Resistors & Circuits

Module 4.0
Current & Voltage

What you'll learn in Module 4.0

After studying this section, you should be able to:

Describe the distribution of electrical potentials (voltages) and currents in electrical circuits.

- Series resistive circuits.
- Parallel resistive circuits.

Calculate the distribution of voltages in a resistive potential divider.

Current & Voltage in Resistor Networks
Finding the Unknown

In addition to working out the resistance, Ohms law can be used to work out voltages and currents in resistor networks. Before trying this it would be a good idea to look at some basic facts about resistor networks.

In the simple **SERIES CIRCUIT** shown in Fig. 4.0.1 the same current flows through all components. Each component however, will have a different VOLTAGE (p.d.) across it. The sum of these individual voltages ($V_{R1}+V_{R2}+V_{R3}$ etc) in a series circuit is equal to the supply voltage (EMF).
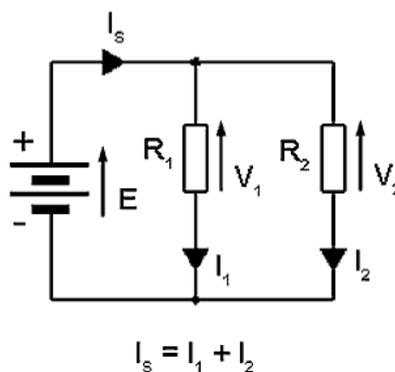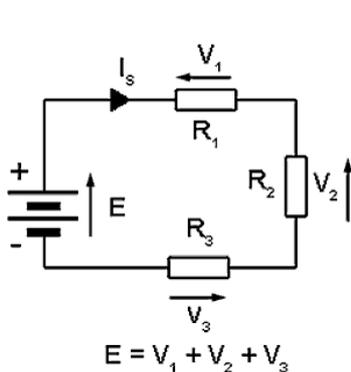
In the simple **PARALLEL CIRCUIT** shown in Fig 4.0.2 however, the same voltage is present across all components but a different CURRENT can flow through each component. The sum of these individual component currents in a parallel circuit is equal to the supply current. ($I_S = I_{R1}+ I_{R2}+ I_{R3}$ etc.)

$$E = V_1 + V_2 + V_3$$

Fig.4.0.1 A Simple Series Circuit

$$I_S = I_1 + I_2$$

Fig.4.0.2 A Simple Parallel Circuit

The Potential Divider Rule

If two or more resistors are connected in series across a potential (e.g. A supply voltage), the voltage across each resistor will be proportional to the resistance of that resistor.

$V_{R1} \propto R_1$ and $V_{R2} \propto R_2$ etc.

To calculate the voltage across any resistor in the potential divider, multiply the supply voltage (E)

$$V_{R1} = E \frac{R_1}{(R_1 + R_2)}$$

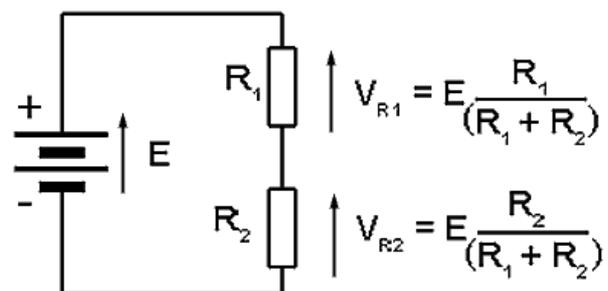$$V_{R2} = E \frac{R_2}{(R_1 + R_2)}$$

Fig. 4.0.3 A Potential Divider

by the proportion of that resistor to the total resistance of all the resistors.

For example if R_2 is double the value of R_1 there will be twice the voltage across R_2 than across R_1. It follows therefore, that the voltage across R_1 will be one third of the supply voltage (E) and the voltage across R_2 will be two thirds of the supply voltage (E). So, if the supply voltage and the resistor values are known, then the voltage across each resistor can be worked out by PROPORTION, and once the voltage across each resistor is known the voltage at any point in the circuit can be calculated.

Using these few facts it is possible to work out an amazing amount of information about the currents and voltages in a circuit, once the values of the circuit resistances are known. Try it out for yourself with our "Find the Missing Value" Quiz on the Network Calculations page.

Module 4.1
Resistors & Circuits

<table>
<tr><td>

What you'll learn in Module 4.1

After studying this section, you should be able to:

Label EMF(E) potential difference(p.d.) and Voltage(V) in a circuit diagram.

Describe the difference between electron flow & conventional current.

Define the Ampere.

