PRACTICAL APPLICATION OF ELECTRICAL CIRCUITS IN MEASUREMENT

Mark Hawkins, Master Electrician

RT Technical, LLC.

The use of electronics is evolving in the measurement industry.

- The technology of measurement and control has evolved over the past few decades.
- Systems have moved from mechanical devices that were read on site to early versions of electronic systems that were polled infrequently.
- Current systems can control several devices such as pumps, meters or injectors simultaneously using advanced electronics to measure, control and communicate at greater frequency than ever.

The need for technicians to understand basic electrical troubleshooting is greater than ever before.

- Due to the increased reliance on advanced electronic systems throughout the industry…
- Due to greater regulatory requirements for analysis andreporting…
- Due to the increased complexity of the electronics that are used in oil & gas industry…

There are two ways to learn a subject:
The first involves:

- Rote Memorization
- Mnemonics
- Tables
- Cramming

The second involves:

- Critical Thinking
- Subject Comprehension
- Complex Ideas
- Multiple Predictable Outcomes

The goal of this class is to provide a starting point for future learning.

The goals of this class are to:

- Define basic electrical theory
- Illustrate that theory with equations
- Provide practical examples of how these equations are used
- List some available resources for future reference

Basic Electrical Theory

- All matter is comprised of "Atoms"
- All "Atoms" are comprised of sub-atomic particles which include"Protons" and "Electrons"
- Protons have a positive (+) charge
- Electrons have a negative (-) charge
- Electrons are arranged in different orbits (Valence Shells). Conductivity is dependent upon the number of electrons in the outershell.

Electrons flow depends upon the conductivity of the material

- Conductors are materials that have an abundance of free electrons (Odd # of valence electrons) e.g. copper, silver
- Insulators are materials that have tightly bound electrons (Even # of valence electrons) e.g. sulfur, glass

- Semi-Conductors are materials that will lose their valence electrons when heated or electrically excited and become temporary conductors e.g. silicon, germanium

Georg Simon Ohm

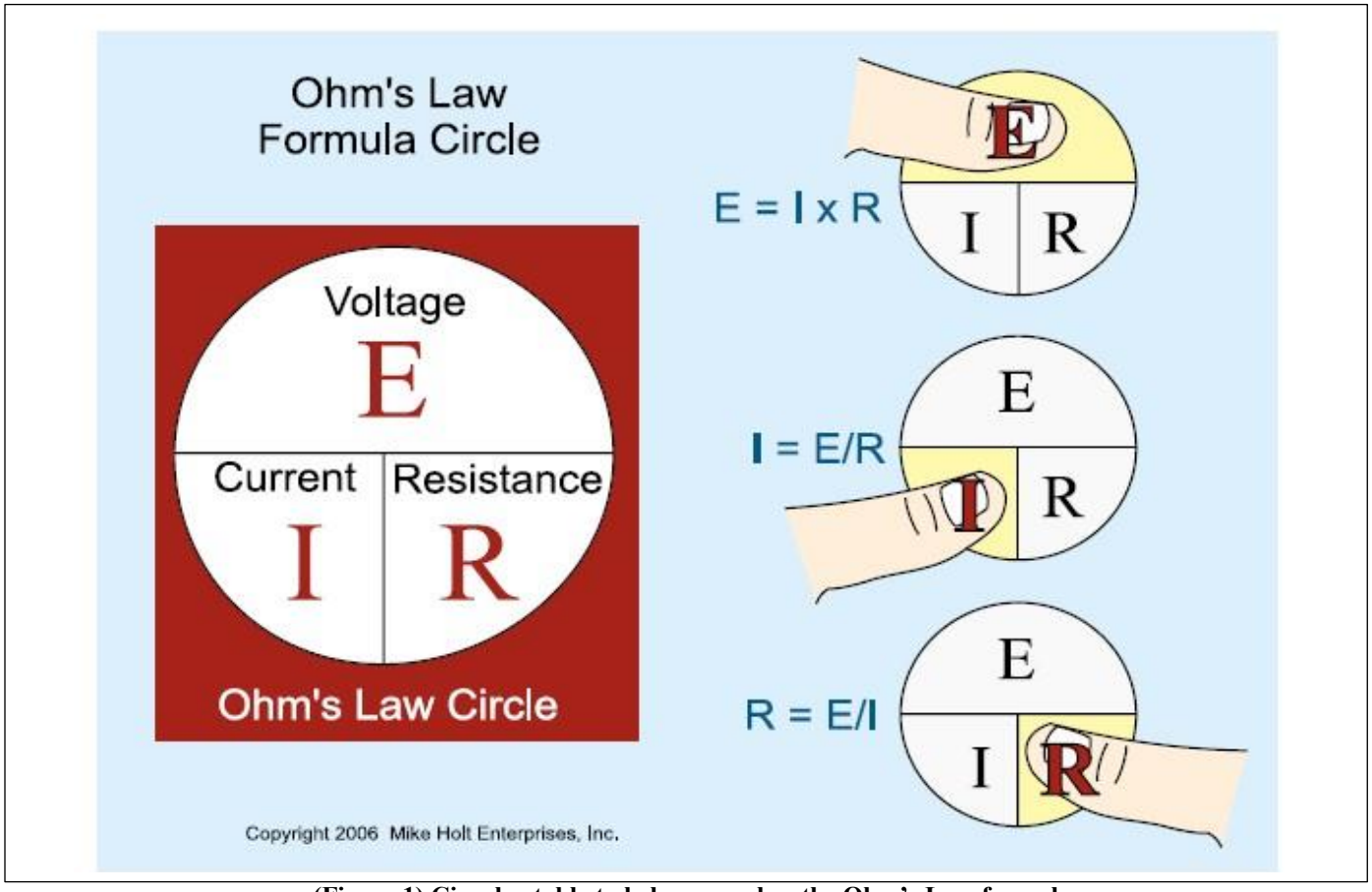
- German mathematician
- Formulated Ohm's Law of Electrical Resistance
- Formulated Ohm's Acoustic Law

Ohm's Law defines the fundamental relationship between voltage, current and resistance

1 Ohm (Ω) = 1 volt (V) / 1 ampere (A) (Equation 1)

Ohm's law states E = I x R where:

I = Electric Current (expressed in Amperes {A}) E = Electromotive Force (expressed in Volts {V}) R = Resistance (expressed in Ohms {Ω})
Alternative expressions of Ohm's law can be written, R=E/I & I=E/R



(Figure 1) Circular table to help remember the Ohm's Law formula.

Alessandro Volta

- Italian physicist
- Inventor of the first battery
- Experimented with capacitance

1 Volt (V) is defined as the difference in electric potential across a conductor when a current of 1 ampere (A) dissipates 1 watt (W) of power

André-Marie Ampere

- French physicist
- Worked on electromagnet repulsion (basis of motors)
- Postulated Ampere's Law of electromagnetism
- Ampere named in his honor

