Use of an oscilloscope

Objectives.
- Upon completion of this experiment you should understand and be able to use the basic functions of an oscilloscope. These include the gain and time base controls, triggering, AC/DC setting and voltage-time (y-t) and voltage-voltage (x-y) modes.
- You should be able to measure the amplitude and frequency of a periodic waveform and to determine the phase shift between two waveforms.
- You should also understand the experimental errors associated with the use of an oscilloscope.

Introduction:
The Cathode ray Oscilloscope (C.R.O.) is a powerful tool used both for displaying and measuring electrical signals – frequently ones which are varying too rapidly to be measured with a meter. The heart of an oscilloscope is a cathode ray tube, similar to that used in a television. Electrons are emitted by a heated filament, then focussed into a beam and accelerated by a high voltage until they strike a phosphor screen, where they give up their kinetic energy and emit a spot of light. Voltages applied to pairs of metal plates can deflect the beam either horizontally or vertically, so moving the spot on the screen.

The oscilloscope is sensitive to external voltages, which are connected to internal amplifiers via sockets on the front panel. The primary use of an oscilloscope is to display the variation of one or two signals with time. The vertical axis then displays a voltage while the horizontal one shows time. The scale of the two axes is set by the gain and time-base controls. In order to obtain a steady state display for a repetitive signal, the time-base may be synchronised to one of the input signals. This is achieved using the trigger controls. A second mode of operation is known as x-y display in which the voltage applied to one input is displayed as a function of the voltage applied to the second input.

Note on errors: There are two sources of errors when making a measurement with an oscilloscope: the calibration error and the reading error. The former is related to the accuracy of the components used within the oscilloscope and can be assumed to be 5% for both voltages and times. The latter results from the precision with which a reading can be made from the screen, and is often related to the linewidth of the trace. The total error of any reading is found by combining the calibration and reading errors. In most cases the reading error will be considerably smaller than the calibration error.

Similarly the error when setting up a waveform on a signal generator will be due to the calibration error (5%) and a setting error, the latter is related to the scale and width of the cursor.

Quite often you will be asked to compare the parameters of a signal produced by a signal generator and that measured by an oscilloscope. In this case both the voltage and frequency (with errors) as set on the signal generator should be compared with the values determined by the oscilloscope. A comment should be made on their agreement or disagreement.

Example
Signal generator output: (1±0.07)V peak-peak, (1000±50)Hz
Oscilloscope measurement: (0.95±0.05)V peak-peak, (1300±70)Hz
In this case the voltages agree (within two standard deviations) but the frequencies do not.
In the following the *Tasks* are points where an answer, comment or sketch is required in your lab diary. You should however include additional material where appropriate so that your diary represents a true and complete record of your experiment.

**Familiarisation with the main oscilloscope controls**

There are a number of different models of oscilloscope in the first year laboratory. All work on the same principal, but there are differences in the labelling of the controls and exact way different modes of operation are selected. You will therefore find alternatives at a number of points in the instructions below, and must determine which is appropriate for the equipment you are using.

Examine the front panel of the oscilloscope, and identify the following:

- The channel 1 and channel 2 inputs – these may be marked “X” and “Y”
- The two associated course and fine gain controls – marked “Volts/div”
- The two vertical shift or position controls
- The time-base frequency control – marked “time/div”
- The trigger or synchronisation control level and slope controls

Now set up the oscilloscope by following the steps listed below

1. Turn on the oscilloscope.
2. Set the time-base control to 1ms per division.
3. Set the time-base fine control and both channel gain controls to the “calibrated” position. (N.B. You should always operate the oscilloscope in “calibrated” mode if you intend to take any measurements).
4. If the oscilloscope has a separate X-Y control, ensure you are NOT in this mode.
5. Similarly make sure the “10 times magnification” is not operating.
6. Turn up the intensity.
7. Set the trigger mode to “AUTO” (or ensure that the “AT/NORM” button is out). This ensures that the time-base sweep operates even when the oscilloscope is not triggered by an external signal.
8. Set the oscilloscope to display channel 1, and set the channel 1 input selector to “GROUND”. (This isolates and earths the channel 1 amplifier, and can be used even when the channel is connected to an external circuit).
9. Now adjust the vertical and horizontal position controls until you have a horizontal line across the middle of the screen. This vertical position now corresponds to 0 V.
10. Adjust the focus and intensity controls so that the trace is sharp and no brighter than necessary (you may need to readjust the intensity as you vary the time-base setting).

If at any time you lose the oscilloscope trace completely, go back to step 2 above.

Now try varying the time-base frequency. At lower frequencies you should see the trace flicker and then become a moving spot. Note that it tracks from left to right at a uniform rate, and then flies back to start again.
**Single channel operation**

1. Set the coupling of channel 1 input to DC and connect the signal generator to this input. (Note that the outer connectors of the coaxial sockets are connected to earth. This means that if one of the signal generators terminals is also grounded, the two grounded contacts must be the ones which are connected together.).
2. Set the generator to produce a sine wave of frequency 1 kHz and amplitude 1 V. (Some signal generators specify the peak-to-peak amplitude or alternatively the r.m.s voltage. In these cases use 2 V p-p or 1.41 V respectively).
3. If the signal generator has the option of adding a DC offset to the signal set this to 0V so that the signal is purely AC.
4. Reset the oscilloscope time-base to 1 ms per division and set the channel gain to 0.5 V per division.

You should now see a display of the waveform on the screen, but it will be probably be moving and difficult to see. This problem can be solved by synchronising the time-base to the input signal as follows:

1. Set the sweep mode to NORMAL (or “NORM”), the trigger source to CH1 and the trigger coupling to AC.
2. Adjust the LEVEL control until a steady state image appears on the screen. (If you struggle to achieve this ask a demonstrator for help).

