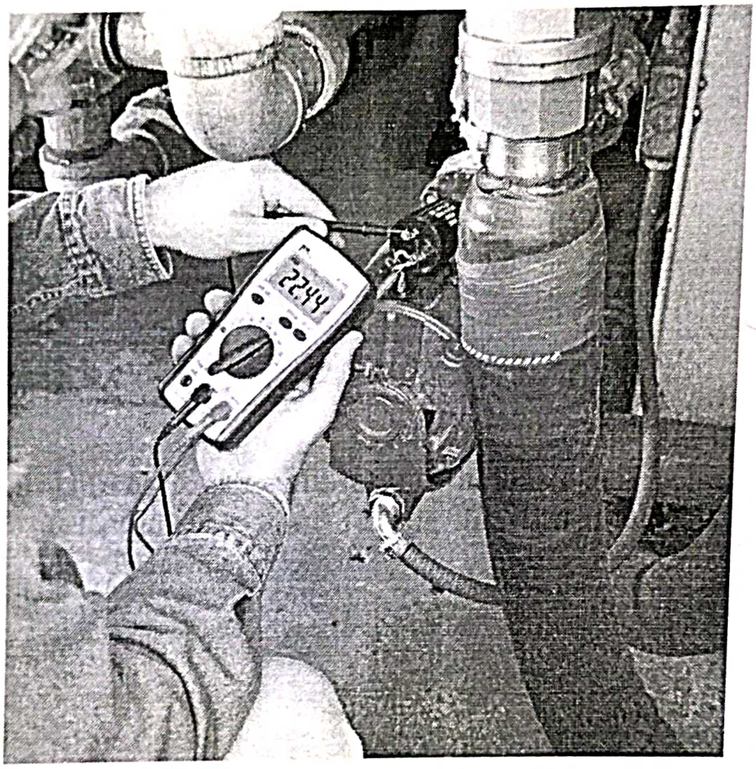
Theoretical

Basic Digital meters

The Basics of Digital Multimeters

A guide to help you understand the basic Features and Functions of a Digital Multimeter.



The Basics of Electricity

To better understand digital multimeters, it's helpful to become clear on the basics of electricity. After all, DMMs always measure some aspect of electricity.

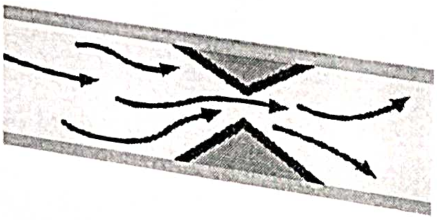
Electricity passing through a conductor is similar to water flowing through a pipe. Every pipe has force that creates a certain pressure, causing water to flow. In the case of electricity, that force might be a generator, battery, solar panel or some other power supply. The pressure created by that power supply is called voltage.

Voltage is the pressure applied to the circuit.

Current is the Flow of the electricity in the conductor.

Resistance is any restriction to the flow of the current in a conductor.

Voltage, current and resistance are the three most fundamental components of electricity. Voltage is measured in volts, current in amps and resistance in ohms.

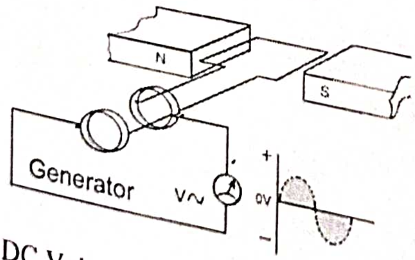


The three components in an electrical system are electrical pressure, or voltage (measured in volts), the amount of electricity flowing, or current (measured in amps), and impedances within the system, or resistance (measured in Ohms)

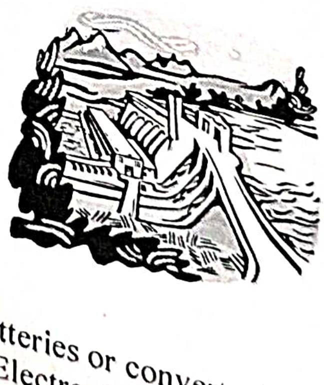
Voltage, Current and Resistance

Voltage is the pressure that is applied to a conductor. There are two common types of power sources, Alternating Current (AC) and Direct Current (DC). Alternating Voltage is the most common form of electricity. It is the power supplied by the utility or generators, which flows through our electrical circuits. The symbol for AC voltage is V~ .

