SRO Electronics Lab

Complete this lab to earn 4 league points.

Deadline: End of Wednesday session

1. What are we doing?

We've given you a brain, motor controllers and other stuff on lovely printed circuit boards. You also have a camera, but this can only see our markers.

Your robot might need some other sensors, so you'll have to build them yourselves.

This lab will teach you how to make and test them. **You can build as many of each sensor as you need.**

To do this, you will need to learn about the electronics equipment in front of you.

Task 1.1 - Identifying equipment

On the bench you will find:

1. A power supply
2. A digital multimeter
3. A signal generator
4. An oscilloscope

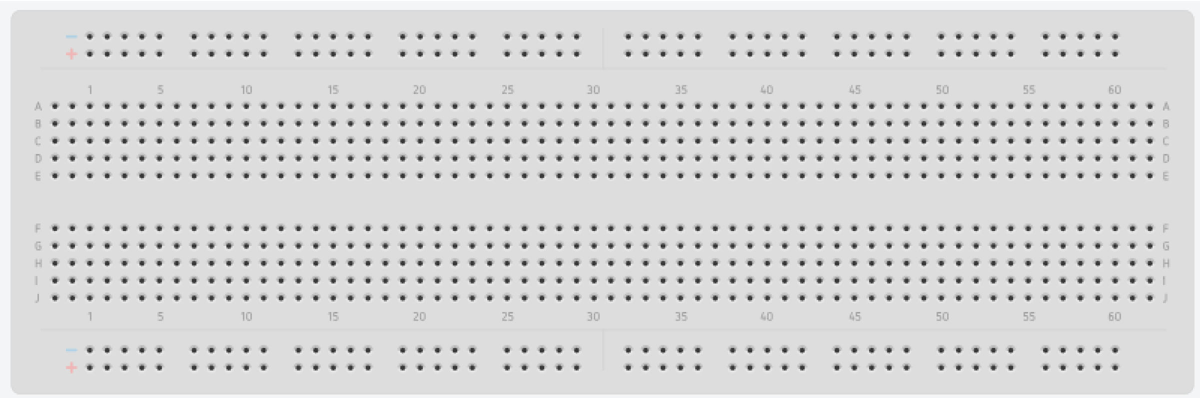
Complete the tasks below and show your mentor.

Task	Mentor tick
Find and identify each device.	
Switch them on.	
Set the power supply to 5.00V 0.30A.	
Point to the "Output Enable" button on the power supply	

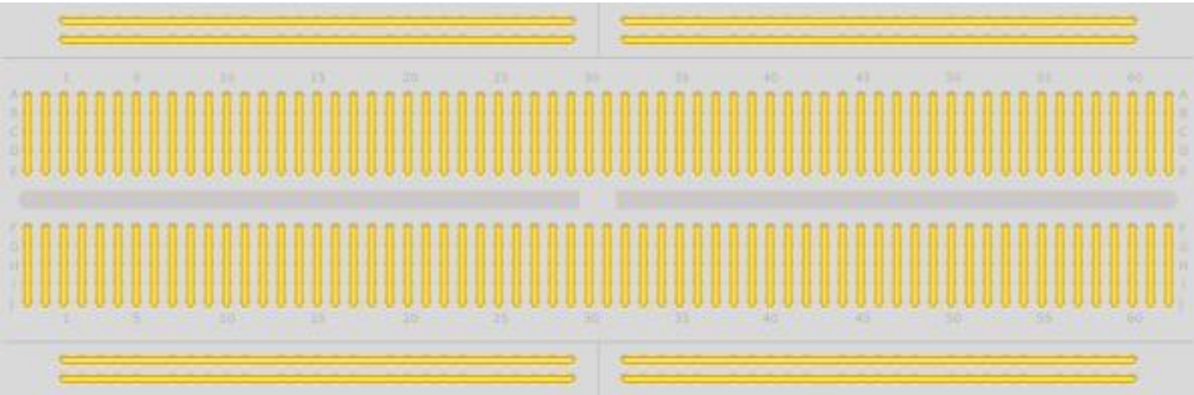
2. How to prototype a circuit

To quickly build and test circuits we use a **breadboard**. You should have a breadboard in front of you. Ask a mentor if you can't find it.

