

Supplementary Notes for Unit 2 - Part A

(Unit 3 and 4 exams also includes the topics detailed in this note)

Series circuits

A series circuit is a circuit in which resistors are arranged in a chain, so the current has only one path to take. *The current is the same through each resistor.* The total resistance of the circuit is found by simply adding up the resistance values of the individual resistors:

The total equivalent resistance of resistors in series is found by adding the individual values of all the resistors connected in series: $R_E = R_1 + R_2 + R_3 + \dots$

It means if the resistances R_1 , R_2 and R_3 connected in series in figure 1 are replaced by one resistance R_E in figure 2, whose value is equal to the sum of R_1 , R_2 and R_3 , then the circuit in figure 2 will behave in the same way as in figure 1. If the same voltage 'V' is connected to both the circuit then the same amount of current 'I' will flow in the circuit.

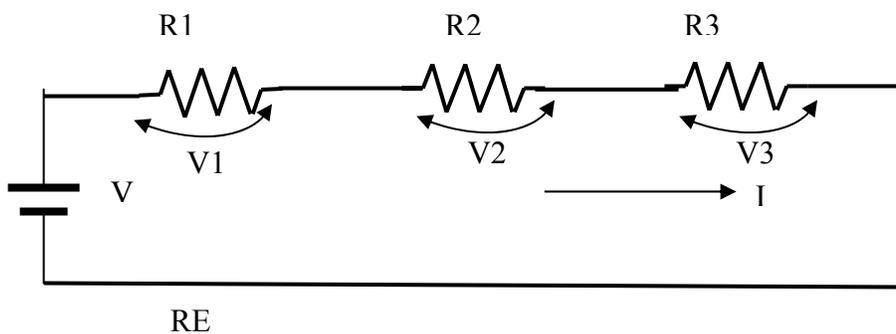


Figure 1. Resistances in series

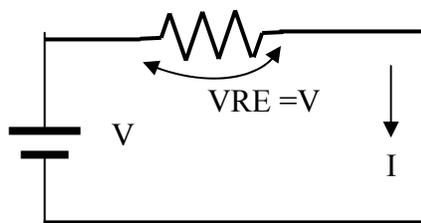


Figure 2. Equivalent circuit of figure 1 if $R_E = R_1 + R_2 + R_3$

In case of series circuit, the voltages across different resistors are different depending on the value of the resistances. It is always true that the sum of the voltages on individual resistor is equal to the total voltage supplied by the battery i.e. $V = V_1 + V_2 + V_3$.

Also note that the voltage on each resistance is equal to the product of the value of the resistance (R) expressed in ohms and the value of the current (I) flowing through it expressed in Amperes. For example the value of voltage (V_1) on resistance R_1 in the above circuit will be

$$V_1 = R_1 \cdot I, \text{ Similarly } V_2 = R_2 \cdot I, \text{ and } V_3 = R_3 \cdot I$$

Example: If the values of the three resistors are:

$$R_1 = 20\Omega, \quad R_2 = 10\Omega, \quad R_3 = 30\Omega$$

$$\text{Then the value of the equivalent resistance } R_E = 20\Omega + 10\Omega + 30\Omega = 60\Omega$$

Current in a circuit can be calculated using the formula: $I = V / R$ i.e. the value of current (I) expressed in Ampere between two points can be calculated by dividing the voltage (V) expressed in Volts by the resistance (R) expressed in Ohms between the two points. This is also known as Ohm's Law.

In the above example, if the battery has a voltage value of 10 V, then the total current in the circuit is: $I = V/R = 10/60 = 1/6$ Ampere = 0.166 A. The current through each resistor would be 0.166 A.

Parallel circuits

A parallel circuit is a circuit in which the resistors are arranged with their heads connected together, and their tails connected together, as shown in figure 3a and is same in figure 3b shown in slightly different arrangements. *The current in a parallel circuit breaks up*, with some flowing along each parallel branch and re-combining when the branches meet again. *The voltage across each resistor in parallel is the same*, because all have the same common points.

