Workstation Familiarisation

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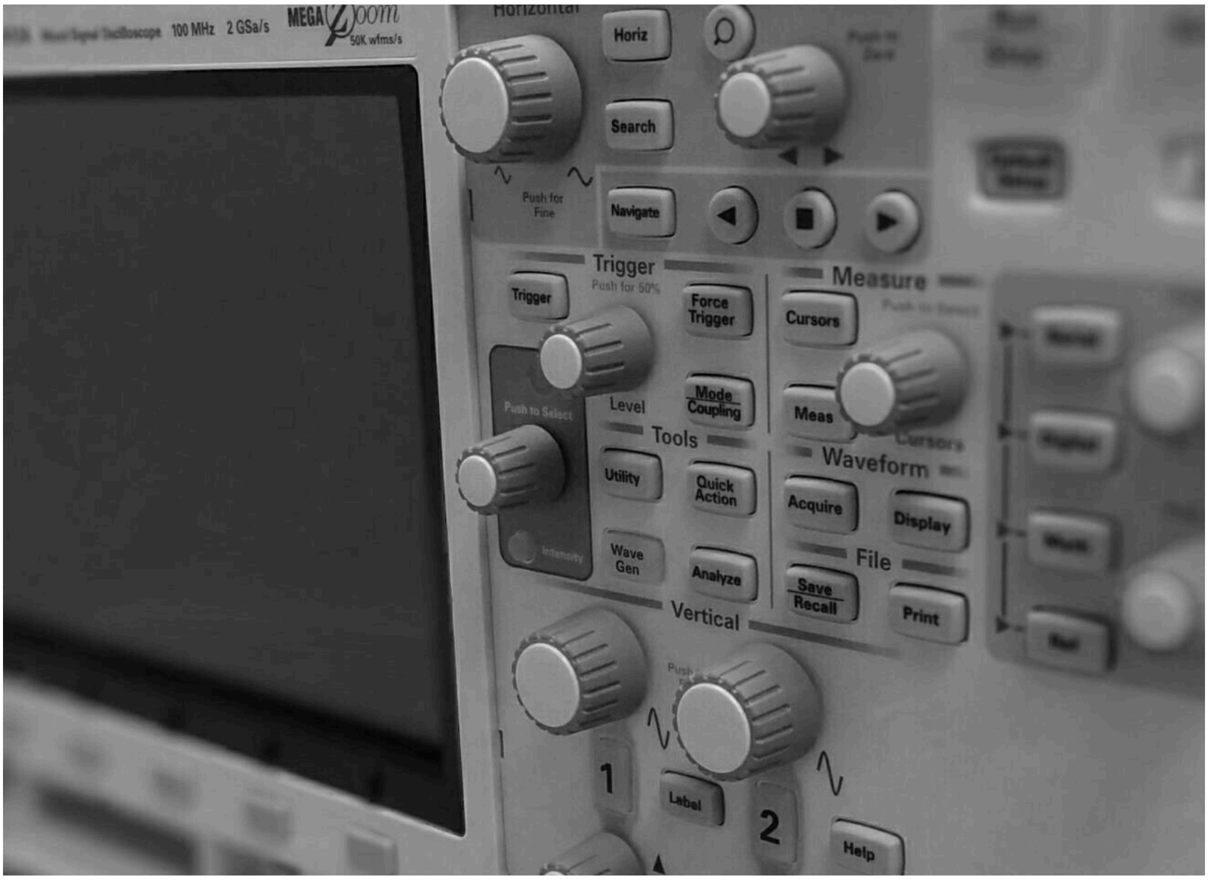


Learning Outcomes

Practical	Be able to make basic measurements using a range of electronic test and measurement equipment
Error	Be able to appreciate the importance of tolerances and errors, and discover some reasons why some measurement instruments can report values with different levels of precision and accuracy.
Build	Be able to build and test electronics circuits on a breadboard and printed circuit board.
Programme	Be able to write a C programme and use an Arduino microcontroller to blink a LED.

Workstation Familiarisation:

Pre-lab Activity

A pre-lab activity must be completed before starting this experiment. Failure to complete these tasks may result in you being refused entry into the laboratory.

1 Aims and objectives

This lab aims to construct circuits, measure their properties and consider the precision and accuracy of the measurement. It also aims to teach the basic principles of workstation instrument usage. To achieve these aims, the following objectives are set:

- Build a simple circuit on a breadboard, consisting of a power supply and two resistors
- Measure the voltages around the circuit and compare them to theoretical values
- Set up a waveform (signal) generator and make measurements of the generated signals using an oscilloscope
- Solder components to a printed circuit board, and test the circuit's functionality using multimeter and Oscilloscope.

- Programme the Arduino microcontroller to blink a LED.

2 Background

2.1.1 Lab equipment

In this activity you will use the standard lab equipment for electronics work:

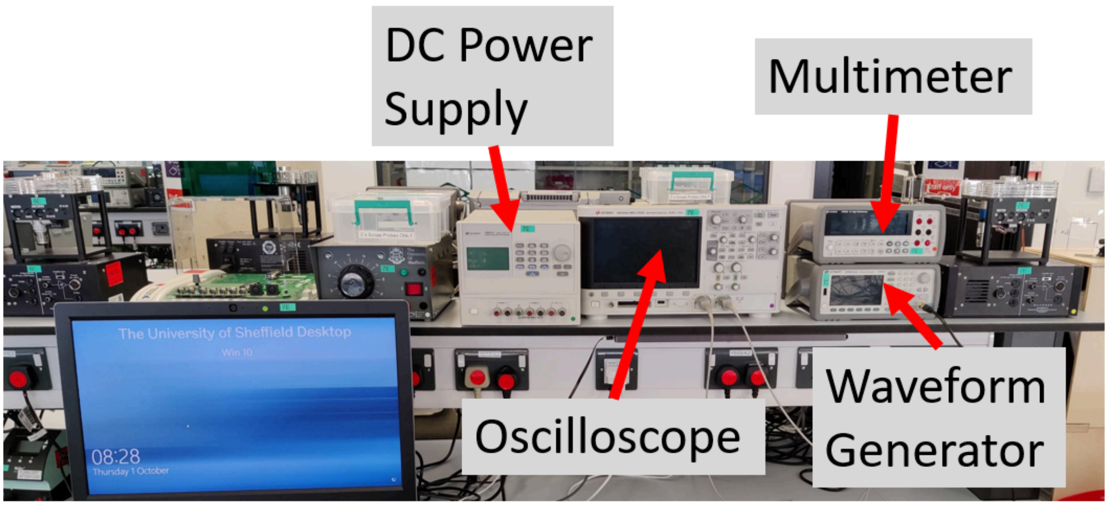
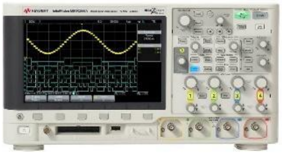


Figure 1: The standard lab equipment used for all practical electronics work

Table 1: Comparing the electronics lab equipment types

			
DC Power Supply	Oscilloscope	Multimeter	Waveform Generator
Provides constant DC power to circuits. Either constant DC voltage or constant DC current can be specified	Displays a real-time graph of voltage against time. Can measure and display both AC and DC voltages.	Can numerically measure voltage, current, resistance, capacitance… and more! Can measure both AC and DC signals.	Provides AC signals to test circuits. Can produce sine, square, triangle or any arbitrary waveforms.

- Make sure you can identify each of these devices. The lab session will instruct you in detail on how to use them, but you do need to know which one is which!

2.1.2 Using basic hand tools

Every workbench has its own dedicated toolkit. It can be found at the right hand side of your bench and is contained in a black box with red clips. Please locate the toolkit and open the box. Inside you need to look for and take out the following items shown in Figure 2:

Figure 2: Hand tools kit

Pliers Wire strippers Side cutters

Figure 3: Circuit construction tools [For prelab Q4, 5 and 6 please see Fig.5]

These basic hand tools are vital to anyone who is building a circuit using a prototype board (also known as breadboard) or using a printed circuit board (PCB). Using construction tools Figure 3 wire cutters, wire strippers and pliers should be a fundamental skill, but if you are unsure read wire cutting and wire stripping instructions. The pliers should be used to bend your wires and also to place them, and associated components, into your circuit board. Doing this accurately using your fingers can be tricky, and if you use your fingers rather than the pliers, you are less likely to build successfully as a beginner. In real life you will find that a combination of using pliers and your hands will work best. The more experience you have of building circuits using hand tools the neater circuits you will be able to build. You can also use the blue solder sucker for any desoldering activity if you are not sure how to use it please ask a member of staff.

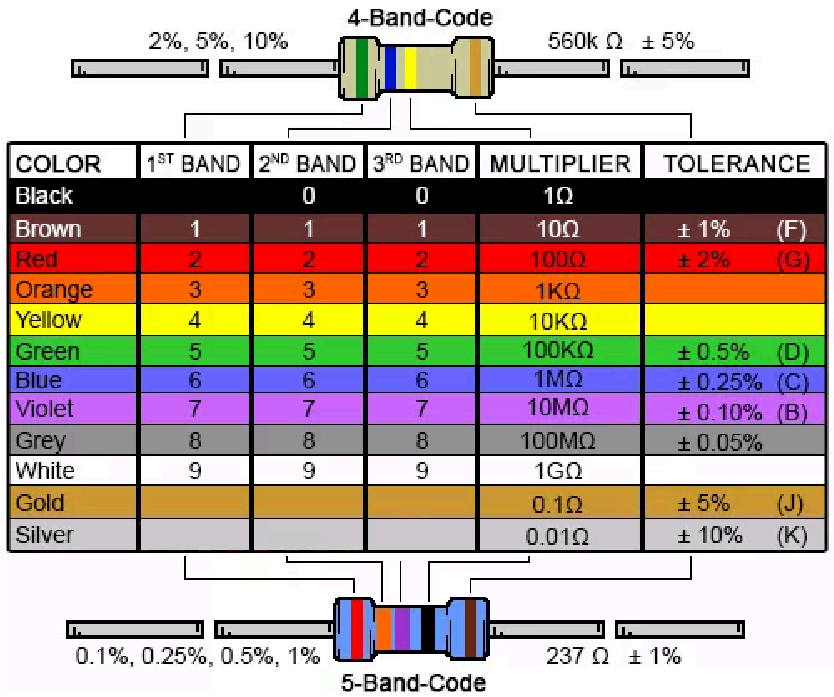
2.1.3 Resistor colour code labelling

Electronic components are small, so it is difficult to print detailed labels on them to describe their characteristics. Instead, we use codes to distinguish the component properties. For resistors, this code takes the form of coloured lines drawn around the body of the component. Figure 4 shows the internationally agreed system for marking resistors.

Sometimes resistors have 4 colour bands, sometimes 5 - look carefully and count them.

For a 4-band resistor, the first two colours provide a numerical value, which is multiplied by the number shown in the third colour. For example, the resistor shown at the top of Figure 4 shows green=5 and blue=6, which makes 56. The third band is yellow=10k. The values are then multiplied i.e. 56 x 10k = 560kΩ.

The final colour band gives the manufacturing tolerance of the resistor. The tolerance specifies the amount that the actual value of the resistance may vary by compared to the theoretical value. In the example at the top of Figure 3, the tolerance band is gold=5%. This means that the resistance of this example resistor could vary by 5% of 560kΩ = 28Ω. Therefore the resistor is only guaranteed to have a value between 532kΩ and 588kΩ.



COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black		0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8	100MΩ	± 0.05%
White	9	9	9	1GΩ	
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

Figure 4: The resistor colour code [1].

