Electrical Tech Note — 213

Biosystems & Agricultural Engineering Department
Michigan State University

Electrical Equations

Ohm's law is the most basic rule describing the behavior of an electrical circuit. It describes the relationship between voltage, current, and resistance. *Figure 213.1* shows a handy method of remembering Ohm's law. Ohm's law is used to find the missing quantity when the other two quantities are known. For example, assume that the voltage of a circuit is 24 volts and the current flowing in the circuit wire is 2 amperes. Ohm's law can be used to calculate the resistance of the circuit in ohms. Resistance for this example is 24 volts divided by 2 amperes to give 12 ohms. Here is how to use *Figure 213.1.* Resistance is usually represented with the letter **R**, current the letter **I**, and voltage the letter **E**.

1. Cover up the quantity you want to calculate such as volts, amperes or ohms.
2. If the remaining two quantities are side by side, then multiply them together to get voltage using *Equation 213.1.* (Amperes times Ohms equals Volts)
3. If one quantity is above the other, then divide the bottom one into the top one using *Equation 213.2* or *Equation 213.3.* (Volts divided by Amperes equals Ohms or Volts divided by Ohms equals Amperes)

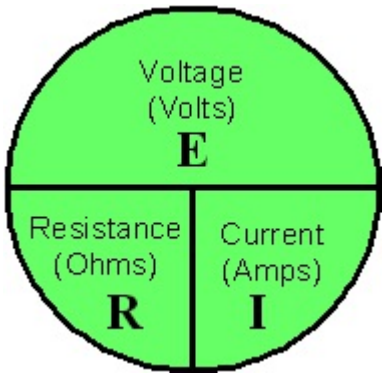


Figure 213.1 *Use this diagram to remember how to determine the missing quantity when the other two are known.*

$$Voltage(E) = I \times R = Amps \times Ohms = Volts(E) \qquad \textbf{Eq. 213.1}$$

$$Current(I) = \frac{Volts}{Ohms} = \frac{E}{R} = Amps(I) \qquad \textbf{Eq. 213.2}$$

$$R = \frac{Volts}{Amps} = \frac{E}{I} = Ohms(R) \qquad \textbf{Eq. 213.3}$$

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The following example will help to illustrate the practical way in which Ohm's law can be used. Assume the objective is to find out how much voltage drop occurs along a wire with a resistance of 2 ohms when there is 15 amperes flowing through the wire. This is illustrated in *Figure 213.2.* The current in amperes and the resistance in ohms are known. Refer to *Figure 213.3* and note that the desired quantity, voltage, is covered up. The current and resistance are side by side, therefore, they are multiplied to get the voltage using *Equation 213.1.* The voltage drop along the wire is 30 volts.

$$\text{Voltage} = \text{Amps} \times \text{Ohms} = 15\ \text{A} \times 2\ \text{ohm} = 30\ \text{V}$$

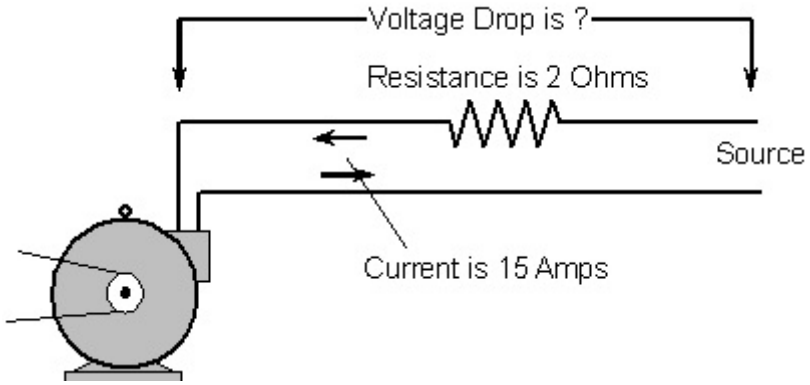


Figure 213.2 *The current flowing to the wire is 15 amperes and the wire resistance is 2 ohms.*

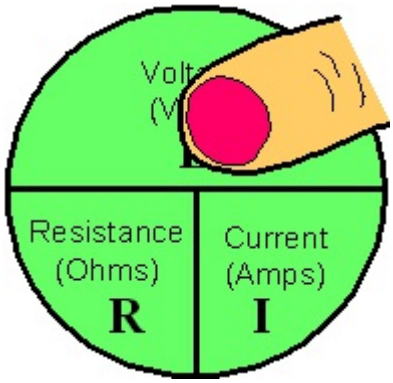


Figure 213.3 *Cover up volts to determine that amperes times ohms will give volts.*