</td></tr>
</table>

Current, Voltage & E.M.F.
Electric Current

Electric current is the flow of electrons in a conductor. A conductor can be any material (usually a metal) that has an atomic structure that allows electrons to be easily detached from their parent atom by an electric force (called a voltage or an electric potential). These "free electrons", which are naturally negatively charged are attracted towards a positive electric charge. This movement is called ELECTRON FLOW and is also called an electric current. So current flows from the negative terminal to the positive terminal in an electrical circuit.

Looking at this a different way, the atoms that are now short of the negatively charged electrons that have been attracted away by the electric potential, must be positively charged. In this state they are called positive ions and they will be attracted towards a negative electric charge. Therefore current (in the form of positive ions) can also be considered to be flowing from positive to negative, so it depends whether current is considered to be due to the movement of electrons or to the movement of positive ions. Both are correct, and both ways of considering current can be used in practice.
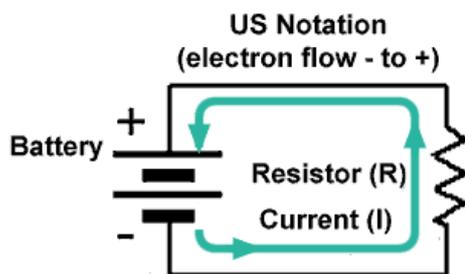
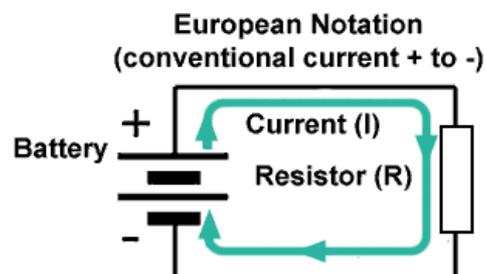

Fig. 4.1.1 Current Flow (US Method)

Fig. 4.1.2 Current Flow (EU Method)

To clarify which current flow is being referred to, the two directions of flow are called:

ELECTRON FLOW – Flows from negative to positive.

CONVENTIONAL CURRENT – Flows from positive to negative.

Whether current is considered as flowing from negative to positive or from positive to negative depends in many cases on where you live. In the USA some text books and diagrams may show current flowing from negative to positive (Electron Flow) although Conventional Current Flow is also used. In Europe Conventional Current flow is the preferred direction, unless specifically relating to the flow of electrons. Which system is used doesn't really matter, so long as you know which system you are using! For most purposes, at www.learnabout-electronics.org CONVENTIONAL CURRENT will be used for our explanations of how circuits work, only using electron flow when the flow of current is entirely, or mostly made up of moving electrons. (As in devices such as transistors). Therefore, unless specifically stated otherwise you can assume that current flows from positive to negative.

This flow is normally shown in diagrams by a small arrow head placed on the conductor and labelled I_1, I_2 etc. as illustrated in Fig. 4.1.3.

Indicating Current Flow in a Simple circuit

Current is measured in Amperes, (often abbreviated as 'Amps') or commonly in milliAmperes or microAmperes in electronic circuits.

An Ampere can be defined as;

The amount of electric charge, measured in Coulombs, which passes a given point in a circuit, per second.

1 Ampere = 1 Coulomb per second.

1 Coulomb is the amount of charge carried by approximately $6.24150948 \times 10^{18}$ electrons, or to be a little more exact: 6,241,509,479,607,717,888 electrons!

The measurement of the Ampere is not made, believe it or not, by sitting there and counting electrons! It is actually defined by calculating the force exerted between the magnetic fields around two parallel wires. If you are really keen to get into the numbers and method of defining the Ampere try this page at the U.S. Department of Commerce website: http://physics.nist.gov/cuu/Units/ampere.html.

Voltage and E.M.F.

Whenever a current is flowing, a voltage must be present. Voltage is sometimes described as an electrical pressure, the force that drives current through the circuit, just as water pressure drives water around a circulating pipe. In electrical terms, a voltage is actually the difference in electric charge at two points in a circuit. This difference in charge at two points will always try and equalise by causing

Fig. 4.1.3 Labelling Voltages and Currents.

the electrons to flow around the circuit. With no potential difference between different points in a circuit there will be no current flow. Equally if there are potential differences, but the circuit is incomplete (i.e. there is a break in the circuit) there will be no current.
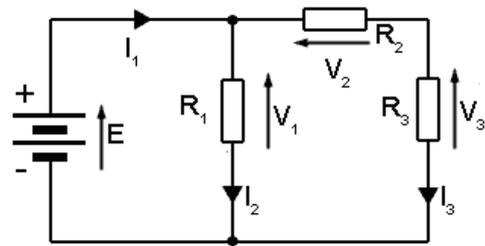
What causes the charge difference is therefore the force that drives a circuit. This may be a device such as a CELL or a BATTERY (a battery is just several interconnected cells) or alternatively the source of electric potential may be derived from the mains (line) supply. Whatever the source of energy used the driving force for the circuit current can be called the ELECTRO-MOTIVE FORCE or E.M.F.