For a 5-band resistor, the principle is similar, except there are now three bands of numerical value, then the fourth band is the multiplier and the fifth band is the tolerance. For the example at the bottom of Figure 3, the numerical value is red=2, orange=3, violet=7 making 237, and the multiplier is black=1Ω. These are multiplied together to give 237 x 1Ω = 237Ω. The tolerance in the fifth band is brown=1%, meaning the true value of this resistance could lie anywhere between 235 and 239Ω.

2.1.4 Current, Voltage and Resistance in series circuits

In the first part of this exercise you will measure the voltages around the circuit that you have constructed on the breadboard. For Ohmic devices such as resistors, we can use Ohm's Law to determine the current and voltage through the circuit. Ohm's law states:

$$V = IR$$

Where V = Voltage, I = Current and R = Resistance.

In the circuit to be built in the lab, two resistors are combined in series, as shown in Figure 5. When resistors are combined in series, the resistances can be combined to find the total resistance i.e. in Figure 5, the total circuit resistance is R1+R2.

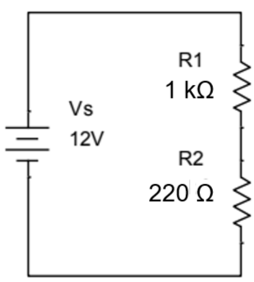


Figure 5: The circuit to be constructed in the lab.

In a series circuit, the current is the same at all points in the circuit. You can calculate the current by finding the total resistance around the series loop, then using Ohms' Law and the source voltage.

Even though the current is the same everywhere, the voltage dropped across each resistor must differ, due to Ohm's Law. Therefore the resistors form a "potential divider" – the total supply voltage is divided between the series resistors in the circuit. The voltage drop across each resistor is different, based on their resistance:

$$V_{R1} = \frac{R1}{R1+R2} V_S \quad \text{and} \quad V_{R2} = \frac{R2}{R1+R2} V_S$$

- Calculate the voltages you would expect to measure across R1 and R2.
  You will need to enter these values into the pre-lab quiz.
- Calculate the current you would expect to flow around the series circuit.
  You will need to enter this value into the pre-lab quiz.

2.1.5 Practical voltage measurement

To measure voltage in the lab, always connect the voltmeter in parallel to the device under test i.e. connect the wires either side of the resistors, as shown in Figure 6.

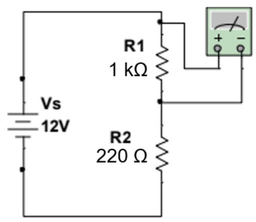


Figure 6: The test equipment connected in parallel with the resistor to be measured.

However, connecting the voltmeter causes a problem. By connecting the measurement equipment in parallel with the resistor that we are measuring, we have created a parallel pathway that current could flow down. In an ideal world, no current would flow through the meter and the circuit would be unaffected. This means that an ideal voltmeter should have an input resistance which is infinitely high.

Figure 7, shows an extract from the datasheet for the measurement device that you will use:

DC Voltage

- Measuring Method:
  - Sigma Delta A-to-D converter
- Input Resistance:
  - >10 GΩ ± 2% range (Selectable 100 mV, 1 V ranges)
  - 10 MΩ ± 2% range (typical)

Figure 7: A sample of the specifications from the datasheet of the multimeter.

2.1.6 Practical current measurement

To measure current, the multimeter should be connected in series with the circuit components, as shown in Figure 8. Compare this to Figure 6 to see how the meter connectivity has changed.

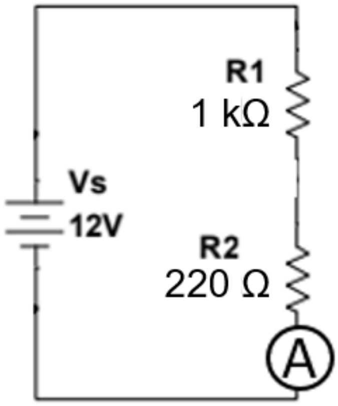


Figure 8: A current meter (the circuit symbol is an A in a circle, for Amps or Ammeter) placed in series with the components.

The different placement of the meter depending on whether voltage or current is being measured (i.e. series or parallel), suggests the properties that the meter should have, so that accurate measurements are made:

- The voltmeter should have very high (ideally infinite) resistance to minimise current flowing through the meter rather than through the circuit being measured
- The current meter should have very low (ideally zero) resistance so that the current through the circuit being measured is not reduced due to the meter itself

2.1.7 Measuring AC Signal Voltages

The second part of this exercise involves measuring AC signal voltage levels. Consider the shape of a sine wave - the value of the voltage (or current) varies with time. When the signal is at its highest point, this voltage is called the maximum amplitude or peak voltage (V_p). Likewise, the signal also reaches a maximum magnitude in the negative direction, called a negative peak. The voltage difference between a positive and negative peak is called the peak-to-peak value of the signal (V_{pp}).

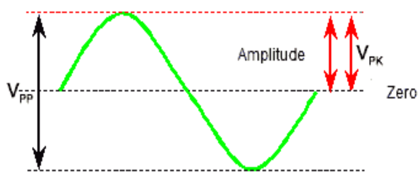


Figure 9: The peak-to-peak voltage V_{PP} (left), and the peak voltage V_{PK} (right) [2].

Since the value of an AC signal is varying continuously in time, it is useful to consider only an effective average value. Finding the average current of an AC signal would appear to be zero! If the current spends half of the time travelling in one direction and half of the time in the opposite direction, the net currents would cancel out. Instead, it is useful to consider the power transferred by the current. The power dissipated in a DC circuit is given by

$$P = I^2R$$

Where P = power (W), I = current (A) and R = resistance (Ω).

We define that an AC signal has an effective current of 1 Amp when it produces the same rate of heat dissipation in a resistor as 1 Amp of DC signal. From the above equation, the amount of power dissipated in a DC circuit can be found by $P = I^2R$. Hence, the power dissipated in an AC circuit is also given by $P = I^2R$.

To calculate how much heat is dissipated on average over a period of time, it is necessary to find the average of the squares of the instantaneous values of current in that period. This value is known as the Root Mean Square (RMS) value.

To calculate the RMS current, we take the square root of the mean value of the square of the current. Since a sine wave is a repeating wave over a period T, we can find the mean over just one period, as this will hold for all time. The equation to find that mean is:

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T \left(V_P \sin sin\,(\omega t)\right)^2 dt}$$

Evaluating this equation gives us the general rule that for a sine wave, the Root Mean Square (RMS) value is equal to $\frac{V_P}{\sqrt{2}}$ or $0.707V_P$.

3 Soldering

3.1 LED

A diode, as shown in Figure 10, is a semiconductor device that conducts conventional current in only one direction, from anode to cathode.

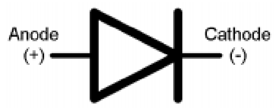


Figure 10: The circuit symbol for a diode. Current only flows from anode to cathode - the direction of the arrow.

The Light Emitting Diode (LED) used in this exercise emits visible light when a current flows through it. It is represented by the symbol shown in Figure 11.

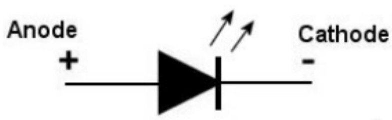


Figure 11: The circuit symbol for a light emitting diode. Current flows + to - as in Figure 10.

The triangle symbol points in the direction of the forward current; the diode will only emit light when 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 LED devices used in this exercise have 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 diode, allowing unrestricted current to flow when a voltage is applied in one direction and preventing current flow in the other direction. When the LED is connected to a supply source capable of delivering a high current, a series resistor is required to limit the LED current to a value within its safe operating range.

3.2 Soldering Techniques

Soldering provides the functions of mechanical and electrical support of component connections cheaply and easily. Joints are formed by metallic bonds between the metals in the joint area (usually the copper track of a circuit board and component leads) and the solder. We use printed circuit boards (PCBs) to form circuits for easy mass production and convenience. Instead of using wires to make connections between components, PCBs have metal tracks running through the board which complete the circuits between components. Soldering can be used to attach components to special “pads”, which ensure they are in the correct position in the circuit.

Modern solder is an alloy, usually of tin and lead (although other alloys are occasionally used, and impurities may be added to conventional tin/lead solder to create changes in properties). This alloy melts at a lower temperature than either of the metals to be joined, which means that joints can be made to metals that form the leads of fragile components. The relatively low melting point also means that many joints may be soldered at the same time with little fear of damaging components. The process of soldering only occurs on certain surfaces, usually metallic, and does not occur on insulating surfaces.

The essential rules of soldering include:

- Always use eye protection when soldering or cutting component leads.
- **Inform staff if you suffer from asthma or other breathing difficulties, so that additional fume extraction can be supplied**
- Always hold the soldering iron by the handle - the barrel and tip are very hot.
- Always return the soldering iron to its stand, never rest it on the bench.

When the soldering iron is first hot, apply some solder to the end of the tip and then wipe it on the metal wool, so that the solder forms a thin film on the tip. 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 a high temperature. For this reason, when you apply the soldering iron tip, keep it in contact with both the track and the component leg - as shown in Figure 12.

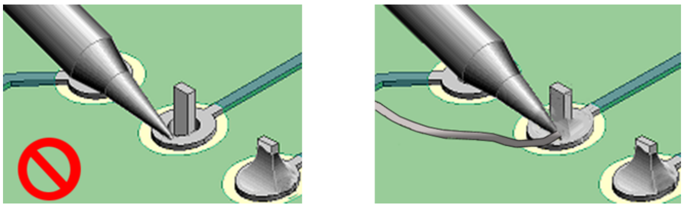


Figure 12: methods of soldering - the correct method on the right has the tip in direct contact with both the component leg and the PCB pad.

First, heat both the circuit board and the component leg coming through the hole. Place the end of the solder wire on to the joint and then apply the tip of the soldering iron to the solder, 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 move in the joint. Examples of good and bad joints are shown in Figure 13.

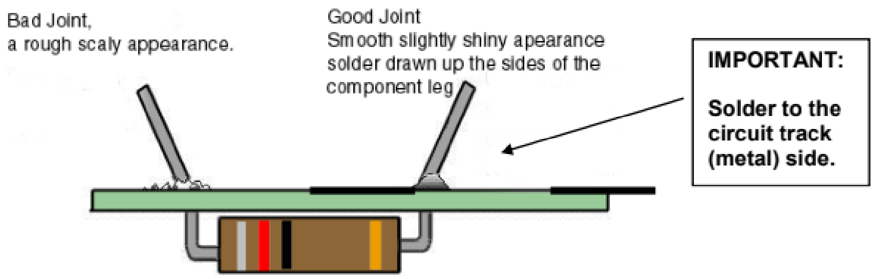


Figure 13: An example of good and bad solder joints, as seen from the side of a PCB.

3.3 LED circuit soldering and testing

If you have not seen it already, please watch the 3 minute soldering instructions and safety video at this link:

https://digitalmedia.sheffield.ac.uk/media/Diamond+Electronics+and+Control+Lab+Soldering+Tutorial+-+Quiz/1_jxmgxov1

3.4 Safety when soldering

- Wear the safety glasses provided
- **The fumes from soldering are safe within this well ventilated laboratory. However, if you suffer from asthma or other breathing difficulties, additional fume extraction units are available and we encourage you to use them – please ask a member of staff about this.**
- Only touch the soldering iron by the handle – never touch the tip or metal shaft
- Always replace the soldering iron in the holder when it is not in use – never leave it on the bench
- Always switch off the soldering iron after use and never leave it unattended while it is powered on

4 Soldering circuit and components function

You will be given the opportunity to further your soldering skills as you will need to be proficient at soldering throughout your course. See the reminder here. In electronic circuits each component has an important role to play. The components can be divided into four categories: input, passive, process and output components.

The resistors are two-terminal passive components designed to limit the flow of current, divide voltage if connected in series and divide current if connected in parallel. The resistor behaviour is similar to mechanical damper or shock absorber used in cars suspension systems.