It looks like this:



Inside the breadboard are metal clips that grip components. They are connected as shown:



The top and bottom lines are used as **power buses**. We connect the power supply to these lines, then use them to power the rest of the circuit.

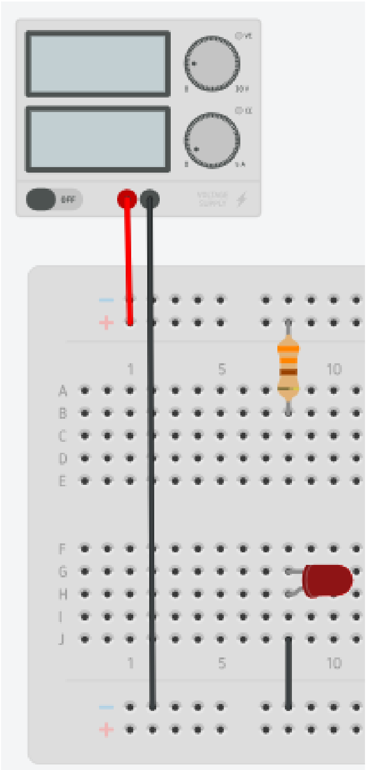
The middle area is used to build the circuit.

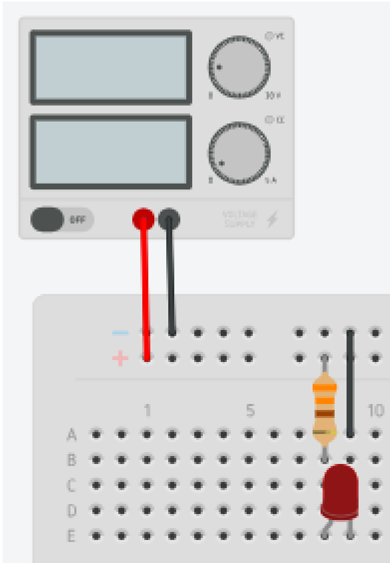
The gap in the middle is the right size for an IC (chip) to fit.

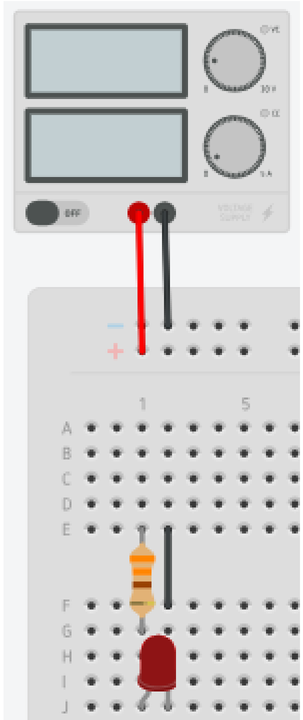
Look at the diagrams carefully and answer the questions on the next page.

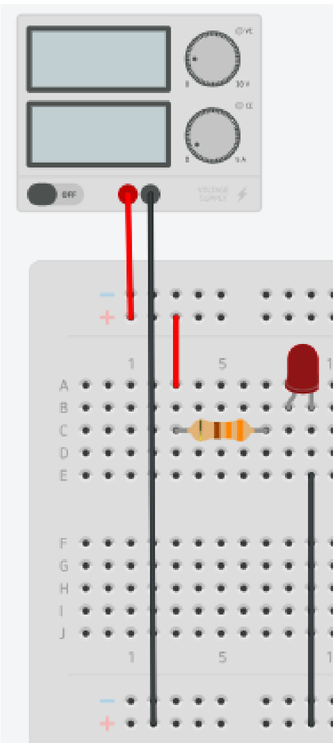
Task 2.1 – Which circuits will work?

