Introduction to Common Test Equipment.

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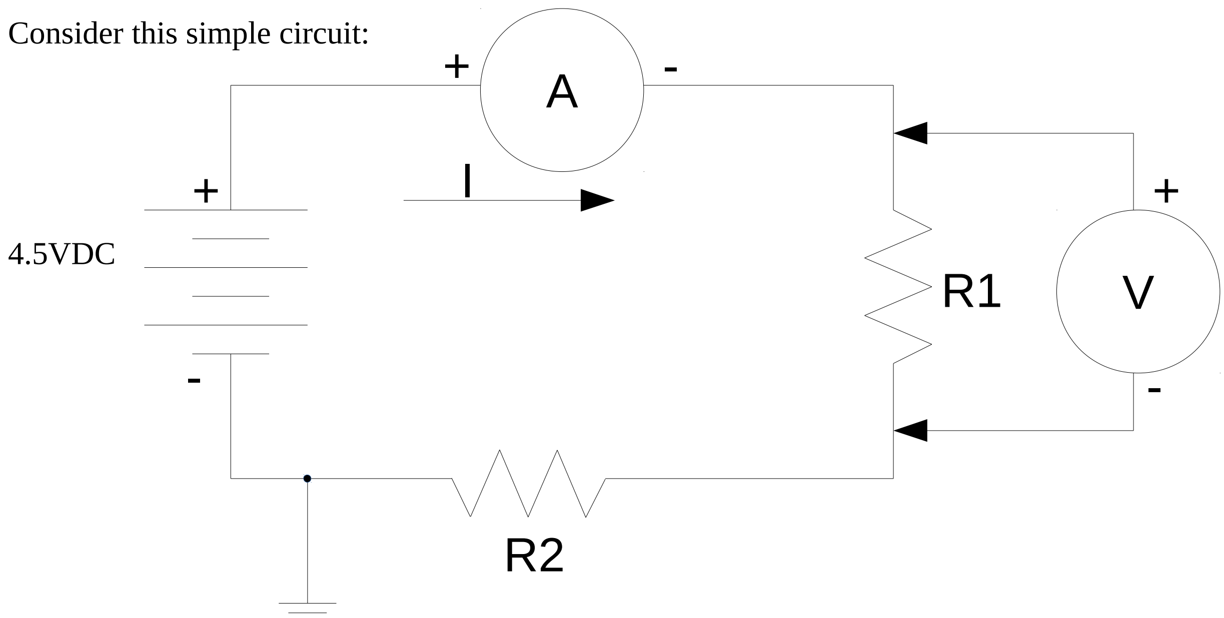
In this presentation you will learn how to safely use analog and digital multi-meters to measure resistance, AC and DC Voltage. We will also learn the basics of oscilloscope use to measure Voltage and frequency.

What are we measuring?

The most common use of a multi-meter is to measure Voltage or Resistance. Current can also be measured but is less common since the setup requires a more involved procedure and can easily lead to damage to the Test Equipment (TE).

Ohm's Law, the relationship between EMF, Current and Resistance: E = I * R.

Consider this simple circuit:



A battery supplies an Electromotive Force (EMF) measured in Volts. The EMF causes a current, "I", to flow. The current is measured in Amperes with a series meter "A". A potential difference or "Voltage Drop" is measured across R1 with a parallel meter "V".

We can determine the resistance of R1 using Ohm's Law by measuring Voltage "V" and current "A."

Alternatively, if we know the value of R1, the current can be found with Ohm's Law by measuring the Voltage across the resistor.

Measurement Techniques:

Volts:

EMF is measured in Volts across (parallel to) a load (Voltage drop) or across a source (Voltage rise). When using an analog meter care must be taken to insure the probe polarity will cause an upward deflection of the meter's needle.

The TE load on the circuit under test affects the test results. So when measuring Voltage we want the meter to exhibit a very high resistance to minimize those affects. If there is no load, the TE becomes the load.