Adjust channel 1 gain and the time base frequency to investigate what effects these have on the trace.

*Task 1.* Using whatever settings you find most appropriate measure the frequency and amplitude of the signal and compare your values with those determined by the settings of the signal generator. Repeat your measurements for a signal of 20 kHz and 1 V amplitude.

*Task 2.* Investigate how altering the LEVEL control and trigger SLOPE affect the displayed waveform. Briefly comment on these effects in you lab diary.

*Task 3.* Investigate the effect of the NORMAL/AUTO triggering control on the display for the two conditions (i) when a stationary waveform is observed for AUTO setting and (ii) when a moving waveform is observed for AUTO setting. Again briefly comment on your observations in your lab diary.

(If you are still unsure as to the function of the LEVEL, SLOPE and NORMAL/AUTO controls ask a demonstrator to explain these to you).

With the signal generator again set at 1 kHz, 1 V, obtain a steady trace displaying approximately two cycles of the waveform. Adjust the trigger controls so that the trace starts at +0.3 V on the negative slope of the cycle. Ask a demonstrator to check your displayed waveform before proceeding.
Two channel operation

1. Connect the signal generator (1 kHz, 1 V) to the input (and ground) of the driver box provided.
2. Connect output one of the box to channel 1 of the oscilloscope and output 2 to channel 2. It is essential that the two earthed sides are connected to each other (and to the earthed connection of the generator, if one exists). Failure to observe this rule will result in part of the circuit under investigation being shorted out!
3. Set the oscilloscope to display both channels 1 and 2 – DUAL display mode. On some oscilloscopes this requires two buttons to be depressed simultaneously.
4. Set both channel couplings to AC, and adjust the gain and position of channel 2 in order to display both traces.

Task 4. Are the waveforms equal in amplitude? in frequency? In phase? Does the amplitude or phase difference vary as the frequency of the signal generator is altered?

Determination of phase difference.

With reference to the above figure the phase difference $\phi$ between waves $A$ and $B$ is defined as

$$\phi = \frac{X}{Y} \times 2\pi \text{ radians} \quad \text{or} \quad \phi = \frac{X}{Y} \times 360^\circ$$

In the above example wave $A$ leads wave $B$ by this phase difference.

Task 5. Determine the phase difference between output 1 and output 2 for an input frequency of 3 kHz. Think carefully about the errors involved (does the calibration error contribute to the error in $\phi$?).

Task 6. Disconnect channel 1 from the oscilloscope. Ensure that you can trigger the time-base from channel 2, to display the remaining wave-form. Note in your lab diary how this was achieved.
Use of the AC/DC function.
A general waveform may contain both an AC and DC component (the latter will appear as an offset of the AC waveform away from 0 V). When set to DC the oscilloscope displays all of the waveform (DC and AC) but in the AC setting the DC component is filtered out and only the AC component is displayed. This may be useful for cases where the DC component is significantly larger than the AC component making a measurement of the latter otherwise difficult.

Task 7. Reconnect channel 1 to output 1 and connect channel 2 to output three which contains both DC and AC components. Sketch the form of the channel 2 waveform for both AC and DC settings. Determine the magnitude of the DC component.

x-y operation
In the previous exercises you have displayed a voltage against time. However it is sometimes more useful to plot one voltage against another; this is possible in x-y mode. Setting up x-y mode depends upon the precise oscilloscope model and may involve a special button or up to 4 other controls – the vertical mode, the time base, the trigger coupling and trigger source.

1. Disconnect the channel 1 and 2 inputs and set the oscilloscope to x-y mode.
2. Move the spot to the centre of the screen.
3. Investigate whether the horizontal shift is controlled by the time-base x-shift or one of the channel position controls. (if the spot is not visible it may be useful to increase the intensity in order to determine to which side of the screen the spot is displaced. Once the spot has been moved back onto the screen reduce the intensity to avoid damaging the screen).
4. Connect output 1 of the driver box to the X input of the oscilloscope. The spot should be deflected into a horizontal line.
5. Adjust the gain so that it occupies a good fraction of the screen. Connect output 2 to the Y input, make similar adjustments and observe the trace.
If the x- and y-inputs are in phase the trace will consist of a straight line at 45° for equal channel gains and signal amplitudes (on some oscilloscopes the x-deflection is reversed so the line has a negative gradient). If sinusoidal inputs of the same frequency are applied which are not in phase, an ellipse is produced. The phase difference between the x- and y-signals may be determined by reference to the previous diagram.

**Task 8.** Set the signal generator frequency to 3 kHz and determine the phase difference between the two signals. Compare this result with your previous determination.

**Lissajou’s Figures**
An oscilloscope can be also used in x-y mode to compare frequencies, as well as phases. For this exercise you will need two signal generators, e.g. one mains and one battery operated.

**Task 9.** Connect one of the signal generators, operating at 1 kHz, to the X input, and another, operating at 500 Hz, to the Y input. Carefully adjust the frequency of the second generator until you obtain a pattern which is as close to stationary as possible. Sketch the display. Repeat this exercise for other frequencies which have simple integer ratios, such as 1:3, 2:3, 3:4 etc. (It should be possible to obtain some pretty patterns, known as Lissajou’s Figures, if the signal generators are sufficiently stable).

**Other Oscilloscope Controls**
There are a number of other controls and modes of operation which have not been discussed. Most of these relate to y-t mode rather than x-y, so if you have time set your oscilloscope back to y-t and try to determine what these additional functions do. Some, such as ADD, are self-explanatory. If you cannot determine what a particular control does, see if the demonstrator can do any better!

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*July 2003*