The total equivalent resistance of a set of resistors in parallel is found by adding up the reciprocals of the resistance values, and then taking the reciprocal of the total as shown below:

$$1/R_E = 1/R_1 + 1/R_2 + 1/R_3 + \dots$$

It means if the resistances R_1 , R_2 and R_3 connected in parallel in figure 3a or 3b are replaced by one resistance R_E in figure 4, whose value is taken such that $1/R_E = 1/R_1 + 1/R_2 + 1/R_3$, then the circuit in figure 3a or 3b will behave in the same way as in figure 4. If the same voltage 'V' is connected to both the circuit then the same amount of current 'I' will be generated in the circuit. However, in parallel circuits the current supplied by the battery splits up in different values, and the amount going through each resistor depends on the resistance.

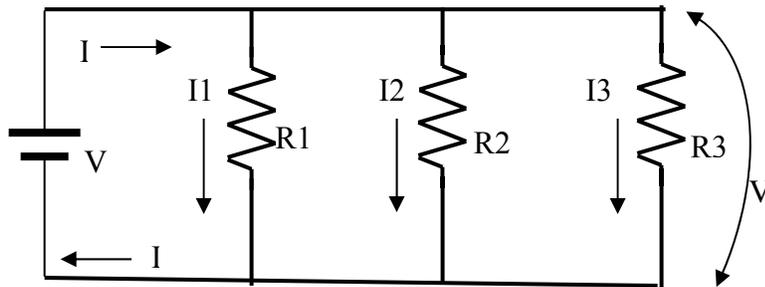


Figure3a. Resistances in parallel

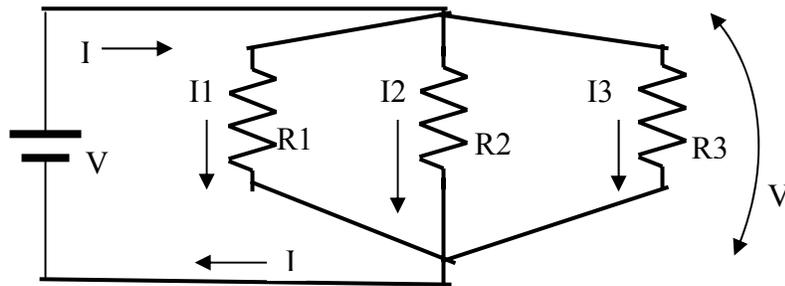


Figure3b. Resistances in parallel same as in 3a

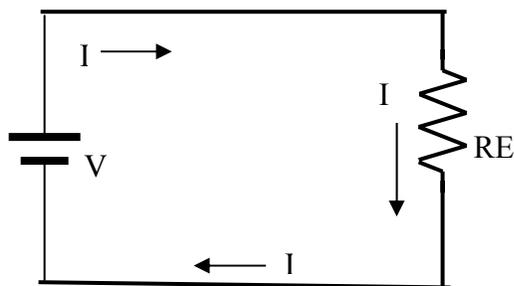


Figure 4. Resistances in parallel same as in 3a

The values of I_1 , I_2 and I_3 will depend on the values of R_1 , R_2 and R_3 respectively and will be discussed in the subsequent units. If $R_1=R_2=R_3$, then the following relationship will be true: $I_1=I_2=I_3$.

The following relationship will always also be true. It means that the current flowing into a node will be equal to the sum of the current flowing out of the node.

$$I = I_1 + I_2 + I_3$$

Example: If the values of the three resistors are:

$R_1 = 10\Omega$, $R_2 = 10\Omega$, and $R_3 = 20\Omega$ Then the equivalent R_E resistance can be calculated as

$$\frac{1}{R_E} = \frac{1}{10} + \frac{1}{10} + \frac{1}{20} = .1 + .1 + .05 = .25$$

So, $\frac{1}{R_E} = .25$ i.e $R_E = \frac{1}{.25} = 4\Omega$

Using the formula of Ohm's Law, as used in series circuit, $V=I/R$ we can calculate the current.

In the above example, if the battery has a voltage value of 10 V, then the total current in the circuit is: $I = V/R = 10/4 = 2.5$ A.

As we discussed that for parallel circuit the voltage across each resistor is same i.e. 10 V, so:

$$I_1 = V/R_1 = 10/10 = 1 \text{ A}$$
$$I_2 = V/R_2 = 10/10 = 1 \text{ A}$$
$$I_3 = V/R_3 = 10/20 = 0.5 \text{ A}$$

Note that $I_1+I_2+I_3 = 1 + 1 + .5 = 2.5$ equals to the total current $I=2.5$ A.

