Bob's TechTalk #11

by Bob Eckweiler, AF6C

Ohm's Law (Part I of IV):

Introduction

Ohm's law is a simple equation that solves the relationship between voltage, current and resistance in a simple electrical circuit. An understanding of the law is necessary to dabble in even the simplest aspects of design and troubleshooting of electrical and electronic circuits. Radio Amateurs should have a solid understanding of Ohm's law if they plan to do anything other than be a total appliance operator. In the 1950's and 1960's the amateur exams, including the Novice exam, had at least one question on Ohm's law, and you were expected to solve the problem(s) on a sheet of paper that was turned in with the exam. Today, all that's needed is to memorize the answers; the values in the problems never change from the question pool to the actual test! That's great to pass the test, but don't you really want to know more? Whether you're learning Ohm's law for the first time or are just a little rusty and want to review it, feel free to join us on this adventure.

Ohms Law:

Ohm's Law says: *The voltage across a resistance is equal to the current flowing through that resistance multiplied by the value of the resistance itself*. In equation form it is:

$$E = I \times R \qquad (1)$$

where E is the voltage in volts; I is the current in Amperes and R is the resistance in ohms. (See the sidebar "Why 'E', Why 'I'"?)

By rearranging the equation two other variations are possible. The first is:

$$I = \frac{E}{R} \qquad (2)$$

This variation allows solving for the current when the voltage and resistance are known. In words, equation (2) says: *The current flowing through a resistance is equal to the voltage across the resistance divided by the value of that resistance*. By dividing both sides of equation (1) by 'I', we get yet another variation of the equation:

$$R = \frac{E}{I} \qquad (3)$$

This variation allows solving for the resistance when the voltage and current are known. In words, equation (3) says: *The value of resistance that allows a given current to flow through it when a given voltage is applied across it is equal to the voltage across the resistance divided by the current flowing through it.*

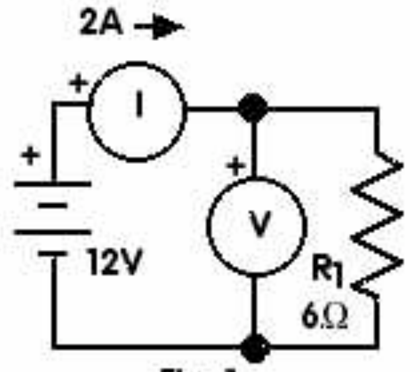
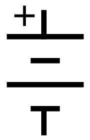


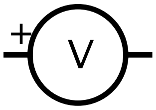
Fig. 1

Let's solve a few problems; but first maybe it would be wise to review a few schematic symbols and a simple circuit such as the circuit of figure 1. The schematic symbol:

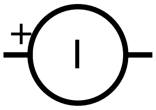


on the left is the symbol for a battery. The longer bar is always the positive terminal (we'll include the plus sign anyway.) The battery voltage is commonly printed next to the battery. It is an ideal battery, that has no internal resistance, will never go dead and can supply infinite current! (I'm told these ideal components are available only at the Radio Shack in ***Diagon Alley***). The voltage of the battery is the electromotive force that the battery exerts to push current through the circuit. Some people relate it to pressure from a water pump. When the battery is not connected to a circuit, the force is present but there is no flow of current. The symbol:

on the right is the symbol for resistance. The resistance could be a resistor, or something more useful, such as a lamp or DC motor. Resistance impedes the flow of electricity. It can be related to a narrow opening in a pipe that reduces the flow of water. The size of the opening is analogous to the resistance. The smaller the opening is, the higher the resistance. The symbol:



is a symbol for a voltmeter; it measures the voltage across the two points where it is connected. The plus sign signifies the meter polarity. It will read positive when this terminal is more positive than the other terminal. Consider our voltmeter ideal; that is, it has infinite resistance and no influence on the circuit to which it is connected. In real life this isn't the case.



is a symbol for an ammeter; it measures the current flowing through the circuit at the point where it is connected. The plus sign signifies the meter polarity (see sidebar on the direction of current flow). Consider our ammeter ideal; that is, it has zero resistance and no influence on the circuit to which it is connected. Again, in real life this isn't the case.