The capacitors are two-terminal passive energy storage components and can be polarised or non-polarised with various types due to dielectric material used in between their plates. The capacitors can store charge similar to a cell or battery but have the properties to store and release the charge very quickly. The capacitor behaviour is similar to a spring.

The transistor is a three-terminal process component made of semiconductor material and can be used as an electronic switch or amplifier in a circuit. In the Figure 14 circuit, we are using the transistor as an electronic switch to control LED switching on/off by controlling the flow of current to the transistor base. There are various types of transistors. In this activity we are using a bipolar junction transistor which has three terminals called “base”, “collector”, and “emitter”.

The LED is a two-terminal output component made of semiconductor material and can emit light. The LED is a polarised component and should be accurately placed on the circuit. The circuit you are going to build for this activity is shown in Figure 14. This is a **Transistor Astable Circuit** (hazard warning light circuit). These circuits are generally used near schools or on remote roads to warn the motorist of potential hazards.

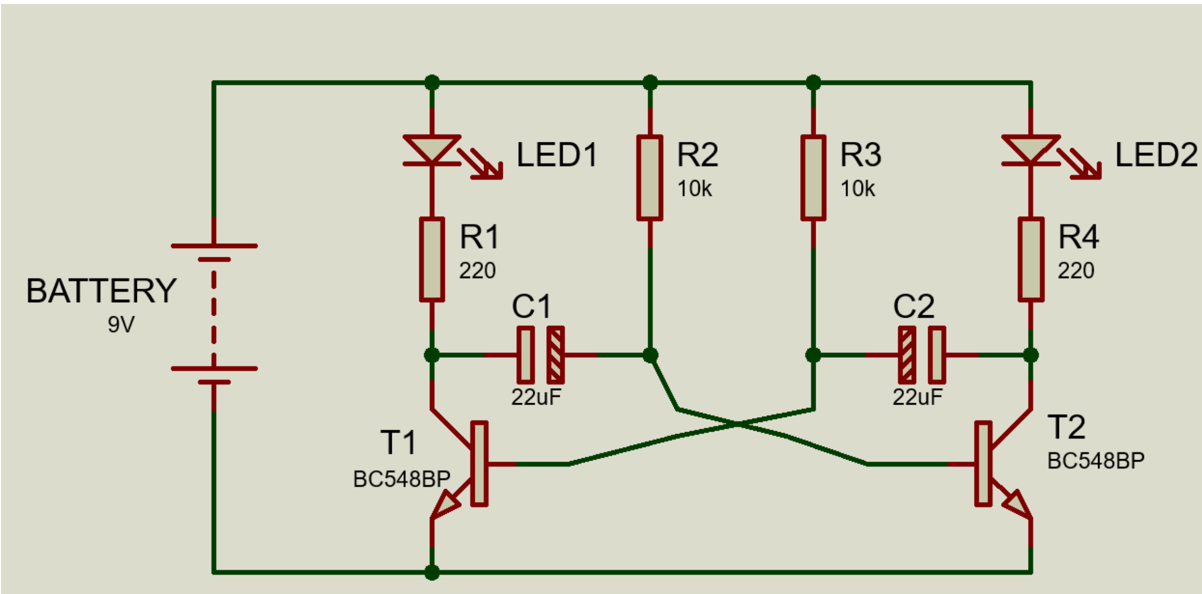


Figure 14: Transistor Astable Circuit (hazard warning light circuit).

This circuit is powered using a 9V PP3 battery and you can also use the 9V DC power supply in the lab.

The circuit uses two transistors, two electrolytic capacitors to oscillate and two LEDs to flash light.

The Transistor Astable Circuit produces pulsed outputs. They are often used to control flashing lights and audible outputs such as buzzers.

The number of complete pulses produced per second is called the “frequency”. Frequency is measured in units called “hertz”, abbreviated Hz.

The length of time taken for one pulse is called the “duration” of the pulse, *T*. The ratio of time on to time off for a pulse is known as the “mark/space ratio”, see Figure 15:

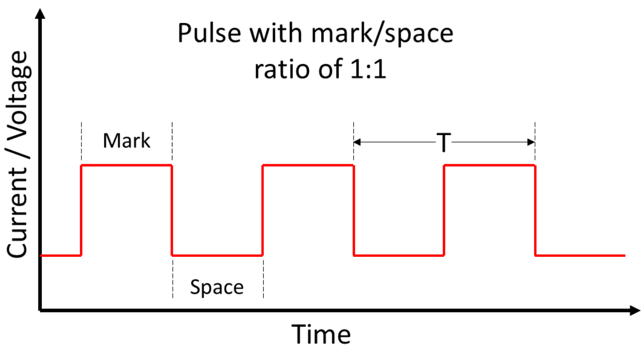


Figure 15: Pulses with mark/space ratio.

This particular exercise is purely based on practical skills and will test your soldering skills and also your accuracy of correctly placing components.

5 Introduction to Arduino

Watch the pre-lab video on the blackboard to see all the possibilities available for working with Arduino hardware and software. You will see some code concepts introduced that will be used in the lab sessions.

Signup for Tinkercad here: https://www.tinkercad.com

Use your university Google account to sign in i.e. use your university email address, and then sign-in using your university credentials as normal. You can access various Arduino activities via Resources / Learning Center. You can also build and test circuits in the TinkerCad by using the Circuits in the Tinker menu.

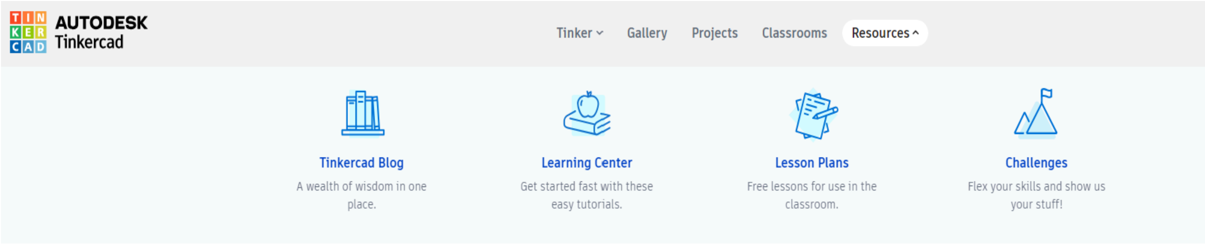


Figure 16: TinkerCad Learning Centre.

Complete the TinkerCad tutorial on blinking LED activity Figure 17 and look at the structure / commands of C++ codes in the code editor. 

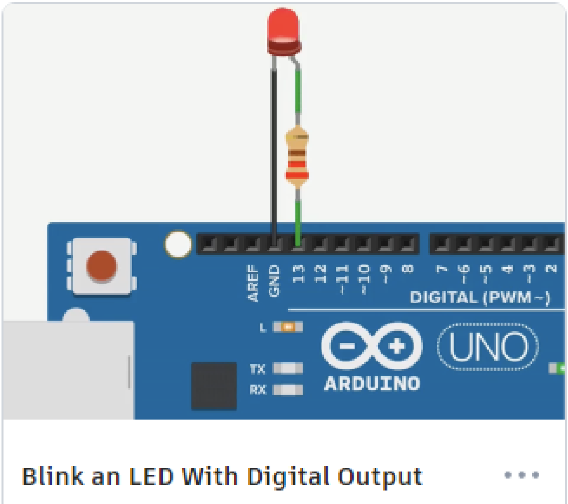


Figure 17: TinkerCad LED blinking activity

If you wish to continue working on any other classes, you can simply log in to the website at https://www.tinkercad.com/ and explore the many other interesting tutorials. It is important for you to develop Arduino skills as you will be using this in your future labs and projects. Additional resources are also available on our Diamond Wednesdays website.

6 References:

[1] "4 Band Resistor Color Code Calculator", Digikey, accessed 2018 online at https://www.digikey.com/en/resources/conversion-calculators/conversion-calculator-resistor-color-code-4-band

[2] "Learn about Electronics - Measuring the Sine Wave", accessed 2018 online at http://www.learnabout-electronics.org/ac_theory/ac_waves02.php

7 Pre-lab tasks to complete

Check the Blackboard page for this experiment and ensure that **all** of the pre-lab tasks detailed there are complete – failure to complete any of the tasks may mean that you are not permitted to take part in the experiment.

Date:

Workstation Familiarisation:

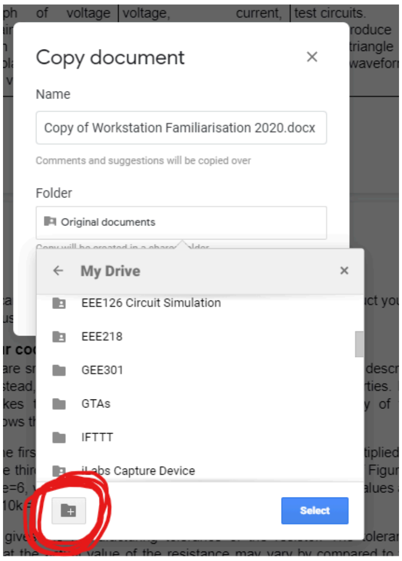
Experimental Record

This section is to be completed during the experiment in the laboratory.

You must make notes on your progress through this experiment. You can do this in your own laboratory notebook on paper, or you can make a copy of this digital lab sheet and edit it with your own notes.

To make an editable copy of this labsheet:

- **Click File > Make a Copy in this Google Sheet window**
- You can now choose a location in your University Google Drive to save the file.
  Click on the box underneath the word "Folder" to choose a place to save.
  If you do not have one already, use this button to make a new folder to store labsheets in, so that you can find them again later:



- You can now proceed with the experiment, making notes as you go by directly editing your copy of the document.
- In particular, you are expected to make notes or complete tables wherever you see this symbol:

1 Procedure

1.1 Measure the resistance

Use the resistor colour code given in the Figure 4 to read the value of the resistors given to you and then using the multimeter validate these values.

- Switch on the multimeter using the white button at the bottom left hand side of the front panel.
- Select resistance measurement by pressing the 

button.
- Connect two 4mm-plug to croc-clip leads to the ports shown below. You need to collect these leads from the cable racks in the lab and put them back when you finish the lab.
- Hold the resistors one by one in the croc-clip to measure their values Figure 19.

Figure 18: Multimeter connected as an ohmmeter to measure the resistance.

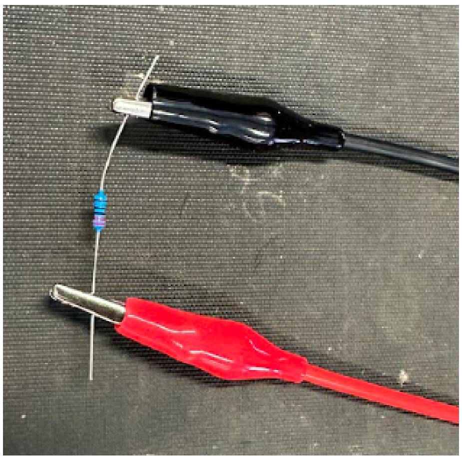


Figure 19: Resistor held with croc-clips.

1.2 **Breadboard circuit construction**

To build the test circuit shown in Figure 20 a breadboard (shown in Figure 21) will be used.

