The University Of Sheffield.

Electronic & Electrical Engineering.

FIRST YEAR LABORATORY 2013 MPW

Work-Station Familiarisation Exercise – Part 1 (WS1)

At some time in your course you will be involved in project work where you are very likely to use some form of electronic measurement equipment**. It is important that you know what the basic instruments are, what they can and cannot do, and how and when to use them.**

Aims

These laboratory exercises will give you:-

1. Practical 'hands-on' experience by using a set of fundamental electronic instruments to measure and observe voltages and waveforms.
2. An appreciation of some of the fundamental considerations you need to apply when using measurement instrumentation equipment.
3. Practical experience of interpreting a simple circuit diagram and building an electronic circuit.
4. An opportunity to test the electronic circuit using the instruments and knowledge gained.

- **The laboratory exercises 1-4 should take up to 2 hours to complete, with the remaining 1 hour for the soldering and circuit construction (exercise 5).**
- **Work in pairs,** but also share experience and knowledge with colleagues.

  Students will have a wide range of greater or lesser experience. Some will find it easy and move through the exercises quickly, while some will take a little longer.
- **A number of experienced demonstrators are available** to check your progress and answer queries. They will guide you through the exercises helping you to work in a logical and sequential manner to construct your conclusions.
- **Read through the lab sheets before starting the exercises.**
- **Write all your results and answers in your laboratory notebook.**

  Answers can be brief – just one short sentence in most cases, and tables for results can be rough and are only suggested as a way to organise your readings.

Note: WS1 is the only time you will be allowed to forget your laboratory notebook without losing marks!

Purpose

The use of electronic measurement equipment is now wide spread across all disciplines of science, engineering, arts and media. Measurement equipment is increasingly interfacing with computers (often remotely through wireless communication) and it is now common place for it to be both operated and read automatically.

This teaching laboratory has 36 workstations each containing a similar range of commonly used test and measurement equipment. The purpose of these laboratory exercises is to give you practical 'hands-on' experience in examining the equipment's operation and specification, and help you explore their suitability for measuring a range of values.

For the final part of the session you will construct a simple LED circuit and test it using the work-station equipment.

Work-Station Description

Each work-station includes the following:-

Mains Distribution Board with Residual Current-operated Circuit Breaker [RCCB]

The RCCB distribution board supplying the power to the equipment is FOR YOUR PROTECTION. It works by detecting any unbalanced current flowing between LIVE and NEUTRAL and is set to 'trip-out' the supply if this exceeds 30 mA.

Stabilised DC Power Supply (PSU), 0-30 V, [Farnell L30-1 or L30-2]

The PSU has a continuously variable output voltage between 0 and 30 V and a current limit of between 0 and 1 Amp (L30-1) or 0 and 2 Amp (L30-2). The output is indicated on its analogue (moving coil) meter. ***(Movement accuracy typically 1.5%).***

Digital Multimeter (DMM), [Thurlby Thandar 1604]

The DMM can measure up to 1000 V DC, 10 Amp DC. It can give an accurate True RMS value ***(V AC accuracy ± 2% over a frequency band of 10 Hz to 20 kHz)*** for measurements up to 750 V AC, 10 Amp AC. Output is indicated on a digital display. ***(Input impedance 10 MΩ nominal).***

Digital Signal Oscilloscope (DSO), 70 MHz/ Function Generator, 0.1 Hz to 20 MHz [Agilent Technologies DSOX2002A]

The DSO has a wide 70 MHz bandwidth, and 2 mV/ division high sensitivity, enabling signals and waveforms to be observed and measured on its large 8.5-inch WVGA display. ***(Input impedance 1 MΩ nominal).***
The 'Wave Gen' – built-in Function Generator is a variable signal source covering the frequency range 0.1 Hz to 20 MHz for sine wave, 0.1 Hz to 10 MHz for square wave/ pulse, 0.1 Hz to 100 kHz for ramp/ triangle wave. The amplitude range is 20 mVpp to 5 Vpp into Hi-Z and 10 mVpp to 2.5 Vpp into 50 ohms.

This integrated instrument has numerous front panel knobs and buttons (softkeys), but only the oscilloscope's 'Horizontal' and 'Vertical' section knobs and a few other controls described later are relevant to these basic familiarisation exercises.

The use of the DSOX2002A will be covered in greater depth in the next laboratory session WS2.

Fixed triple-output Power Supply (PSU), [BBH 5017]

The stabilised PSU provides three fixed DC outputs of 12 V, 12 V and 5 V at 1 A max.

Soldering Iron, [Weller SP-3D]

The Soldering Station consists of a safety transformer, 240 V x 24 V and a magnastat 45 W TCP soldering iron giving a temperature range of between 50 – 450°C depending on the tip type.