1 Ampere (A) is the current produced by the force of 1 Volt (V) acting through the resistance of 1 Ohm (Ω)

James Watt

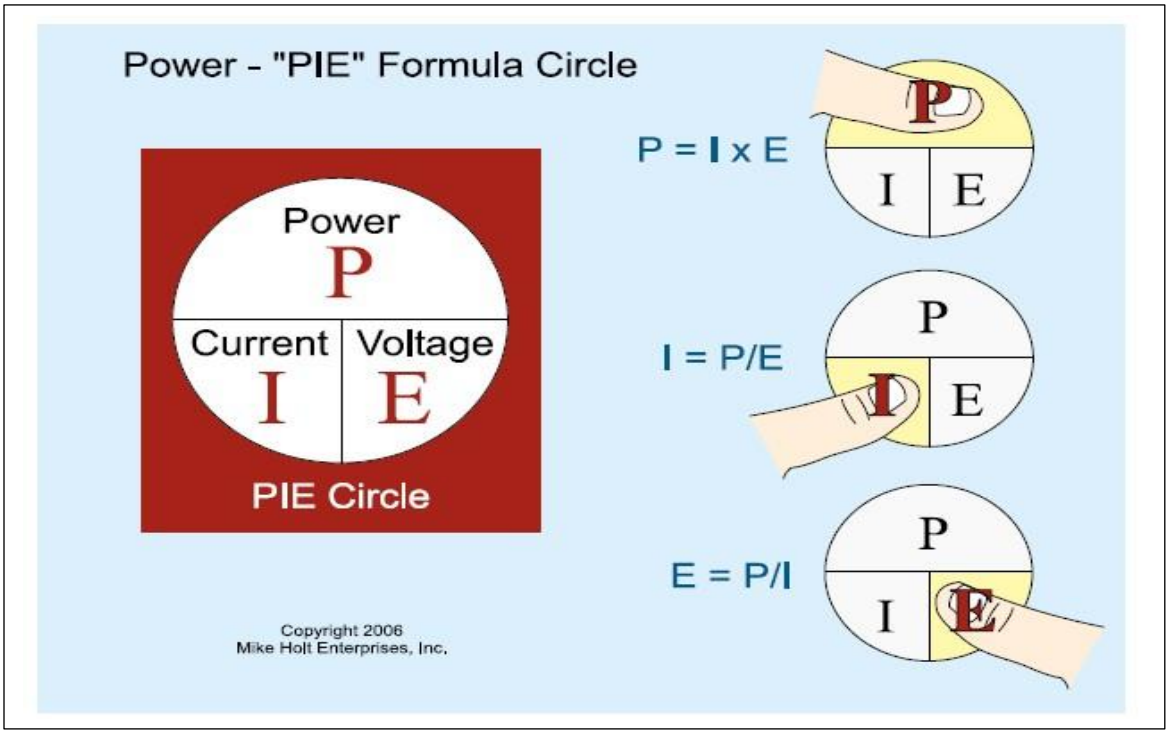
Scottish Engineer
Invented the modern steam engine
The Watt was named in his honor, although he did not experiment with electricity

A Watt (W) is a unit of power in which 1 Ampere (A) of current flows across a potential difference of 1 Volt (V)

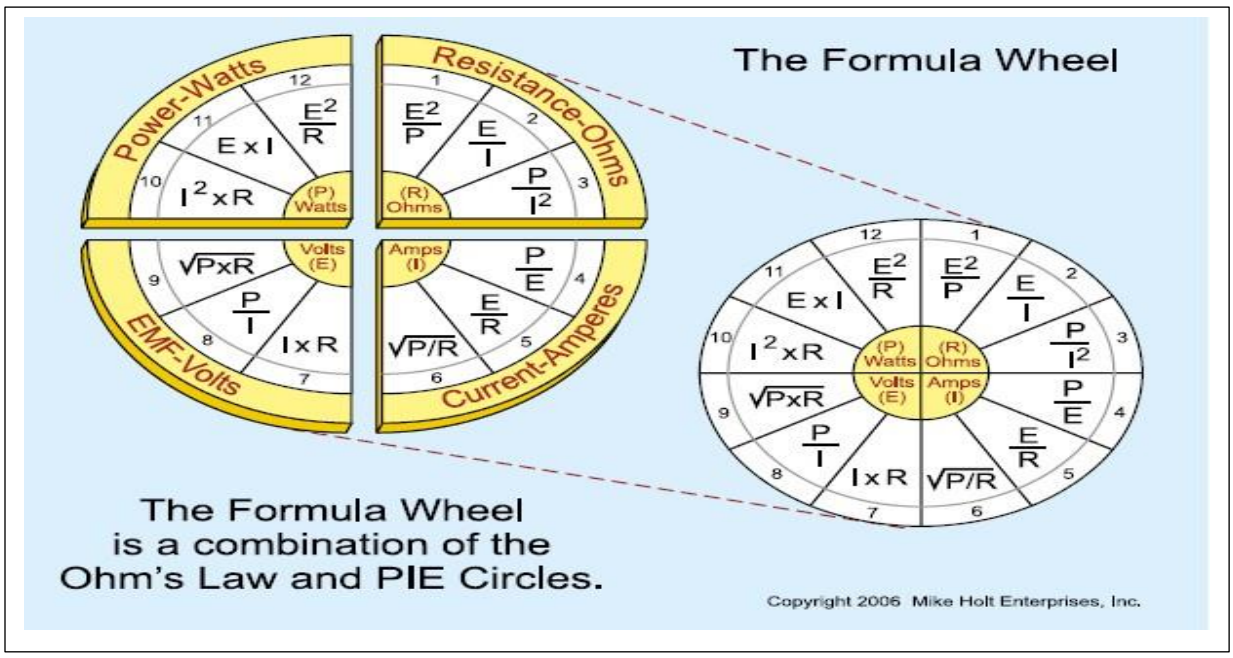
- Formula for finding Power is P=I x E
- P = Power in Watts or Volt/Amps,
- I = Current in Amperes and
- E = Electromotive Force in Volts
- 1 Horsepower = 745.7 Watts
- Watt vs. Volt/Ampere

1. Watt is true power (with heat losses)
2. VA is apparent power (no losses)
3. Power factor equals Watts/Volt Amps

Watt is 1 Volt impressing a current of 1 Amp
Joule is the energy equal to passing 1 Amp through 1 Ω for 1 Second
Watt = Joule/Sec