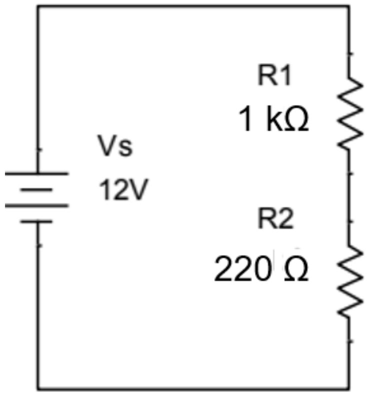


Figure 20: Test circuit

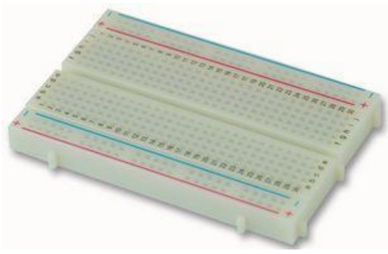


Figure 21: Breadboard

The long columns of holes on the outside of the breadboard, as shown in pink at the top of Figure 22, are all connected together. Each small row of 5 holes in the middle of the breadboard, as shown in blue in the middle of Figure 22, are also connected together.

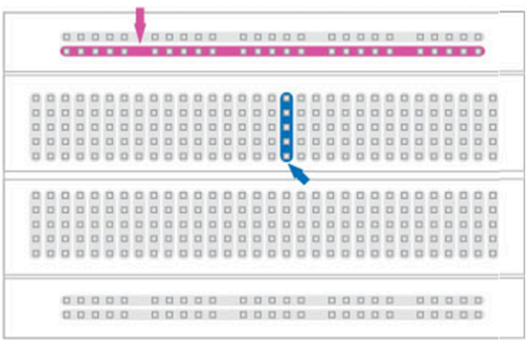


Figure 22: How the holes on a breadboard are connected internally [1]

To make connections on the breadboard, wire can be used to join the rows of holes together e.g. to make a connection between point A and point B in Figure 23 a wire (cable) can be used between anywhere in the pink (upper horizontal) region and anywhere in the blue (small vertical) region.

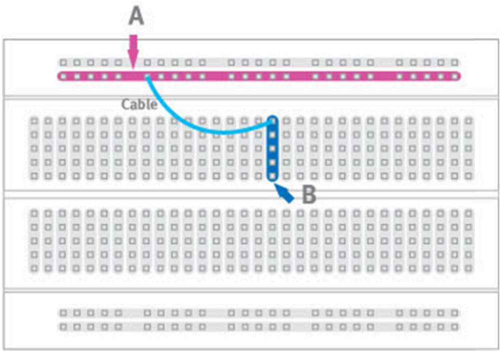


Figure 23: How to connect two regions of a breadboard together [1]

When inserting components into a breadboard, each leg of the component must be inserted into a different row of holes. For example, in Figure 24 the LED on the left is connected correctly, as it has one leg in each row of five holes. The LED on the right has both legs in the same row – this means that the legs are connected, so no current will flow through the LED.

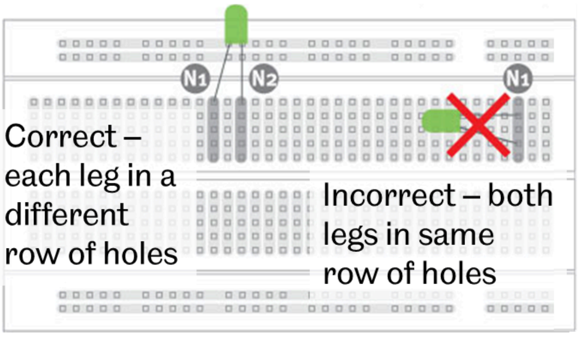


Figure 24: Correct and incorrect connection of an LED to a breadboard [1].

- Use the resistor colour code or multimeter to identify the two resistors required. You can find a resistor colour code in the pre-lab reading, or you can search for it online.
  Sometimes resistors have 4 colour bands, sometimes 5 - look carefully at the resistors you have and count them before starting to use the colour code!
- Construct the circuit shown in Figure 20 on the breadboard. The finished circuit should appear similar to Figure 25.

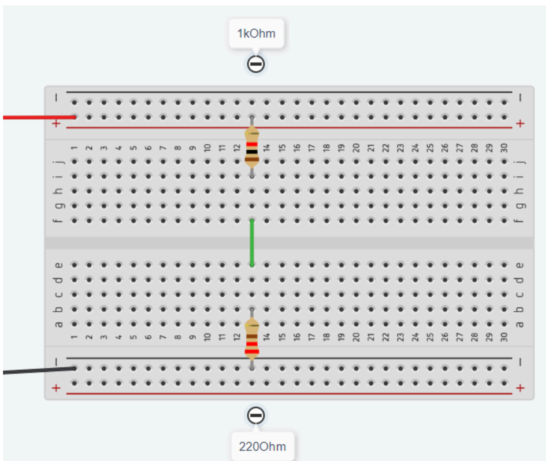


Figure 25: An example of completed circuit construction on the breadboard.

1.3 DC Power Supply setup

The DC power supply to be used in this experiment is shown in Figure 26. It is capable of supplying variable DC voltages from three outputs.

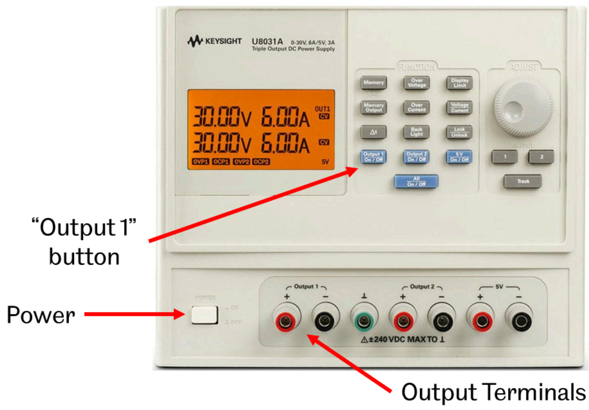


Figure 26: DC power supply

- To set up the DC power supply, firstly ensure there are **no connections** made to any of the terminals.
- **Switch on** the power supply using the button on the bottom left hand side. The display should read “OFF OFF”.
- Press the blue “Output 1” button, and adjust the control wheel to give **12 V output**.
- Press the “Output 1” button again to turn off the output, ready to connect the circuit.

1.4 Connection of the DC power supply to the test circuit:

- Collect the croc-clips leads from the cable racks.
- Connect the Output 1 red terminal to the red wire on the breadboard using a plug to crocodile clip lead (see Figure 27), connected to a small breadboard lead (Figure 25).

Figure 27: Plug to croc-clips leads

- Connect the Output 1 black terminal to the black wire on the breadboard using a plug to crocodile clip lead, connected to a small breadboard lead (Figure 25).
- Check the connectivity of the full circuit – follow the wires in a continuous loop from the power supply, through the breadboard, through both resistors in turn and back to the power supply.
- **Show the circuit to a member of staff and ask them to check your setup before continuing.**

1.5 Circuit voltages

There are three voltages around the circuit to be measured, as shown in Figure 28.

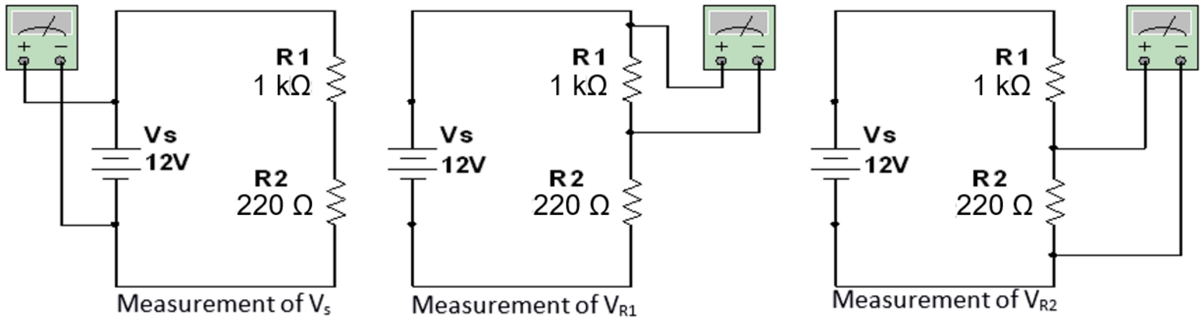


Figure 28: The three voltage measurements to be performed on the circuit

During the pre-lab, the theoretical voltages across each of the components in the circuit should have been calculated using the potential divider formulas. In this experiment, the aim is to see how real measurements compare to the theoretical expectations.

- Write the theoretically calculated voltages V_{R1} and V_{R2} into the first column of Table 2.

Table 2: Voltage measurements

Measurement	Theoretically Calculated (V)	 Multimeter (V)
V_s		
V_{R1}		
V_{R2}		

1.6 Measuring voltages

- Switch on the multimeter using the white button at the bottom left hand side of the front panel.
- Select DC voltage measurement by pressing the  button.

- Collect the croc-clips leads from the cable racks.
- Connect two plug to croc-clip leads (see Figure 27) to the ports shown in Figure 29.

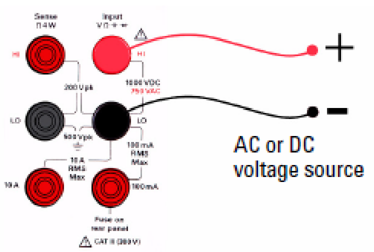


Figure 29: Multimeter connections for voltage measurement (top lead = red, bottom lead = black).

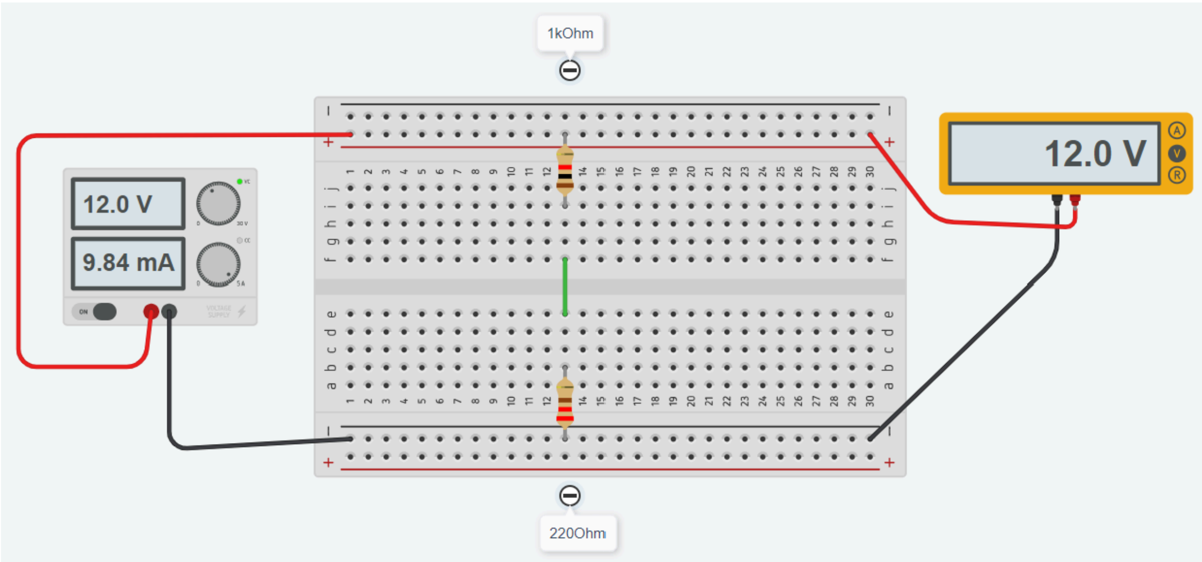


Figure 30: Breadboard connections for supply voltage measurement.

- Connect the croc-clips to the breadboard to make a measurement of the supply voltage, V_s, as shown on the left of Figure 30.
- An example of the breadboard connections to measure the voltage across the power supply is shown in Figure 30.
- **Switch on** the power supply output using the blue button, and record the voltage measured in Table 2.
- **Switch off** the power supply output using the blue button.
- Repeat this process to make measurements of the voltages across R1 and R2, V_{R1} and V_{R2}, as shown in the middle and right of Figure 28. You can measure the voltage across R1 and R2 in a similar way by using the multimeter across the components R1 and R2.
- Record all measurements in Table 2. **Take care to record an appropriate number of significant figures.**
- Always **switch off** the power supply between measurements.