Analogue Multimeter, [TENMA 72-6171]

The analogue meter (not normally part of the WS equipment), has a moving coil meter display with manually switched measurement ranges of up to 1000 V AC & DC, 500 mA (with 10 A on separate socket). ***(Input impedance of 20 kΩ/ V DC, 8 kΩ/ V AC).***

Note:-

(i) Digital multimeters (DMM's) have virtually replaced analogue, moving coil type meters when measuring resistance, voltage and current. There are good technical reasons for this such as very high input impedance (10 MΩ compared to 1-20 kΩ for analogue meters), the ease of reading and increasingly cheaper manufacturing costs in recent years. A digital multimeter is essentially a digital voltmeter (DVM) that contains several conversion circuits to allow the measurement of voltage, current, resistance etc. in one instrument. Analogue meters are still used where a visual indication of change is useful.

(ii) Digital Signal/ Storage Oscilloscopes (DSO's) are a critical tool for making voltage and timing measurements on a diverse range of analogue and digital electrical circuits. A DSO is an electronic measurement instrument that unobtrusively monitors input signals and then graphically displays these signals in a simple voltage versus time format.

- **After reading the brief descriptions (above) of each of the instruments, switch 'On' all the over-bench work-station equipment, but NOT the soldering iron or battery operated analogue meter.**

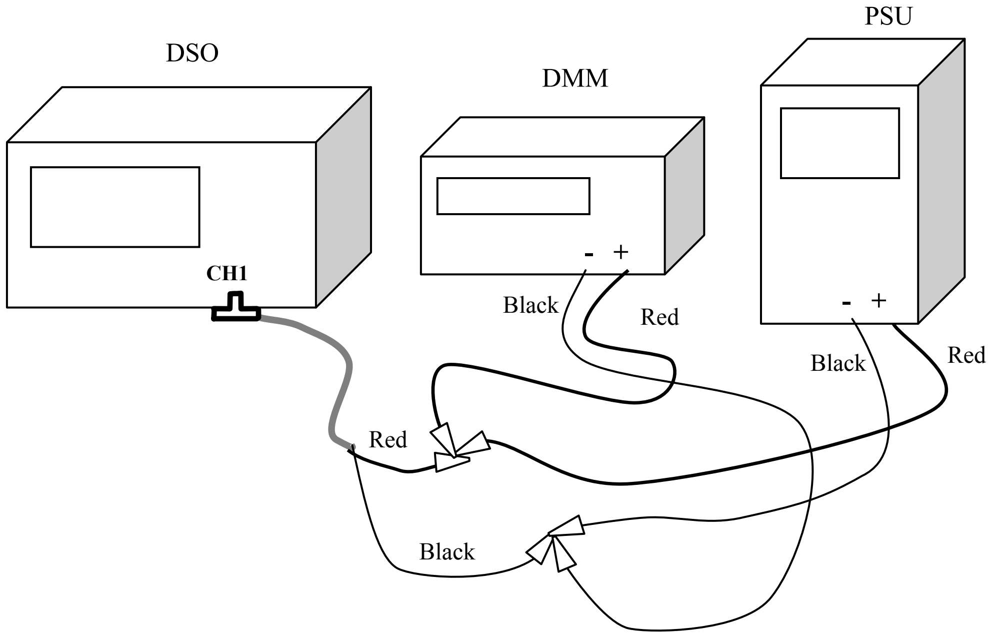
Exercise 1 – DC Measurements

In this exercise we compare the use of an analogue meter display, an oscilloscope display and a digital display by measuring direct current (DC) voltage levels.

A DC voltage is a voltage which has a constant level with respect to time.

- Using the cables provided, connect the Farnell power supply unit (PSU) to the Thandar digital multimeter (DMM) and channel 1 (CH1) of the oscilloscope (DSO) as in the diagram below.

  [The 3 red 'positive' leads should be connected together (+ve), and the 3 black 'negative' leads connected together (-ve).]
- Set the DMM to read DC Volts. *Press the 'Operate' button on the lower left of the DMM to switch the display on; press DC (for DC measurements) followed by V (for voltage measurements*) and the DC V symbol (⎓) should appear on the lower left of the display.
- Press the 'Default Setup' key on the oscilloscope front panel (resets the basic controls to factory settings).



Oscilloscope Measurement Technique

An oscilloscope is a device which provides you with a visual representation of an electrical signal. The vertical direction (Y-axis) represents the amplitude of the signal, whereas the horizontal direction (X-axis) displays time and frequency information. In this exercise we are measuring a DC (time invariant) signal so we will only concern ourselves with measuring the signal amplitude (vertical, Y-axis).

