In today's electronic environment, it is important to use instruments that read true rms quantities (Fig. 14). Electronic equipment is nonlinear. That is to say, the current wave shape does not follow the voltage wave shape. As mentioned previously, several techniques used to measure rms quantities are only valid for purely sinusoidal signals. When electronic equipment is present in a circuit, the current drawn by the load contains harmonic components, currents of frequencies other than the 60 Hz fundamental. Table 1 shows the error produced by three different meter types when measuring nonsinusoidal quantities.

For the true rms method, the instrument displays the correct value for the rms quantity under test. However, the peak detection method and the average responding method produce an error when measuring quantities that are not purely sinusoidal.

Transducers

Many DMMs on the market today can measure current. The maximum current that can be measured directly is usually less than 10 A rms. In most cases it is necessary to interrupt, or break, the circuit under test in order to measure current. DMM manufacturers have recognized this as a problem and now offer current probes or transducers (CTs) for use with their equipment. These CTs are usually clamp-on type devices that allow you to clamp around a conductor without interrupting the circuit. The CTs also extend the range of the

Figure 13. Photograph of the Fluke 87 III true rms multimeter. Reproduced with Permission from Fluke Corporation.

Figure 14. Photograph of the Fluke 8060A true rms multimeter. Reproduced with Permission from Fluke Corporation.

DMM and allow the user to measure current up to 1000 A rms. The CT uses the same principles as a regular transformer except that the turns ratio is designed to give a low-level voltage or current on the secondary winding of the CT that is proportional to the current passing through the primary winding (the jaw of a clamp on CT). As with transformers, CTs are only capable of transforming ac signals. The electric field around a current-carrying conductor changes with time for an ac signal. Therefore the flux and the resulting voltage induced in the secondary of the CT coil change also. For dc, the flux does not change, and no voltage is induced in

Figure 15. Example of a clamp on DMM. Photo by Bill Dabbs.

the secondary of the CT. For dc measurements, a Hall effect current probe must be used. Hall effect CTs work off the magnetic field produced by current flowing through a conductor. These devices often require a separate voltage source to drive the circuits internal to the current probe. Figure 15 illustrate several different models and styles of current probes that can be used with DMMs.

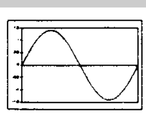
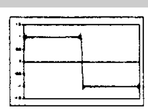
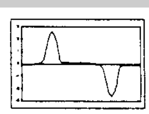
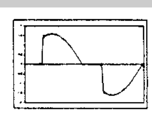
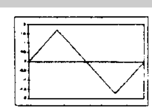
Several manufacturers of DMMs incorporate the clamp-on CT into the design of the DMM. This type of DMM is capable of measuring currents into the hundreds of amps as well as voltage, resistance, and other electrical quantities. Figure 16 is an example of this type of instrument.

SAFETY

As with any instrument used to measure electricity, some safety concerns must be addressed. This section deals with several safety considerations that must be kept in mind when using multimeters. It is not intended to be the final word on safety, nor is it intended to supersede any manufacturer's safety practices or recommendations. Several standards are cited, and the reader is encouraged to review these standards prior to purchasing and using any instrument.

When working with electrical circuits it is ultimately your responsibility to ensure your safety. Working on dead or de-

Table 1. Methods for Measuring Voltages and Currents in Multimeters

Meter Type	Circuit	Sine Wave	Square Wave	PC Current	Light Dimmer	Triangle Wave
						
Peak method	Peak/1.414	100%	82%	184%	113%	121%
Average responding	Sine avg. × 1.1	100	110	60	84	96
True rms	rms converter	100	100	100	100	100

Source: Reference 4.

Figure 16. Example of common current probes available for use with DMMs. Photo by Bill Dabbs.

energized circuits whenever possible is recommended. However, certain situations do not allow measurements to be performed on dead circuits. If working on live or energized circuits, remember the following:

Never work alone. Always work in pairs in case you accidentally come in contact with the circuit you are measuring. Your partner can disconnect the circuit or knock you away from the live circuit.

Always use protective gear. You should always wear eye protection and insulated gloves with leather protectors. This equipment should be tested annually to ensure that its electrical withstand capability has not degraded. Never wear jewelry, watches, or other metallic articles of dress when working on electrical circuits. Any electrical conductor coming in contact with a live circuit can have disastrous results. Flame resistant clothing is also a good idea.

When performing measurements on live circuits, follow these basic steps to ensure your safety:

1. Always connect the ground lead first then the hot lead. Removal of the test leads is in reverse order. Remove the hot lead first then the ground lead.
2. Use the three-point test method. When performing measurements, it is important to ensure that the test equipment is functioning properly. First, perform a similar measurement on a known source prior to connecting the instrument to the test circuit. Second, perform the measurements on the circuit under test. Third, test the meter on the known circuit to verify its operation after the measurement.
3. Use one hand. Whenever possible, only use one hand when connecting and disconnecting test leads from a live circuit. This lessens the chance that you will come in contact with a live circuit. More important, it lessens the chance that you will receive an electrical shock across your chest and through your heart.

