

## Episode 123: Alternating current

The aims are to distinguish alternating from direct currents and to remind your students of why ac is so important (they should already have met this at pre-16 level).

### Summary

**Demonstration: The output of a generator. (10 minutes)**

**Student experiment: Measuring ac with a CRO. (20 minutes)**

**Discussion: R.m.s. values as equivalent dc values. (20 minutes)**

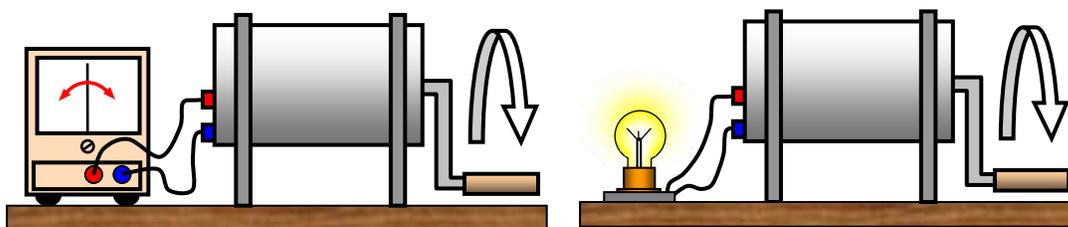
**Demonstration: Finding the r.m.s. value. (15 minutes)**

**Student questions: Practice on ac (20 minutes)**

### Demonstration:

#### The output of a generator

A simple hand-turned generator can be used to create an alternating voltage that can be seen on an analogue demonstration voltmeter (needle swaying back and forth). This can be used to emphasise the ideas of frequency and peak value. Follow up by connecting the generator to a lamp and showing how the brightness depends on frequency of rotation.



Don't get bogged down with electromagnetic induction but do compare what charges are doing inside a lamp filament when it is connected (a) to a dc supply and (b) to an ac supply (in the first case they drift in one direction in the second they move back and forth).

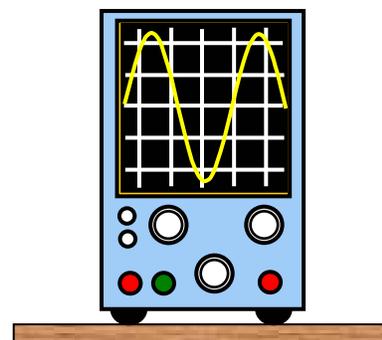
TAP 123-1: Generating alternating current

### Student experiment:

#### Measuring ac with a CRO

Measuring the peak value (amplitude), peak-to-peak value, and frequency of an ac supply using an oscilloscope.

This exercise builds on their introduction to oscilloscopes and sets the scene for the next demonstration. Make sure they are able to identify and measure peak and peak-to-peak values and



to work out frequency from the time period of the voltage variation.

TAP 123-2: Measuring the peak value (amplitude), peak-to-peak value, and frequency of an ac supply using an oscilloscope

BEWARE: a lot of oscilloscopes have 'calibration positions' on their variable y-gain and time base settings. Students will need to be reminded to set these prior to making measurements otherwise they will get systematic errors throughout.

## Discussion:

### R.m.s. values as equivalent dc values

Ask the class what the average value of an ac voltage or current is over a whole number of cycles. It is obviously zero. So how can ac transfer energy? Remind them that power is calculated by  $P = IV$  and point out that both  $I$  and  $V$  change sign together, so power is always positive but varies over the cycle, having a maximum value of  $I_p V_p$  and a minimum of zero. This should also make it clear that the average power is LESS than  $I_p V_p$ . Good mathematicians may know that the average value of a sine or cosine squared over a whole number of cycles is just  $1/2$ . Weaker students might be persuaded by the symmetry (either side of  $V=1/2$ ) of a graph of sine-squared or cosine-squared against time. Either way you need to lead them to the idea that average power delivered by ac is:

$$P = 1/2 I_p V_p = 1/2 I_p^2 R = 1/2 V_p^2 / R \quad (\text{using } V = IR)$$

The same power would be delivered by a dc with values  $I$  and  $V$  if:

$$P = I^2 R = 1/2 I_p^2 R \quad \text{or} \quad P = V^2 / R = 1/2 V_p^2 / R$$

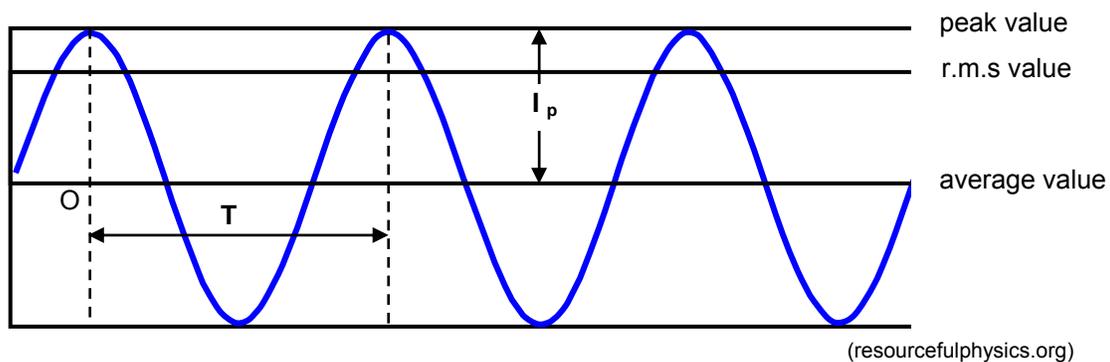
These lead to the equations:

$$I^2 = I_p^2 / 2 \text{ giving } I = I_p / \sqrt{2} \quad \text{and} \quad V^2 = V_p^2 / 2 \text{ giving } V = V_p / \sqrt{2}$$

This links the dc equivalent values to ac peak values. The point is that a sinusoidal ac supply of peak value  $V_p$  delivers the *same average power* as steady dc of value  $V_p / \sqrt{2}$

We call these '*dc equivalent values*' the r.m.s. values for ac and we can use them in the same way as steady dc values: e.g. average ac power  $P = I_{\text{rms}} V_{\text{rms}}$

You ought to say that r.m.s. stands for 'root-mean-square' but it is only really worth going into the meaning of this in detail with groups who can handle the mathematics.



## Demonstration:

### Finding the r.m.s. value

To reinforce the idea of dc equivalence show them a demonstration in which a filament lamp is lit from first a dc and then an ac supply and the supplies are adjusted to make the lamp equally bright (equal powers). From the previous discussion you should be able to coax them to predict that the peak value of the ac (shown on an oscilloscope) is root-two times the steady dc value.

TAP 123-3: Showing the equivalence of ac and d.c

## Student questions:

### Practice on a.c

End the session by discussing the mains supply. Ac currents and voltages are usually quoted as r.m.s. values so 230 V 50Hz mains ac varies from +325 V to - 325 V and has a period of 1/50 (0.02) seconds. 230V is its r.m.s. value, 325 V is its peak value and 650 V is its peak to peak value.

## Questions on ac signals

TAP 123-4: Questions on Alternating Current

## **TAP 123- 1: Generating alternating current**

### **Apparatus required:**

Hand-driven generator (e.g. bicycle dynamo)

Large centre-zero demonstration voltmeter

Lamp

Oscilloscope (optional)

### **Procedure**

Connect the output of the generator to the voltmeter. Turn the generator.

Show that the output from the generator alternates (positive and negative swings on the voltmeter).

Show that the frequency (and the peak value) of the output depend on the rate of turning.

Show that the output can light a lamp and that the lamp appears to stay on all the time if the generator is turned rapidly.

Turn off the CRO time base. Connect the CRO in place of the voltmeter. Observe the spot going up and down as you turn the generator.

Repeat, with the time base switched to a slow setting; you should see a (roughly) sinusoidal trace.

## TAP 123- 2: Measuring the peak value (amplitude), peak-to-peak value, and frequency of an ac supply using an oscilloscope.

### Apparatus required:

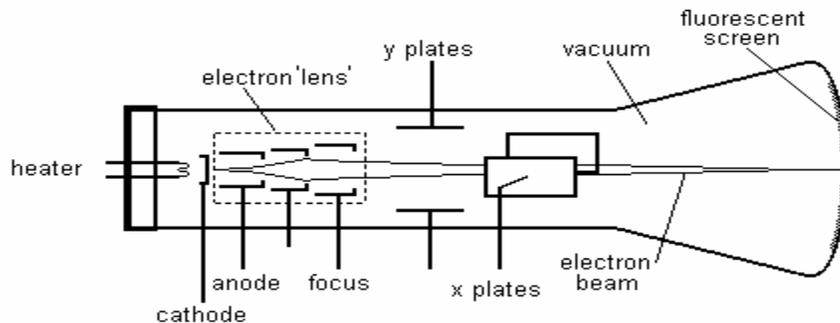
oscilloscope (CRO)  
signal generator  
battery pack  
connecting cables

### How the CRO works

Inside the oscilloscope, an electron beam is fired at the screen. On the way to the screen it passes between two pairs of plates - one pair (the x-plates) on either side horizontally and the other pair (the y-plates) vertically above and below the beam.

If the x-plates are connected to a pd the beam will deflect horizontally.