The controls/ knobs near the bottom of the oscilloscope in the 'Vertical' section set the vertical scaling and this 2-channel oscilloscope (CH1, CH2), has two pairs of vertical scaling controls. The larger knob for each input channel in the 'Vertical' section sets the vertical scaling factor in Volts/ division. This is the Y-axis graphical scaling of your waveforms.

The grid lines on the screen of the oscilloscope are there to assist you in taking accurate measurements. There are eight vertical "divisions" on the screen, (number of divisions occupied by waveform × scaling factor (Volts/ division) = signal amplitude (Volts)).

To view relatively large signals (high peak-to-peak voltages) you would typically set the Volts/ div setting to a relatively high value. If viewing small input signal levels you would set the Volts/ div setting to a relatively low value. The Volts/ div setting is displayed in the top left-hand corner of the screen. For the greatest accuracy in measurement, the vertical scaling should always be set to the most sensitive range of Volts/ div (without the trace disappearing off the screen).

The smaller controls/ knobs for each channel in the 'Vertical' section are the position/ offset controls. You use this knob to move the waveform up and down on the screen.

- The voltage we are measuring is positive (with respect to EARTH), so the oscilloscope trace can be referenced to zero by **very carefully** turning the CH1 vertical position control (smaller vertical knob) anti-clockwise, until the earth marker symbol (⏚) on the left-hand side of the screen is aligned along the very bottom horizontal grid line. ***(Note - if the knob is turned too far the trace will be below the bottom of the screen and the earth marker will disappear.)*** Having your zero reference point precisely positioned on the **bottom** grid line allows you to use the **whole** of the screen to make the most accurate visual DC V measurements.
- Set the PSU meter as accurately as possible to 5 V **(as indicated by the PSU meter)**, by using the 'Coarse' and 'Fine' voltage adjust controls, and ensure the output is switched 'On'.
- Set the oscilloscope CH1 vertical scaling to 1 V/ div and you should now have a straight line trace (ignoring any slight signal noise you may observe) somewhere across the top half of the screen.
- Use the grid lines on the oscilloscope screen to help measure the DC voltage and note the DMM reading.

Record the results in your laboratory notebook using a comparison table similar to the one shown below.

- Increase the output voltage of the PSU **(as indicated by the PSU meter)** to the values shown in the table and repeat the procedure for taking readings on the oscilloscope and DMM, adjusting the vertical scaling (Volts/ div) on the oscilloscope when necessary.

PSU meter	*Oscilloscope*	*DMM*
5 V		
12 V		
18 V		
30 V		

Questions:-

1. Which instrument do you believe is giving the most accurate reading?
2. What factors do you think limit the accuracy of the other two?

Write your conclusions in your laboratory notebook.

Exercise 2 – AC Measurements

In this exercise you will look at measuring alternating current (AC) voltage levels on the oscilloscope and the DMM. An AC Voltage is a voltage which has a value that varies with time about the zero level. One of the most common waveforms found in electrical engineering is the sine wave. In calculations we have to use a value of voltage (or current) known as the Root Mean Square or RMS value. This will be fully explained later in the course.

There are basically two types of **AC meters**:-

i. Those that read the **average** value of a half-wave or full-wave rectified AC input and display it on a scale calibrated to read RMS on the assumption that the voltage being measured is sinusoidal. Moving coil meters and most low cost DMMs are of this type.
ii. Those that give the **True RMS** *(Square **ROOT** of the **MEAN** of the **SQUARES** of the (current) or (voltage))* value of a waveform by squaring it, averaging and square rooting before displaying the reading. The work-station Thurlby Thandar DMM is of this design.

Root mean square of an alternating current or voltage,

$Power\ (W) = V_{RMS}^2/R = I_{RMS}^2\,R$

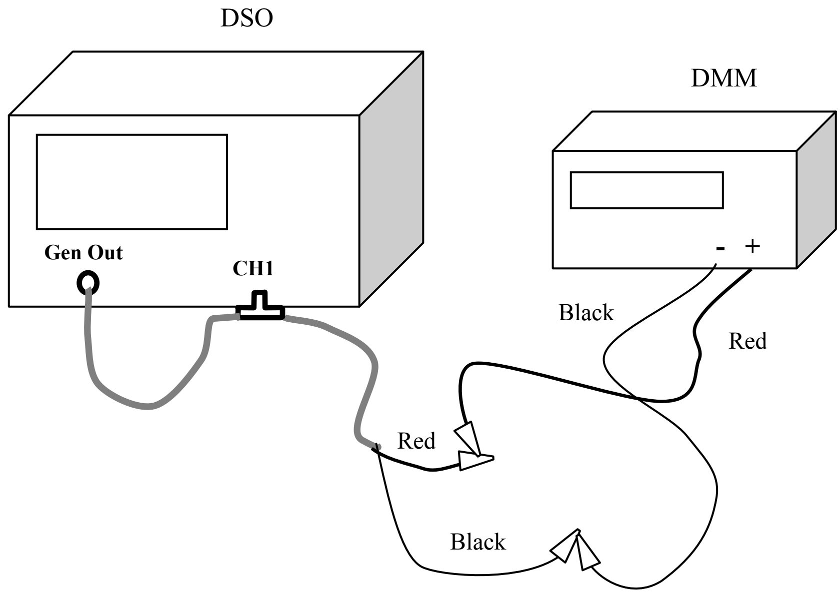
For a given resistance (R) Power is proportional to the square of the voltage or current.