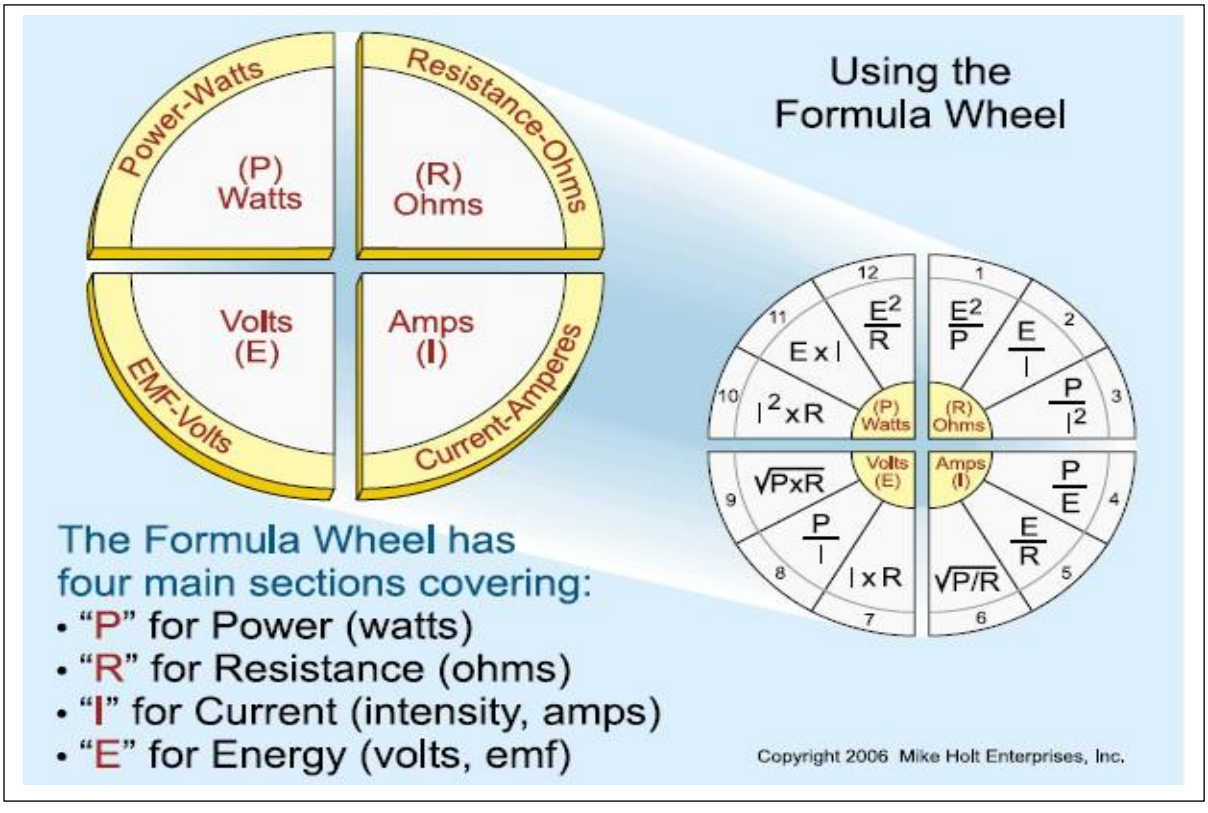


(Figure 2) Circular table to help remember the Power Formula

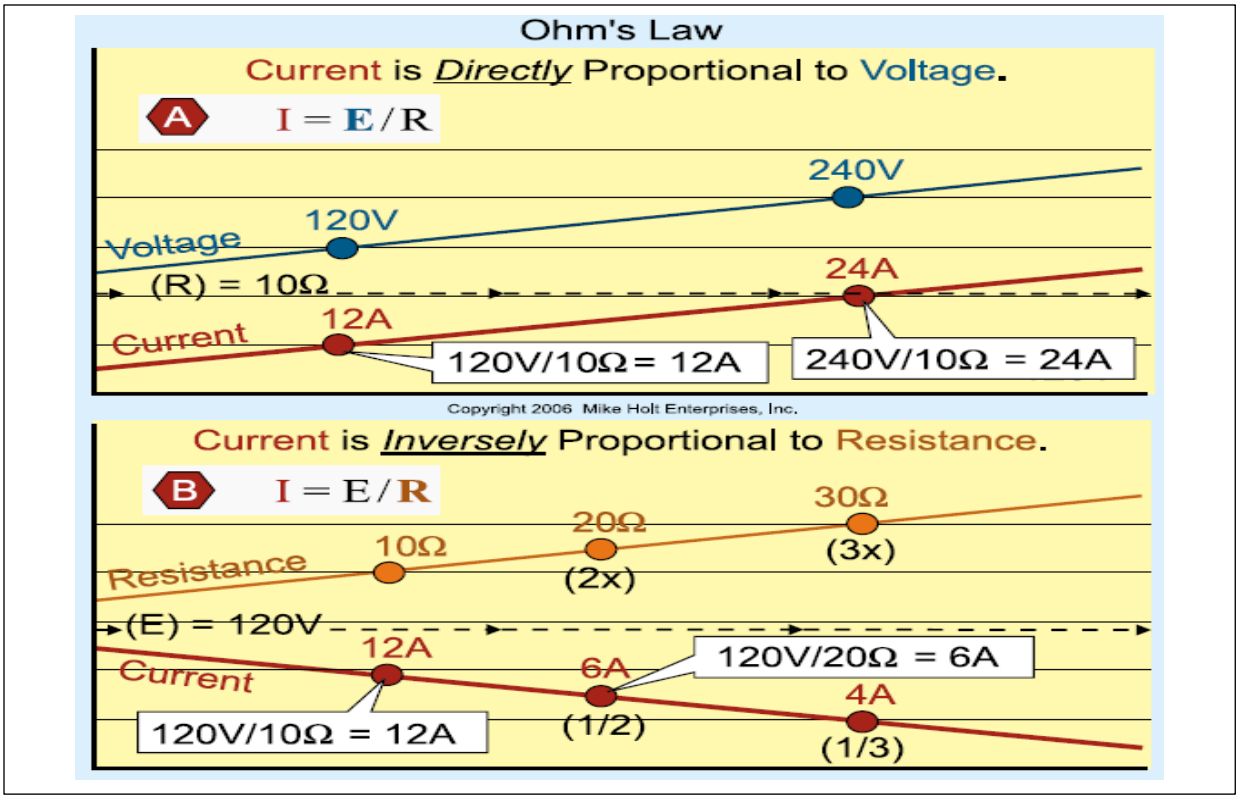


(Figure 3) The Formula Wheel

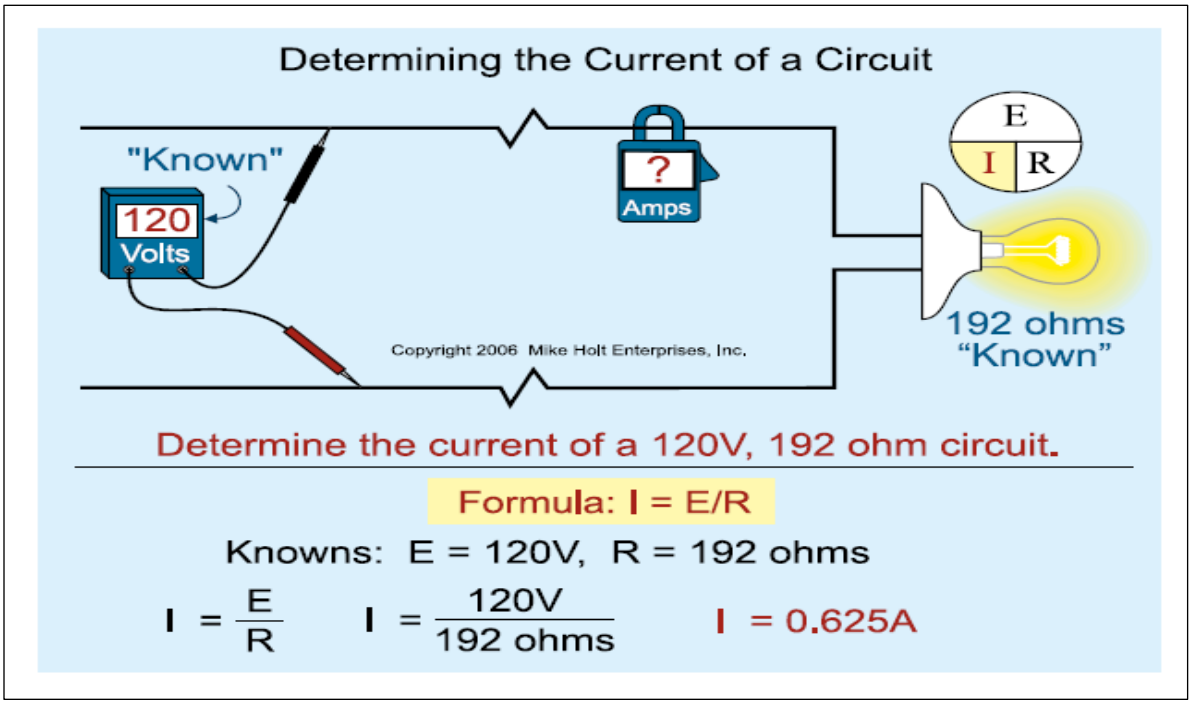
Almost any electrical calculation can be derived with two "Knowns"