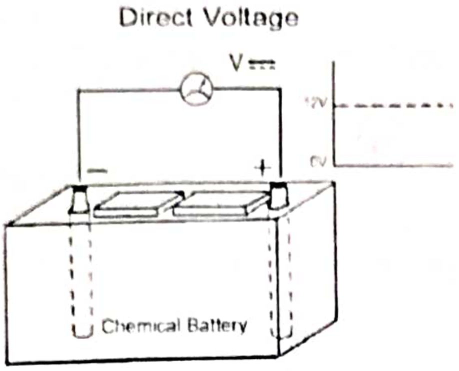
Alternating Voltage



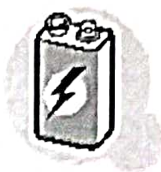
A generator creates electricity from two opposite magnetic fields, as the wire turns between these two fields, electrons are pulled first in a positive, then in a negative direction



DC Voltage is a constant level of stored energy. It is stored in batteries or converted from alternating voltage through the use of electronic rectifiers. Electronic products like TVs, VCRs and computer equipment run on DC power. The symbol for DC voltage is V⎓.



Unlike alternating voltage, direct voltage is a steady flow of positive energy. It is commonly stored in batteries for use in electronic equipment



Current is the flow of electricity through a conductor. As with voltage, there are two types of current, AC and DC. The symbol for current is the letter **A**.

The third component is resistance, measured in Ohms. Resistance in the circuit impedes the flow of current through a conductor. The symbol for resistance is the Greek Omega, **Ω**, sometimes referred to as the horseshoe.

Ohm's Law

Together, voltage, current and resistance comprise Ohm's Law. Ohm's Law is an important equation for electricians. By using a DMM, they can establish values for the three variables which help in diagnosing electrical problems.

Ohm's Law can be expressed in equation form in this way:

$$\mathbf{V = A \times \Omega}$$

Voltage = Current × Resistance

Ohm's Law is expressed in an equation: V=A x Ω

Tech Note: *Voltage determines the flow of current; the greater the voltage, the greater the current. If resistance is increased, the current will decrease. Lower the resistance, and current will increase. The relationship of these three elements of Ohm's Law; Volts, Ohms and Amperes, must mathematically balance.*

Let's take an example; say we have a 120 Volt outlet and a hair dryer. If the hair dryer is set on low, it would draw 7 amps. The load resistance is around 17 ***Ω****, but if we change the setting to high, the current draw would increase to 12 amps, and the load resistance will decrease to 10* ***Ω.***

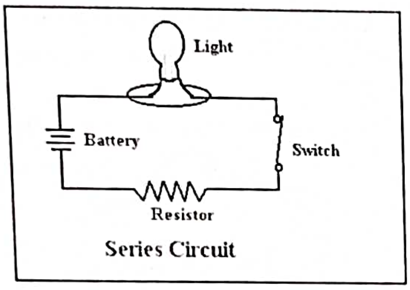
V	=	A	x	Ω
120	=	7 ↓	x	17 ↑
120	=	12 ↑	x	10 ↓

If Ohms (Ω) increase, current (A) decreases, and if Current (A) increases, Ohms (Ω) decreases

For useful formulas See Appendix A

Electrical Circuits
In an Electrical system, there are two ways that loads are connected in a circuit, in Series or in Parallel.