Let's look at figure 1. If the ammeter reads two amps and the resistor value is six ohms, what does the voltmeter read? We want to solve for 'E', the voltage across the resistor. Look at equations 1 through 3; equation (1) solves for voltage across a resistance. Since the voltage across the resistor equals the current through the resistor times the resistance, we get:

$$E = I \times R; \qquad E = 2 \times 6; \qquad E = 12V$$

This is what we'd expect since the battery is 12 volts and the meters are ideal and don't influence the circuit. (Remember: Voltmeters appear as open circuits and ammeters appear as short circuits!)

Looking at figure 1 again; let's pretend we don't know what the ammeter is reading and solve for I, the current. This time we'll use equation (2) that solves for the current flowing through a resistance when the resistance and voltage across the resistance are known. Since the current through the resistor equals to the voltage across the resistor divided by the resistance, we get:

$$I = \frac{E}{R}; \qquad I = \frac{12}{6}; \qquad I = 2\,\mathrm{A}$$

Looking at figure 1 one more time, lets say we want to solve for the value of R, the resistance. We know the readings on the voltmeter and ammeter. Equation (3) solves for the resistance when we know the current flowing through the resistance and the voltage across the resistor. Since the resistance that allows a given current to flow through it equals the voltage across the resistor divided by the current flowing through the resistor, we get:

$$R = \frac{E}{I}; \qquad R = \frac{12}{2}; \qquad R = 6\Omega$$

Figure 2 is a little more difficult. We want to calculate what the voltmeter and ammeter read. To do this we need to know what happens when resistors are connected in series; you can review this in the ARRL Handbook. Simply, resistors that are in series may be replaced by one resistor whose resistance is the sum of the series resistors.

Thus, R1 and R2 may be replaced by a single resistor whose value is the sum of the two resistors. Since R1 and R2 may be replaced with one 24 ohm resistor, the circuit simplifies to that shown in figure one with R = 24 ohms. From equation (2) the current can be calculated:

$$I = \frac{E}{R}; \qquad I = \frac{12}{24}; \qquad I = 0.5A$$

Now that the current flowing through R1 and R2 is known, equation (1) can be used to find the voltage across R2. Read the description of equation (1) carefully. The current flowing through R2 is known, and the value of R2 is known. Using equation (1):

$$E = I \times R; \qquad E = 0.5 \times 14; \quad E = 7V$$

The circuit in figure 2 is often called a voltage divider circuit. It is very common and we'll be discussing it in more detail later in this series.

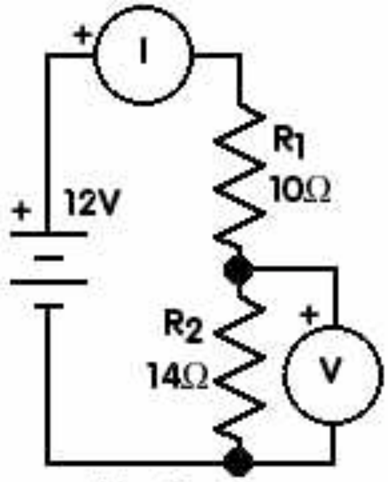


Fig. 2

Figure 3 is a bit more difficult than figure 2. The problem is to find the current flowing in the two ammeters. To solve this problem, knowledge of calculating resistors in parallel is required. This is more difficult than resis-

The Direction of Current Flow

Electrical current is the amount of electrons that flow past a given point in a circuit in one second. That number is large, 6,250 million - billion electrons! But electrons flow from the negative terminal of a battery to the positive terminal. They also flow from the cathode of a vacuum tube to the plate. Why is current flow commonly shown in the other direction?