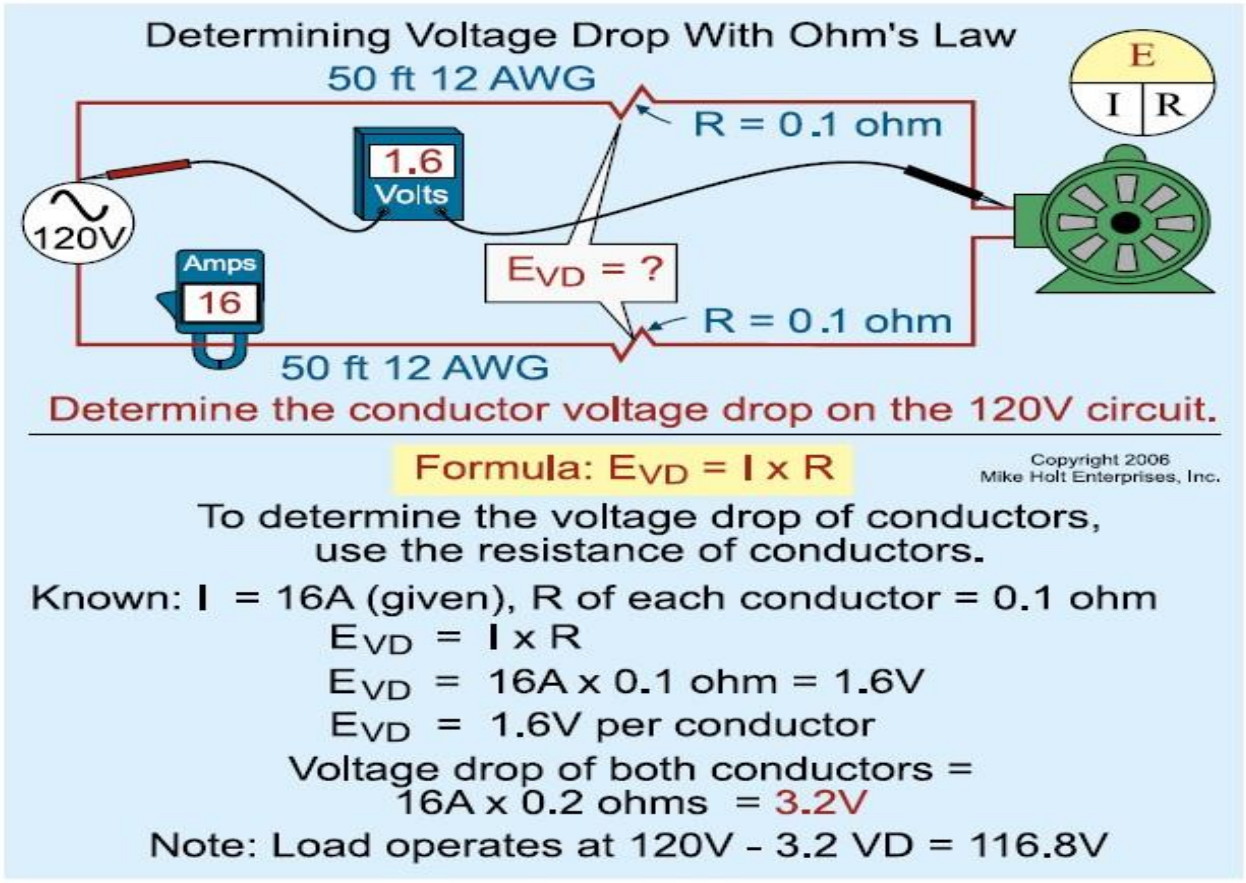
(Figure 4) Using the Formula Wheel



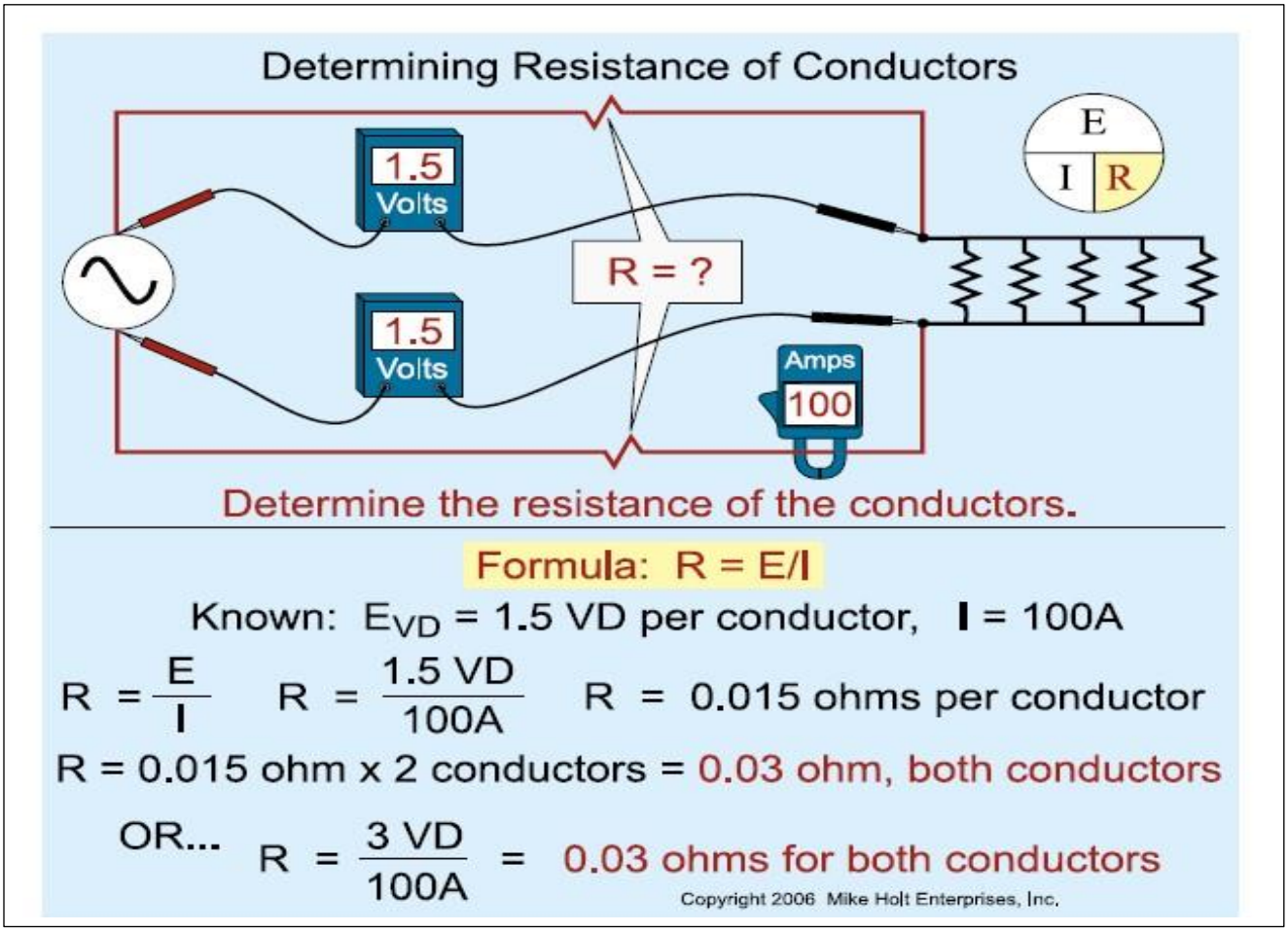
(Figure 5) Proportionality in Ohm's Law



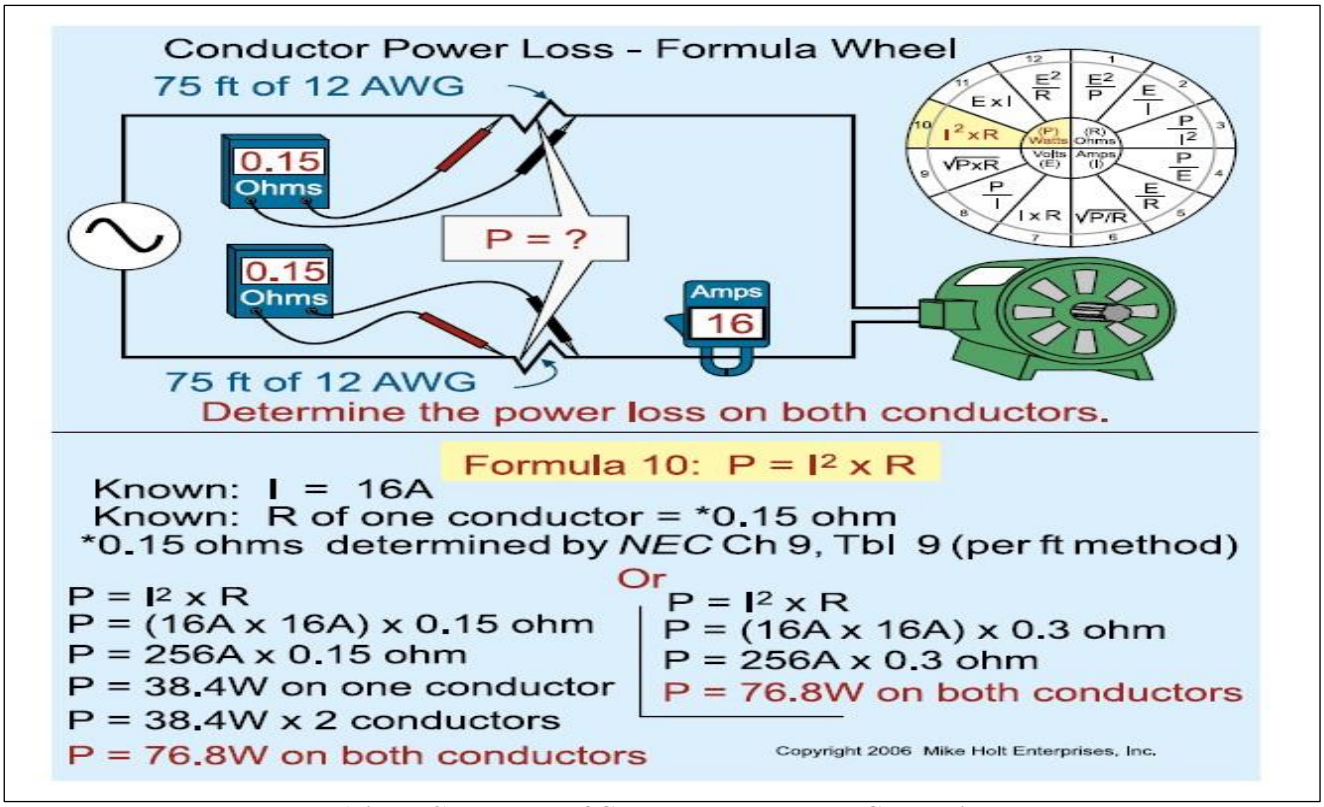
(Figure 6) Example of basic Ohm's Law current calculation