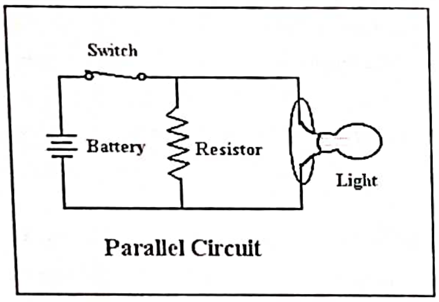
In a Series Circuit, each device is connected together in a line. Current flows through each device connected to the circuit. If you were to increase the resistor in the *Series Circuit* shown below, the light would dim. You have restricted the flow or available current to the light.



Series Circuit

In a series circuit, loads within the circuit have an impact on the flow of electricity to the other loads.

In Parallel Circuit, the same amount of voltage is applied to each device. Current can flow freely through each device without affecting another. Our homes are wired in Parallel for this reason.



Parallel Circuit

In a parallel circuit, loads within the circuit will not impact the flow of electricity to the other loads.

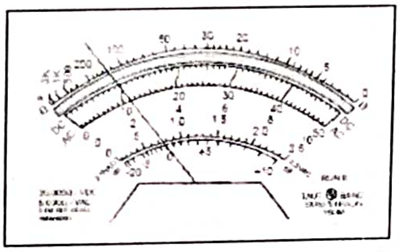
When making measurements with a digital multimeter, it is important to remember that Voltage measurements are made with the test leads connected in Parallel, and Current measurements are made with the test leads connected in Series.

Tech Note: *The number one mistake made when using modern multimeters is to try and measure voltage with the test leads in the current input jacks. The input impedance of the current inputs jacks is in the range of 0.1 ohm to around 8 ohms, depending on the manufacturer. This low impedance is like a short circuit when making a voltage measurement. Because of this low resistance and possible short circuit condition most multimeters current input jacks are fused for protection. Well constructed meters will use a high energy fuse for this protection but you will blow the fuse if you test in this manner.*

Types of Multimeters

There are two common types of Multimeters, Analog and Digital. Digital Multimeters (DMMs) are the most common. They use a liquid crystal display (LCD) technology to give more accurate readings. Other advantages include higher input impedances, which will not load down sensitive circuits, and input protection.

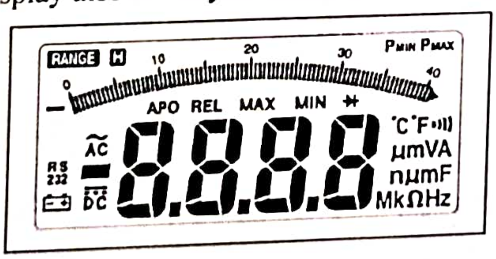
Analog meters use a needle movement and calibrated scale to indicate values. These were popular for years, but recently their numbers have declined. Every voltmeter has an internal resistance or impedance. The input impedance of an analog meter is expressed in "Ohms per Volt"



The input impedance of an analog meter is expressed in "Ohms per Volt" In this example the impedance for AC volts is 5000 ohms per volt. If I want to measure 120Vac the input resistance would be 5000 x 120 or 600,000 ohms.

Tech note: Analog Meters *The internal impedance of the meter is in parallel to the measured circuit. You want this impedance to have as little effect on the measurement as possible so the higher the impedance the better. For most electrical measurements this effect is minimal, but for sensitive electronics of today the effect of the added resistance could be significant. This is just one of the disadvantages of an Analog meter. There are however a few useful applications for analog meters, so they aren't going away tomorrow.*

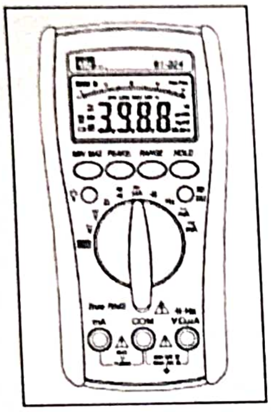
The Digital Multimeter (DMMs) feature a digital or liquid crystal display (LCD). Measurement readings are displayed as numerical values on the LCD Display. The display also alerts you to any pertinent symbols and warnings.