Note - Read the separate laboratory sheet which explains Root Mean Square (RMS) value of an alternating current or voltage.

Oscilloscopes give a visual image of a changing voltage and can display an accurately scaled version of the wave-shape. The most convenient parameter to measure is the peak-to-peak value (the top of the waveform to the bottom of the waveform), often abbreviated to Vpp.

- **Important – Set the PSU to 0 Volts, switch it off and remove the connecting leads!**

- Leave the DMM and oscilloscope leads connected, and fit the coaxial 50 Ω BNC – BNC cable between the oscilloscope's function generator output (Gen Out) and the CH1 input BNC T-piece, as in the diagram below.
- Set the DMM to read AC V (~ symbol on upper left of display).
- Align the earth marker symbol (⏚) on the left hand side of the oscilloscope screen with the **centre** horizontal grid line.
- Press the 'Wave Gen' front panel softkey to activate the function generator.

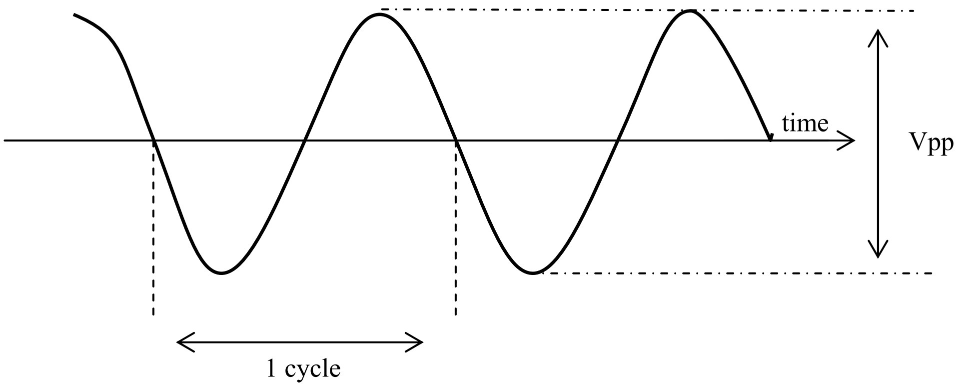


Oscilloscope Measurement Technique

In this exercise we are measuring an AC (time varying signal) so we will now consider the horizontal (X-axis) which displays time information.

The controls/ knobs near the top of the oscilloscope in the 'Horizontal' section are the horizontal controls.
The larger knob sets the horizontal (X-axis) scaling in seconds/ division of the displayed waveform. One horizontal "division" is the Δ-time between each vertical grid line. If you want to view faster waveforms (higher frequency signals), then you will set the horizontal scaling to a smaller sec/ div value. If you want to view slower waveforms (lower frequency signals), then you typically set the horizontal scaling to a higher sec/ div setting. The sec/ div setting is displayed near the top right-hand corner of the screen.
The smaller knob in the 'Horizontal' section sets the horizontal position of the waveform. In other words, with this control you can move the horizontal placement of the waveform left and right. The horizontal controls (time (s)/ div and position) are often called the oscilloscope's main **"timebase"** controls.

- Using the softkeys just below the screen (in conjunction with the 'Select' curled green arrow **Entry** control knob), set the waveform generator to give a 300.0 Hz sine wave output at an amplitude of 1 V peak-to-peak (1.00 V pp).
- To obtain the required waveform on the screen set the Vertical Volts/ div scaling factor to 200mV/ div and select the Horizontal scaling (timebase) to show 3 cycles of the sine wave.
- Position the bottom of the sine wave on a suitable horizontal grid line and move the trace so that the top of a cycle is on the centre vertical grid line. This allows you to use the smaller sub-divisions on the centre vertical grid line for greater accuracy in measuring the signal amplitude.
- Read off the peak-to-peak (Vpp) value from the oscilloscope screen.



