Module
3

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Resistors & Circuits

Module 3.1
Ohm's Law

What you'll learn in Module 3.1

After studying this section, you should be able to:

Describe Ohm's Law involving metalic conductors:

- Resistance, Voltage & Current.
- Define:
  The Ohm, Ampere & Volt.

Ohms, Volts & Amperes.

The resistance of a conductor is measured in Ohms and the Ohm is a unit named after the German physicist George Simon Ohm (1787-1854) who was the first to show the relationship between resistance, current and voltage. In doing so he devised his law which shows the inter-relationship between the three basic electrical properties of resistance, voltage and current. It demonstrates one of the most important relationships in electrical and electronic engineering.

Ohm´s Law states that: "In metallic conductors at a constant temperature and in a zero magnetic field, the current flowing is proportional to the voltage across the ends of the conductor, and is inversely proportional to the resistance of the conductor."

In simple terms, provided that the temperature is constant and the electrical circuit is not influenced by magnetic fields, then:

- With a circuit of constant resistance, the greater the voltage applied to a circuit, the more current will flow.
- With a constant voltage applied, the greater the resistance of the circuit, the less current will flow.

Notice that Ohm's law states "In metallic conductors" This means that the law holds good for most materials that are metal, but not all. Tungsten for example, used for the glowing filaments of light bulbs has a resistance that changes with the temperature of the filament, hence the reference in Ohm's Law to 'at a constant temperature'. There are also components used in electronics that have a non-linear relationship between the three electrical properties of voltage, current and resistance, but these can be described by different formulae. For the majority of circuits or components, which can be described by Ohm's Law:

Resistance is indicated by the letter R and is measured in units of Ohms, which have the symbol Ω (Greek capital O).

Voltage is indicated by the letter V (or sometimes E, an abbreviation for Electromotive Force) and is measured in units of Volts, which have the symbol V.

Current is given the letter I (not C as this is used for Capacitance) and is measured in units of Amperes (often shortened to Amps), which have the symbol A.

Using the letters V, I and R to express the relationships defined in Ohms Law gives three simple formulae:

$$V = IR \quad \text{or} \quad I = \frac{V}{R} \quad \text{or} \quad R = \frac{V}{I}$$

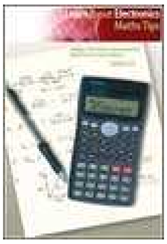
Each of which shows how to find the value of any one of these quantities in a circuit, provided the other two are known. For example, to find the voltage V (in Volts) across a resistor, simply multiply the current I (in Amperes) through the resistor by the value of the resistor R (in Ohms).

Note that when using these formulae the values of V I and R written into the formula must be in its BASIC UNIT i.e. VOLTS (not millivolts) Ohms (not kilohms) and AMPERES (not micro Amperes) etc.

Briefly 15KΩ (kilohms) is entered as 15 EXP 03

and 25mA (milliAmperes) is entered as 25 EXP-03 etc.

This is easiest to do using a scientific calculator.



How to use your calculator with the engineering notation used extensively in electronics is explained in our free booklet entitled "Maths Tips" Download it from our Download page.

Defining The Ohm, Ampere & Volt

1 OHM

Can be defined as "The amount of resistance that will produce a potential difference (p.d.) or voltage of 1 Volt across it when a current of 1 Ampere is flowing through it."

1 AMPERE

Can be defined as "The amount of current which, when flowing through a resistance of 1 Ohm will produce a potential difference of 1 Volt across the resistance."

(Although more useful definitions of an ampere are available*)

1 VOLT

Can be defined as "The difference in potential (voltage) produced across a resistance of 1 Ohm through which a current of 1 Ampere is flowing."

*These definitions relate Volts, Amperes and Ohms within the quantities described in Ohm´s Law, but alternative definitions using other quantities can also be used.

TRY SOME SIMPLE CALCULATIONS USING Ohms Law.

Module 3.2
Ohm's Law Quiz

What you'll learn in Module 3.2

After studying this section, you should be able to:

Calculate basic problems involving Ohm's Law

- Use appropriate units and sub-units.
- Use a scientific calculator with engineering notation.