1.7 Measure currents

When measuring current, the circuit must be changed so that the current meter can be inserted in series with the circuit – see Figure 31.

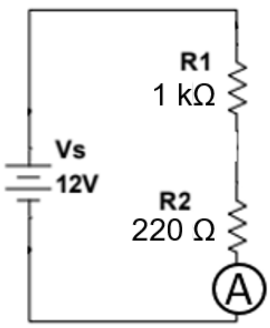


Figure 31: A circuit diagram representation of making a current measurement

For the voltage measurements that we have already performed, the meter was connected in parallel, and as little current as possible should flow through it. For a current measurement, all current should flow through the meter with as little impedance as possible. This is shown in Figure 32 along with a breadboard connection in Figure 33. Note that the current is the same everywhere in this simple series circuit, so the meter can be placed in series anywhere.

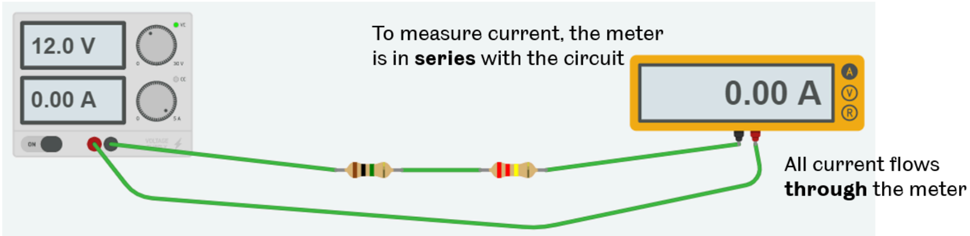


Figure 32: A pictorial representation of making a current measurement

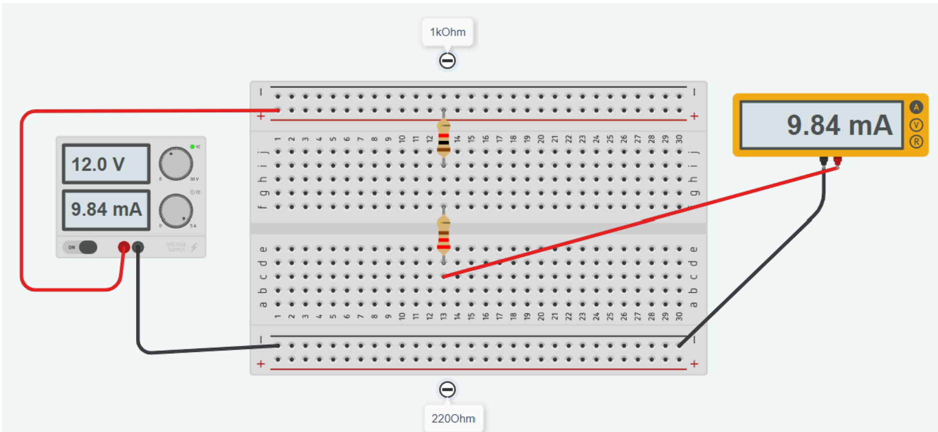


Figure 33: Breadboard layout for making a current measurement

Different multimeter ports must be used for current measurements instead of voltage measurements, as shown in figure 34. For this measurement **use 10A port** this is to avoid any damage to the fuse.

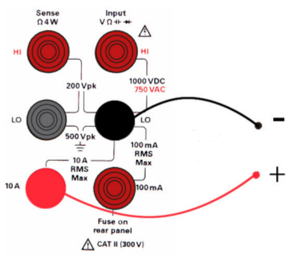


Figure 34: The ammeter ports used to measure current through the circuit

- **Turn off** the DC Power supply before making any changes to the circuit.
- Connect the plug to croc-clip cables into the multimeter ports shown in Figure 34.
- Then connect the multimeter into the circuit – remember that to measure current, **the current must flow through the meter, so the circuit must be adapted from the first experiment** – trace the path around the circuit with your finger if you are unsure.

- Select DC Current measurement by pressing the 

button.
- **Ask a member of staff to check your circuit**, then turn on the DC Power Supply.
- Record the current flowing in the circuit below. Make a note of the current measurement in the space below. Always note down the **units** with every measurement.

Look closely at the DC power supply display screen. The display should show both the voltage and the current that it is supplying to the circuit. The voltage reading is probably correct, but the current reading might not match what you have recorded in the box above. What does the power supply say, and why?

Calculate the power delivered by the DC power supply to the circuit using formula [P=V I] and power dissipated by the resistors using formula [$P = I^2 R$]. Are these two values equal? If not, why?

When making measurements it is important to ensure that the measurement range of the instrument is suitable to both precisely and safely measure the quantity you are interested in.

1.8 Errors and uncertainty

Using the calculated theoretical value as a reference (from Table 2), calculate the percentage error in the measurements of V_{R1}. Remember percentage error = $\frac{measured-reference}{reference}\times100\%$.

Consider the data that you have recorded in Table 2. List all potential sources of error or uncertainty in the readings taken. Hint: what information does the resistor colour code provide? And how are the components connected together?

Show a member of staff your answers before continuing.
Unplug the circuit from the DC Power supply – it is no longer needed!

2 Generate a signal from the waveform generator

The waveform generator can produce voltage waveforms e.g. sine waves, square waves, pulses etc. We use the waveform generator as a voltage source, and connect it into circuits to test their response to variable voltage inputs. In this lab session we will directly measure the output of the waveform generator, just to learn how to use it.

- Turn on the waveform generator using the button at the bottom left of the front panel.
- Plug in a BNC to croc-clip cable to the “Output” connector at the bottom right of the front panel. This type of cable is shown in Figure 35. You need to collect the BNC cable from the cable racks in the lab.

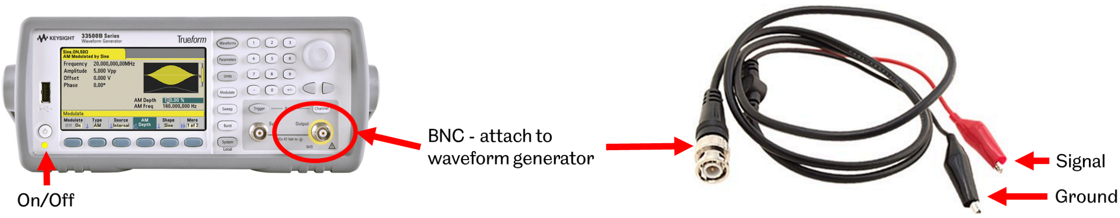


Figure 35: Waveform generator and BNC to croc-clip cable.

Whenever circuits are constructed using grounded instruments, all Ground connections MUST be in the same place.

Always connect the black clips from the waveform generator to the same place in the circuit as the black clips from the oscilloscope.

To change the waveform type (sine, square, ramp (triangle) etc.) press the button 

and use the buttons along the bottom of the screen.

- Set up the Waveform Generator to output a **Sine** wave

- Ensure that the Waveform Generator output is on by pressing **Channel** then checking that **Output -> On** is highlighted: 

press the button below the screen to set this if required.

- **Adjust** the Channel output impedance to High-Z by pressing the channel button for menu and then press the output load button to change from 50 Ohms to High-Z.

To change the waveform parameters (frequency, amplitude, offset etc.) press the button. Use the buttons along the bottom of the screen to choose the parameter to change. Use the number keys to enter the value, and then choose the units using the keys at the bottom of the screen. Remember there is a difference between **mVpp, Vpp, mVrms** and **Vrms** – see the pre-lab for a reminder.

- Set up the Waveform Generator to output a wave at a **frequency of 50 kHz, amplitude of 2 Vpp, offset of 0.0 V and phase of 0°.**

3 Measure waveforms using the oscilloscope

In the first part of this lab, multimeters were used to measure static DC voltages. An oscilloscope is usually used for measurements of electrical signals that vary over time (AC), as it can show a real-time graph of the voltage.

Figure 36 shows the oscilloscope display forming a graph of voltage (y-axis) against time (x-axis). The next part of this lab sheet will demonstrate how to set up an oscilloscope.

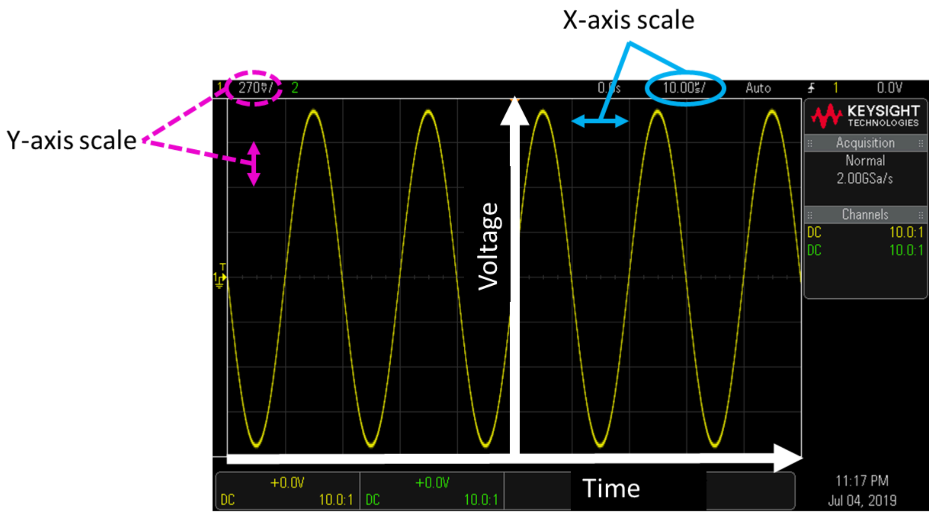


Figure 36: An example oscilloscope display labelled with key features

- Press **Default Setup** at the top-right of the oscilloscope. This resets all settings.
- Find the oscilloscope probes on your desk in a white box – a probe is shown in Figure 37.

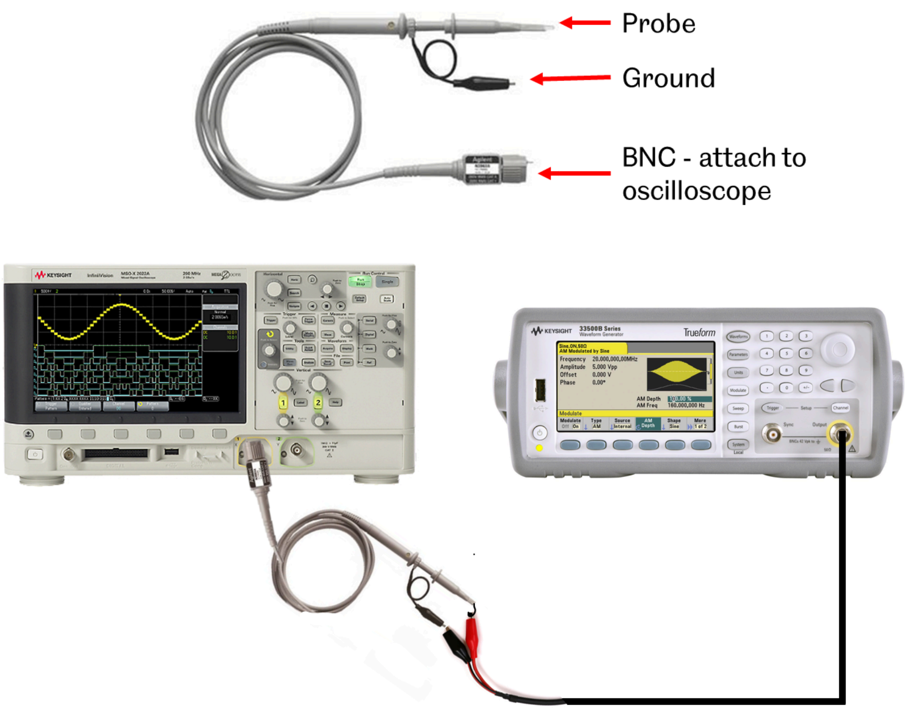


Figure 37: An oscilloscope probe with a ground clip and connection with waveform generator.