When the human body comes in contact with live electrical circuits, current flows through the body. If this current flow is across the chest and heart, the result can be disastrous. Table 2 lists different levels of current and their effect on the human body. Using the information in Table 2, we can calculate a threshold for a hazardous voltage. Under dry conditions the approximate skin resistance across a human body is 1000 Ω. Using Ohm's law, a voltage of 35 V would produce a current of 35 mA. From Table 2 it can be seen that this would cause of loss of breathing and possible death. When the skin is wet, the hazardous voltage can be as low as 10 V.

Voltage Rating

All multimeters are tested against and are rated in accordance with safety standards. The International Electrotechnical Commission (IEC) has several safety standards by which instruments are tested. One standard, IEC 1010, is a test procedure that uses three criteria to determine a multimeter's voltage rating. They are the steady-state voltage, peak voltage, and source impedance. These three criteria are used to describe the meters true withstand capability. Ta-

Table 2. Effects of Current on the Human Body

Current Applied to Skin	*Effect of Prolonged Contact*
6 A or more	Sustained myocardial contraction followed by abnormal rhythm. Temporary respiratory paralysis. Burns on contact area.
0.1 to 2–3 A	Ventricular fibrillation. Respiratory center intact.
30 to 50 mA	Pain, fainting, exhaustion. On prolonged duration, death often results.
16 mA	"Let Go" current, muscle contraction.
1 mA	Threshold of perception, tingling.
Current Applied to Myocardium	*Effect of Prolonged Contact*
100 μA	Ventricular fibrillation.
10 μA	Recommended maximum leakage current for patient connected biomedical equipment.

Table 3. Transient Test Values for Overvoltage Withstand Capabilities

Overvoltage Category	Working Voltage (volts)	Peak Impulse Transient (volts)	Test Source Impedance (ohms)
CAT I	600	2500	30
CAT I	1000	4000	30
CAT II	600	4000	12
CAT II	1000	6000	12
CAT III	600	6000	2
CAT III	1000	8000	2

ble 3 lists the different levels of overvoltage categories and the values used for each criterion.

Another concern with safety are the test leads. If an instrument is rated CAT III 600 V, but the leads are only CAT II 600 V, the leads become the actual rating of the measurement system. In other words, don't overlook the test leads. Choose test leads that are certified in the same category and voltage rating as the meter or higher. Test leads are also rated by IEC 1010.

Another safety concern is that the meter is connected properly. Many DMMs can measure both voltage and current. When a voltage measurement is made, there is a high input impedance (usually 10 MΩ) on the voltage circuit. This impedance conditions the voltage or reduces the voltage to appropriate levels for the circuitry within the instrument. However, when measuring current, the instrument is placed in series with the load under test. The burden, or input impedance, is typically 0.01 Ω or less. This low impedance doesn't affect the current that the instrument is trying to measure. The voltage developed across the burden is read, and using ohm's law, the measured current is displayed. In order to avoid confusion, meter manufacturers typically use a common jack (COM), a volts jack (VΩ), and an amps jack (A); see Fig. 17. When performing voltage measurements, the leads are connected to "COM" and "VΩ." When performing current measurements, the leads are connected to "COM" and "A." However, if the leads are left connected to "COM" and "A" and a voltage measurement is performed, the low impedance of the burden is effectively a short circuit. This short circuit occurs even if the selector switch or dial of the meter is turned to volts. For this reason fuses must protect the amp terminals, and one must make sure to use the fuses specified by the manufacturer. These fuses are generally high energy and have an interrupting capacity to protect users (4).

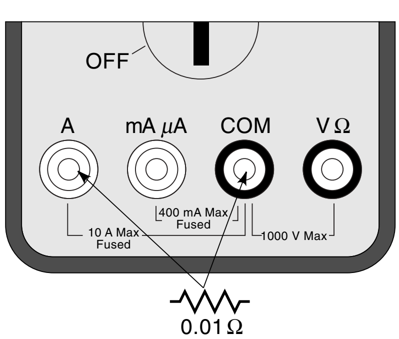


Figure 17. Example DMM connection jacks.

SUMMARY

Multimeters are used worldwide by many people and in different professions. Since their invention, they have proved to be invaluable tools for technicians, electricians, engineers, and homeowners. Multimeters can be used to troubleshoot equipment, verify proper operation of equipment, and determine values of electrical components. Advances made in multimeter technology have made them more affordable and economical for practically any individual to own.

When used properly, multimeters serve the user well. Safety is of the utmost importance, and meter manufacturers take great pains to ensure that they produce safe products for the consumer. International committees have developed standards that rate multimeters. Consumers should use these ratings to ensure that the multimeter they are using meets or exceeds the requirements of the work being performed.

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MULTIMETERS, DIGITAL. See Digital multimeters.