The term E.M.F. is only used to describe that difference in charge or difference in "voltage" that is the actual **source** of power for our circuit. Differences in voltage between any other points in the circuit are called "potential differences" (abbreviated to p.d). Both EMF and potential difference are measured in Volts, and so are often both (inaccurately) called "voltages". In addition voltages may each sometimes be labelled E just to add to the confusion.

Strictly speaking the Electrical potential that drives the circuit is called an EMF (measured in volts) and is labelled E.

The difference in electric potential between any other two points in the circuit is called a POTENTIAL DIFFERENCE or p.d. (also measured in Volts) and labelled V.

A voltage in a circuit (either EMF or potential difference) may be shown by an arrow alongside the two points in the circuit (often the two ends of a component) where the potential difference or EMF exists. Conventionally the arrow head is at the more positive potential. Multiple voltages and currents may be labelled V_1, V_2, I_1, I_2 etc. as illustrated in Fig. 4.1.3.

Module 4.2
Series & Parallel Resistors

What you'll learn in Module 4.2

After studying this section, you should be able to:

Calculate total resistance values in series resistance networks.

Use appropriate formulae to calculate resistance in parallel resistance networks.
- Reciprocal of the sum of reciprocals.
- Product over sum.

Calculate total resistance values in series/parallel networks.

Calculations in Series & Parallel Resistor Networks

Components, including resistors in a circuit may be connected together in two ways:

IN SERIES, so that the same current flows through all the components but a different potential difference (voltage) can exist across each one.

IN PARALLEL, so that the same potential difference (voltage) exists across all the components but each component may carry a different current.
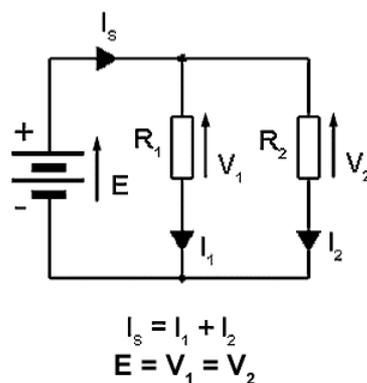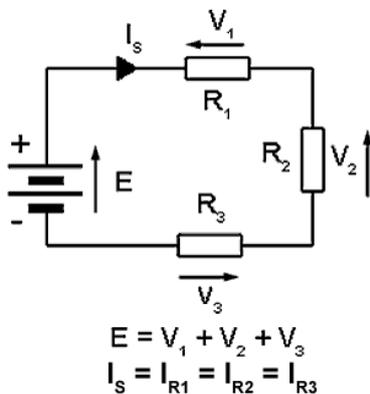
In either case (for resistors) the total resistance of that part of the circuit containing the resistors can be calculated using the methods described below.

Being able to calculate the combined (total) value of resistors in this way makes it easy to work out unknown values of resistance, current and voltage for quite complex circuits using relatively simple methods. This is of great use in

$E = V_1 + V_2 + V_3$
$I_S = I_{R1} = I_{R2} = I_{R3}$

$I_S = I_1 + I_2$
$E = V_1 = V_2$

Fig. 4.2.1 Resistors in Series **Fig. 4.2.2 Resistors in Parallel**

fault finding.

BEFORE GOING ANY FURTHER, PRACTICE USING THE FORMULAE FOR CALCULATING THE TOTAL VALUES OF SERIES AND PARALLEL RESISTORS.

For resistors in series:

The total resistance of two or more resistors connected **in series** is given by simply adding the individual values of the resistors to find the total sum (R_{TOT}):

$$R_{TOT} = R_1 + R_2 + R_3 \ldots \text{etc.}$$

For resistors in parallel:

To calculate the total resistance of a circuit that involves parallel resistors the following formula can be used.

$$\frac{1}{R_{TOT}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots \text{etc.}$$

Notice however that this formula does NOT give you the total resistance R_{TOT}.

It gives you the RECIPROCAL of R_{TOT} or:

$$\frac{1}{R_{TOT}}$$

This is a very different value - and is NOT the total resistance. It is 1 divided by R_{TOT}. To obtain the **correct** value for R_{TOT} (which will be reciprocal of $1/R_{TOT}$, i.e. $R_{TOT}/1$ simply press the reciprocal key on your calculator (marked $1/x$ or x^{-1}).

Another way to calculate parallel circuits.