- Connect the oscilloscope probe BNC connector to the oscilloscope channel 1 input – **twist** the connector clockwise until it clicks into place
- Connect the oscilloscope probe to the waveform generator output (red croc clip to the probe tip, and black croc clip to ground clip) as shown in Figure 37.

Remember that the black croc-clips are both already connected to the same ground point via the measurement instruments – this means the black clips must also be connected together.

The oscilloscope screen should now show a small signal across the middle of the screen. Look carefully at the gridlines at the background of the oscilloscope display. How many gridlines are there across the whole screen?

Horizontal (X-axis):

Vertical (Y-axis):

Each grid line in the y-axis direction spans a unit of voltage shown by the y-axis scale, as shown at the **top left** in Figure 36.

The waveform should be displayed as large as possible on the screen, but without going off the top or bottom of the display. This ensures that no information on the waveform is lost.

- Turn the Channel 1 Vertical Y-axis Scale knob (see Figure 38) clockwise to increase the scale of the waveform shown on screen.

Vertical Y-axis Scale (zoom)

Vertical Y-axis Offset (up and down)

Figure 38:The oscilloscope vertical Y-axis control knobs.

- Make sure that the waveform is as large as possible on the screen without the sine wave disappearing off the top or bottom.
- Push the Channel 1 Scale knob inwards. The knob now operates in a fine control mode. Use the knob to increase the waveform to be as large on screen as possible without going off the top or bottom.

Having optimised the scale, the Channel 1 vertical scale setting value at the top left of the screen (see the top left of Figure 36) should have changed.

What is the voltage scale of each gridline in the vertical (y-axis)?

Next, the x-axis can be scaled in the same way, to optimise the signal seen on the screen. For a high quality measurement only 3-6 periods of the waveform should be visible on screen.

- Turn the Horizontal (X-axis) scale knob (see Figure 39) so that 3-6 periods of the waveform are visible on the display.

Figure 39: The oscilloscope horizontal x-axis controls

- Try turning the Horizontal Offset (left and right) knob (see Figure 39) to see the effect of this control.

3.1 Oscilloscope Triggering

- Set the Waveform Generator to a Frequency of 25 kHz, Amplitude of 1 Vpp, Offset of 0.5 V and Phase of 0.0°.

Use the same process as before to get the signal looking clear on the screen:

- Press Default Setup
- Use the Vertical Scale knob to make the waveform as large as possible without going off the top or bottom of the screen (previously shown in Figure 38)
- Use Vertical Offset knob to move the waveform up or down to the centre of the screen (previously shown in Figure 34) and then use the Vertical Scale knob to zoom in further if possible

This time, there is a problem – the oscilloscope no longer displays a static waveform image, but a constantly moving image across the display. The oscilloscope requires **Triggering**.

Triggering is the method of telling the oscilloscope where to freeze the display and show a consistent waveform on the screen. There is a constant sine wave being input to the oscilloscope from the waveform generator, so the oscilloscope needs a method to synchronise the waveform display with the input signal.

Press the **Trigger** button on the oscilloscope panel and three menu options should appear at the bottom of the screen, as shown in Figure 40.

Figure 40: The oscilloscope Trigger menu options.

The oscilloscope is looking for a trigger signal which is:

- An edge – a transition from one voltage level to another…
- … on source 1 – this is the channel that the probe is attached to…
- … with a rising voltage – the arrow is going upwards in the slope setting).

These requirements sound good, as the probe is connected to channel 1, and a sine wave has lots of rising edges! However, the oscilloscope is looking for the rising edge as it crosses a specific voltage. This voltage is marked T on the left of the screen, as shown in Figure 41.

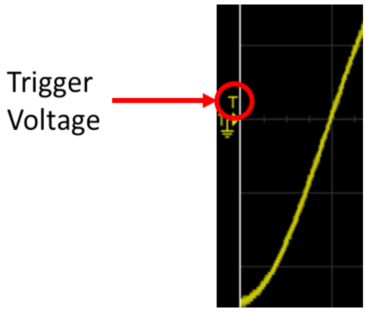
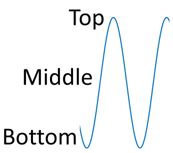


Figure 41: The Trigger voltage as shown on the left of the oscilloscope display.

The oscilloscope will only Trigger and pause the waveform display if it detects a rising voltage at the voltage level marked with a T. If the signal never reaches the voltage marked T, or does not show a rising edge crossing that voltage, the display will never Trigger and freeze.

Where on a sine wave is the voltage moving upwards most quickly i.e. where is the gradient highest? At the top, the middle, or the bottom? **Ask a member of staff if you are unsure.**



- Using your answer to that question, use the Trigger level knob (shown in Figure 42) to adjust the trigger level so that the "T" voltage level is in the correct waveform region.

Figure 42: Trigger level knob at the centre of the trigger menu buttons

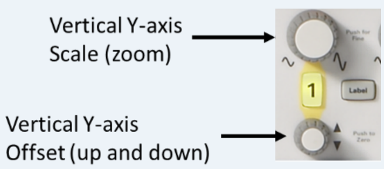
The waveform display should now be static and clear to read. It is always important to set up the oscilloscope trigger so that the display is frozen, to ensure a good quality measurement.

3.2 Putting it all together – one final oscilloscope set up test

- Set up the Waveform Generator to a frequency of 97 kHz, Amplitude of 0.6 Vpp, Offset of -0.7 V and Phase of 0.0°.

Use this handy guide to set up the oscilloscope to display the waveform as clearly as possible:

- Press Default Setup
- Use the Vertical Scale knob to make the waveform as large as possible without going off the top or bottom of the screen
- Use Vertical Offset knob to move the waveform up or down to the centre of the screen and then use the Vertical Scale knob to zoom in further if possible
- If the waveform display is not static, check the Trigger settings are for a rising edge on the correct channel



- If the waveform display is not static, set the Trigger voltage to a region of the waveform containing a rising edge
- Use the Horizontal Scale knob to show 3-6 periods of the waveform

Figure 43: The oscilloscope horizontal x-axis controls

Ask a member of staff to check your oscilloscope display before continuing.

4 Measurements using the oscilloscope

There are several ways of making measurements using the oscilloscope, including:

- Manually reading the value from the screen
- Fully automated

4.1 Manually reading the value from the screen

The oscilloscope x-axis gridline scale and y-axis gridline scale are labelled in Figure 36. These values tell you the scale of each axis, just like the axis labels on a graph.

What values for each gridline are shown on the oscilloscope display?

Horizontal (X-axis):		Vertical (Y-axis):	

By eye, estimate how many grid squares the signal covers from peak-to-peak in the vertical direction. Include an approximate error in the answer e.g. ± 0.5 grid squares. The answer to this question should be at least 6, or the oscilloscope is not correctly set up to use the full height of the display!

If each gridline has a scale of 200 mV (for example), then the peak-to-peak voltage of a waveform covering 7.5 squares vertically is 7.5 x 200 mV = 1.5 V.

What is the peak-to-peak voltage of the waveform shown on screen?
Use your previous answer, and the gridline scale, to calculate this.
Include an error range in the answer e.g. 2.7 ± 0.003 V.

The same measurement can be made in the horizontal direction.
What is the number of grid squares in the x-axis for one whole period of this waveform? Remember that a period is the time between two positive peaks, or two negative peaks, or two rising edges – use whichever method is easiest to measure.

Using the x-axis gridline scale (see Figure 36), calculate the period of the waveform. Include an error range in the answer and take care with units (s, ms, μs, ns etc.)

Finally, convert the period to a frequency (remember period $T = \frac{1}{f}$).

Does this frequency match the frequency that the waveform generator was originally set to produce? If so, then all of your measurements will have been correct. However, take note that you will have included quite a wide error range due to reading the oscilloscope display by eye.

4.2 Automated oscilloscope measurement

- Without changing any other oscilloscope settings, press the “Meas” button on the front of the oscilloscope (near the centre of the panel of buttons).

On the right of the display, the oscilloscope should be showing measurements of the signal Frequency (shown as **Freq(1)**) and Vpp (shown as **Pk-Pk(1)**).

What is the value of the waveform frequency as measured by the oscilloscope? Include errors in the answer e.g. 84 ± 0.5 kHz. The oscilloscope will not tell you an error value – it is for your interpretation from the fluctuation of numbers on the display!

What is the value of the waveform peak-to-peak voltage as measured by the oscilloscope? Include errors in the answer e.g. 830 ± 25 mV. The oscilloscope will not tell you an error value – it is for your interpretation from the fluctuation of numbers on the display!

There is one key practicality to remember with this automated measurement method - the oscilloscope can only make good automatic measurements if it is set up correctly – it can only make measurements on the display that is shown on the screen, just like a human!

Before pressing “Meas” always ensure that the waveform fills the full height of the screen, has 3-6 periods on display, and is triggered to show a static pattern.

5 Extension activity 1 - Soldering

This concludes the main part of this lab activity which covers the circuit breadboarding, measurement of voltage and current using multimeter, understanding of waveform generator and oscilloscope functionality and purpose.

You should now speak to a member of staff, who will talk through your answers to the questions in this lab sheet.

However, if you have time left in the session (at least 30 minutes for a pair working together), we

strongly encourage you to try out soldering, a key practical skill for engineers.

Speak to a member of staff who will provide you with safety goggles, equipment and components.

You must wear safety goggles while completing the soldering activity and tie back long hair. You must comply with this to adhere to the Health and Safety requirements.

The essential rules of soldering include:

- Always use eye protection when soldering or cutting component leads.
- **Inform staff if you suffer from asthma or other breathing difficulties, so that additional fume extraction can be supplied**
- Always hold the soldering iron by the handle - the barrel and tip are very hot.
- Always return the soldering iron to its stand, never rest it on the bench.

- **The soldering iron enters standby mode and cools to 180 °C if left unused for more than two minutes.**
- **To warm it up again, you need to tap the "up arrow" button on the control unit, which looks like or .**

When the soldering iron is first hot, apply some solder to the end of the tip and then wipe it on the metal wool, so that the solder forms a thin film on the tip. 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 a high temperature. For this reason, when you apply the soldering iron tip, keep it in contact with both the track and the component leg - as shown in Figure 44.

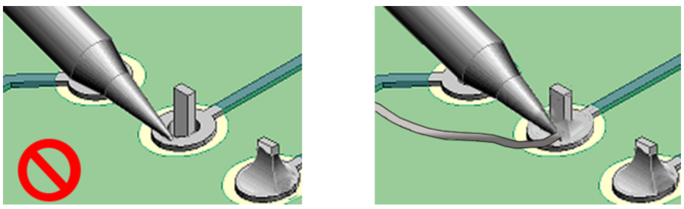


Figure 44: methods of soldering - the correct method on the right has the tip in direct contact with both the component leg and the PCB pad.

First, heat both the circuit board and the component leg coming through the hole. Place the end of the solder wire on to the joint and then apply the tip of the soldering iron to the solder, 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 move in the joint. Examples of good and bad joints are shown in Figure 45.