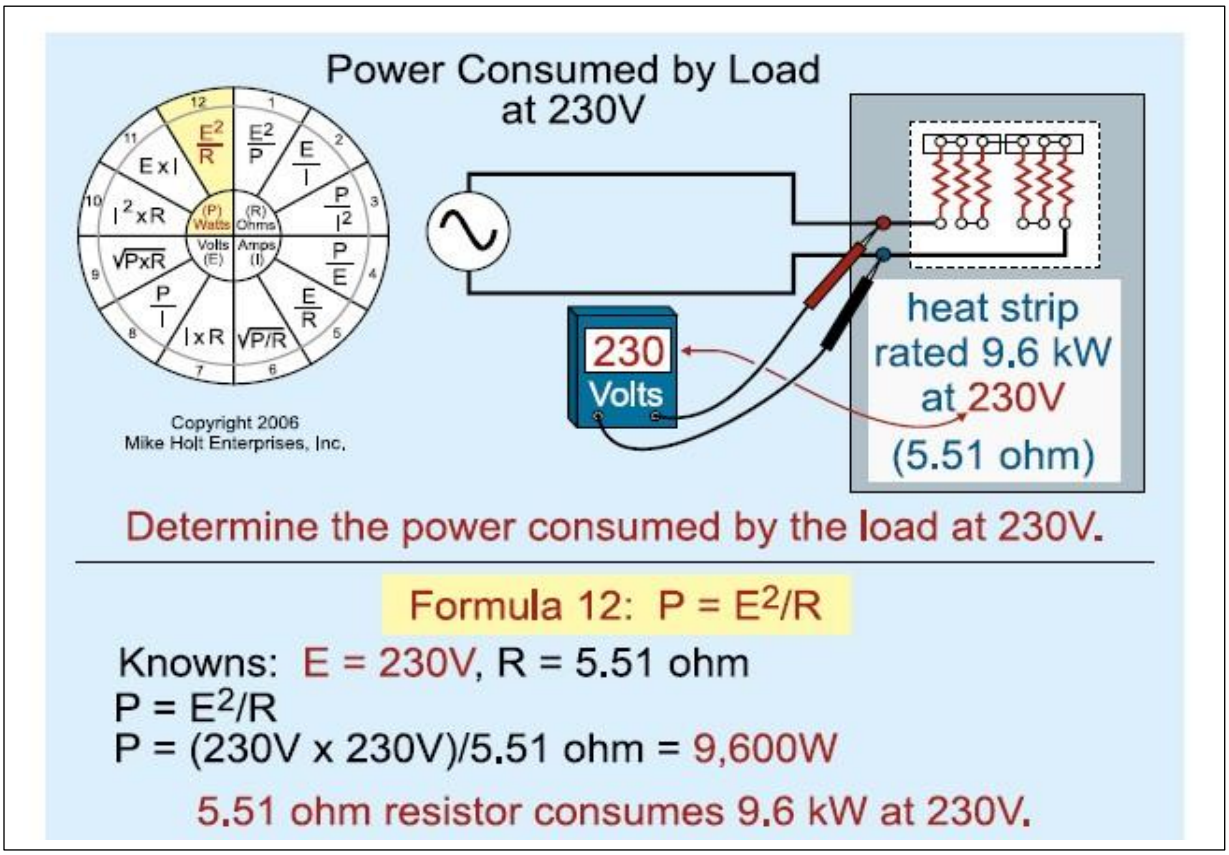
(Figure 7) Example of a simple Voltage Drop Calculation



(Figure 8) Example of Conductor Resistance Calculation

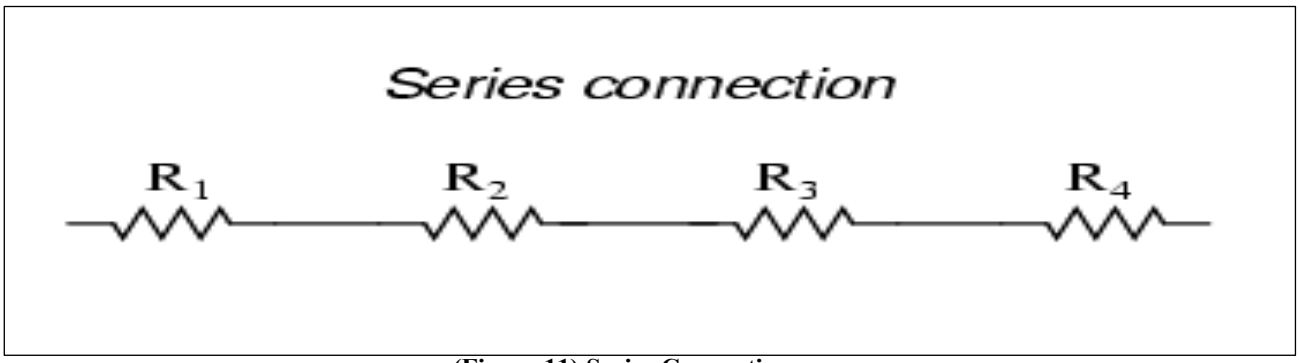


(Figure 9) Example of Conductor Power Loss Calculation



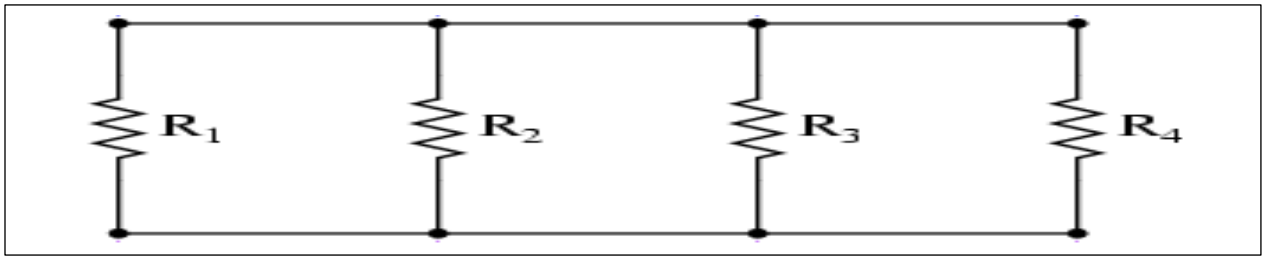
(Figure 10) Example of Power Consumed by Load calculation - E^2/R

Series & Parallel Circuits generally occur as parts of a more complex electrical system
Series Circuits have only one path for electrons to flow