This problem is particularly vexing when measuring small Voltages across large loads, for example:

A technician places a 20,000 Ohm/Volt Simpson 260 multi-meter, set to read 2.5 Volts full-scale, across a one megOhm resistor. A 1.5uA constant current source is providing current flow through the circuit. What is the unloaded Voltage across the resistor and what Voltage will the meter indicate?

> The unloaded Voltage across the resistor is 1E6 Ohms x 1.5E-6Amps = **1.5 Volts.**
>
> The meter will place a 50kOhm load across the resistor. The resulting parallel resistance is 47.6kOhms.
> The Voltage across the parallel network is 47.5E3 Ohms x 1.5E-6 Amps = **0.07 Volts.**

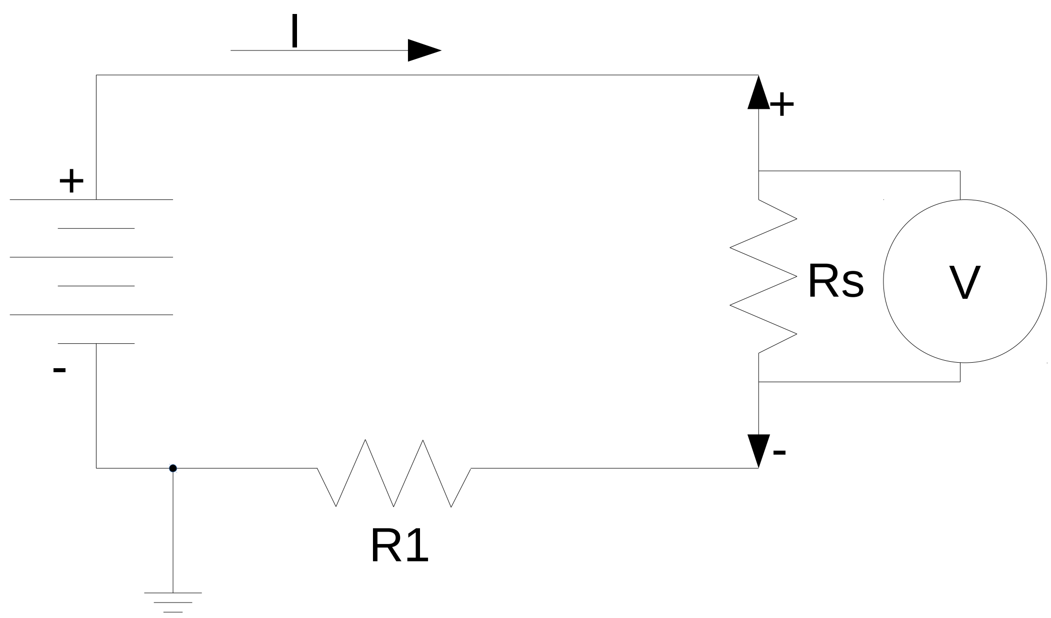
The technician uses a 10 megOhm digital meter to take the same reading:

> In this case the resulting parallel resistance is 909kOhms.
> The Voltage across the parallel network is 9.09E5 Ohms x 1.5E-6 Amps = **1.4 Volts.**

Amps:

Current is measured in Amperes in series with a load. Again an analog meter requires close attention to probe polarity.

The TE load affects the test results. When measuring current we want a very LOW meter resistance. This is done by placing a very small, precise, resistance in series with the current flow and measuring the Voltage drop across that resistance. Application of Ohm's Law produces the current.