Remember, on AC V ranges, the DMM reads the **True RMS** (Root Mean Square) value. You need to convert the DMM readings to peak-to-peak (Vpp) values, so that you can compare them with the oscilloscope readings.

For a sine wave the relationship is:- $\quad Vpp = 2 \times \sqrt{2} \times V_{rms}$

Record the results in your laboratory notebook using comparison tables similar to the ones shown below.

- Change the function generator (Wave Gen) amplitude to 3.00 Vpp, adjust the Volts/ div scale accordingly and again measure your oscilloscope and DMM readings.

Function Generator	*Oscilloscope*	*DMM*	
pp (volts)	*pp (volts)*	*RMS (volts)*	*pp (volts)*
1.00 V			
3.00 V			

- Now set the output of the function generator to 60 Hz at 4.00 Vpp**.** Adjust the horizontal and vertical controls so that 3 cycles of sine wave fill the **whole screen** on the oscilloscope.
- Measure the output (Vpp) on the oscilloscope (adjusting the timebase to maintain 3 cycles) and the DMM over the 3 frequencies 60 Hz, 6 kHz and 60 kHz.
- Reset the function generator to 6 kHz and adjust the horizontal scaling of the oscilloscope to display 3 cycles of the sine wave.
- Press the 'Waveform' softkey, 'Select' square wave and note the DMM value.
- 'Select' ramp (triangle wave) and again note the DMM value.

Function Generator	*Oscilloscope*	*DMM*	
Frequency (Hz)	*pp (volts)*	*RMS (volts)*	*pp (volts)*
60			
6 k			
60 k			
6 k square wave			
6 k triangle wave			

Questions:-

3. What can you say about the suitability of each of the two instruments for measuring waveforms?
   (Clue: What does the DMM not tell you? What can't the oscilloscope give you?)
4. What do you think is causing the DMM to show a slightly higher voltage value at 60 kHz?
   (Clue: look at the equipment descriptions on page 2.)

5. Why are the DMM readings not the same for sine, ramp (triangle) and square waveforms? *(Clue: look back at the section on AC meters ii. at the beginning of the exercise.)*

Write your conclusions in your laboratory notebook.

Exercise 3 – Time/ Frequency Measurements

In this exercise you will look at how to measure the time and frequency of voltage waveforms.

- Leave the equipment connected as for exercise 2.
- Press the Hz button on the DMM to select frequency measurement.
- Set the function generator to sine wave with an output of 2 kHz at 4 Vpp and display 1 complete cycle to fill the whole screen.
- Measure the corresponding frequencies indicated on the DMM and on the oscilloscope (by the technique outlined below) and repeat the procedure for the other frequencies listed in the table.

Record the results in your laboratory notebook using a comparison table similar to the one shown below.

Oscilloscope Measurement Technique

Although digital oscilloscopes can give a direct measurement of frequency (and many other wave-form parameters), you can of course still visually measure the **time period of one cycle** as accurately as possible on the screen, and then **take the reciprocal to obtain the frequency.**

$$f = \frac{1}{T}$$

- Using the Horizontal position control, set the zero crossing of the sine wave at the left-hand end of the centre horizontal grid line. Adjust the timebase (Time/ div) to get the start of the next cycle as far to the right of the centre horizontal grid line as possible, and read off the time for one cycle.

Function Generator	*Oscilloscope*		*DMM*
Frequency Hz	*Time Period*	*Frequency*	*Frequency*
2 k			
6 k			
16 k			

Questions:-

6. Which instrument do you think is the most accurate in measuring frequency?
7. When might you choose to use an oscilloscope to measure frequency instead of a DMM?

Write your conclusions in your laboratory notebook.

Exercise 4 – Instrument Impedance and Measurement Accuracy

In this exercise you will look at the effect of instrument impedance on a circuit under test.

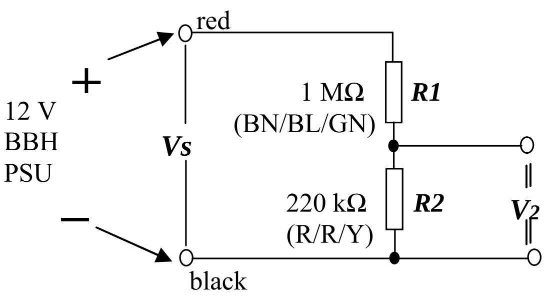
In an AC circuit, impedance (measured in ohms) is the opposition offered by a material to the flow of an electrical current. Impedance has two parts - resistance and reactance. Reactance is made up of two elements, capacitive reactance and inductive reactance. The properties of these last two elements are dependent upon the frequency.