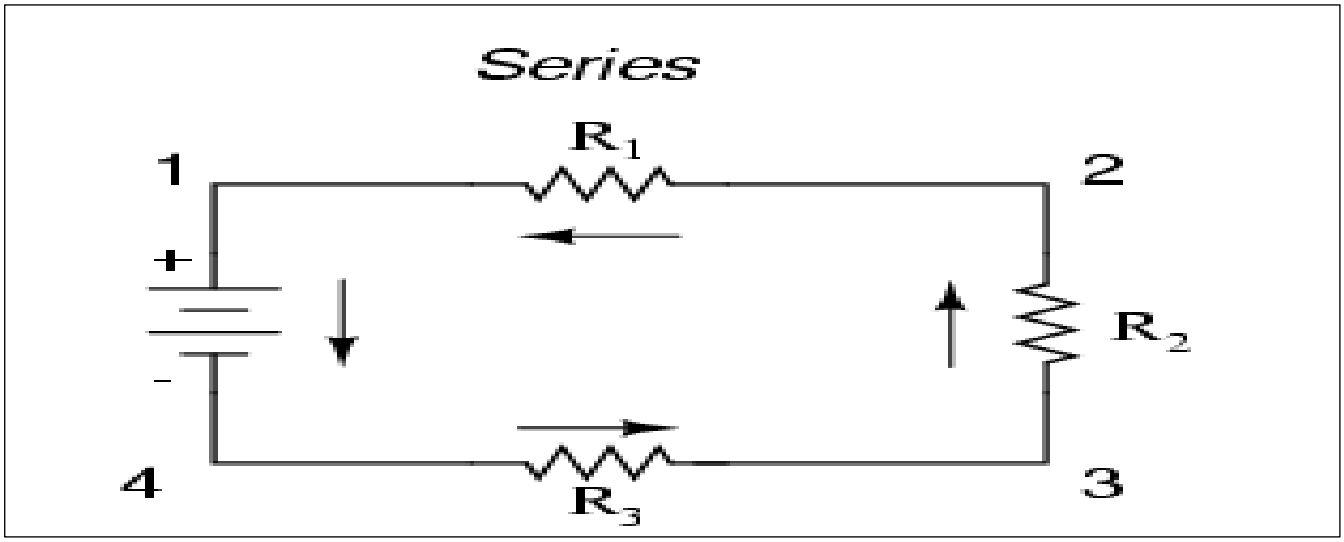
(Figure 11) Series Connection

Parallel Circuits have multiple paths



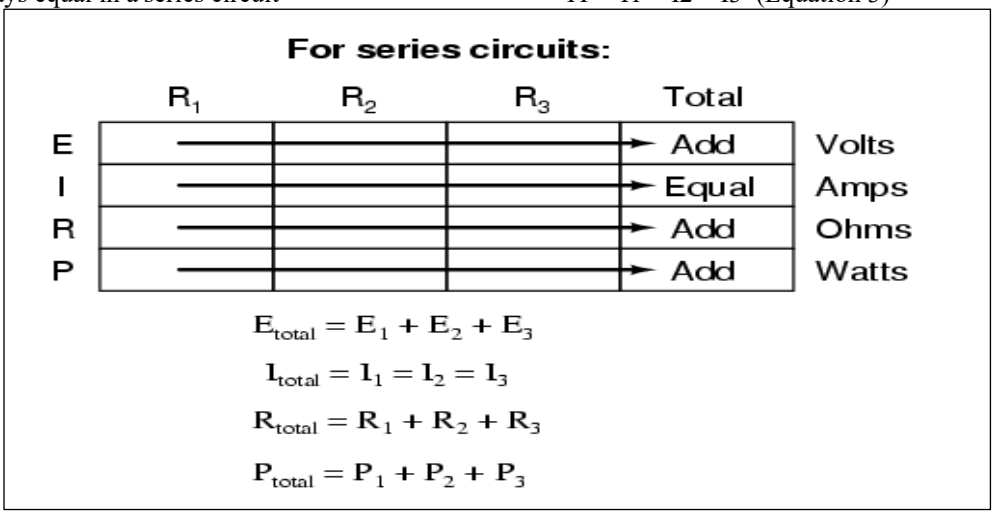
(Figure 12) Parallel Circuits

In a series circuit the Total Resistance is equal to the sum of the individual resistances.
RT = R1 + R2 + R3 (Equation 2)



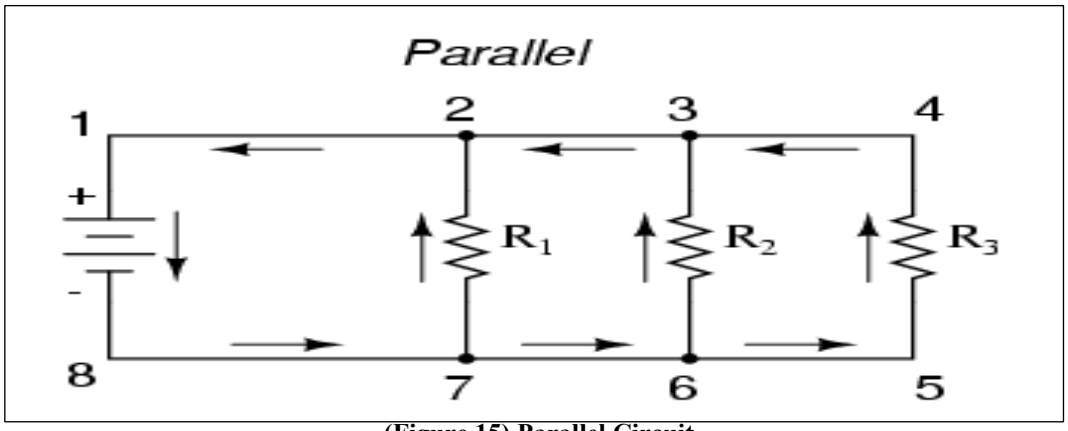
(Figure 13) Series Circuit Total Resistance

Current is always equal in a series circuit IT = I1 = I2 = I3 (Equation 3)



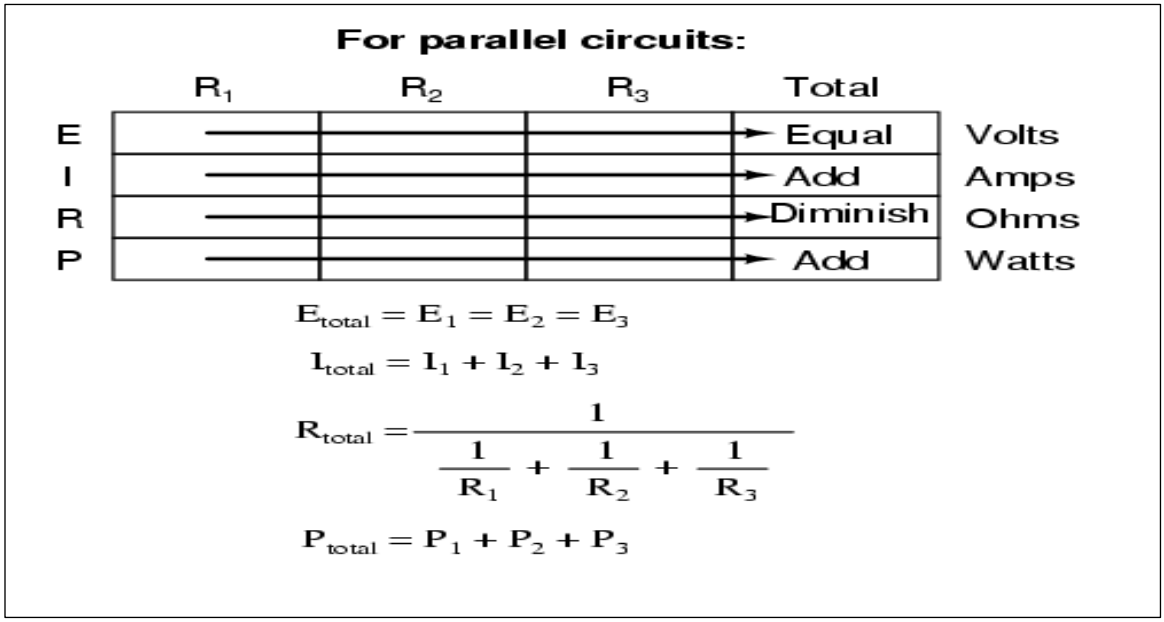
(Figure 14) Series Circuit

In a parallel circuit the Total Resistance is less than any individual resistance.
RT = 1 / (1/R1 + 1/R2 + 1/R3) (Equation 4)