Important points to Remember on Series and parallel Circuits:

For Serial Circuits:

- Series circuits have only one path, so the amount of flow of current is same through all resistors. If any part of the series circuit is broken no current will flow through the circuit.
- The amount of current in circuit is: $I=V/R_E$. (V in volts, R_E in Ohms and I in amperes)
- Voltage on each resistor will be different depending on the value of the resistor.
 $V_1=IR_1$, $V_2=IR_2$, $V_3=IR_3$
- The sum of the voltage on individual resistor is equal to the output voltage of the source.
 $V = V_1+ V_2+ V_3$
- The equivalent resistor in series can be calculated with the formulae: $R_E = R_1+R_2+R_3$

For Parallel Circuits:

- Voltage is the same for along parallel paths, but current splits to different branches.
- Parallel circuits have two or more paths for flow of current. Amount of current through a path depends on the value of the resistors. Formulas; $I_1 = V/R_1$, $I_2 = V/R_2$ and $I_3 = V/R_3$
- The sum of the current through individual path is equal to the total current that flows from the source.
 $I = I_1+ I_2 + I_3$
- The equivalent resistor in parallel can be calculated with the formulae: $1/R_E=1/R_1+1/R_2+1/R_3$
- If one of the parallel path is broken, current will continue to flow through the remaining path.
- If one of the parallel path is short circuited (i.e. connected with a wire meaning resistance =0) then all current will flow through the short circuit and R_E will become zero ohm.

Visit the URL: '<http://home.att.net/~basicelectronics/parallel.htm>' for more explanation with figures and in an easy to understand approach.

Also visit: http://www.antonine-education.co.uk/Physics_AS/Module_3/Topic_3/topic_3__series_and_parallel_cir.htm

Circuits with combination of series and parallel components

Many circuits have a combination of series and parallel resistors. Generally, the total resistance in such a circuit is found by reducing the different series and parallel combinations step-by-step to end up with a single equivalent resistance for the circuit. This allows the current from the source to be determined easily. The current flowing through each resistor can then be found by undoing the reduction process.

General rules for doing the reduction process may be completed in the following steps:

1. First, each of the parallel connections can be reduced to one resistor using the equivalent resistance equation for resistors in parallel. Note that two (or more) resistors with their heads directly connected together and their tails directly connected together are in parallel.
2. In the next step the resistors (including the equivalent resistors calculate from the parallel connections) in series can be reduced to one equivalent resistor using the equation for resistors in series. Note that two

resistors connected together so that the tail of one is connected to the head of the next, with no other path for the current to take along the line connecting them, are in series.

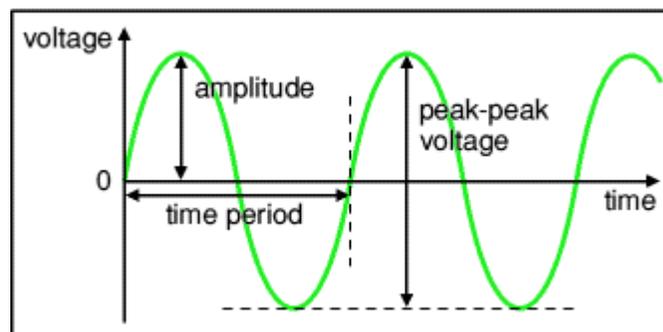
A parallel resistor short-cut

If the resistors in parallel are identical, it can be very easy to work out the equivalent resistance. In this case the equivalent resistance of N identical resistors is the resistance of one resistor divided by N, the number of resistors. So, two 40-ohm resistors in parallel are equivalent to one 20-ohm resistor ($40/2$ ohm); five 40-ohm resistors in parallel are equivalent to one 8-ohm resistor, ($40/5$) etc.

When calculating the equivalent resistance of a set of parallel resistors, do not forget to flip the $1/RE$ upside down, putting $1/5$ of an ohm instead of 5 ohms, for instance.