Ideally, when making a measurement or observing a parameter of a system, e.g. waveform, frequency, voltage, current, etc., the measuring device should not affect or alter the system at all. The measuring device should not take energy from or add energy to the system being measured. In practice this is impossible, but by choosing the correct measurement instrument you can make the smallest possible change to the system state.

When measuring voltage for example, all measuring instruments have input impedance (resistance is normally the major factor to consider at DC and low frequencies). Connecting the voltmeter will cause a current to flow from the circuit being measured into the input circuits of the voltmeter. That current comes from the source being measured and thus has disturbed the system. Clearly, the smaller the current taken, the smaller the disturbance will be and the greater the accuracy of the measurement.

The following exercise demonstrates how the choice of measuring instrument can give different results when measuring DC voltages.

- At the end of each bench there is an analogue voltmeter (TENMA 72-6171) with a circuit board attached to it. Take one of these sets, complete the exercise below and then return the set to the end of the bench for someone else to use.



- **Remove** the BNC lead connection from the function generator 'Gen Out' socket.
- Turn the analogue meter to the **'OFF'** position until you take a reading.
- Connect the analogue meter's circuit board red and black leads to the +ve (positive) and -ve (negative) terminals, respectively, of one of the fixed **12 V** outputs on the BBH 5017 power supply.

- Set the DMM to read DC V and measure the **exact** output voltage, ***Vs***, from the DC supply and make a note of the reading **in your laboratory notebook.**

Output voltage ***Vs*** =	

- Using this value, by the potential divider theory below, **calculate** the voltage, ***V2***, across the 220 kΩ resistor.

$$V_2 = \frac{R_2}{R_1 + R_2} \times V_s$$

- Using the solder pins on the underside of the circuit board to make your connections, first **measure *V2*** solely with the DMM connected, then solely with the oscilloscope connected **(set to 500 mV/ div),** and finally solely with the analogue meter switched 'On' **(set to DC V, 10 V range).**

Record the results in your laboratory notebook using a comparison table similar to the one shown below.

Note: your readings should be different on each instrument.

	V2
Calculated	
DMM *	
Oscilloscope *	
Analogue meter	

* When taking these readings the analogue meter must be in the **'OFF'** position.

Questions:-

8. Why do you think the 3 instruments each give different readings?
9. Which gives the most accurate reading and why?
10. When measuring the voltage (V_2) in this circuit; is it best that the measuring instrument has high or low input impedance?

Write your conclusions in your laboratory notebook.

Before moving on to the soldering exercise, have your work checked and signed in your laboratory notebook by a demonstrator:

Demonstrator's signature	....

Exercise 5 – Soldering and circuit construction

This exercise will help you to relate a circuit diagram to a printed circuit board (PCB) and to improve your technique when soldering electronic components.

Read through the following section of information before beginning the soldering exercise.

VERY IMPORTANT!

- **Always use the eye protection provided when soldering or cutting the component leads.**
- **Inform one of the demonstrators if you suffer from asthma as some portable fume extraction units are available on request.**
- **Please ask for help if this is your first attempt at soldering.**
- **Be careful with the soldering iron, the barrel and tip are very hot and will burn you if touched. Always hold the iron by the handle and return it to it's holder when not soldering – don't rest it on the bench.**