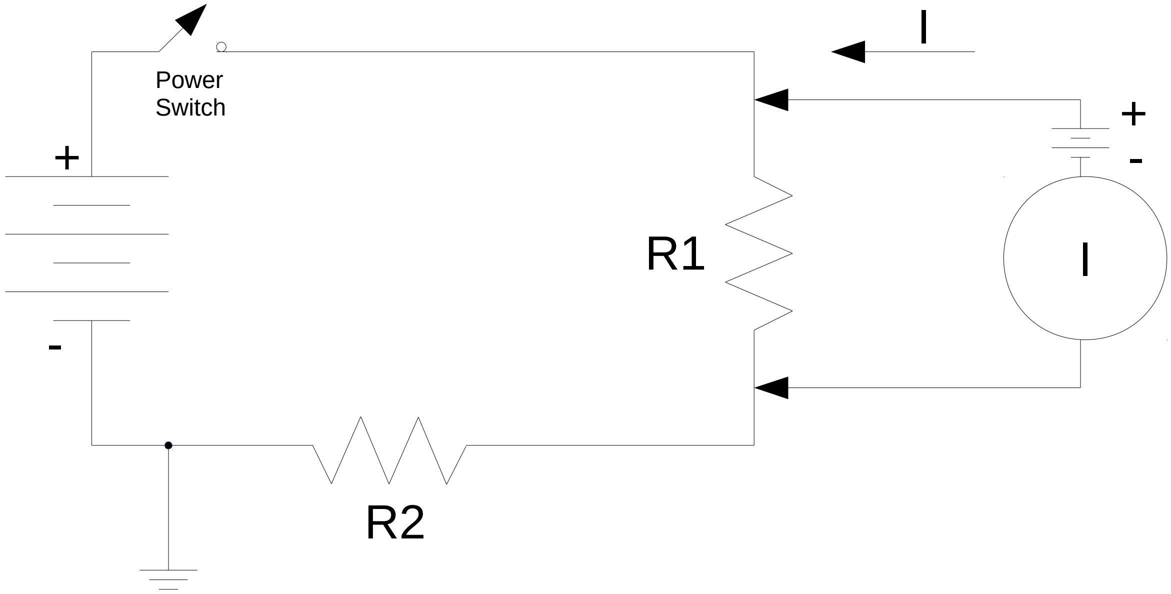


DANGER: If you try to measure current ACROSS a load, as if you were measuring Voltage, the very small TE load will draw a very high current, BOOM!

If you're lucky the TE fuse will blow. If you're not so lucky, either the TE, the circuit under test, or both could be set aflame!

Ohms:

Resistance is measured by energizing a circuit with a known voltage and measuring the current.



It is not a good idea to measure resistance in an energized circuit.

Real world circuits are normally more complex than what is shown here. Multiple parallel paths may exist. They are not always obvious. Also, capacitors and inductors in the circuit can cause the TE to return strange results. Finally, a semiconductor in the circuit may produce different readings depending on the probe polarity.

Bottom line? Resistance measurement results taken across a component in-circuit are frequently not the same as a measurement out-of-circuit.

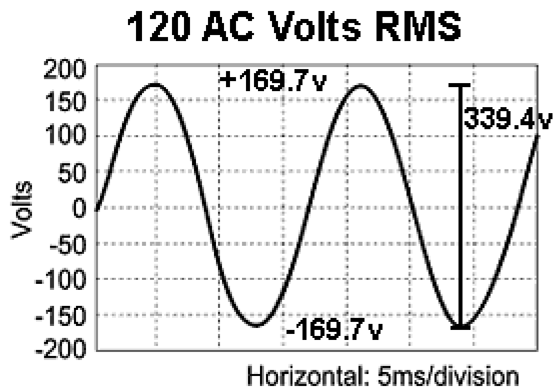
A word about "common" aka ground, signal ground, chassis ground, Earth et. al. These terms are related but different. For our purposes simply think of common as a universally accepted reference point for measuring Voltage.

Alternating Current:

In most cases the TE will convert an AC Voltage to DC then measure the DC Voltage as described above.

RMS Voltage.

Common multi-meters are designed to accurately measure a 50-or-60 Hz sinusoidal Voltage such as that found from the ubiquitous wall outlet. If you wish to accurately characterize a signal other than this you need an oscilloscope.



As can be seen in the attached image, if you looked at a wall outlet signal with an oscilloscope you would see a continuously varying Voltage, centered on zero and cycling between +169.7 and -169.7 Volts.

A multi-meter measuring this signal should read 120VAC. This is the "equivalent" DC Voltage representing the EMF of this complex waveform.

