

Online Radio & Electronics Course

Reading 4

Ron Bertrand VK2DQ
<http://www.radioelectronicschool.com>

OHMS LAW

Ohm's Law describes the relationship between current, voltage and resistance in an electric circuit.

Ohm's Law states:

The current in a circuit is directly proportional to voltage and inversely proportional to resistance.

Let:

I = current

E = voltage

R = resistance

Part of Ohms Law says: **current is directly proportional to voltage.**

Using the symbols given, we can write an equation to show a direct proportion between current and voltage.

$$I = E$$

Normally the above equation is read I 'equals' E. It can just as easily and more understandably be read as: **I is directly proportional to E.**

I know I harp on the direct proportion and inverse proportion stuff a lot. I do so because it is so important to thoroughly understand this when we come to more complex equations.

$$I = E$$

Means that if the voltage is increased or decreased in a circuit then the current will increase or decrease by the **same** amount. Double the voltage and you double the current. Halve the voltage and you halve the current. This is a direct proportion.

The other part of Ohm's Law says that current is inversely proportional to the resistance. This can be written as:

$$I = 1/R$$

Now $1/R$ is a fraction with a numerator (the top part, 1) and a denominator, R.

$1/R$ is a fraction just like $1/4$, $1/2$ and $3/8$ are fractions.

R is the denominator in the fraction. What happens to the whole fraction if the denominator is changed? Watch.

1/2, 1/3, 1/4, 1/5, 1/6

As the **denominator increases the fraction decreases**. In fact if the denominator doubles then the fraction is half the size. 1/4 is half the size of 1/2.

I is the same as 1/R. This is an inverse proportion. If I is the same as 1/R and R is increased in size by three times, then the fraction 1/R is a third the size now, and since 1/R is the same as the current, then the current is a third the size also.

The complete equation for Ohm's Law then is:

$$I = E/R$$

This equation, derived from ohms law, enables us to find the current flowing in any circuit if we know the voltage (E) and resistance (R) of the circuit.

For example: A resistor of 20 ohms has a 10 volt battery connected to across it. How much current will flow through the resistor?

$$I = 10/20 = 1/2 = 0.5 \text{ Amperes}$$

The equation $I = E/R$ can be transposed for E or for I.

In some texts a thing called the Ohm's Law triangle is used to help you rewrite the equation for E and R - I don't like this method, as you do really need to know how to transpose equations - not just this one. If you learn to transpose this equation then you will be able to do it with many others. There is a memory wheel on the web site for you to download that will help you remember equations for Ohm's law and power. You will also find a tutorial on transposing equations and using a calculator in the downloads area if you feel you might need some extra help. Always write to your facilitator if you need assistance as well.

We want to transpose $I = E/R$ for E and R. The rule is: **do whatever you like to the equation and it will always be correct as long as you do the same to each side of the equals sign**. For example, if I multiply both sides of the equal sign by R, we get:

$$I \times R = \frac{E}{R} \times R$$

On the left hand side (LHS) we have $I \times R$. On the RHS we have E multiplied by R and divided by R. Can you see that the R's cancel on the RHS? R/R is 1/1.

$$I \times R = \frac{E}{1} \times 1$$

There is no need to show the 1's at all since multiplying or dividing a number by 1 does not change the number, therefore:

$$I \times R = E$$

Rewriting the above with E on the LHS we get:

$$E = I \times R \text{ or just } \mathbf{E=IR}$$

When there is no sign between two letters in an equation, like IR above, it is assumed the IR means I x R.

Now transpose the equation for R:

$$I = \frac{E}{R}$$

Multiply both sides by 1/E (which is the same as dividing both sides by E):

$$I \times \frac{1}{E} = \frac{E}{R} \times \frac{1}{E}$$

On the RHS the E's cancel out so we can rewrite the equation as:

$$I \times \frac{1}{E} = \frac{1}{R}$$

Or

$$\frac{I}{E} = \frac{1}{R}$$

Turning both sides upside down (remember we can do anything as long as we do the same to both sides):

$$\frac{E}{I} = \frac{R}{1}$$

Remove the '1', and reverse the sides to get:

$$\mathbf{R = E/I}$$

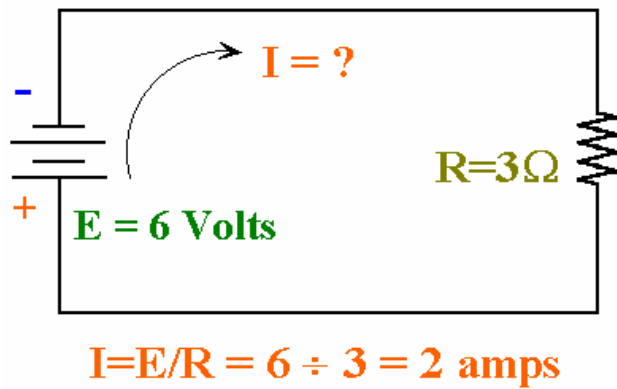
So the three equations are:

$$I = E/R \quad E = IR \quad R = E/I$$

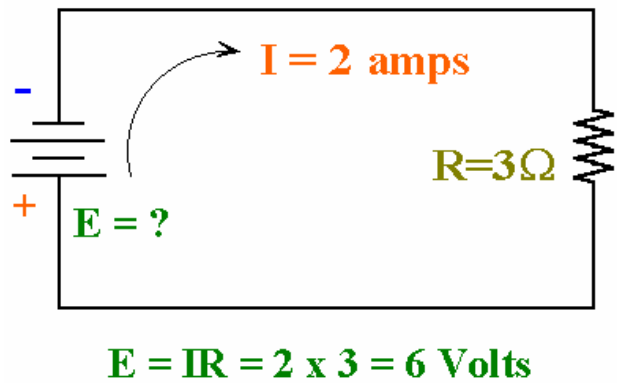
I have probably made you bored by now - however it is really important to be able to transpose equations for yourself; for a start, you don't need to remember so many equations.

So if you know **any two** of the three in 'E', 'R' and 'I' then you can calculate the missing one.

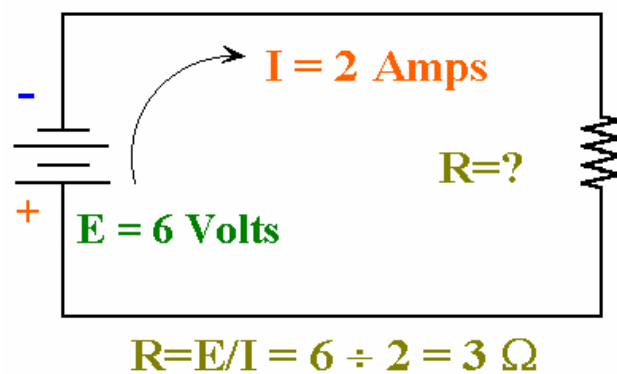
Finding I when you know E and R:



Finding E when you know I and R:



Finding R when you know I and E:



POWER

The unit of electrical power is the watt (W), named after James Watt (1736-1819). One watt of power equals the work done in one second by one volt of potential difference in moving one coulomb of charge.

Remember that one coulomb per second is an ampere. Therefore, power in watts equals the product of amperes times volts.

Power in watts = volts x amperes

$$P = E \times I$$

Example: A toaster takes 5 A from the 240V power line. How much power *is* used?

$$\begin{aligned} P &= E \times I = 240 \text{ V} \times 5 \text{ A} \\ P &= 1200 \text{ Watts} \end{aligned}$$

Example: How much current flows in the filament of a household 75 watt light bulb connected to the normal 240 Volt supply?

You know P (power) and E (volts). You need to transpose $P=EI$ for I and you get:

$$I = P/E$$

Therefore:

$$\begin{aligned} I &= 75/240 \\ I &= 0.3125 \text{ Amperes} \end{aligned}$$

This amount of current is best expressed in milliamperes. To convert amperes to milliamperes multiply by 1000 or think of it as moving the decimal point 3 places to the right, which is the same thing. This gives:

$$312.5 \text{ mA}$$

Power in watts can also be calculated from:

$$\begin{aligned} P &= I^2 R, \text{ read, "power equals I squared R".} \\ P &= E^2/R, \text{ read, "power equals E squared divided by R".} \end{aligned}$$

Watts and Horsepower Units.

$$746 \text{ W} = 1 \text{ horsepower.}$$

This relationship can be remembered more easily as 1 horsepower equals approximately 3/4 kilowatt. One kilowatt = 1000 W.