Tech Note: Digital Multimeters and ClampMeters *use different techniques internally, to measure AC, DC voltage, Resistance and Amperes. An advantage of a digital multimeter is their accuracy and input protection. Their input resistance or impedance is very high, in the range of 1,000,000 to 10,000,000 ohms, so there is little effect on the measurement. On good quality meters, their inputs are also protected from faults and misuse. Test instruments today devote a good deal of architecture to overload protection. Most digital* *meters meet some safety standard such as UL601010 or IEC (International Electro-technical Commission).*

DMMs at a Glance

The port panel is where you plug in your test leads. The diagram below explains where the test leads go for specific tests.



Digital multimeters are more commonly used because of a few key features, including higher accuracies, higher input impedances and input protection.

Multimeter Safety

When making a meter selection look for a tester that is independently certified to some safety standard, UL, IEC, CSA.

Pay close attention to how and where you are using the equipment. Never use equipment that is outside of its manufacturer specified measurement range, or outside of its category rating.

Over Voltage Category	Description of Category
CAT IV	Primary supply, Overhead or underground utility service.
CAT III	Distribution level mains, fixed installation
CAT II	Local level mains, appliances, portable equipment.
CAT I:	Signal level, special equipment or parts of equipment, telecommunication, and electronics.

Tech Note: Multimeter Safety. *The major issue addressed by the UL601010 standard was to look at fault potential to available energy and define limited by category to each. The most common fault was high voltage transients on high energy circuits. If a transient were to cause a fault within an instrument with high energy present, it could result in a cascading failure of meter, equipment, and possibly personal injury.*

The easiest way to understand the different category ratings of the IEC standard is to think of the potential Short Circuit energy. The higher available short circuit energy, the higher the category.

For additional information on Meter Safety refer to the IDEAL whitepaper on METER SAFETY

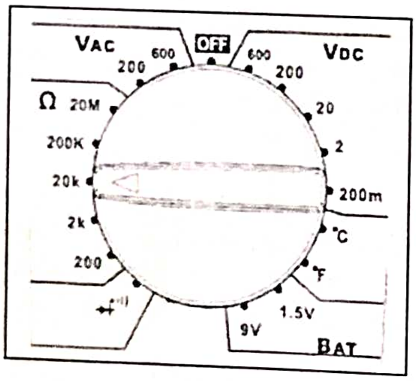
The Dial

Setting the Function

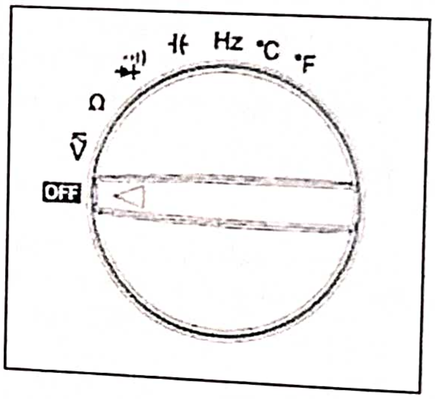
The dial of the DMM allows you to choose the function you're interested in measuring. Whether you intend to measure one of the three elements of Ohm's Law, or a more advanced function like frequency or capacitance, you must first set the dial to the appropriate function.

Setting the Range

The dial also plays another essential role in measuring electricity – that of determining the range of measurement. The range you select on the dial determines the placement of the decimal point as it appears on the LCD. In turn, the position of the decimal point determines how refined, or precise, your reading is. This is called resolution.