Measuring AC Current.

Measuring AC current is different than anything discussed so far in that no physical connection to the circuit is needed. A special probe is coupled to a current carrying wire inductively. There is no ground connection.

AC Current measurements must deal with the same limitations as AC Voltage. An oscilloscope can be used to characterize AC current if a special current probe is used. Current probes are not common.

AC "Resistance."

Resistance is strictly a DC property. The AC equivalent is call Impedance. Impedance is not a scalar value and requires special TE such as a Vector Impedance Meter to be characterized. This type of instrument is beyond the scope of this discussion.

Analog or Digital?

Why would anyone ever need to use an "antique" analog meter? Digital is so much better, right?

Analog:

Analog multi-meters are delicate and easy to damage. They are inaccurate under certain extreme conditions. They need special attention to probe polarity. They can be difficult to read and are easy to misread due to parallax. So why would you want to use one?

Analog multi-meters do have some advantages over digital.

- First, they can measure Voltage and current without being powered. If the battery quits on your fancy digital meter you are out of luck. An analog meter only needs a battery when measuring resistance.
- They can't be beat for adjusting a circuit that requires a maximum or minimum value. Digital bar-graphs are just not as smooth when making touchy adjustments.
- They give a more intuitive feel for what is happening in a situation where values are slowly changing value and direction.
- Reading an analog scale is easy with a little training. High precision and accuracy is obtainable if you know what you are doing.
- Parallax can be eliminated with a mirrored scale.

Digital:

OK, so analog meters are the cat's meow, why would anyone want one of those newfangled digital affairs? The precision is limited by the number of displayable digits and you can't interpolate readings.

Digital multi-meters are wonderful!

- They have very high input impedance, so there is only slight loading of the circuit under test.
- They are stable even under heavy vibration.
- They are very easy to read.
- They can mimic many of the advantages of an analog meter with a bar-graph.
- They are rugged and forgiving. You don't need to worry about probe polarity.
- You can always carry spare batteries.

So analog and digital both have their places. You should learn how to use both.

The Mysterious Measurement Category:

Cat 1, 2, 3, 4. Measurement Categories are used to rate test instruments on their ability to resist a voltage spike. Using a low Cat meter in a high Cat measurement situation can overload a circuit and cause electrical and physical damage.

Category I is for measurements of voltages from specially protected secondary circuits. Such voltage measurements include signal levels, special equipment, limited-energy parts of equipment, circuits powered by regulated low-voltage sources, and electronics.

Category II refers to local-level electrical distribution, such as that provided by a standard wall outlet or plug in loads. Examples are measurements performed on household appliances, portable tools, and similar modules.

Category III refers to measurements on hard-wired equipment in fixed installations, distribution boards, and circuit breakers. Other examples are wiring, including cables, bus bars, junction boxes, switches, socket outlets in the fixed installation, and stationary motors with permanent connections to fixed installations.

Category IV refers to utility level measurements on primary over-current protection devices.

Electrical Safety:

DON'T work with potentials above 50 Volts unless you have training on how to do so safely.

Always work with a 'safety man' if working with more than 50 Volts. (ask Joe about KARS)

Even when working with low Voltage there are dangers to be aware of. If a circuit is capable of delivering high currents you can suffer serious burns if something highly conductive causes a short. This can happen when jewelry is worn while working on energized equipment. The jewelry causes a short-circuit and quickly rises in temperature. It can be unpleasant to wear a gold wedding band when the metal temperature rises several hundred degrees a second.

Even a small battery can deliver an impressive amount of current for a short time, so can capacitors and inductors.

Don't touch metal part of probe. Don't put the probe in your mouth! (ask Joe about Jim Phalan)

Repair or dispose of damaged probes.

Use the correct color probes for each polarity and use. Black to common, Red to Volts or Amps.

Don't use a lower class probe in a higher class meter.

Don't use a probe above its Voltage rating.

If your TE is not auto-ranging start with highest range and work down.

Don't work on energized circuits unless you really need to.