Alternating Current - Periodic Signal

Direct current (DC) from a battery moves in one direction only, from positive to negative. In **alternating current (AC)** the direction is changing all the time. Power supplies in our homes are AC supply and are periodic in nature.



<http://www.kpsec.freeuk.com/acdc.htm>

- The signal in the graph is called a **sinusoidal waveform** or a **sine wave**.
- **Amplitude** is the maximum voltage reached by the signal. It is measured in **volts, V**. Amplitude is also known as **Peak Voltage**.
- **Peak-to-peak voltage** is twice the peak voltage (amplitude).
- One complete alternation that is repeated over time is called a **cycle**. The **Time Period** is the time taken for one cycle. It is measured in seconds (**s**). Normally time period tends to be very small. So it is often expressed in milliseconds (**ms**, one thousandth part of a second: 10^{-3} seconds or 0.001s), microseconds (**µs**, one millionth of a second: 10^{-6} seconds or 0.000001s), nanoseconds (10^{-9} seconds) etc.
- The **frequency** is the number of cycles in one second. Units are **hertz (Hz)**. 1 Hz means that the signal has 1 cycle in 1 second. Frequencies tend to be very high. So, it is often expressed in kilohertz (**KHz**; 1000 Hz or 10^3 Hz), Megahertz (**MHz**; 1,000,000 Hz or 10^6 Hz) etc. 1 KHz means that the signal has 1000 cycles in 1 second i.e. the period will be $1/1000$ second or 1 millisecond. Similarly, a signal with frequency of 1 MHz will have a period of 1 microseconds).
- If frequency is denoted by f and period by T , then the formula is $f = 1/T$.
- The current follows exactly the same wave form as voltage.
- The terminologies frequency, period, cycles etc. are applicable to all signals that are periodic in nature e.g. triangular, square wave etc.

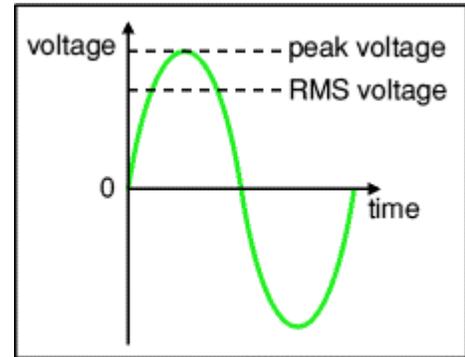
The frequency of AC supply is 50 Hz (cycles per second) in UK; 60 Hz in USA. A frequency of 50 Hz means a period of $1/50 = .02s = 20ms$.

Root Mean Square (RMS) Values

The value of an AC voltage is continually changing. We use the **root mean square voltage** (V_{RMS}) to express AC signals. RMS is expressed in terms of **peak voltage** (V_{peak}) given by the following formula:

$$V_{RMS} = 0.7 \times V_{peak} \quad \text{OR} \quad V_{peak} = 1.4 \times V_{RMS}$$

These equations also apply to **current**. These equations apply only for sine waves, which is the most common type of AC. The values 0.7 and 1.4 are different other shapes.



The **RMS value** is the **effective value** of a varying voltage or current. It is the equivalent steady DC (constant) value which gives the same effect.

For example, a lamp connected to a **6V RMS AC** supply will light with the same brightness when connected to a **steady 6V DC** supply. However, the lamp will be dimmer if connected to a **6V peak AC** supply because the RMS value of this is only 4.2V (it is equivalent to a steady 4.2V DC). In everyday use AC voltages (and currents) are always given as **RMS values**. It should be clearly stated if peak value is indicated.

Note that RMS value is NOT average value of the signal. In fact the average voltage (or current) of an AC sine wave signal is zero because the positive and negative parts exactly cancel out.

Visit URL <http://www.kpsec.freeuk.com/acdc.htm> for more details.