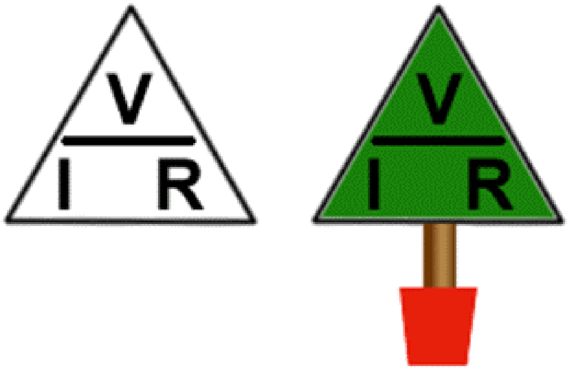


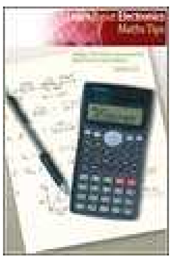
Fig. 3.2.1 The Ohm's Law Triangle or (if you prefer) A 'VIR' Tree

Volts Amperes & Ohms

Try a few calculations based on Ohms Law. For these you just need to use the three basic formulae described in Resistors & Circuits Module 3.1. Hopefully it'll be a breeze. The important thing to remember is to use the correct version of the formula, and to get it the right way up (I = V/R is good but I = R/V is definitely NOT!). A simple visual aid to remembering the correct formula is the Ohms Law Triangle. Setting out V, I and R in this way is a reminder that R = V over (divide by) R and I = V over (divide by) R, and V = IR (I multiplied by R) as shown in Fig 3.2.1.

Work out the answers using pencil and paper; if you don't write out the problem you WILL get mixed up half way and end up with the wrong answer. Of course the answer is not just a number, it will be a certain number of Ohms or Volts or Amperes, but wait, there is worse to come - those Ohms Volts or Amperes are very probably going to be kilohms or millivolts or microamperes, right? So you have to show that in your answer. No good just writing 56. Fifty-six what? Maybe 56Ω? Well if the real answer was 56KΩ you are still wrong, your answer is a thousand times too small!

But don't worry, to get you off on the right track you should download our "Maths Tips" booklet, which shows you how to use your calculator with exponents and engineering notation to get the right answer every time.



Not got a scientific calculator? The "Maths Tips" booklet explains what you need (and what you don't need so you don't spend your money unnecessarily). If you don't want to buy a scientific calculator, you can always pick up a free one on the net. PC users can try Calc98 from www.calculator.org/download.html. Whichever calculator you choose, read the instructions to become familiar with the working methods you should use as these do vary from calculator to calculator.

OK so now you have read these instructions, you are ready to start. Here is a way to set out a typical problem on paper so you (with practice) don't get confused.

First write down what is known from the question, and what is not known:

V = ? (V is the unknown quantity.)

I = 500mA (500 x 10^{-3}Amperes) 500E-3 or 500EXP-3 when entering it into your calculator, depending on which model you use.

R = 50Ω

So given I and R the correct formula to find V can be found from the Ohm´s law triangle:

V= I x R so substituting the figures given in place of I and R gives:

V = 500E-3 x 50 (for E press the E, the EE or the EXP key and for - press the change sign +/− or (-) key, NOT the minus (-) key. So the calculator display should read:

V = 500E-3 x 50 and pressing = gives the answer **25**

The correct answer is therefore **25V**

Note: If you are using Calc98 for your calculations you need to set the View>Option>Display menu to Engineering (under the "Decimal" choices).

It would be a good idea whilst you are in this menu to select 2 from the "Decimals" drop down box to set the number of digits displayed after the decimal place. This will round your answer down to two decimal places, which is sufficiently accurate for most uses and stops you getting silly answers such as 4.66666666667µA, which would be too accurate measure in a practical situation!

Ohm´s Law Calculations Practice - Resistance, Voltage and Current.

(Calculate your answers with pencil, paper and calculator, then check your answers at www.learnabout-electronics/Resistors/resistors_12.php)

1. What will be the potential difference across a 50Ω resistor if a current of 500mA is flowing through it?

a) 0.25 Volts b) 25 Volts c) 5 Volts d) 50 Volts

2. What current will be needed to produce a voltage of 5V cross a 12kΩ resistor?

a) 2.4mA b) 416.67mA c) 240mA d) 416.67µA

3. What value of resistor will be needed to produce a current of 100mA when a voltage of 12V is applied across the resistor?

a) 120Ω b) 8K3 c) 1K2 d) 830

4. What voltage will be developed across a 560Ω resistor if a current of 20mA is flowing through it?

a) 11.2mA b) 112 Volts c) 112mA d) 11.2 Volts

5. What current passing through 10kΩ resistor will produce a voltage of 8V cross it?

a) 800mA b) 800µA c) 8mA d) 80µA

Module 3.3
Conductance

What you'll learn in Module 3.3

After studying this section, you should be able to:

Describe the property of Conductance (G)

Describe the property of Mutual transconductance (g_m)

The Opposite of Resistance

The Ohms Law formula for resistance is R = V/I. If this for R formula is inverted it would become R = I/V. This is still a useful formula, but NOT for resistance. Resistance is a property that, as it increases, reduces current flow. I/V therefore must give a unit that, as it increases, also INCREASES current flow, exactly the opposite effect to resistance. This unit must be proportional to current. (Resistance is INVERSELY proportional to current).