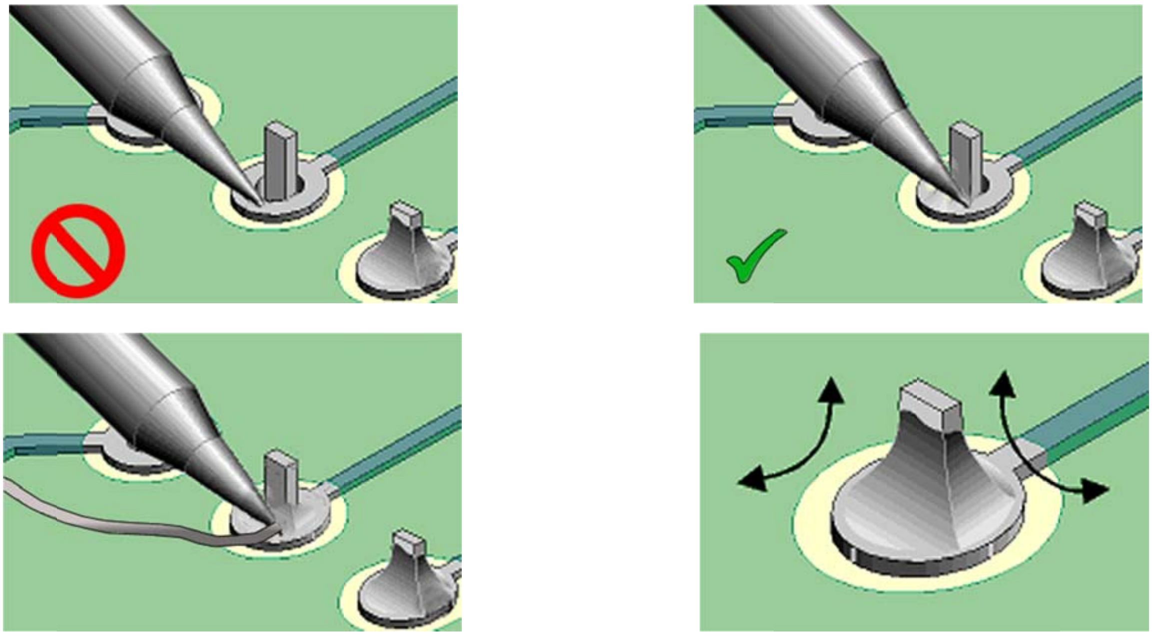
Introduction:-

The following is a basic guide to the first steps in soldering electronic circuits. A more detailed description of the terminology and processes involved is available on a separate sheet (***Soldering – terminology and processes WS1 & WS2)*** which is useful to keep for future reference.

- When the soldering iron is first hot, apply some solder to the end of the bit and then wipe it on the damp sponge so that the solder forms a thin film on the bit. **This procedure is known as 'tinning the bit'.**

Solder will flow evenly and make a good mechanical joint only if both parts of the joint are at an equal high temperature. Even though it may appear that there is a good metal to metal contact between iron, components or circuit board, very often there exists a film of oxide on one or more surfaces that effectively insulates the parts.

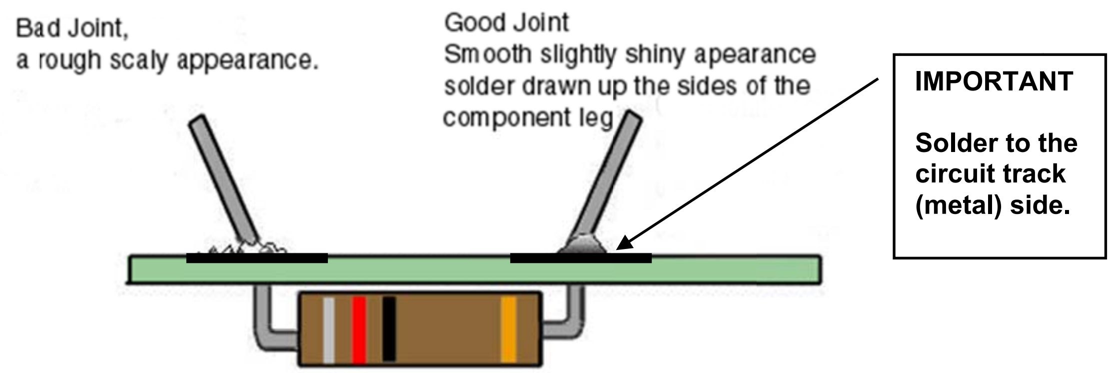
For this reason when you apply the soldering iron tip, keep it in contact with both halves of the joint - the track and the component leg - as shown in the picture (page 10, top right).



Put the end of the solder wire on to the joint and then apply the tip of the soldering iron on to the solder, and in contact with both parts of the joint. It is the flux in the molten solder that both cleans the surfaces to allow ‘wetting’ and also assists in the rapid transfer of heat. Gradually feed in a little more solder wire so that solder just runs up the surface of the component leg, remove the solder wire and iron and allow the joint a few seconds to cool without disturbing it.

On a good joint the solder will have a smooth shiny appearance and if the wire (leg) is pulled it should not pull out of the joint.

In a properly made joint the solder will bond the components very strongly indeed, since the process of soldering is similar to brazing, and to a lesser degree welding, in that the solder actually forms a molecular bond with the surfaces of the joint.



It is important to use the right amount of solder. Too little solder will result in poor heat transfer to the joint, too much and you will suffer from the solder forming strings as the iron is removed, causing splashes and bridges to other contacts. Too little solder will also give the joint a half finished appearance; a good bond where the soldering iron has been, but no solder at all on the other part of the joint.