The total Resistance of **two resistors in parallel** that does not involve reciprocals is given by:

$$R_{TOT} = \frac{R_1 \times R_2}{(R_1 + R_2)}$$

This formula is often referred to as 'Product over Sum'.

Does it only calculate TWO resistors in parallel? Well, yes, but that´s not a big problem. If there are more than two parallel resistors, just choose two of them and work out the total resistance for these two - then use that total as if it was a single resistor and make another pair with a third resistor. Work out the new total, and so on until you have included all the parallel resistors in that particular network.

Oh, one more thing to remember about product over sum, see the brackets around the sum (bottom part) of the formula? That means you have to work this out BEFORE you use it to divide the product (top part) by. If you don't, your answer will be wrong.

Sounds complicated? Not really, it is just a matter of repetition, and in practice you don't often come across many parallel networks with much more than two resistors. Still, which formula you choose is up to you, reciprocals or product-over-sum.

Tips

Using the Reciprocal Method

If you use the RECIPROCAL METHOD for parallel circuits DON'T FORGET, when you have added the reciprocals of the individual resistors - You must find the reciprocal again. $1/R1 + 1/R2 + 1/R3 = 1/R_{TOT}$ and to find R_{TOT} you must find the reciprocal of $1/R_{TOT}$.

Simplifying Circuits

For combined series and parallel circuits, work out a section of the circuit (series or parallel) first. Then re-draw the circuit replacing the section you have found the resistance of, with a single resistor. You now have a simplified circuit in which to find R_{TOT}.

You can use the product over sum formula:

$$R_{TOT} = \frac{R_1 \times R_2}{(R_1 + R_2)}$$

For circuits with more than two parallel resistors, simply work out two parallel resistors at a time using the product over sum formula, and then re-draw the circuit replacing the two resistors with a single resistor whose value is the combined resistance of the two.

Now you can use your first combined value as a single resistor with the next parallel resistor, and so on. In this way a large number of parallel resistors can be worked out using product over sum.

When all the parallel resistors are the same value.

If a number of identical parallel resistors are connected, the total resistance will be the resistor value multiplied by the reciprocal of the number of resistors.

i.e. Two 12K resistors in parallel have a combined resistance of

12K x 1/2 = 6K

Three 12K resistors in parallel have a combined resistance of

12K x 1/3 = 4K etc.

Checking your answer

The combined value of any number of parallel resistors will always be LESS than the value of the smallest individual resistor in the network. Use this fact to check your answers.

Series and Parallel Combined

Try a few calculations based on series and parallel resistor networks. For these you need to use the information in this Module. You are asked to work out the total resistance for each circuit, and you can choose which formula to use.

You can also find help with the maths by downloading our free 'Maths Tips' booklet from:

http://www.learnabout-electronics.org/Site/downloads.php.

Before starting, think about these few tips. They will make the problems easier if you follow them carefully.

1. Work out the answers using pencil and paper; redraw the circuit you are working on.

2. Of course the answer is not just a number, it will be a certain number of Ohms, don't forget to show the correct unit (e.g. Ω, KΩ or MΩ) or your answer is meaningless.

3. When you put values into your calculator convert all KΩ or MΩ values to Ohms by using the EXP key. If you slip up here it will give get really stupid answers, thousands of times too big or too small.

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

Series and Parallel Circuit Example.
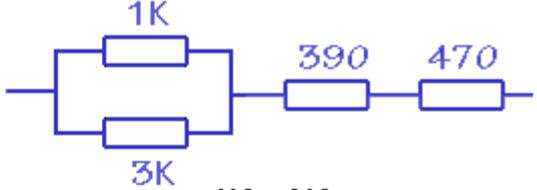
Ok, well plenty to remember there, so why not try some practice questions in Resistors & Circuits Module 4.5 on finding the total resistance of some resistor networks?

Module 4.3
Open Circuit Faults

What you'll learn in Module 4.3

After studying this section, you should be able to:

Describe the effects of open circuit components in basic resistive circuits.

Diagnose open circuit component faults in resistive circuits.

Open Circuits

Current will only flow IN A CIRCUIT. That is, around a continuous path (or multiple paths) from and back to the source of EMF. Any interruption in the circuit, such as an open switch, a break in the wiring, or a component such as a resistor that has changed its resistance to an extremely high value will cause current to cease.

The EMF will still be present, but voltages and currents around the circuit will have changed or ceased altogether. The open switch or the fault has caused what is commonly called an OPEN CIRCUIT.

Remember that wherever an open circuit exists, although voltage may be present there will be no current flow through the open circuit section of the circuit. Also, as Power (P) is V x I and the current (I) = 0, no power will be dissipated.