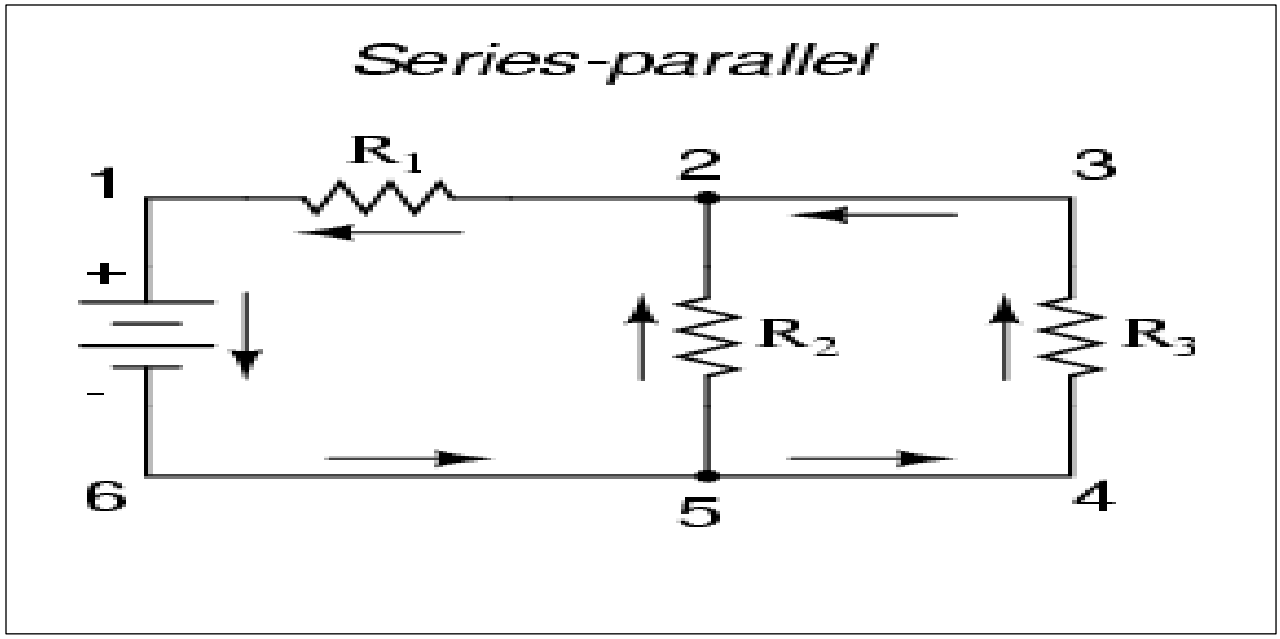
(Figure 15) Parallel Circuit

Voltage is always equal in parallel circuits ET = E1 = E2 = E3 (Equation 5)



(Figure 16) Parallel Circuits

To find the resistance of a series-parallel circuit the components must be broken into individual series and parallel circuits, calculated and then summed as a series circuit



(Figure 17) Figuring resistance of series-parallel circuit

Component Failure Analysis is a "Process" used to pinpoint the cause of a system failure

- Troubleshooting is more than "Parts Changing" or guessing what iswrong
- Failure of individual components create changes in a circuit that can be observed using a meter
- These changes can be calculated using the formulas previously presented
- The result of these calculations can be used to identify the source ofthe failure

Developing a "Troubleshooting Strategy"

- Have I seen this before? Investigate the most likely problems first. (do not let this blind you to other possibilities)
- Isolate likely sources of failure and eliminate them with appropriate test
- Divide the system and work from the center out. Repeat the process until you zero in on the component causing the problem

Use your Senses to aid you in diagnosing the problem

- Look for signs of heat damage (blue metal, melted insulation, bulging electronic components)
- Smell for burned copper or insulation
- Feel for loose connections and broken parts
- Listen for sounds of arcing or noises during operation that don't soundright

Consider the source

- Always consider the source of the signal to be measured:
- Is it AC or DC?
- What is the voltage?
- Is the source sinusoidal, inverted or rectified?
- Are you looking of Peak to Peak or Root Mean Square (RMS), Average or a variation of a Modified Square Wave?

Most multimeters are RMS and Average compensated

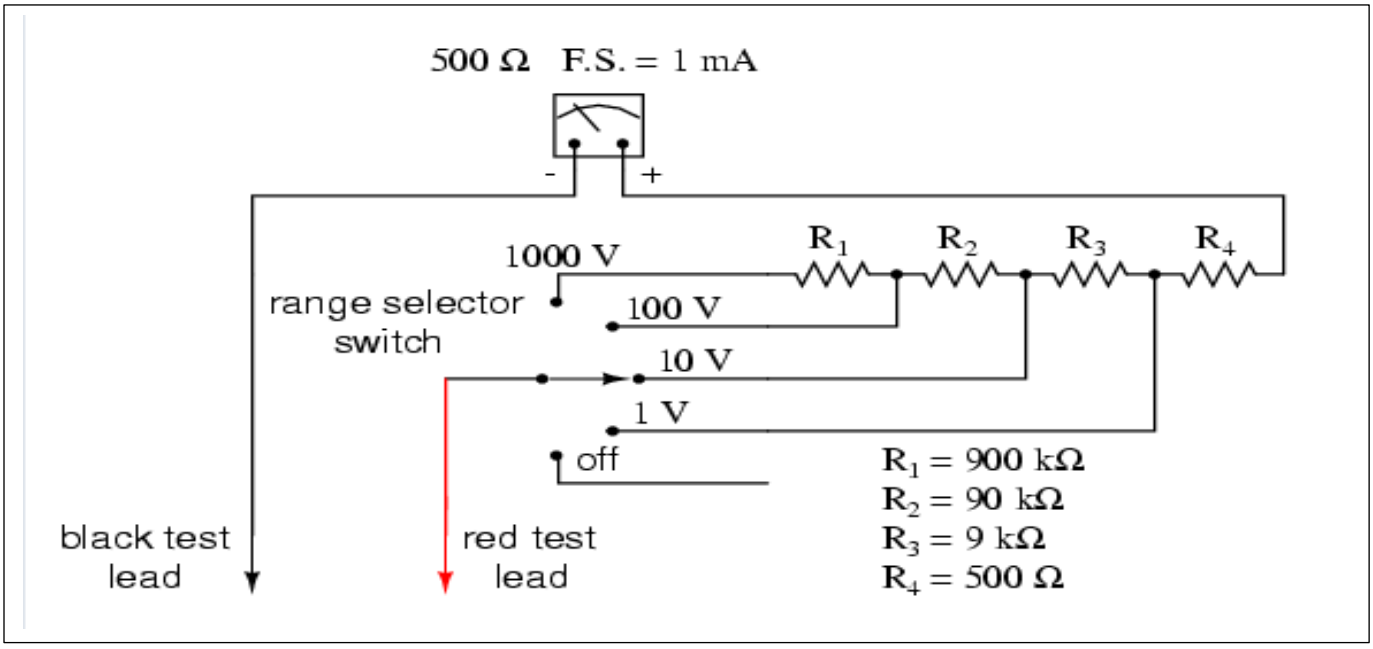
- Peak Voltage = 170 Volts
- RMS Voltage = VP x $1/\sqrt{2}$ (Equation 6)
  = 170 x 0.707 = 120
- Mechanical meters deliver an Average Voltage =
  VAV = $2VP/\Pi$
  = 170 x 0.637 = 108 (Equation 7)
- Average to RMS Conversion Factor 0.707 / 0.637 =
  1.11

Average Volts = 108 x 1.11 = 120 Volts

The arrangement of resistors determines the meter's function

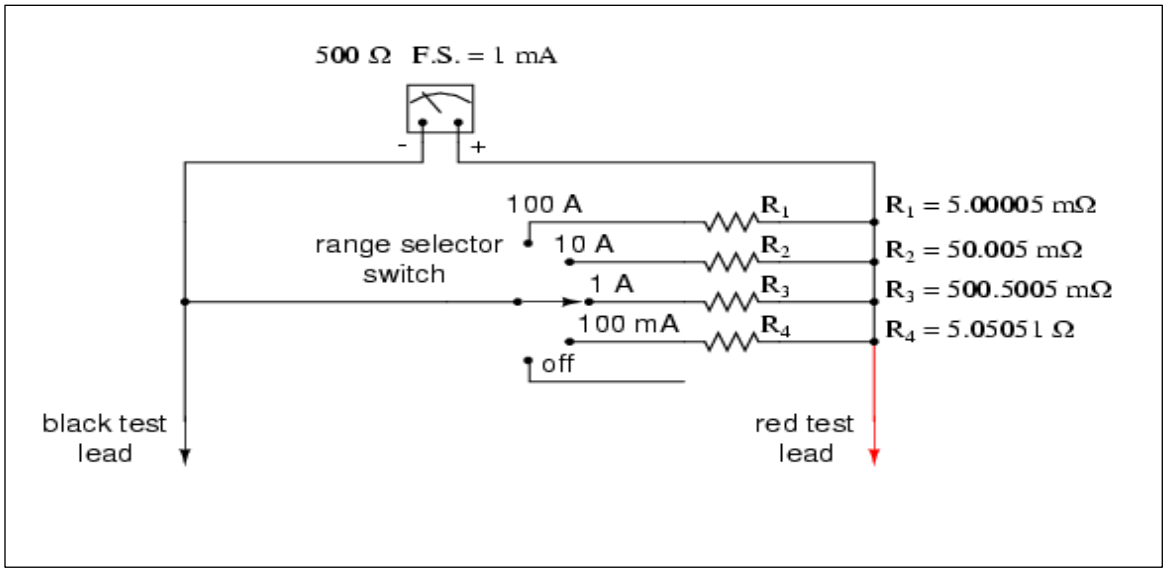
- All electrical multimeters meters are variations of a current measurement device (ammeter)
- Many meters achieve full scale deflection with as little as 50 microamps current
- In order to measure higher current or voltages, resistors must be placed in the meter's circuitry to limit the actual current passing through the meter mechanism