Measuring Instruments and Power Sources:

Measuring Instruments: Voltmeter, Ammeter, Multimeter, Oscilloscope

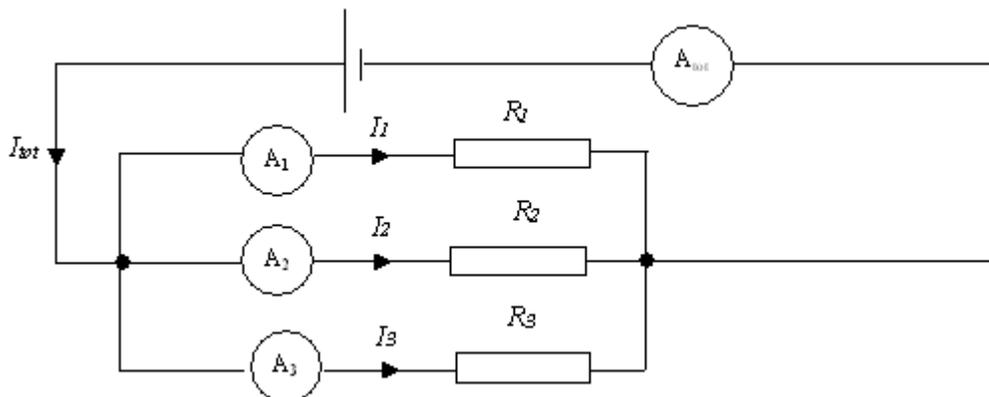
Power Sources: DC power supply and Function Generator

Read from the lab manual.

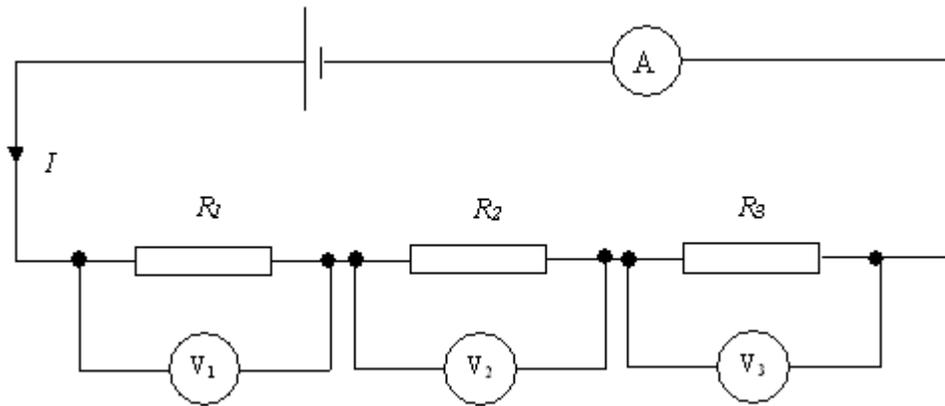
See the 'supplementary material for unit 2 - Part B', posted on this subject's web page, that includes picture of equipments with explanations that are used for unit 2 and subsequent experiments.

Important points to Remember on Measuring Instruments:

- For measurement of current the instrument must be connected in series to the measuring path, as shown in the figure. For example, for measuring current in each of the parallel path of resistances R_1 , R_2 and R_3 the ammeters (A_1 , A_2 , and A_3) must be in series with each of the resistors R_1 , R_2 and R_3 . If you have only one measuring instrument you can measure one after the other.



- The resistance of current measuring instrument is low.
- For measurement of voltage the measuring instrument must be connected in parallel between the two points for which the voltage is to be measured, as shown in the following figure. For example, for measuring voltage across resistance R_1 it should be placed in parallel to R_1 and so on.
- The resistance of voltage measuring instrument is very high.



- For measurement of resistance the power supply must be disconnected from the circuit. The instrument applies a known voltage across the resistor and measures the current to determine the value of the resistance.
- You must set the appropriate range before start of measurement. The range must be set to a higher value than the expected measured value.
- You must make sure that the connections made are appropriate to the quantity you want to measure. For example, to measure resistance with a multimeter the jacks must be connected to COM and Ω inputs of the multimeter. The measurement select switch must be in the ohm (Ω) measuring position and proper range selected.
- Oscilloscope measures only voltage and have high input resistance. Read the manual for selection of the volts/div and Time/div switches.
- AC voltmeters and ammeters show the **RMS value** of the voltage or current. DC meters also show the RMS value when connected to varying DC providing the DC is varying quickly, if the frequency is less than about 10Hz you will see the meter reading fluctuating instead.

Fig. Source - http://www.antonine-education.co.uk/Physics_AS/Module_3/Topic_3/topic_3__series_and_parallel_cir.htm