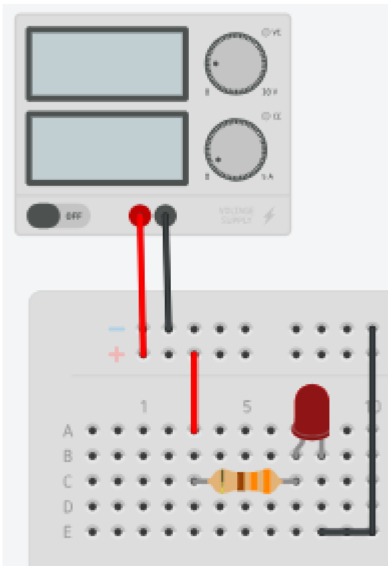
Look at each circuit carefully and decide if it works. Tick or cross each box. Ask your mentor to check your answers.

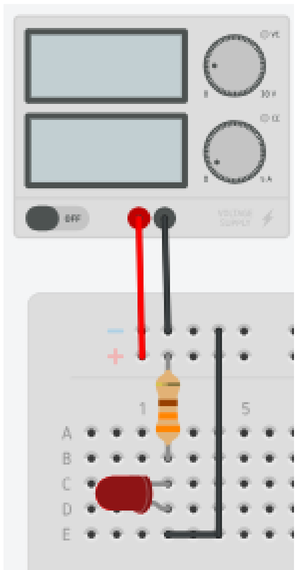






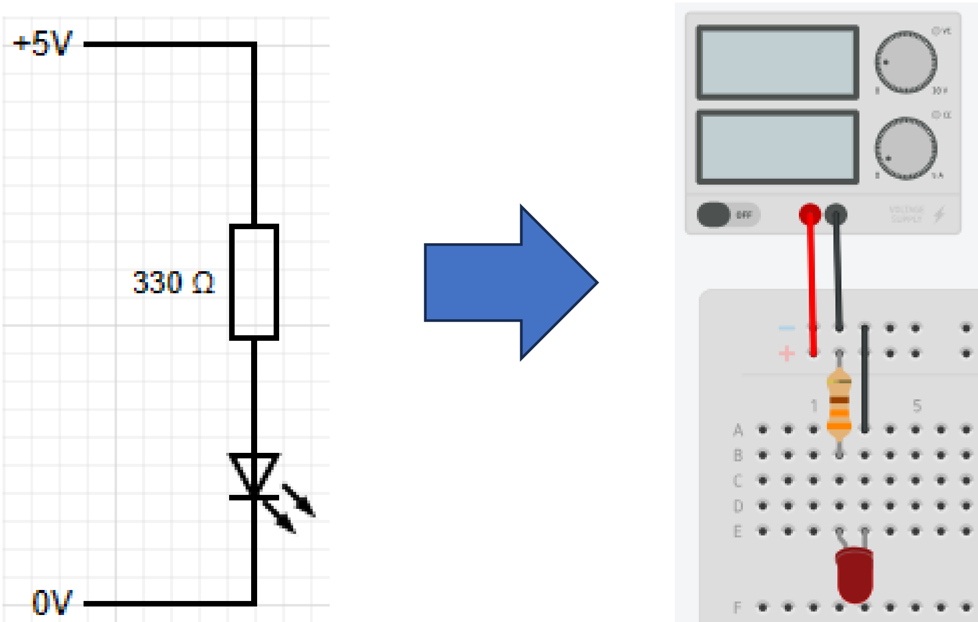






Task 2.2 – Hello World!

Now you've got the idea, let's build a working circuit.

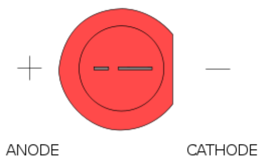


Build the circuit and show your mentor that the LED lights up.

If it doesn't work, double check your connections, try the tips below, then ask your mentor.

Troubleshooting:

- LEDs must be the correct way around. The two legs are called the Cathode (short leg) and Anode (long leg). Current can only flow from **anode to cathode**.
  The easy way to remember: **SHORT TO NOUGHT.**
- If the legs have been cut, look at the LED from above. The cathode will have a flat edge.