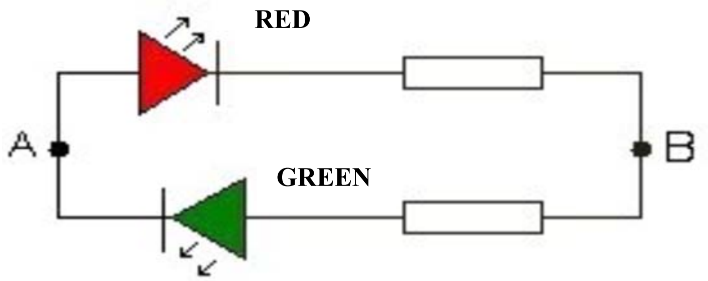
<u>Useful Hints</u>

(i) **Keep your iron tip clean.**
(ii) **Keep the iron tip in contact with the PCB track and component leg at the same time.**
(iii) **Most beginners tend to use too much solder and heat the joint for too long.**

(*iv*) **Don't move the joint until the solder has cooled.**
(*v*) **Use the proper type of iron and tip size.**

- **Switch on the soldering iron. Wear the eye protection (safety glasses) provided.**
- **Construct and test the following circuit using the kit provided.**

Circuit diagram



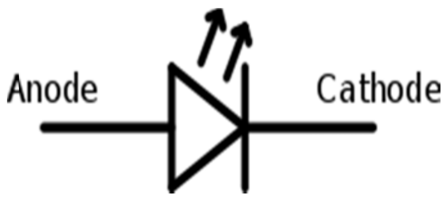
The kit comprises:

1 red LED
1 green LED
2 resistors (470 ohm)
1 printed circuit board

Diodes and LED's

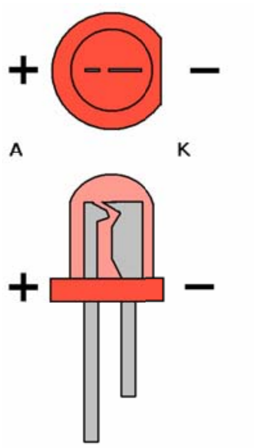
A diode is a semiconductor device consisting of two layers – an N-type layer (cathode)**, k,** and a P-type layer (anode)**, a.** It conducts convectional current in only one direction, from anode to cathode; while actual electron flow is in the opposite direction from cathode to anode.

The Light Emitting Diode used in this circuit is a passive, semiconductor device that emits visible light when a forward current flows through it. It is represented by the symbol:-



The symbol points in the direction of the forward current and the diode will only emit light when an appropriate current flows in this direction. Light output is directly proportional to the forward current, i.e. the higher the current the brighter the light. The devices used in this exercise operate at an optimum brightness for a forward current of between 10 mA to 20 mA.

An LED acts in much the same way as a conventional rectifying diode allowing unrestricted current to flow in one direction and preventing current flow in the other direction. Where the LED is connected to a supply source capable of delivering a high current, then an external series resistor is usually employed to limit the LED current to within its safe operating range.



Mount the components on the PCB by feeding the component legs through the holes on the plain (blank) side of the circuit board and make the connections by soldering the leads to the metal track on the reverse of the board. **Make sure that you have correctly orientated the LED's or the circuit will not function properly,** (the longer leg is positive - anode).

Write all the answers to questions 11-17 in your laboratory notebook.

Testing:-

- Using the PCB track end plates (labelled A and B on the circuit diagram) to make your connections, connect the circuit to the fixed **5 V** output on the BBH power supply, connecting point **A** to the positive terminal of the PSU and point **B** to the negative terminal.

11. Switch on and note what happens.

- Now reverse the connections to the PSU, so that point **A** is connected to the negative terminal and point **B** is connected to the positive terminal.

12. What changes do you observe and why does this happen?

- Turn off the PSU and disconnect the circuit.
- Refit the coaxial 50 Ω BNC – BNC cable between the function generator (‘Gen Out’ socket) and one side of the BNC T-piece connected to CH1. Connect the circuit to the other side of the T-piece.
- Activate the ‘Wave Gen’ and set the generator to produce a **1 Hz, 5 V, square wave.**
- Slowly increase the frequency from 1 Hz to10 Hz and observe the LED’s.

13. Comment on the changes you see?

14. Can you suggest a practical use for this circuit? *(Clue: current flow)*

- Slowly increase the frequency from 10 Hz to 50 Hz and observe the LED’s.

15. What changes do you observe?

- Now slowly adjust the frequency back to the precise point where you think the LED’s stop ‘flashing’ and appear to be continuously lit.

16. Note this frequency.

Compare your result with other people, the point at which you observe the LED’s to be continuously lit may be slightly different as the limits of human vision vary between individuals. However everyone observes the LED’s as continuously lit at 50 Hz, (this is the frequency used in the electrical mains AC power supply and the reason why you do not ‘see’ the lights in this room continually flashing ‘On’ and ‘Off’).

17. What is the function of the series resistor in the circuit?

Have your soldering work checked and signed in your laboratory notebook by a demonstrator:

Demonstrator’s signature	....

Before leaving, make sure that your mark is entered on the attendance register.

<u>Closedown</u> – Please make sure that ALL the equipment is switched ‘OFF’.

The circuit board is yours to keep if you wish!