Don't defeat protective devices! (ask Joe why he moved to Gainesville)

THINK about what you are doing. FOCUS on taking your measurement safely.

Try to anticipate problems and plan a recovery strategy.

Basics of Oscilloscopes:

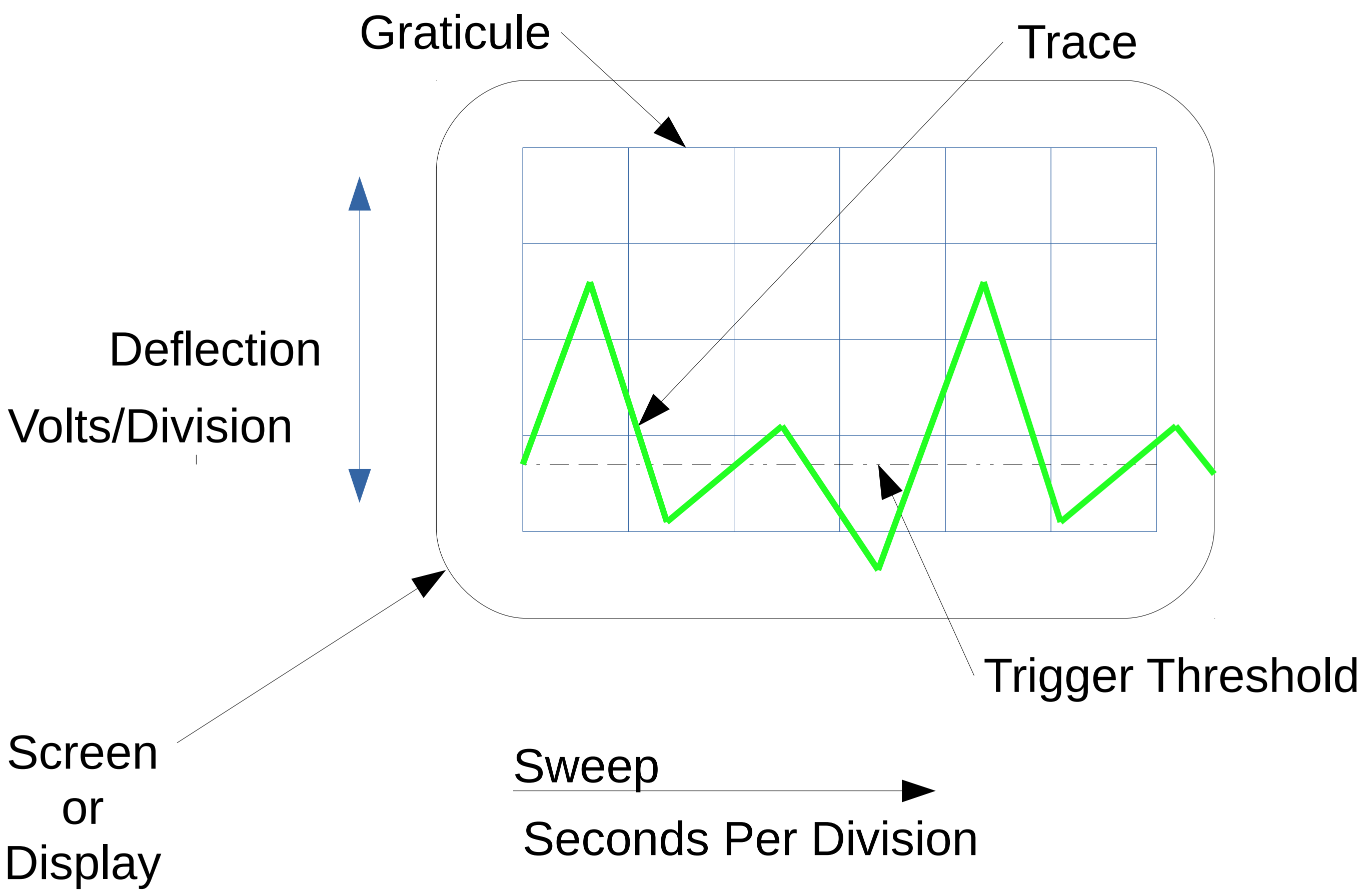
An Oscilloscope (o'scope) graphically displays Voltage vs. Time. It is considered by many to be one of the most useful diagnostic tools available for electrical/electronic systems.