Looking further at the simple resistive circuit introduced in Resistors & Circuits Module 4.1 let's put some actual voltages and currents in and see what happens when 'Open Circuit' faults occur.

Fig 4.3.1 on page 9, shows a number of open circuit conditions that might occur in different parts of the circuit. Notice how the voltages and currents around the circuit change depending on where the break in the circuit (the open circuit) occurs. Checking the voltages around a circuit with a voltmeter, and noticing where they differ from what would be expected in a correctly working circuit, is one of the main techniques used for tracing a fault in any circuit. Making sense of this method depends on understanding a few basic facts about the circuit:

1. The current I_S supplied to the circuit by the battery (E) is divided into two currents I_1 flowing through R_1 and I_2 flowing through R_2 and R_3.

2. Because R_2 and R_3 are connected in series, the same current (I_2) flows through both resistors.

3. Both branches of the circuit (R_1 and R_2/R_3 have the same resistance in this circuit (150Ω, commonly shown in circuit diagrams as 150R).

4. Therefore half of the 40mA supply current (20mA) flows through each 150Ω branch of the circuit, causing the shown voltages to be developed across each resistor.

5. It would be unusual in practice to be given all of the current and voltage information on every circuit diagram. The voltages and currents would need to be worked out where needed by applying the methods described in Resistors & Circuits Module 4.0 (Current and Voltage in Resistor Networks).