On a manual ranging meter, the function and range must be selected



Auto ranging meters will automatically choose the measurement range

Symbols	Measurement Functions	Descriptions
V~	AC Voltage	Measures amount of AC Electrical Pressure
V⎓	DC Voltage	Measures amount of DC Electrical Pressure
mV	Milli Volts	.00V or 1/1000V
A	Amperes	Measures amount of electron flow
mA	Milli Amperes	.001 or 1/1000A
Ω	Ohms	Measurement of resistance to the flow of electron
-⊳|-	Diode	Device used to control direction of electron flow
•)))	Audible Continuity	Audible indication of continuity for low resistance
-|(-	Capacitance	Device used to store electrical potential

For A complete listing See Appendix B

Auto vs. Manual Ranging

***Tech note: Manual ranging multimeters** force us to think about the measurement before we select the range of the meter. As an example, if I want to measure 120V AC on a manual ranging meter I would turn the Dial or switch to the VAC section and select the 200V Range. This gives you ample measurement range and the maximum resolution for the measurement. If the voltage is unknown, start with the maximum or highest range and step down to achieve the maximum resolution on the display. Note that OL or overload means that you need to select a higher range and this should not damage the meter.*

***Tech Note: Auto ranging multimeters**, only the measurement function needs to be selected. The multimeters circuitry will "automatically" select the best range for the measurement. There are two things to remember about an auto ranging meter. One thing is that the timing for the meter to achieve and settle on a range can take a few seconds. The other is the symbols and numerical expression used on the display. If a user fails to pay close attention to what the display is telling them, an error can occur with the interpretation of the displayed value. As an example, 240mV could be interpreted as 240V if the user doesn't pay close attention to the little "**m**" in the "**mV**" icon on the display.*

Understanding Count, Resolution and Accuracy

The count is the maximum number of digits that can be shown on the display. In most cases this value is one less that the Count of the display. For example if you have a 2000 count unit, the maximum reading per range is 1999 or one less that 2000.

To get a better understanding of resolution, let's take an example. If you are using a manual ranging unit that is set on 20V and you're measuring an application that puts out more than 20V, the display will read "OL", or overload. You must reset the dial to a higher range and take a new reading. The most refined reading, therefore, uses the range that provides the best resolution without overloading. Select the range just higher than the expected reading.

Range Setting	Maximum Range and Resolution
2V	1.999V
20V	19.99V
200V	199.9V
1000V	1000V

Meter Accuracy:

Most meter's accuracy are expressed as a +/- percentage of input + a +/- number of counts, expressed as +/-{ X% + No. of counts}. For example, the Ideal 61-342 is a 4000 count display with a basic DC Voltage accuracy of +/-{0.5% + 5} The +5 is called the count or floor and refers to the least significant digit of the display in reference to range and resolution.

If we want to determine the maximum error of the meter that is measuring a source of 12V, first determine the percentage error and add the count or floor.

The % accuracy for a 12V source would be 12 x 0.005= 0.06

To determine the count, we must determine the meter's range and resolution. If the display is a 4000 count display, we need to determine the best range and resolution. For 12 V this would be the 40V range. The display maximum resolution is 39.99 and the least significant digit would be 0.01 with a total count of 0.05

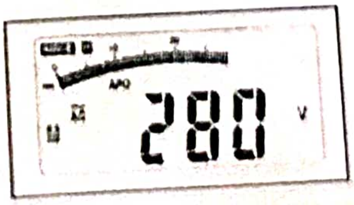
The accuracy of the meter is +/- (0.06 +.05) which is = +/- 0.11, so the Low limit is 11.89 and the High limit would be 12.11

Tech Note: Display Counts & Resolution
The display count is the maximum digital resolution of the multimeter. A 2000 count display, has a maximum reading of 1999, one less than the display count. A 4000-count display has a maximum reading of 3999. These two displays are the most common, 5000, 20,000 and even 50,000 count displays are also available. The display count determines maximum range and resolution.

A 2000 count unit is often called a 3-½ digit display. The 3 refers to the number of full digits, and the ½ refers to the capabilities of the most significant digit (furthest to the left) which can be either a 1 or 0. Most meters today are 4000 count units. This means that the most significant would be 0 to 3 or one less that the count of the analog to Digital Converter.