WORK

$$\text{Work} = \text{Power} \times \text{Time}$$

Practical Units of Power and Work. Starting with the watt, we can develop several other important units. The fundamental principle to remember is that power is the time rate of doing work, while work is power used during a period of time. The formulas are:

$$\begin{aligned}\text{Power} &= \text{work} / \text{time} \\ \text{and} \\ \text{Work} &= \text{power} \times \text{time}\end{aligned}$$

With the watt unit for power, one watt used during one second equals the work of one joule. To put it simply, one watt is one joule per second. Therefore, $1 \text{ W} = 1 \text{ J/s}$. The joule is a basic practical unit of work or energy.

A unit of work that can be used with individual electrons is the **electron volt**. Note that the electron is charge, while the volt is potential difference. Now 1eV is the amount of work required to move an electron between two points having a potential difference of one volt. Since 6.25×10^{18} electrons equal 1C and a joule is a volt-coulomb, there must be $6.25 \times 10^{18} \text{ eV}$ in 1J .

Kilowatt-hours. This is a unit commonly used for large amounts of electrical work or energy. The amount is calculated simply as the product of the power in kilowatts multiplied by the time in hours during which the power is used. This is the unit of energy you need to know.

Example: A light bulb uses 100 W or 0.1 kW for 4 hours (h) , the amount of energy used is:

$$\begin{aligned}\text{Kilowatt-hours} &= \text{kilowatts} \times \text{hours} \\ &= 0.1 \times 4 \\ &= 0.4 \text{ kWh.}\end{aligned}$$

We pay for our household electricity in kilowatt-hours of energy.

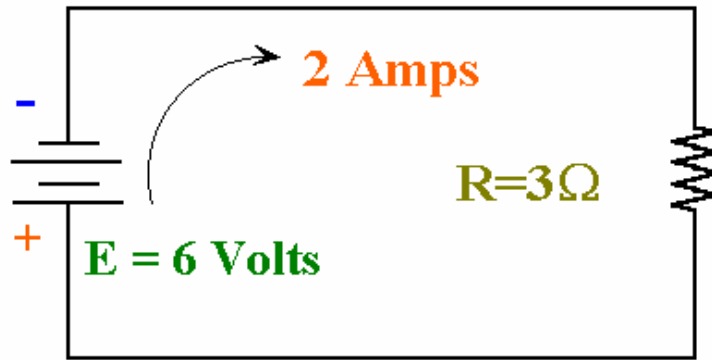
POWER DISSIPATION IN RESISTANCE

When current flows in a resistance, heat is produced because friction between the moving free electrons and the atoms obstructs the path of electron flow. The heat is evidence that power is used in producing current. This is how a fuse opens, as heat resulting from excessive current melts the metal link in the fuse.

The power is generated by the source of applied voltage and consumed in the resistance in the form of heat. As much power as the resistance dissipates in heat must be **supplied** by the **voltage source**; otherwise, it cannot maintain the potential difference required to produce the current.

Any one of the three formulas can be used to calculate the power dissipated in a resistance. The one to be used is just a matter of convenience, depending on which factors are known.

In the following diagram, the power dissipated with 2 A through the resistance and 6 V across it is $2 \times 6 = 12 \text{ W}$. Or, calculating in terms of just the current and resistance, we get 2^2 times 3 , which equals 12 W . Using the voltage and resistance, the power can be calculated as 6^2 or 36 , divided by 3 , which also equals 12 W .



$$\begin{aligned}
 P &= EI = 6 \times 2 = 12 \text{ watts} \\
 P &= I^2 R = 2 \times 2 \times 3 = 12 \text{ watts} \\
 P &= E^2 / R = 6 \times 6 \div 3 = 12 \text{ watts}
 \end{aligned}$$

We have introduced a new schematic symbol here too. The schematic symbol of a battery is shown at the left. Note the small bar at the top is the negative terminal. The direction of current flow is shown correctly, from negative to positive

No matter which equation is used, 12 W of power is dissipated, in the form of heat. The battery must generate this amount of power continuously in order to maintain the potential difference of 6 V that produces the 2 A current against the opposition of 3 ohms.

In some applications, the electrical power dissipation is desirable because the component must produce heat in order to do its job. For instance, a 600 W toaster must dissipate this amount of power to produce the necessary amount of heat. Similarly, a 300 W light bulb must dissipate this power to make the filament white hot so that it will have the incandescent glow that furnishes the light. In other applications, however, the heat may be just an undesirable by-product of the need to provide current through the resistance in a circuit. In any case, though, whenever there is current in a resistance, it dissipates power equal to $I^2 R$.