The misconception of current flow from positive to negative came from the early days of electricity and has stuck with us to the present. Current flow has come to be defined as opposite to electron flow. This works, except when studying the physics of vacuum tubes and semiconductors where electron flow is used. We'll keep with convention and use positive-to-negative current flow.

Why 'E', Why 'I'?

You may ask why these letters were chosen to symbolize the component they do in Ohm's Law. Using 'R' to represent resistance is straight forward, but why not 'V' for voltage and 'C' or 'A' (Amperes) for current? Actually 'V' is occasionally used instead of 'E', which represents Electromotive Force, a more descriptive term for voltage. The use of 'I' to represent current is less easy to explain; 'I' was chosen because other, more appropriate characters were already in use. 'I' (and 'i' in AC circuits) has since become the universal symbol for current.

tors is series. Review the section on resistors in parallel in the ARRL Handbook if you need a refresher. When only two resistors are in parallel equation (5) may be used. This is derived from the more general equation (4) that is good for any number of resistors.

$$R_{Total} = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}\right)} \qquad (4)$$

$$R_{Total} = \frac{R_1 \times R_2}{R_1 + R_2} \qquad (5)$$

Where n is the number of resistors in parallel.

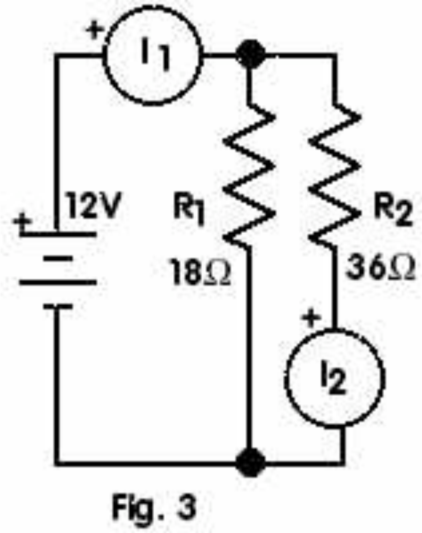


Fig. 3

Equation (5) might need some clarification for those who are unfamiliar with this type of notation. First take the reciprocal of each resistor (Divide the resistance into one - The reciprocal of 4 is 1/4 or 0.25). Next add up the reciprocals of all the resistances and take the reciprocal of that sum to get the total resistance. For example, what is the total resistance of a 1-ohm, 2-ohm, 4-ohm, 8-ohm and 10-ohm resistor, all in parallel. The reciprocals of these resistors, in order, are: 1.0, 0.50, 0.25, 0.125 and 0.10. The sum of these reciprocals is 1.975. Taking the reciprocal or 1.975 yields 0.506 ohms. One simple check is that the resistance will always be smaller than the value of the smallest parallel resistor.

Looking again at figure 3, the total resistance of R1 and R2 in parallel, from (5), is:

$$R = \frac{18 \times 36}{18 + 36} = \frac{648}{54} = 12\Omega$$

Since the parallel resistors can be replaced with one 12-ohm resistor, I1 can be solved using equation (2)

$$I_1 = \frac{E}{R} = \frac{12}{12} = 1.0 \text{ amps}$$

Solving for I2 is even easier. R1 is not involved in the solution. The voltage across the resistor and the resistance is already known. Again, using equation (2):

$$I_2 = \frac{E}{R} = \frac{12}{36} = 0.333 \text{ amps}$$

Following are some problems. They are a bit more complex, but should not be too difficult to solve using the processes and equations above. Some clues have been included to get you started. Have fun; the answers are given elsewhere in this issue of RF.

Next month, we will review these problems and then introduce you to Thévenin's Theorem. This theorem simplifies common linear circuits. You'll probably have some trouble solving the last problem. It will be a lot easier to solve after Thévenin's Theorem is introduced next month. For now, study problem #3 and see if you can find a solution.

Here are three problems:
Try them and see how you do:

Problem #1:
Find I_1, I_2 and V. in the diagram for Problem 1.

Problem #2:
Find I_2 in the diagram for Problem 2.