The display count is important in determining the maximum resolution (number of digits after the decimal point) of the reading. As an example, let's look at the difference when measuring a 240-volt supply with a 2000 count and 4000-count multimeter and what range you would set the meter to.
The 2000 count display would be in the 600V range and display 280 volts. The maximum resolution is 1 volt. The 4000-count multimeter would be in the 400V range and have a maximum resolution of .1V. The unit would display the measurement as 280.0 volts.

Range	Reading	Resolution
600	600	1V
200	199.9	.1V
20	19.99	.01V
2	1.999	.001V
200mV	199.9	0.1mV

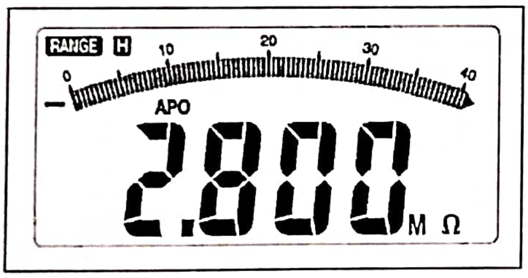


The 2000 count unit would need to be set on the 600 volt range to measure 280V On the 600V range the maximum resolution would be 1 Volt.

Range	Reading	Resolution
600	600	1V
400	399.9	.1V
40	39.99	.01V
4	3.999	.001V
400mV	399.9	0.1mV

The 4000 count unit would be set on the 400V range to measure 280V, and have a maximum resolution of .1V In this case the 4000 count unit would give you the best resolution

It is important that we understand our numerical expressions to properly setup or read the display of a Multimeter. In this example we have an auto ranging meter, measuring a 2,800,000 ohm resistor. The display reads 2.800 M Ω. M is the Symbol for Mega or one million ohms.



In this example the meter reading is 2.800 M Ω, expressed as 2.8 Meg Ohms or 2,800,000 ohms

Numerical Display notation

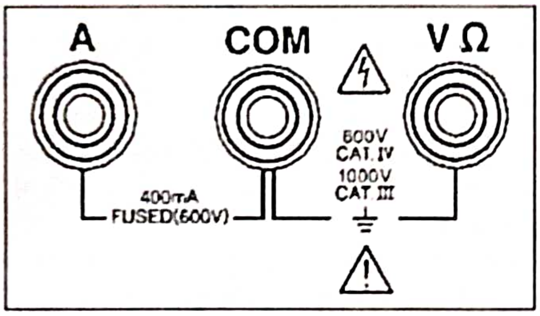
Terms	Numerical Values	Symbol	Expression
Giga	1,000,000,000	G	$x10^{9}$
Mega	1,000,000	M	$x10^{6}$
Kilo	1,000	K	$x10^{3}$
Milli	.001	m	$x10^{-3}$
Micro	.000001	m	$x10^{-6}$
Nano	.000000001	n	$x10^{-9}$

Port Panel

The port panel is where you plug in your test leads. The diagram below explains where the test leads go for specific tests.

Instrument Input Jacks or Ports

The input jacks or ports of your meter are the working ends of the instrument. Use care when connecting leads to your instrument. Pay close attention and be sure to connect the leads into the correct port that is marked for the measurement selected on the dial.