If the y-plates are connected to a pd the beam will deflect vertically.



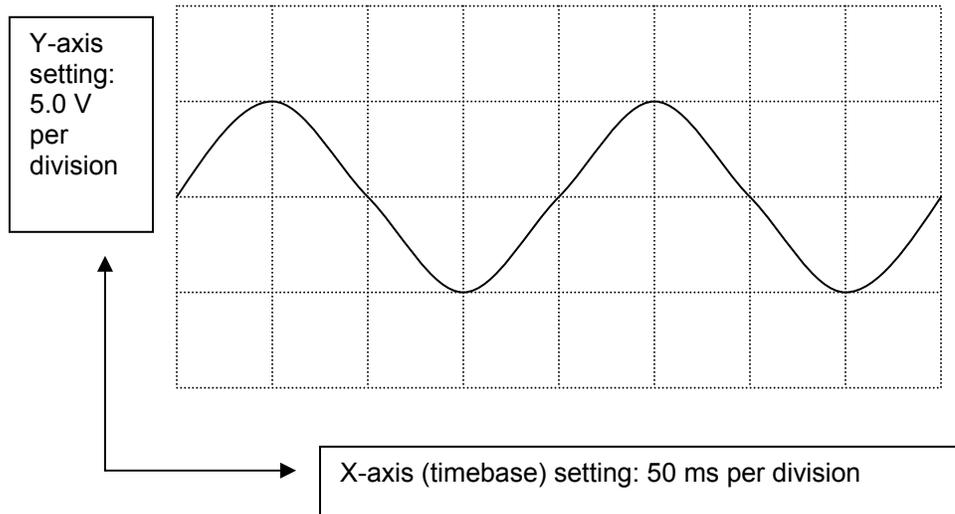
The Cathode Ray Oscilloscope

The x-plates are supplied with a 'timebase' signal that makes the beam scan rapidly from left to right and then jump back to scan repeatedly across the screen. Adjusting the timebase changes the rate of scanning. Timebase settings tell you how long it takes for the beam to cross one square on the screen - e.g. 10 ms per division.

The signal to be displayed and measured is applied to the y-plates (the input). The larger the input voltage the greater the deflection. If the voltage alternates then the beam oscillates up and down. The amount of deflection per volt can be adjusted by changing the y-gain control on the oscilloscope - e.g. 2.0 V per division or 50 mV per division (the second is more sensitive so the same input signal will cause a bigger vertical deflection on this setting).

The combination of scanning on the x-axis and an input voltage on the y-axis gives a display on the screen that is effectively a graph of voltage against time. Here is an example in which an ac voltage has been applied to the y-input.

From this we can work out the amplitude and frequency of the signal.



Amplitude = one division = 5.0 V

Period  $T = 4$  divisions = 200 ms = 0.2 s

Frequency  $f = 1 / T = 1 / (0.2 \text{ s}) = 5 \text{ Hz}$

## Exercises

1. Switch on the oscilloscope and identify the timebase and y-input controls. Adjust the oscilloscope until you have a horizontal line in the middle of the screen. Use the x-shift and y-shift to move it around and adjust focus and brightness until it is sharp and clear (but not too bright). Make sure the input switch is set to 'dc'.
2. Connect a cell to the input. Use the oscilloscope to measure its emf (the voltage across its terminals - it should be about 1.5 V for a single cell. Why is the trace on the screen a straight horizontal line? What happens if you move the input switch to earth and then back to dc? This can be useful because the earth position ensures a 0V input (it shows you where zero is).
3. Now connect the output of the signal generator (an 'audio frequency oscillator') to the y-input of the oscilloscope. If the signal generator and CRO have earthed terminals make sure that the earthed lead of the CRO (often black) is connected to the earthed terminal of the supply (often yellow), or you will short out the signal generator through the CRO. Set the frequency of the signal generator to about 500 Hz and its amplitude to about 3 V. Adjust the oscilloscope until you have a stable trace. You may have to alter the triggering to get the trace to stay still on the screen. How does the trace change when you switch between square wave, sawtooth and sinewave outputs on the signal generator?

4. Now use the oscilloscope to check the calibration of the signal generator:
  - (a) At 500 Hz adjust the peak value (amplitude) in 1.0 V steps (according to the dial) and measure the actual amplitude on the screen. Tabulate your results. Include peak and peak-to-peak values in your table.
  - (b) Keeping the amplitude constant measure the frequency of the signal when the signal generator is set at 100 Hz, 500 Hz, 1000 Hz, 10 000 Hz and 50 000 Hz. Tabulate your results.

Comment on the accuracy of the calibration on the audio frequency oscillator.