Conductance

This property given by I/V is called CONDUCTANCE because the larger its value, the more a circuit conducts (passes more current). The property of Conductance is given the letter G and is measured in units of Siemens (S). As conductance is the opposite of resistance it can also be calculated as the RECIPROCAL of resistance.

$$\textbf{Conductance (G)} = \frac{1}{R}$$

Enter the resistance of a circuit (in Ohms) into a scientific calculator and simply press the reciprocal button (labelled 1/x or sometimes x^{-1}) and you have Conductance in Siemens, note that the symbol for Siemens a capital S (small s is used for seconds). Conductance is not widely used in electronics calculations, resistance being generally a more useful property.

Transconductance

Conductance is used however in connection with Field Effect Transistors (FETs) used as amplifiers and with operational amplifier integrated circuits (Op Amp ICs). In these devices a change in output current is related to a change in input voltage by a ratio called the Transconductance or mutual Transconductance of the (amplifier) device.

Mutual Transconductance is given the symbol g_m and gives an indication of the gain of a device (i.e. how much it amplifies a signal). The formula for g_m is given below and relates a change (Δ) in output Current (I_{out}) to a change of input Voltage (V_{in}).

$$\textbf{Mutual Transconductance } (g_m) = \frac{\Delta I_{out}}{\Delta V_{in}}$$

Module 3.4
Power & Energy

What you'll learn in Module 3.4

After studying this section, you should be able to:

Carry out calculations involving power, voltage, current and resistance.

- using appropriate units and sub-units

Differentiate between power and energy in electrical circuits.

Power in Resistors

When a current flows through a resistor, electrical energy is converted into HEAT energy. The heat generated in the components of a circuit, all of which possess at least some resistance, is dissipated into the air around the components. The rate at which the heat is dissipated is called POWER, given the letter P and measured in units of Watts (W).

The amount of power dissipated can be worked out using any two of the quantities used in Ohms law calculations. Remember, as with any formula the BASIC QUANTITIES must be used in the formula, i.e. VOLTS, OHMS and AMPERES, (not milli, Meg etc).

To find the power P using V and I

$$P = I\,V$$

To find the power P using V and R

$$P = \frac{V^2}{R}$$

To find the power P using I and R

$$P = I^2\,R$$

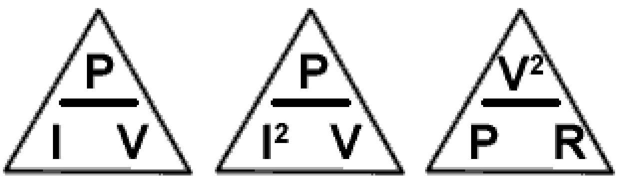
Before starting, think about these few tips, they will make the problems easier if followed carefully.

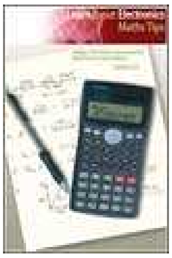
1. Work out the answers using pencil and paper; otherwise it is easy to get mixed up half way through and end up with the wrong answer.

2. Of course the answer is not just a number, it will be a certain number of Watts (or multiple or sub units of Watts). Don't forget to show the correct unit (e.g. W or mW etc.) as well as the number or the answer is meaningless.

3. Convert all sub units such as mV or kΩ to Watts when you put them into the appropriate formula. A slip up here will give really stupid answers, thousands of times too big or too small.

4. Although the structure of these power formulae seems very similar to the Ohms Law formulae, there is a subtle difference - they contain some squared terms (I^2 and V^2). Be very careful if using the triangle trick to transpose these formulae. If you need to relate power to resistance, then either I or V must be squared (multiplied by itself). However you can construct a triangle to fit either of the formulae to give R, as shown below.





Don't forget to download our ‘Maths Tips’ booklet, which shows you how to use your calculator with exponents and engineering notation to deal with those sub-units and get the right answer every time.

Not got a scientific calculator? The ‘Maths Tips’ booklet explains what you need (and what you don't need so you don't spend your money unnecessarily). If you don't want to buy a scientific calculator, you can always pick up a free one on the net. PC users can try Calc98 from www.calculator.org/download.html. Whichever calculator you choose, read the instructions to become familiar with the working methods you should use as these do vary from calculator to calculator.