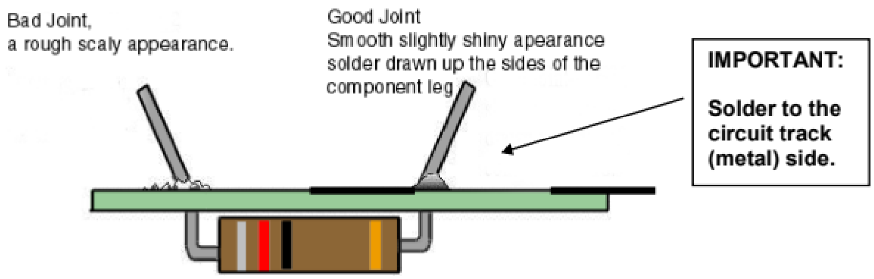


Figure 45: An example of good and bad solder joints, as seen from the side of a PCB.

5.2 Soldering and testing

If you have not seen it already, please watch the 3 minute soldering instructions and safety video at this link:

https://digitalmedia.sheffield.ac.uk/media/Diamond+Electronics+and+Control+Lab+Soldering+Tutorial+-+Quiz/1_jxmgxov1

5.3 Safety when soldering

- Wear the safety glasses provided
- **The fumes from soldering are safe within this well ventilated laboratory. However, if you suffer from asthma or other breathing difficulties, additional fume extraction units are available and we encourage you to use them – please ask a member of staff about this.**
- Only touch the soldering iron by the handle – never touch the tip or metal shaft
- Always replace the soldering iron in the holder when it is not in use – never leave it on the bench
- Always switch off the soldering iron after use and never leave it unattended while it is powered on

5.4 Build your PCB

You will need to build the circuit using the Printed Circuit Board (PCB) Provided. If you need a recap about soldering please see here. Follow the procedure outlined in the steps below to solder and test your PCB:

Ask the GTA to provide you with PCB board and collect the following components from the Trolleys:

- 2 x 220Ω Resistor
- 2 x BC548B Transistor
- 2 x 10kΩ Resistor
- 2 x 22uF electrolytic capacitor
- 2 x LEDs
- PP3 Battery strap.

Step 1: Locate the fixed resistors (R1 and R4 are 220Ω, R2 and R3 are 10kΩ) by using colour code or checking using a multimeter. Place them through the correct holes in the PCB board. If you do the resistors first, you should be able to hold on to the legs as you turn the board upside down and put the resistors flat on the table. You could then solder the resistors straight away, or fold the legs over as shown in Figure 46. Folding the legs over has the benefit of keeping the resistors in place as you solder them, but more care must be taken to not let the legs touch after they have been snipped short.

As with all components, double check that you have put them in the correct place before you solder them. It is much easier to **eliminate mistakes before soldering**. Put the resistors tolerance band side facing right or top of the PCB board. It's just a best practice for PCB assembly but has no impact on the function of the resistors in the circuit (IPC PCB standard).

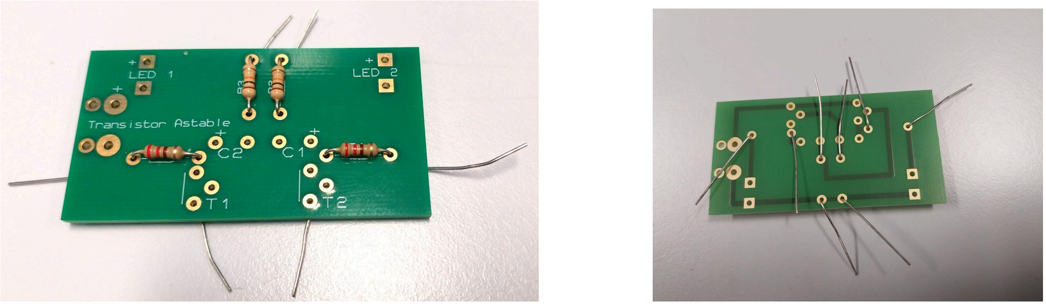


Figure 46: Putting resistors on the board.

Step 2: Once the resistors are in the correct place solder them in and clip the excess wire using side cutters

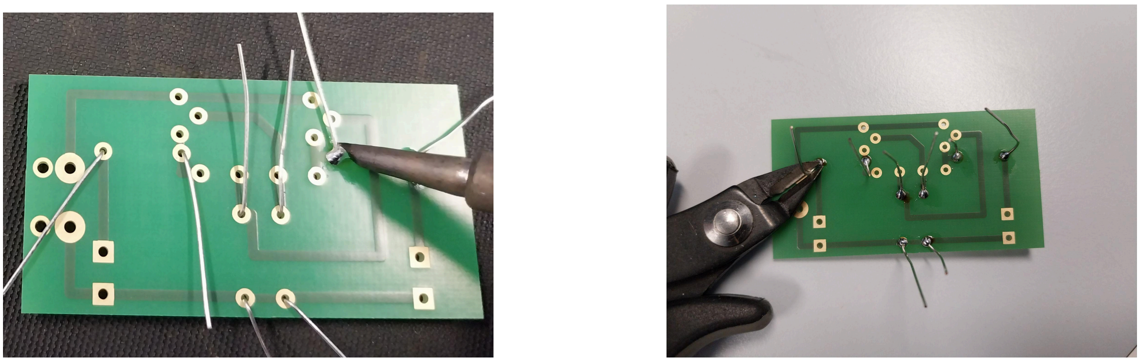


Figure 47: Soldering resistors on the board.

Step 3: Insert the transistors into the board in the correct place. Make sure that you put them in the correct way around. You will need to bend the centre leg back slightly to allow it to fit. Look carefully at the board, you will see a vertical line next to T1 and T2. This indicates the flat side of the transistor.

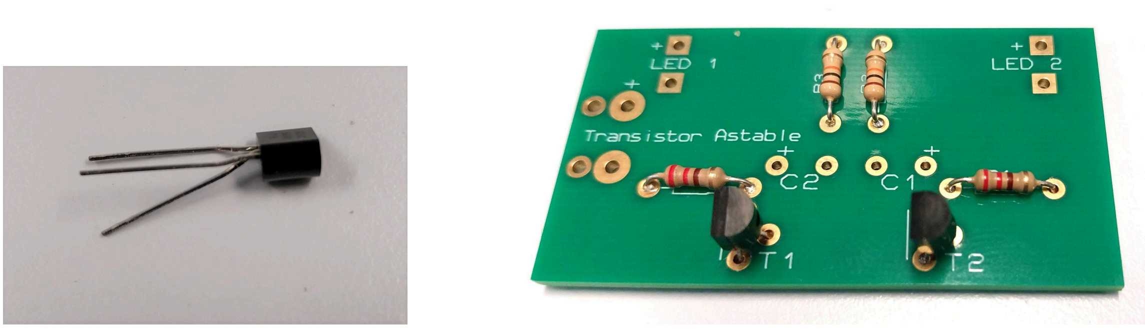


Figure 48: Putting and soldering transistors on the board.

Step 4: You now need to repeat this process with the two electrolytic capacitors. The lighter coloured stripe on the body of the capacitor indicates negative. Sometimes there is also a “-” sign on the stripe. Find C1 and C2 on your circuit board then locate the + sign which indicates the positive side.

Solder the capacitors in place when you are happy that you have them inserted correctly.

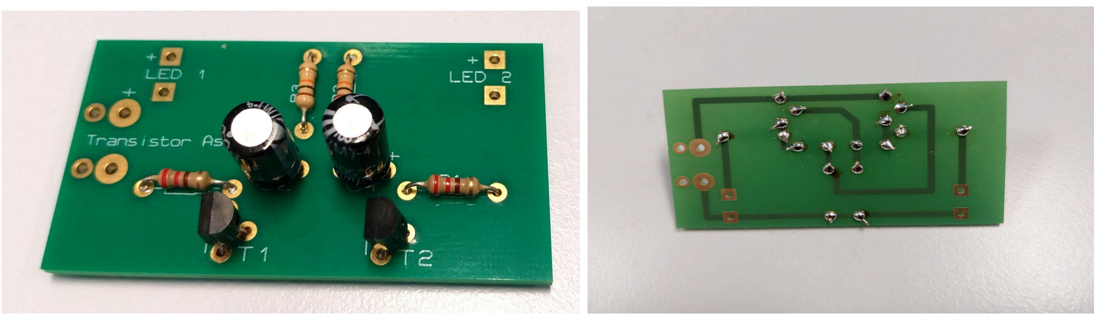


Figure 49: Putting and soldering capacitors on the board.

Step 5: Repeat this process again with the LEDs. Once again, LEDs are polarised so you need to ensure that the long leg goes through the + hole in the circuit board.

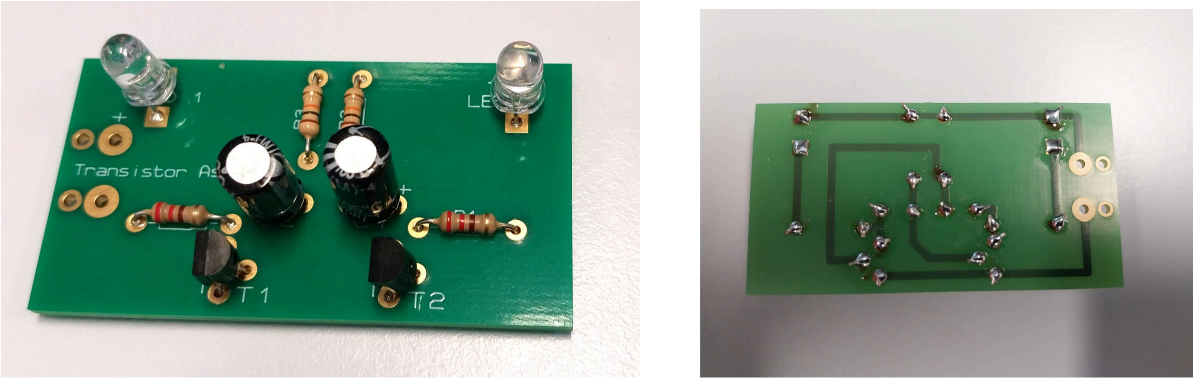


Figure 50: Putting and soldering LEDs on the board.

Step 6: You now need to connect your battery terminal. You will notice that your circuit board now leaves two larger holes. The reason for this is so that the wires of the battery connector can be threaded through to eliminate the risk of the wires getting pulled out of the board if they become entangled. Establish which wire goes through which hole (red is positive) and thread up through the outer of the holes at the edge of the board as shown:

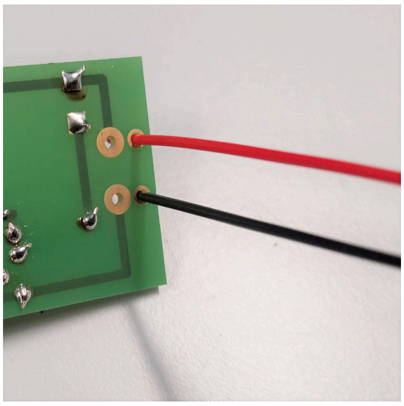


Figure 51: Putting battery wires on the board.

Step 7: Once you have pushed the wires up through the board, fold them back down the other side and back through the other hole before soldering the stripped ends into place.