In Voltmeters "proportioning circuits" with multiplying resistors applied inSERIES allow the meter to handle higher voltages



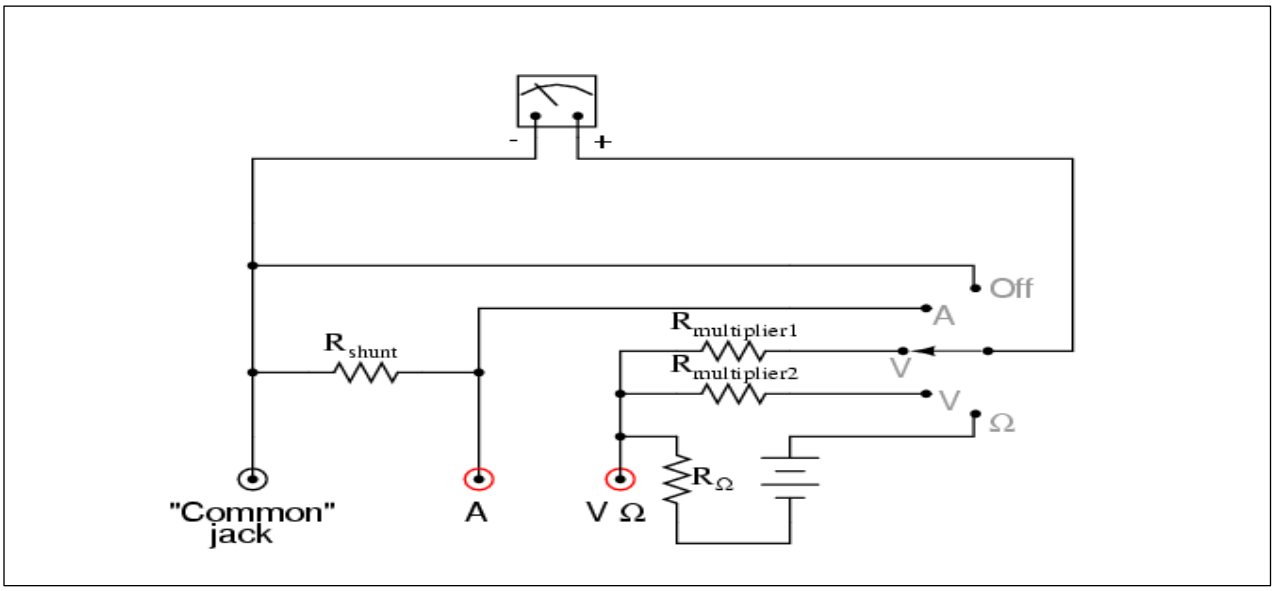
(Figure 18)

Ammeters use proportioning circuits with very low ohm resistors placed in PARALLEL to handle higher currents



(Figure 19)

A Multimeter has a combination of the circuits in Volt-Ohm-Ammeter



(Figure 20)

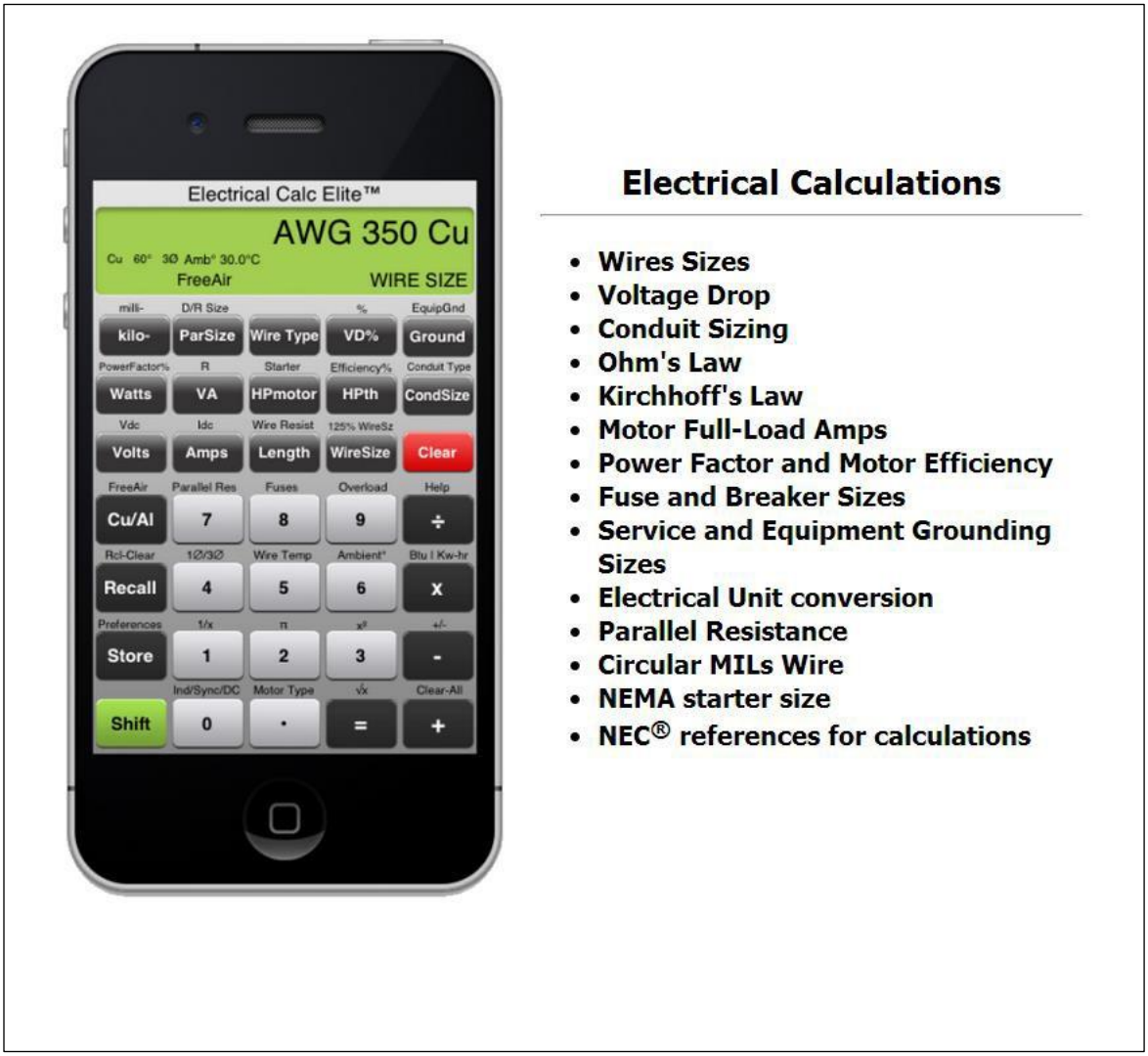
Some things to consider when using meters for diagnostics

- Meters *contribute* to the measurements by their introduction into the circuit
- Resistive losses due to the length of the conductor might need to be accounted for in cases of long runs at low voltage
- Digital Multimeters are more susceptible to "Phantom Voltages" than analog meters due to their capacity to pick up trace readings and the fact that will display the highest voltage found.

Use your meter to help you play detective when troubleshooting

- Using an Analog Meter or a Digital Meter with an analog display allows you to see what a circuit is really doing; as opposed to where it finally settles on the display
- Switching the equipment being measured "On/Off" allows the technician to deduce the nature of the circuit, i.e. resistive, inductive, capacitive or *known technology*.
- Isolate components of the circuit prior to measuring to reduce feedback

New Calculator Apps are inexpensive tools to assist with most electrical calculations



(Figure 21)

Think Safety

- Maintain your meters with routine lead and case inspections
- Check voltages at the highest meter rating prior to setting the meter to the appropriate operating range
- When using an Ohmmeter, make sure the circuit is de-energized
- Wear the appropriate PPE for the job

Acknowledgement of use of copyrighted materials

- Graphics used with permission and provided through the courtesy of:

- Mike Holt Enterprises – Electrician's Math and Basic Electrical Formulas (http://www.mikeholt.com)

- Tony R. Kuphaldt
  Lessons in Electric Circuits (http://www.faqs.org/docs/electric/index.htm)
  & (stutz@dls.com)