It is important to be aware of the effect of power dissipation in components, the greater the power, the more heat must be dissipated by the component. This generally means that components dissipating large amounts of power get hot, also they will be considerably larger in size than low power types. If a component is required to dissipate more power than it is designed to, it will not be able to get rid of the heat generated fast enough. Its temperature will rise and the overheating may cause complete failure of the component and possibly damage to other components and the printed circuit board (PCB) itself. As a precaution, large power resistors are often mounted clear of the PCB by using longer lead out wires encased in ceramic sleeves. High power wirewound resistors may even be encased in a metal heat sink and bolted to a large metal area such as the equipment case, to get rid of unwanted heat. Examples of high power resistors are shown on the Resistors & Circuits Module 2.0 Resistor Construction page.

Components such as resistors have a particular power rating quoted by the manufacturer (in Watts or milli Watts). This rating (parameter) must be checked when replacing a component so that no over rating will occur. This is an important safety consideration when servicing electronic equipment.

TIP

The heat generated by high power resistors is a major cause of early failure in many circuits. Either the resistor itself fails by going "open circuit", especially in wire wound resistors. In carbon composition resistors, overheating over a long period can cause the value to change. This may increase in high resistance types, or more dangerously reduce (allowing an increased current flow) in low value types. The increase in current flow caused by this reduction in resistance only accelerates the process and eventually the resistor (and sometimes other associated components) burns up!

Energy in Resistors

If a certain amount of power is dissipated for a given time, then ENERGY is dissipated. Energy (power x time) is measured in Joules and by including time (t) in the power formulae, the energy dissipated by a component or circuit can be calculated.

Energy dissipated = $\mathbf{Pt}$ or $\mathbf{VIt}$ or $\mathbf{V^2Rt}$ or even $\mathbf{I^2Rt}$ **Joules**

Note that in formulae for energy, quantities such as power, time, resistance, current and voltage must be converted to their basic units, e.g. Watts, seconds, Ohms, Amperes, Volts etc. No sub units or multiple units! As described in the ‘Maths Tips’ booklet.

All of the above units are part of an integrated system of internationally standardised units; the S.I. (Système International d´Unités) System. This system sets out the basic units for any electrical, mechanical and physical property and their relations to each other. It also includes the standard form of multiples and sub multiples described in the ‘Maths Tips’ booklet.

Module 3.5
Power & Energy Quiz

Try a few calculations based on Power and Energy, using the information in the Resistors & Circuits Module 3.4 Power and Energy page. Some are easy, some are not. Because more than one formula may be needed to solve some of the problems its important to remember to use the correct formula at the right time.

Before starting, think about these few tips, they will make the problems easier if followed carefully.

1. Work out the answers using pencil and paper; otherwise you WILL get mixed up half way through and end up with the wrong answer.

2. Of course the answer is not just a number, it will be a certain number of Watts or Joules, don't forget to show the correct unit (e.g. W mW J etc.) or your answer is meaningless.

3. Convert all sub units such as mW to Watts before you put them into the appropriate formula. A slip up here can give really stupid answers, thousands of times too big or too small.

To help you on the right track why not read about our "Maths Tips" booklet, as described in the Resistors & Circuits Module 3.4 Power and Energy page.

OK so if you have read these instructions, you are ready to start.

Power and Energy Quiz

(Calculate your answers with pencil, paper and calculator, then check your answers at www.learnabout-electronics/Resistors/resistors_16.php)

1. What is the power dissipated by a circuit that passes a current of 1.6A when a voltage of 6V is connected across it?

a) 3.75 W b) 9.6 W c) 3.75 J d) 267 mW

2. What power is dissipated by a 40 Ω resistor when a voltage of 6V is connected across it?

a) 267 W b) 6.67 W c) 267 mW d) 900 mW

3. How much power is dissipated by a 150 Ω resistor when a current of 100 mA flows through it?

a) 1.5 W b) 66.67 mW c) 2.25 mW d) 2.5 W

4. A resistor is needed to reduce the voltage supplying a circuit by 7V when the circuit draws a current of 100mA. Choose the best resistor for the job from the values below.

a) 700 Ω 2 W b) 70 Ω 0.5 W c) 680 Ω 5 W d) 68 Ω 1 W

5. How much energy is used by a light emitting diode when it is illuminated by a 10 mA current at a voltage of 2 V for 30 minutes?

a) 20 mW b) 36 J c) 0.6 J d) 600 mW