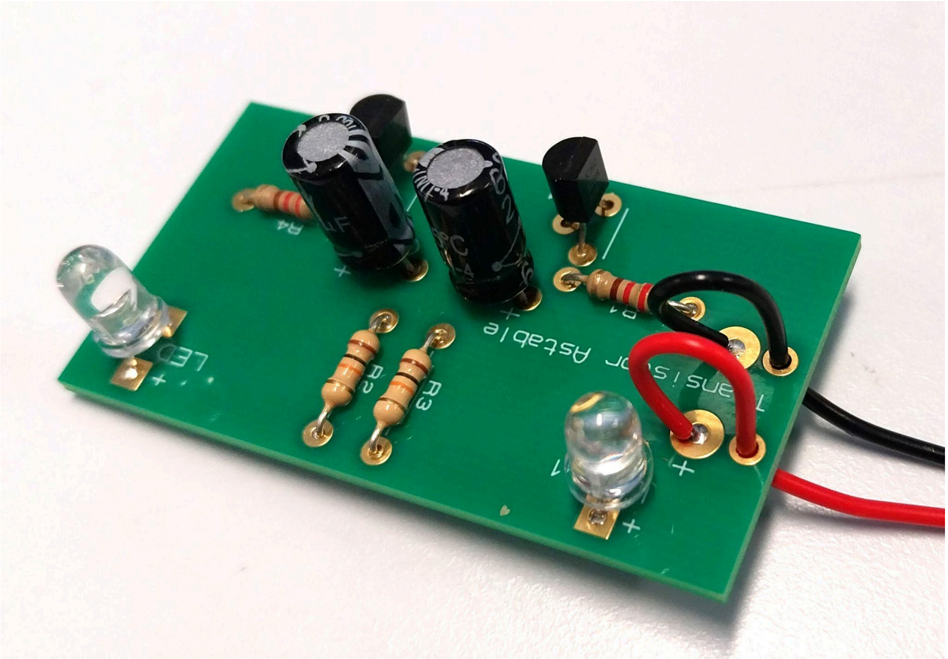


Figure 52: Soldering battery wires on the board.

Step 8: Once soldered you can pull the wires down to the board to eliminate the loops. You may find that you want to shorten your wires, if so cut them using side cutters and re strip them before soldering them into place.

Step 9: You are now able to test your finished PCB. Set the DC power supply output 1 to 9V and attach the croc-clips lead to the circuit battery clip. Ensure red is connected with red and back with black. Now check that both LEDs are flashing alternatively.

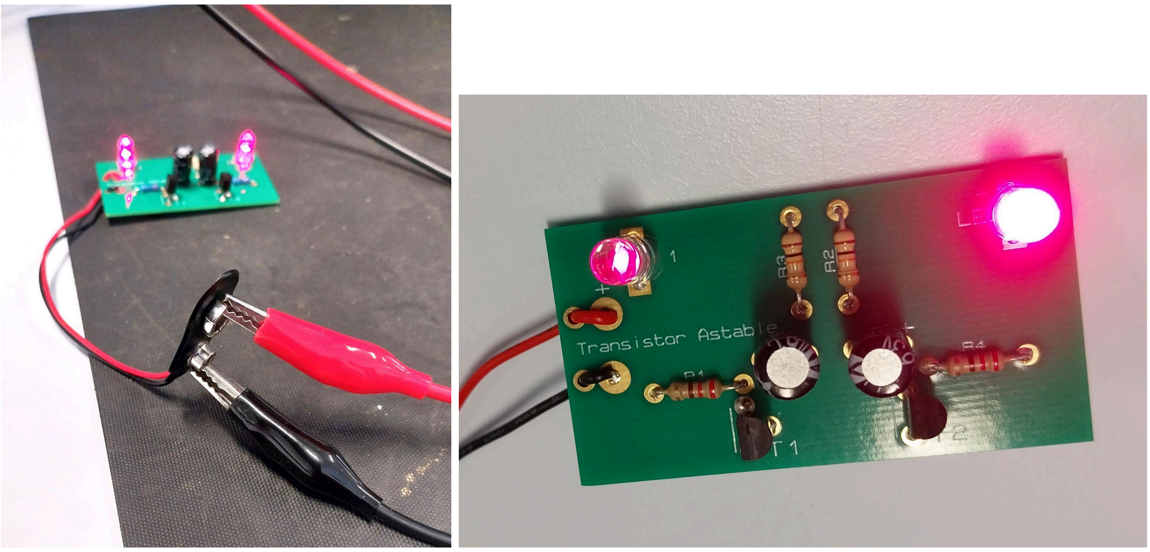


Figure 53: Circuit test using 9V power supply.

If your circuit isn’t working properly, check your soldering and also if you have placed a component incorrectly.

Ask a staff member to check your work.

5.5 Questions

What would happen to your circuit if you altered the value of the 10kΩ resistors to 20kΩ?

What would happen if you change the value of the capacitors to 10 μF ?

5.6 Measuring voltages

- Switch on the multimeter using the white button at the bottom left hand side of the front panel.
- Select DC voltage measurement by pressing the 

 button.
- Connect two plug to croc-clip leads (see Figure 27) to the ports shown in Figure 54.

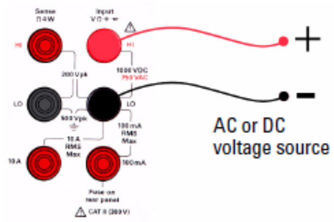
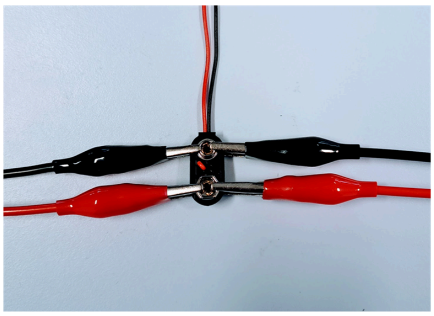


Figure 54: Connections for voltage measurement (top lead = red, bottom lead = black).

- Connect the multimeter croc-clips on either side of the battery clip Figure 55 and record the voltage measured in Table 3.

Circuit
\+ -

Power Supply - +



\- + Multi Meter

Figure 55: Connections of power supply and multimeter coc-clips for voltage measurement.

Table 3: Voltage measurements

Measurement	 **Multimeter (V)**
V_s	

- Repeat this process to make measurements of the voltages across R1, R2, R3 and R4 by putting the multimeter croc-clips on either side of each resistor. You will see the voltage keeps changing. The measurement across the resistors can be done effectively using an oscilloscope. **Use the Oscilloscope probe as shown in Figure 56 to see the changing resistor voltages.**

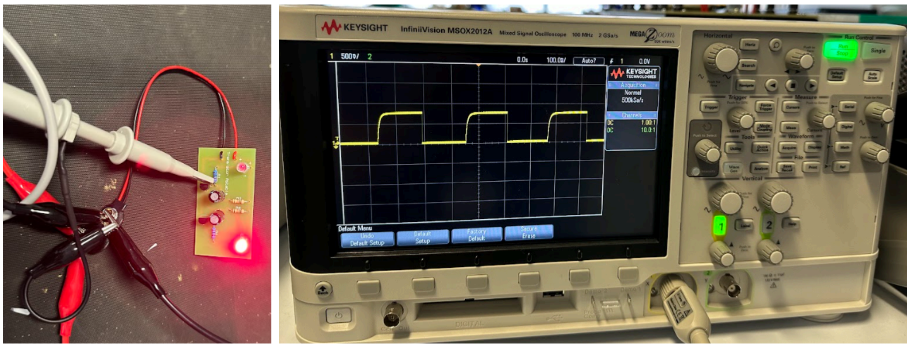


Figure 56: Voltage measurement with an Oscilloscope.

5.7 Questions

Why are resistor voltage values continuously changing?

What is happening with the capacitor and transistors?

6 Extension Activity 2 - Blinking an LED with Arduino

If you have any time left please complete this activity. You need to ask the staff to provide you with the **Arduino kit**, **220Ω resistor** and a **LED** or you can also collect these components from the trolley. Construct the circuit on the breadboard as shown below in Figure 57. There are many other ways to connect the circuit as well. If you are confident with the breadboarding please feel free to connect using your own way. Ensure the LED is connected in correct polarity. The longer leg is Anode (+) and short leg is Cathode (-).

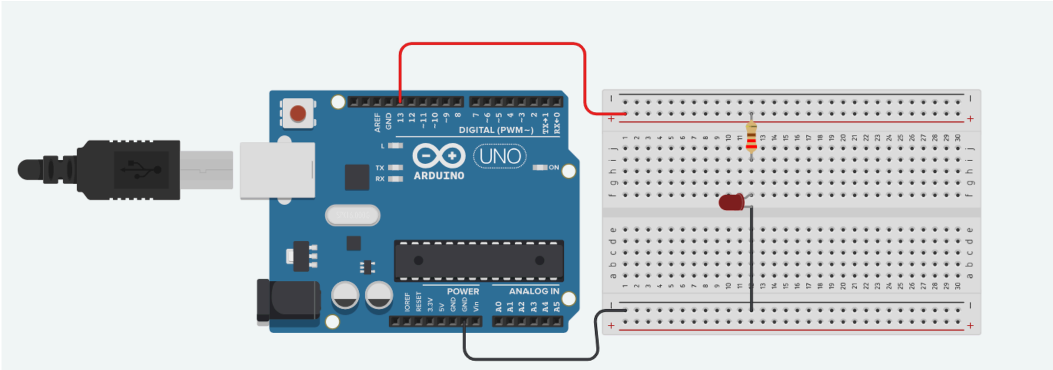


Figure 57: LED blinking circuit with Arduino

- Connect the Arduino with the computer USB port and open the Arduino software on the computer.
- In Arduino software, go into the “Tools” menu. Under “Board” select “Arduino UNO” and under “Port” select the highest available COM port (it will usually have “Arduino Uno” listed against it).
- Type up the programme in the Arduino software and then compile to check for any errors. If there are no errors, upload the programme to the Arduino board using the upload button in the Arduino software.
- After your programme is uploaded the LED will start blinking.
- Now make some changes to the delay function and observe any changes to the LED blinking speed.
- You can also consider changing the Arduino output pin on the circuit board and adapt your codes to reflect this change.

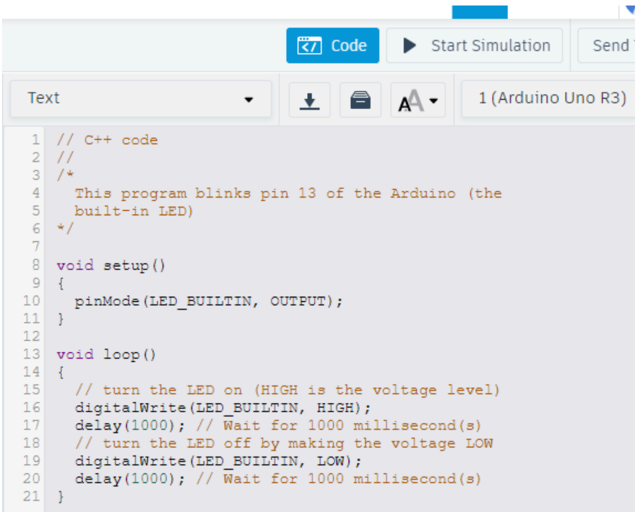


Figure 58: Arduino LED blinking circuit codes

7 Conclusions

It is very difficult to visualise concepts in electronics – it is tricky to see electrons whizzing around a circuit, and even more difficult to “see” the electromotive force (voltage)!

However, the experiments today have introduced methods of measuring voltage and current, and even visualising voltage waveforms in real-time. Also, soldering on the PCB and controlling the circuit with the Arduino microcontroller. These are very important skills for your future study and career as an engineer.

Remember! how to use these tools effectively, as they will be useful for future experiments.

Please complete the post-lab Quiz independently on the Blackboard within the two weeks after your lab session.

What did you learn from this lab? [Reflection]

Write short 100-150 words reflective commentary on your lab experience, knowledge, skills and behaviours developed by using multimeter, waveform/signal generator, oscilloscope, power supply, breadboarding, soldering, Arduino, PPE and safe working practice.

Show your commentary to a GTA to be signed off at the end of your lab session.

Tidy your workstation, use a brush and pan and put in a blue WEEE waste bin in the middle of the lab.

Put all the croc clip and BNC cables back on the racks.

8 References

[1] Hernando Barragán, “Wiring”, wiring.org.co, accessed online 2019
[2] James Turner, “Build a custom-printed circuit board”, IEEE Spectrum, 2010
[3] Equipment manufacture guidance