Electrical Power: The power equation is the relationship between voltage, current and watts. This is a very useful equation especially in the electrical trade. *Figure 213.4* can be used to remember how to determine the missing information when two of the quantities are known. *Figure 213.4* is a special case of the power equation which only applies to direct current loads and certain alternating current loads such as incandescent light bulbs and electric heaters (resistive loads). This equation as shown in *Figure 213.4*, does not work for loads such as alternating current motors and many other alternating current loads. Here is how to use *Figure 213.4.* For this discussion of the use of the power equation in alternating current circuits see *Tech Note 223.*

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1. Cover up the quantity to be calculate such as volts, amperes or watts.
2. If the remaining two quantities are side by side, then multiply them together to get wattage as shown in *Equation 213.4.* (Volts times Amps equals Watts)
3. If one quantity is above the other, then divide the bottom one into the top one using either *Equation 213.5* or *Equation 213.6.* (Watts divided by Amps equals Volts or Watts divided by Volts equals Amps)

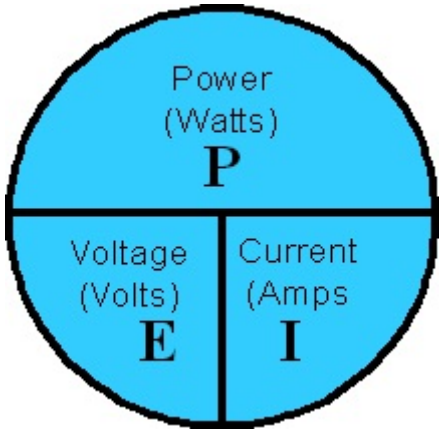


Figure 213.4 *Use this diagram to remember how to determine the missing quantity when the other two are known. (A fourth quantity called power factor must be included in most alternating current power calculations.)*

$$Power(P) = Volts \times Amps = E \times I = Watt(P) \qquad \textbf{Eq. 213.4}$$

$$Current(I) = \frac{Watts}{Volts} = \frac{P}{E} = Amps(I) \qquad \textbf{Eq. 213.5}$$

$$Volts(E) = \frac{Watts}{Amps} = \frac{P}{I} = Volts(E) \qquad \textbf{Eq. 213.6}$$

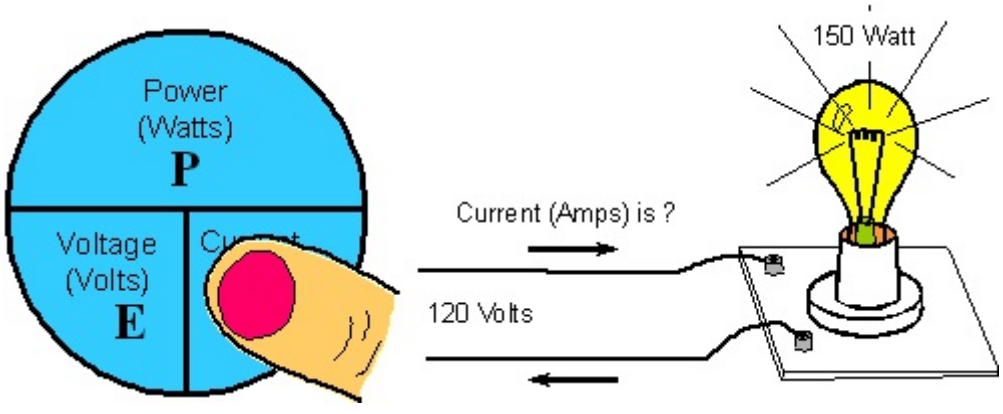


Figure 213.5 *Cover up amperes and than divide watts by volts to determine amperes.*

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Voltage Divider Equation: When multiple resistors are connected in series the voltage divider rule can be used to determine the voltage across one of the resistors provided the source voltage of the circuit is known. This is based on a fundamental law of electrical circuits called the Kirchhoff voltage law. In a series circuit the sum of the voltages across each resistor is equal to the source voltage of the circuit. *Equation 213.7* is illustrated in *Figure 213.6.*

$$E_T = E_1 + E_2 \qquad \textbf{Eq. 213.7}$$

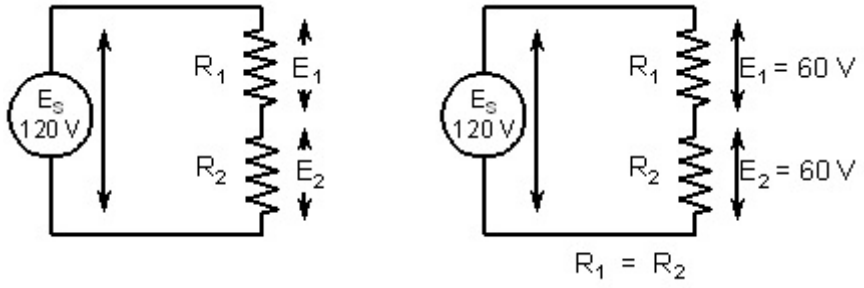


Figure 213.6 *Kirchhoff voltage law states that the voltages across each element of a series circuit must be equal to the total source voltage of the circuit.*