## **Practical advice**

Settings on all devices can drift. You could always check some settings of the time base against mains frequency. If possible it is a good idea to switch on devices some time before they are needed so that they warm up to a steady temperature. This can reduce a lot of the drift.

Make sure you know how to set up the oscilloscopes. Pupils will press buttons and may then get problems.

## TAP 123-3: Showing the equivalence of ac and dc

### Apparatus required

dual beam oscilloscope

12V lamp

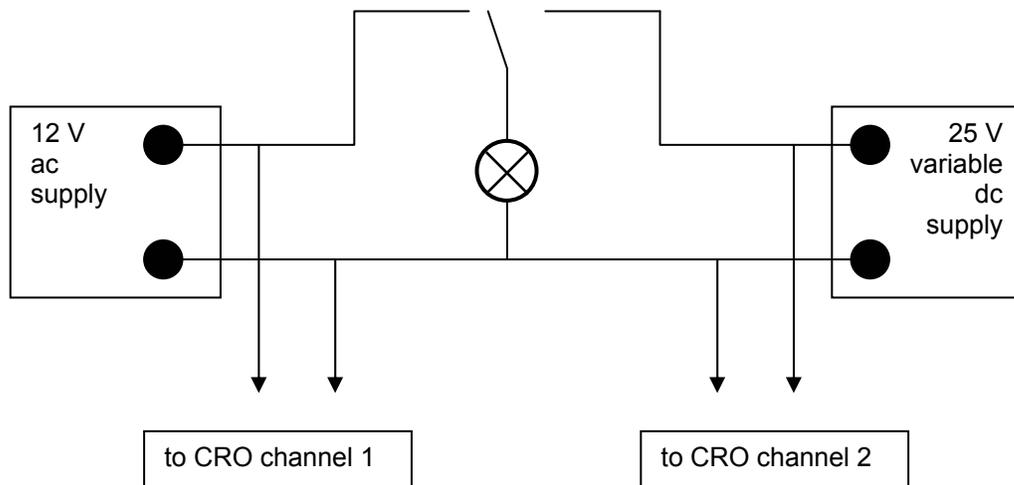
12V ac supply

continuously variable 25 V dc supply (smoothed)

multimeter

leads

### Circuit



### Procedure

Start with the spdt switch connecting the lamp to the ac supply so the lamp is bright.

The dc supply should be at 0 V.

In a darkened room, switch the spdt switch back and forth between the ac and dc supplies, gradually increasing the dc supply until the students agree that the lamp is equally bright from both power supplies.

Now compare the traces on the oscilloscope.

The ratio of peak ac to steady dc should be about 1.4 (i.e.  $2^{0.5}$ ).

## TAP 123-4: Questions on alternating current

1. The mains ac supply in some countries is 110 V r.m.s at 50 Hz (sinusoidal).
  - (a) What is the peak value of voltage?
  - (b) What is the peak-to-peak value of voltage?
  - (c) How long does one cycle of this ac supply last?
  - (d) A 100 W lamp is designed for use with 110 V ac What is the resistance of its filament?
  
2. Which will light a lamp more brightly, 12 V peak ac or 12 V steady dc? Explain.
  
3. UK mains ac has an r.m.s. value of 230 V and a frequency of 50 Hz. Sketch a graph of voltage against time for one cycle of this ac and include values for peak voltage and time period on the axes.
  
4. What is the ratio of powers delivered by 20 V dc and 20 V peak ac to the same load?

## Answers and Worked Solutions

1. (a)  $110 \times \sqrt{2} = 155.6 \text{ V}$   
(b)  $2 \times 155.6 = 311 \text{ V}$   
(c)  $1 / 50 \text{ Hz} = 0.02\text{s}$   
(d)  $P = V^2/R$   $R = 110^2/100 = 121\Omega$
  
2.  $12 \text{ V}$  peak ac is equivalent to  $12/\sqrt{2} \text{ V} = 8.5 \text{ V}$  dc equivalent. So  $12 \text{ V}$  peak to peak is dimmer.
  
3.  $230 \times \sqrt{2} \text{ V} = 325\text{V}$ , so graph varies between  $+ 325 \text{ V}$  and  $-325 \text{ V}$ .  
One time period =  $1 / 50 \text{ Hz} = 0.02\text{s}$
  
4.  $P = V^2/R$  so the ratio of powers is ratio of voltages squared.  $20 \text{ V}$  peak ac is equivalent to  $20/\sqrt{2} \text{ V}$  dc i.e.  $14.14 \text{ V}$  so dc power / ac power =  $20^2 / 14.14^2 = 2$   
or  
 $\text{dc } V^2 / (\text{ac peak} / \sqrt{2})^2 = (\sqrt{2})^2 = 2$