Originally the o'scope used a cathode ray tube (CRT) to display information. The CRT electrostatically steered an electron beam as it passed between a pair of horizontal and a pair of vertical plate electrodes. The beam would strike the phosphorous coated face of the CRT causing a glowing line to be traced across the screen.

While still in use today, the CRT based o'scope has been mostly replaced by a computer controlled LCD display. These new computer TEs have the ability to do the job of the CRT device and much more. However, the existing base of knowledge, techniques and documentation maintains a nearly universal preference to mimic the functions of the original o'scope as if it were still steering a beam of electrons.

Contrast and brightness have replaced intensity and focus controls, but other than that, working with an LCD o'scope is just like working with a CRT o'scope.

Refer to the example o'scope screen below.



The Graticule:

The face of the o'scope is divided into a grid known as the graticule. The divisions on the graticule allow you to measure time in the X-axis and Voltage in the Y-axis.

Time Base Control:

The trace sweeps across the X-axis from left-to-right. The sweep speed is controlled with the Time-Base control. The time-base adjusts the sweep in units of Seconds-Per-Division. For example, a time-base setting of 10 uSec/Div would produce a line on the example screen that would take 60 microSeconds to sweep from the left edge of the graticule to the right edge.

The sample waveform in the example begins to repeat after approximately 3.8 divisions. A sweep of 3.8 divisions represents a period of 38 microSeconds. The frequency of a repeating 38 microSecond waveform is 26.3 kHz.

O'scopes with multiple time bases designate them with letters, e.g. Time Base-A, Time Base-B.

Trigger Control:

The trigger circuit controls how the sweep repeats. There are two common trigger modes.

- Normal; In normal trigger mode the trace only starts if the user defined trigger conditions are met. Otherwise the screen will be blank.
- Auto; In auto mode the trace will trigger as if in normal mode. If no trigger is received in a predetermined amount of time the sweep will start anyway. This is useful for measuring DC voltage.

In addition to trigger modes there are options for trigger source.

- Channel; the signal on channel-# is the source of the trigger signal. This is the most common trigger source.
- Line; the trigger signal is in synchronization with the AC power line. This mode is useful for identifying noise signals that are related to the power line.
- External; the trigger comes from an external source, such as a I^2C clock.

Slope controls whether the trigger occurs on a rising or a falling Voltage.

Threshold controls the Voltage level that must be reached for a trigger to occur.

Holdoff inserts a delay between the satisfaction of trigger criteria and the occurrence of the trigger.

Vertical Deflection:

The vertical channel control allows the operator to set the sensitivity of deflection on the Y-axis. The control operates in units of Volts-per-Division.

Vertical coupling choices are:

- AC; A series capacitor blocks DC and centers the waveform around the zero-Volt line.
- DC; The waveform floats at a DC Voltage level if one is present.
- GND; Zero vertical deflection. A horizontal line is drawn at zero Volts.

O'scopes with multiple channels designate them with numbers, e.g. Channel-1, Channel-2.

Additional Controls:

Modern o'scopes contain multiple time-bases and multiple vertical deflection channels. Controls exist to determine the relationships between time-bases and between vertical channels.

Channels can be displayed independently or combined as 1 + 2 or 1 + inverted-2. When displaying multiple channels they can be drawn "alternate" (all of 1 then all of 2) or "chopped" (part of 1, part of 2, repeat). Sweep speed determines which selection is best.

Multiple time bases can be applied as "A-only", "B-only", "A&B" or "A intensified by B." The best selection depends on what you are trying to display.

In addition, there are controls for positioning each vertical channel, positioning each horizontal sweep and a plethora of optional features. Every model o'scope has its own unique selection of extra features. Read the owner's manual to learn about them.