Problem #3:
Find I_2. in the diagram for Problem 3.

Hints for Problem #1:

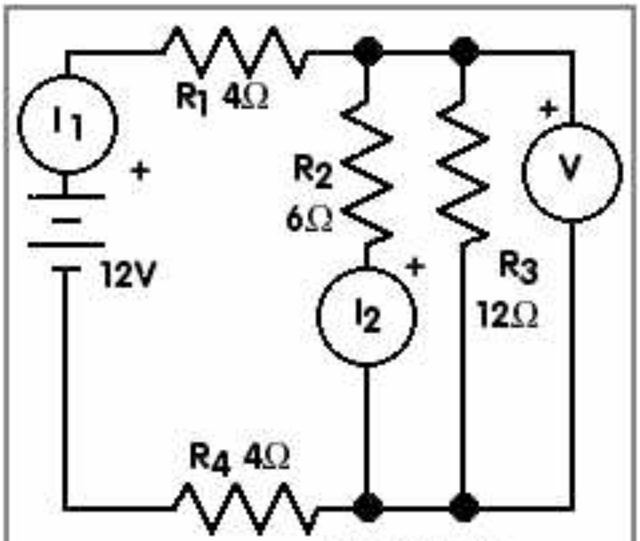
- First calculate resistance R_2 II R_3
- (That's R_2 in parallel with R_3).
- Then calculate the series resistance of R_1, R_4 and R_2 II R_3.
- Now I_1 may be calculated.
- Now V, the voltage across R_2 II R_3 may be calculated.
- Finally I_2 may be calculated because V and R_2 are known.

Hints for Problem #2:

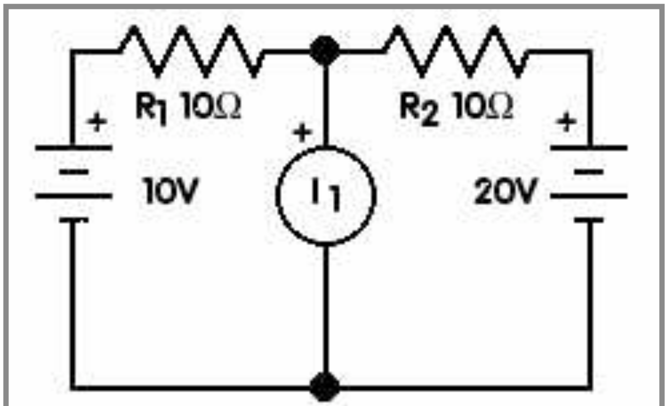
- Don't let the second battery scare you.
- Remember the definition of the perfect ammeter.

Hints for Problem #3:

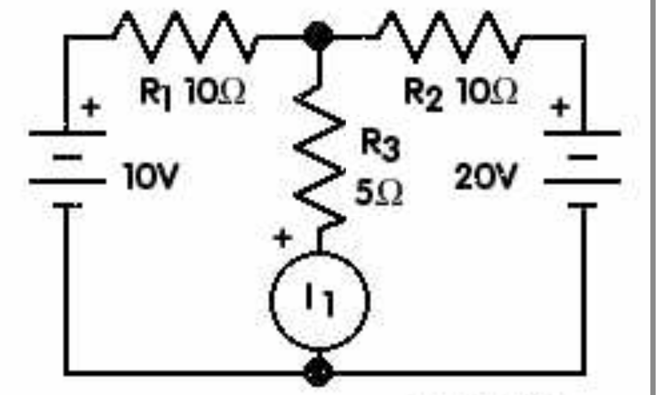
- Only one resistor has been added.
- Now the problem becomes more difficult.
- See if you can solve it.
- Next month Thévenin will help us find I1!



Problem #1



Problem 2



Problem 3

Answers:
#1a) I1 = 1 amp
#1b) I2 = 0.667 amps
#1c) V = 4 volts
#2) I1 = 3 amps
#3) I1 = 1.5 amps

73, from AF6C

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