Fault finding techniques vary with the complexity of the circuit involved but all rely to some degree on the basic methods shown here, and very often on the application of Ohms Law. These examples, whilst not intended to be typical of faults encountered in already built printed circuits, may often be encountered when building circuits on breadboard (Proto board) when components may be wrongly inserted, or not make a good connection.
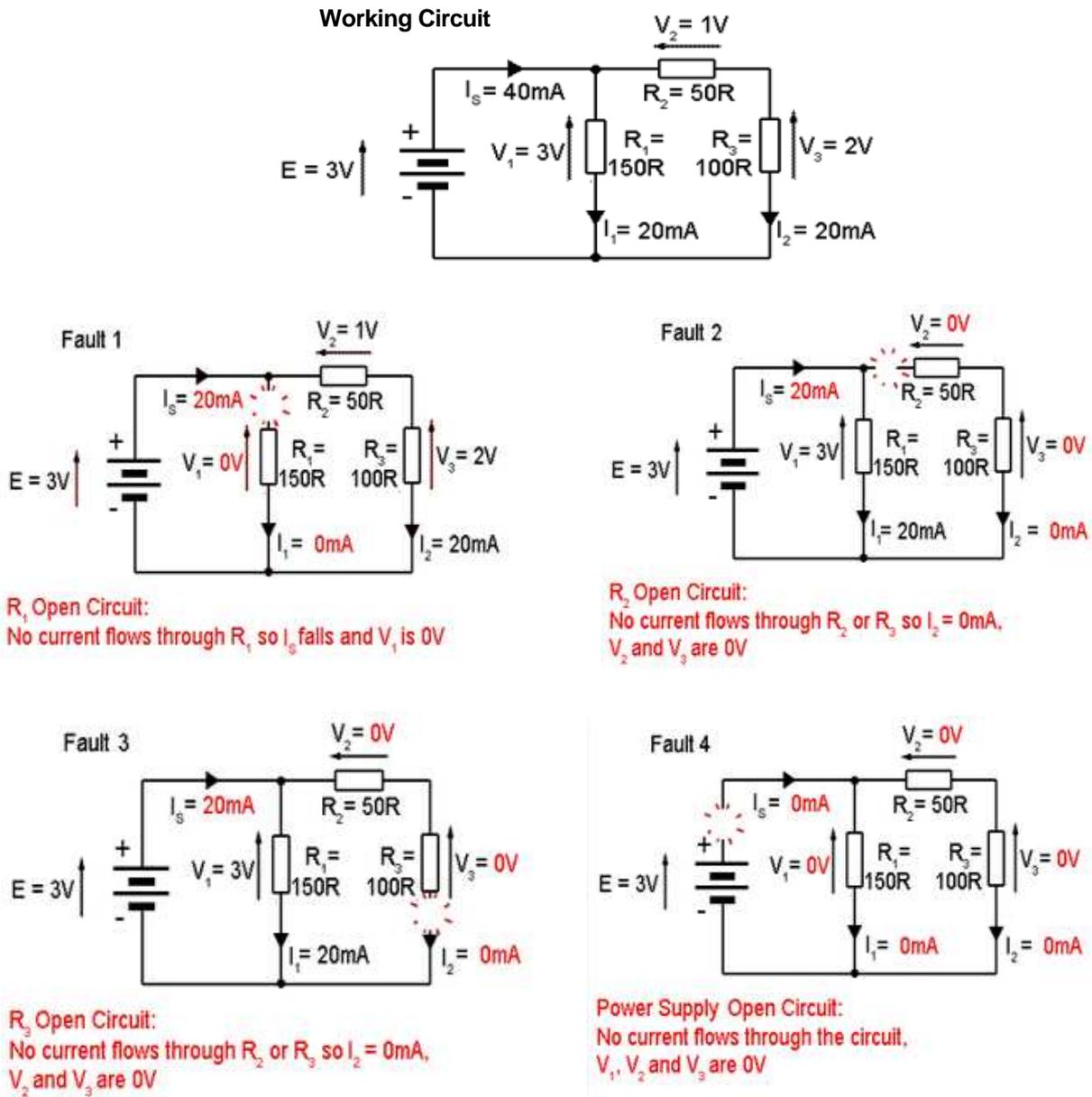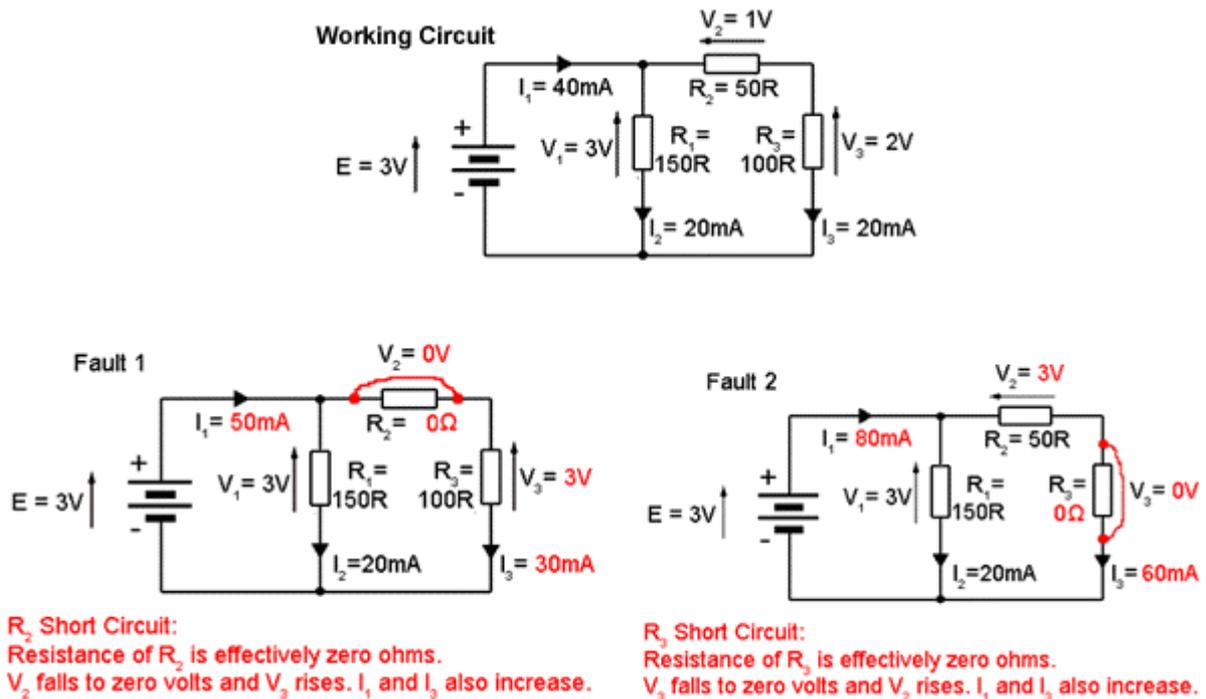
Working Circuit

Fig. 4.3.1 Open Circuit Faults

The opposite extreme fault condition to having an open circuit is having a component or components go 'Short Circuit', which is dealt with in Resistors & Circuits Module 4.4.

Module 4.4
Short Circuit Faults

What you'll learn in Module 4.4

After studying this section, you should be able to:

Describe the effects of short circuit components in basic resistive circuits.

Diagnose short circuit component faults in resistive circuits using current and voltage measurements.

Short Circuits

If two points in a circuit are connected by some component or conductor having a resistance of zero (or practically zero) ohms, the two points are said to be SHORT CIRCUITED or that there is a short circuit present. Under these conditions a larger current will flow, due to the reduction in resistance, and there will be NO (or almost no) potential difference between the ends of the short circuit.

These conditions are illustrated in Fig 4.4.1.