The term $I^2 R$ is used many times to describe unwanted resistive power losses in a circuit. You will hear of the expression $I^2 R$ losses as we go through this course.

ELECTRIC SHOCK

While you are working on electric circuits, there is often the possibility of receiving an electric shock by touching the "live" conductors when the power is on. The shock is a sudden involuntary contraction of the muscles, with a feeling of pain, caused by current through the body. If severe enough, the shock can be fatal. Safety first, therefore, should always be the rule.

The greatest shock hazard is from high voltage circuits that can supply appreciable amounts of power. The resistance of the human body is also an important factor. If you hold a conducting wire in each hand, the resistance of the body across the conductors is about 10,000 to 50,000 ohms. Holding the conductors tighter lowers the resistance. If you hold only one conductor, your resistance is much higher. It follows that the higher the body resistance, the smaller the current that can flow through you.

A safety rule, therefore, is to work with only one hand if the power is on. Also, keep yourself insulated from earth ground when working on power-line circuits, since one side of the line is usually connected to earth. In addition, the metal chassis of radio and television receivers is often connected to the power line ground. The final and best safety rule is to work on the circuits with the **power disconnected** if at all possible, and make resistance tests.

Note that it is current through the body, not through the circuit, which causes the electric shock. This is why care with high-voltage circuits is more important, since sufficient potential difference can produce a dangerous amount of current through the relatively high resistance of the body. For instance, 500 V across a body resistance of 25,000 Ω produces 0.02 A, or 20 mA, which can be fatal. As little as 10 μ A through the body can cause an electric shock. In an experiment on electric shock to determine the current at which a person could release the live conductor, this value of "let-go" current was about 9 mA for men and 6 mA for women.

In addition to high voltage, the other important consideration in how dangerous the shock can be is the amount of power the source can supply. The current of 0.02 A through 25,000 Ω means the body resistance dissipates 10 W. If the source cannot supply 10 W, its output voltage drops with the excessive current load. Then the current is reduced to the amount corresponding to how much power the source can produce.

In summary, then, the greatest danger is from a source having an output of more than about 30 V with enough power to maintain the load current through the body when it is connected across the applied voltage. In general, components that can supply high power are physically big because of the need for heat dissipation.

RESISTANCE OF EARTH

The earth, no not the ground, I am speaking of planet earth, is not made of metal (in any great concentrated amount) so one may expect that it is not a good conductor. However if you recall the equation $R = \rho L/A$, where A is the cross sectional area - well the earth indeed does have a huge cross sectional area. This means for many applications the earth itself can be used as a conductor to save us having to run two conductors from the source to the load. Such circuits are called **earth return** and they have been used for power distribution and telephone communications.

Some Revision.

By now you should have a good concept of current, voltage and resistance, among other things. It should be clear in your mind that current flows in a circuit pushed and/or pulled along by voltage. Current is restricted from flowing in a circuit by resistance.

You should be aware by now that statements like; "the voltage through the circuit" are in error. Voltage is electrical pressure. Voltage is never through anything. You can have

voltage across the circuit or a component but you can never have voltage through anything. Current flows through the circuit pushed along by voltage and restricted by resistance.

VOLTS PUSH AMPS THROUGH OHMS

A final point. You can have voltage without current. However you cannot have current without voltage. A battery sitting on a bench has a voltage on its terminals – but no current is flowing. Voltage is electric pressure just like the water pressure in your tap. Current is the flow of electrons just like the flow of water from a tap. If the tap is turned off you do not have a water flow however the pressure is definitely still there. Likewise it is possible (like on a disconnected battery) to have voltage (electric pressure) and no current (flow).

However you cannot have any flow without pressure. So voltage can exist on its own, current cannot.

The unit of current is the Ampere – when 6.25×10^{18} electrons flow past a given point in a circuit in one second the current is said to be one ampere.

Since 6.25×10^{18} electrons is a coulomb, this can be used in the definition of an ampere. An ampere of current is said to flow when one coulomb passes a given point in one second.

If you feel you could use some more help with using a calculator or transposing equations there are extra readings provided on these topics in the supplementary download area of the web site at <http://www.radioelectronicschool.com>

Also available is a set of 9 video math tutorials on one CDROM – write to the Manager for more information.

End of Reading 4.

Last revision: November 2001

Copyright © 1999-2001 Ron Bertrand

E-mail: manager@radioelectronicschool.com

<http://www.radioelectronicschool.com>

Free for non-commercial use with permission