DC Voltage Measurements: To measure DC voltage, we place the Red lead into the V Ω port and black lead into the **COM** port. Turn the dial or switch to V_{DC} or V ⎓
If it is a manual ranging meter set it for the proper range. As in the example below, we want to measure a 9V battery so the best range would be the 20 V range. If you have an auto-ranging meter you only need to set the function on the dial to V_{DC} or V ⎓

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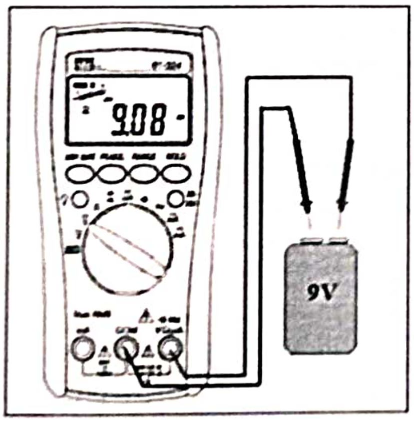


Most Digital Multimeters are auto-polarity sensing devices. This means that we don't have to worry about having the Red lead on the hot or positive and the Black Lead on the Neutral or negative.

If you do not pay close attention to polarity when using an Analog meter the meter movement or meter could be damaged

AC Voltage Measurement: To measure AC voltage, we place the Red lead into the V Ω port and black lead into the **COM** port. Turn the dial or switch to V_{AC} or V ~
If it is a manual ranging meter set it for the proper range. As an example the meter would be set to the 200 V range to measure a 120V outlet. . If you have an auto-ranging meter you only need to set function to V_{AC} or V ~ .

Remember that it is always a good practice to connect the black lead first then the red.

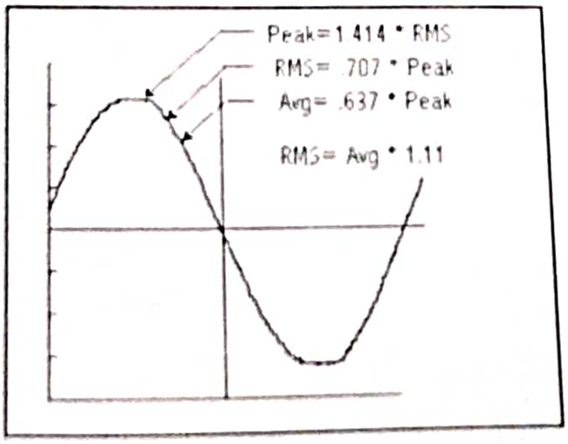
Tech Note: Voltage Measurements
Voltage measurements are perhaps the most common function used on a multimeter. Voltage is measured between two points so we must make sure that we have solid contact at each point. The proper way to connect a meter is to connect the low or ground (black lead) first and the High (Red lead) next. We remove the leads in reverse order, Red first and then Black.
Whenever making live voltage measurements use the Three Point method. Measure a known live circuit or source first, then the unknown circuit, then back to the known circuit.

Average Responding vs. True RMS
The RMS or Root Mean Square value of an AC measurement is the "Effective Value" or "Equivalent Value" of the waveform to do work in relationship to DC. Test Equipment use two methods to measure an AC waveform. One is Average responding RMS calibrated and the other is True RMS. Both are designed for periodic type perfectly sinusoidal waveforms and most are AC coupled, meaning that is blocks any DC bias that may effect the measurement.

Average Responding voltmeters use a *simple* circuit to provide a general-purpose voltmeter a low cost method to calculate the RMS value of *a* sinusoidal *waveform. The True effective value can be obtained as long as the AC waveform is a periodic sinusoidal waveform.*

When measuring complex waveforms with harmonics, such as square waves or AC signals which have been rectified *or electronically controlled in some way* by *devices like diodes,* SCR's *or triac's, the True RMS or "effective heating value" cannot be accurately measured using an Average responding meter. You must use a True RMS meter to make an accurate measurement.*

True-RMS voltmeters use an integrated *circuit that* computes the true root-mean-square value of *a* complex *waveform. Most are AC coupled, but in some higher end meters "AC + DC" coupling is available which gives you the "effective heating value" of both the AC and DC component of the waveform.*



The Root Mean Square value is a measurement of the "Effective Value" of the waveform or the ability to do work.
Average responding meters measure the average value of a pure sine waveform and calculate the RMS value
Ave of .637 x 1.11= RMS of .707