Example: If there are two resistors in a series circuit, R_1 and R_2, both of which have the same value, each resistor will have the same voltage across it which will be half of the source voltage as shown in *Figure 213.6.*

Because of the ***Kirchhoff voltage law****,* if the source voltage is known and the value of each resistor is known, the voltage across each resistor can be determined by proportions. The voltage across the resistor with the largest value will have a higher resistance across it than the resistor with the smaller value. Illustrated in *Figure 213.7* the value of the voltage across each resistor can be calculated using the voltage divider equation as show in *Equation 213.8.*

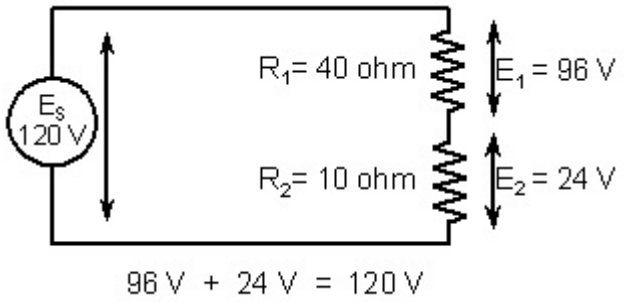


Figure 213.7 *The resistor with the larger value will have the greater voltage across it and the two voltages will sum to the value of the source voltage of the circuit. This is Kirchhoff's voltage law.*

The voltage divider equation can be used to determine the voltage across any resistor of a series circuit if the values of the resistors are known and the value of the source voltage is known. *Equation 213.8* is the voltage divider equation.

$$E_1 = \frac{R_1}{R_1 + R_2} \times E_S \qquad \textbf{Voltage divider equation} \qquad \textbf{Eq. 213.8}$$

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Example of the voltage divider equation: The values of the voltage across each resistor of *Figure 213.7* can be determined using the voltage divider equation. There are other methods of determining the voltage across each resistor, but using the voltage divider equation is the most useful method.

$$E_1 = \frac{40\Omega}{10\Omega + 40\Omega} \times 120V = 96V \qquad E_2 = \frac{10\Omega}{10\Omega + 40\Omega} \times 120V = 24V$$

Current Divider Equation: The current divider equation shown here is for two resistors that are connected in parallel, the value of each resistor is known, and the total current flowing through the resistors is known. The current divider equation is based on the ***Kirchhoff current law***. The sum of the currents flowing through each resistor must be equal to the total current. This is illustrated in ***Figure 213.8.*** The current divider equation is shown in *Figure 213.8* as well as *Equation 213.9.*

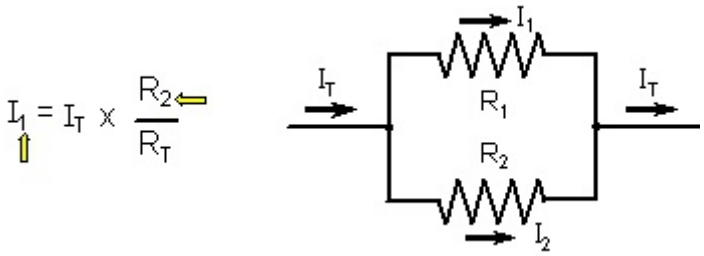
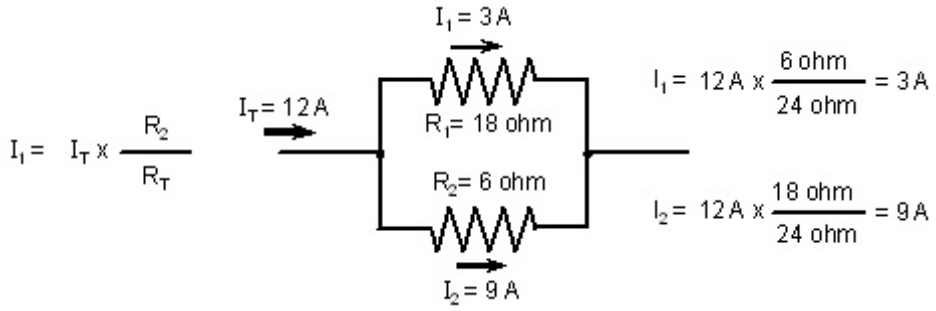


Figure 213.8 *With two resistors in parallel the total current will divide with the larger current flowing through the resistor with the smaller resistance.*

Current divider equations:

$$I_1 = I_T \times \frac{R_2}{R_T} \qquad I_2 = I_T \times \frac{R_1}{R_T} \qquad \textbf{Eq. 213.9}$$

Example: For this current divider example, resistor R_1 has a value of 18 ohms, resistor R_2 has a value of 6 ohms and the total current is 12 amperes. To determine the current through R_1 use resistor R_2 divided by R_T. To determine current through R_2 use resistor R_1 divided by R_T. The calculations are shown below.



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