Working Circuit

$V_2 = 1V$

$I_1 = 40mA$ $R_2 = 50R$

$E = 3V$ $V_1 = 3V$ $R_1 = 150R$ $R_3 = 100R$ $V_3 = 2V$

$I_2 = 20mA$ $I_3 = 20mA$

Fault 1

$V_2 = 0V$

$I_1 = 50mA$ $R_2 = 0\Omega$

$E = 3V$ $V_1 = 3V$ $R_1 = 150R$ $R_3 = 100R$ $V_3 = 3V$

$I_2 = 20mA$ $I_3 = 30mA$

R_2 Short Circuit:
Resistance of R_2 is effectively zero ohms.
V_2 falls to zero volts and V_3 rises. I_1 and I_3 also increase.

Fault 2

$V_2 = 3V$

$I_1 = 80mA$ $R_2 = 50R$

$E = 3V$ $V_1 = 3V$ $R_1 = 150R$ $R_3 = 0\Omega$ $V_3 = 0V$

$I_2 = 20mA$ $I_3 = 60mA$

R_3 Short Circuit:
Resistance of R_3 is effectively zero ohms.
V_3 falls to zero volts and V_2 rises. I_1 and I_3 also increase.

Fig. 4.4.1 Short Circuit Faults

The opposite extreme fault condition to having a short circuit is having a component or components go 'Open Circuit', which is dealt with in Resistors & Circuits Module 4.3.
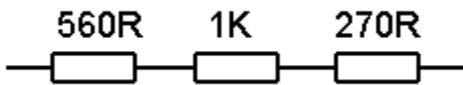
Module 4.5
Resistor Circuits Quiz

Resistor Networks Calculation Practice
For each circuit, calculate the total resistance of the network.

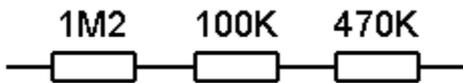Work out your answers with pencil, paper and calculator.

Use the tips given in Circuits & Resistors Module 4.2. Submit your answers on line at the quiz page in Circuits & Resistors Module 4.5. on http://www.learnabout-electronics.org/Resistors/resistors_20.php and see how many you get right. If you get any answers wrong. Just re-check our tips and your calculations to find the right answer, and learn more about series and parallel resistor calculations as you go.

1.

560R   1K   270R

a) 831Ω   b) 1.83KΩ

c) 831KΩ   d) 151KΩ

2.

1M2   100K   470K

a) 571KΩ   b) 1.77MΩ

c) 42.2MΩ   d) 1.47MΩ

3.

470R   680R

a) 1.36KΩ   b) 1.15KΩ

c) 1.45KΩ   d) 278Ω

4.

1K   2K   2K   5K

a) 10KΩ   b) 5.5KΩ

c) 454Ω   d) 2KΩ

5.

1K8   2K2

470R   270R

a) 624Ω   b) 8.87KΩ

c) 1.48KΩ   d) 4.7KΩ
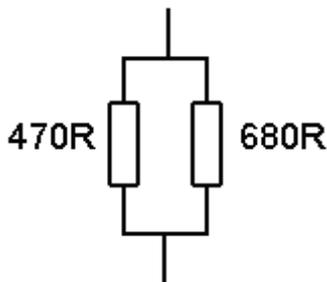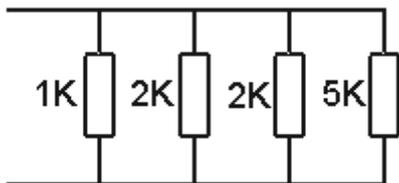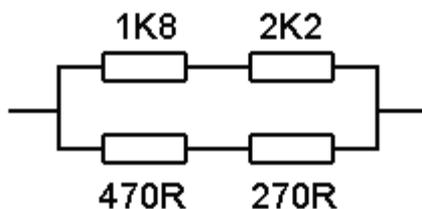
6.
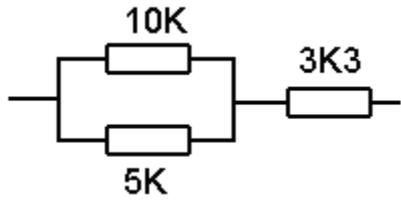
a) 10.8KΩ   b) 3.3KΩ

c) 6.63KΩ   d) 18.3KΩ

7.
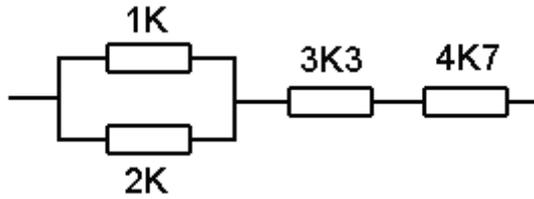
a) 9.5KΩ   b) 11KΩ

c) 8.67KΩ   d) 12KΩ
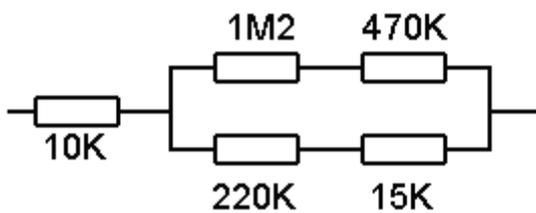
8.
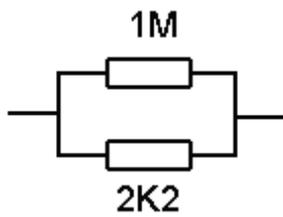
a) 1.2MΩ   b) 688Ω

c) 3.3MΩ   d) 2.19KΩ

9.
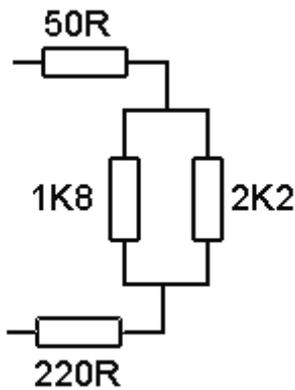
a) 990Ω   b) 271KΩ

c) 1.26KΩ   d) 2.71KΩ

10.

a) 206Ω   b) 216KΩ

c) 24.5KΩ   d) 206KΩ

Module 4.6
Network Calculations Quiz

Voltages & Currents in Resistor Networks

Ohms law calculations and a few basic facts such the Potential Divider rule are really useful tools to work out voltages, currents and resistances in resistor networks, and are essential skills in understanding how circuits work and, when fault finding, understanding why they don't work! Build your skills by working out some unknown values in the circuits below. Before you try this quiz however, it may be a good idea to look at some the basic facts about voltages and currents in resistor networks and some Ohms Law basics.
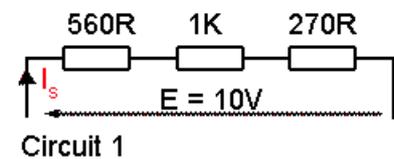
Ready to Go?

Use the tips given in our Resistors & Circuits Module 4 and Module 3 pages, work out your answers with pencil, paper and calculator. Then check your answers in the on line quiz at:

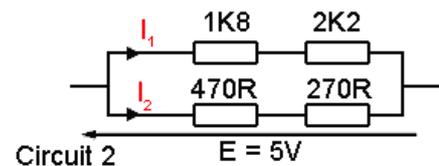www.learnabout-electronics.org/Resistors/resistors_23.php

1. What is the value of the supply current Is in Circuit 1?
a) 183mA   b) 5.46mA   c) 12mA   d) 2.4mA

Circuit 1

2. What is the value of the component current I_1 in circuit 2?
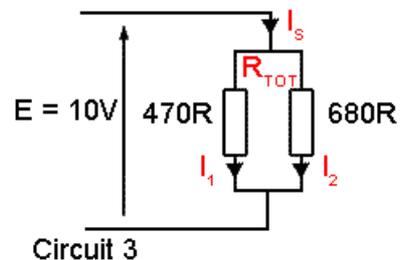a) 1.25mA   b) 800mA   c) 1.25A   d) 1.26μA

3. Calculate the value of I_2 in Circuit 2
a) 148mA   b) 148μA   c) 6.7mA   d) 39μA

Circuit 2

4. Calculate the total resistance R_{TOT} of Circuit 3
a) 1.36KΩ   b) 278Ω   c) 1.15KΩ   d) 319Ω

5. What is the value of I_1 in Circuit 3?
a) 500mA   b) 8.7mA   c) 21.3mA   d) 47mA

Circuit 3

6. Calculate the value of I_2 in Circuit 3
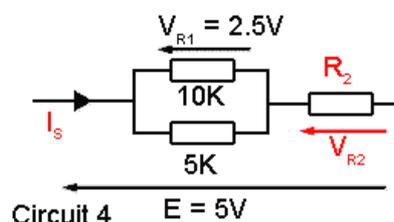a) 6.8mA   b) 21μA   c) 21mA   d) 14.7mA

7. What is the supply current I_S in Circuit 3?
a) 36mA   b) 8.7mA   c) 47mA   d) 6.8mA

8. Calculate the potential difference V_{R2} across R_2 in Circuit 4
a) 3V   b) 2.5V   c) 3.3V   d) 4.5V

Circuit 4

9. In Circuit 4, what is the value of the supply current I_S?
a) 1.5mA   b) 1mA   c) 751μA   d) 500μA

10. In Circuit 4, what is the value of R_2?
a) 7.2KΩ   b) 5KΩ   c) 3.3KΩ   d) 33KΩ