- Check the resistor value using the colour code in the appendix. This resistor should have Orange, Orange, Black, Black.

Mentor Checked	

2a. Some quick theory

To understand circuits we need to know some basic definitions, which you will have studied in school. Here's a quick recap.

Charge (Q) is a fundamental property of matter, so some particles have it and some don't. It can be positive or negative. It is measured in coulombs (C)

Current (I) is the rate of flow of charge. This means "how much charge flows in one second". It is measured in amperes (A). 1A = 1C/s.

Potential difference (aka Voltage) (V) is the change in energy for each unit of charge between two points. It is measured in volts (V). 1 volt = 1 joule of energy per coulomb of charge.

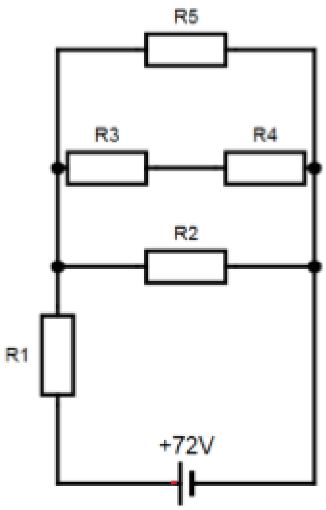
Resistance (R) is defined by the equation:

$$Resistance = \frac{Voltage}{Current}$$

Or:

$$R = \frac{V}{I}$$

Bonus Challenge



Component	P.D	Current	Resistance
Battery	72.0V		Negligible
R1			
R2			2.0Ω
R3		4.0A	5.0Ω
R4			1.0Ω
R5			3.0Ω

Complete the table.

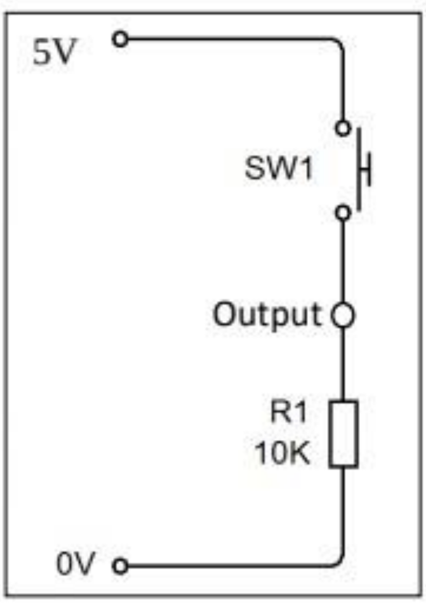
Ask your mentor to check your answers.

Mentor Checked	

3.1 Building a digital bump sensor

It might be useful to know if your robot has bumped into something (like a wall or other robot).

We can do this using a switch and a resistor.



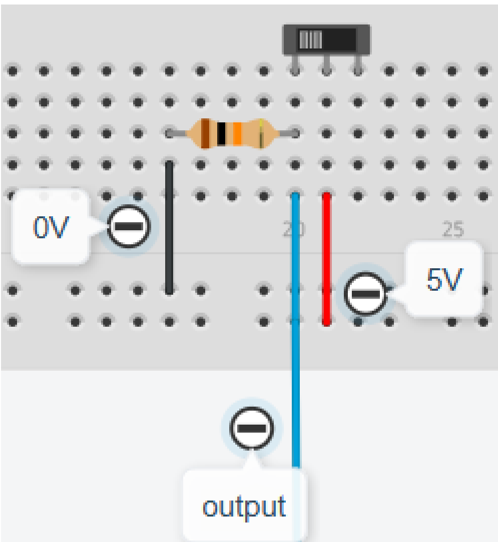
- When the switch is not pressed no current flows through the resistor.
- $V = IR$ so there is no **change in voltage** across the resistor.
- So the output is 0V.
- When the switch is pressed the output terminal is connected to the 5V line, so the output is 5V.

We need the resistor to **pull down** the output to 0V when the switch is not pressed. Without the resistor this point would be **floating**, meaning it would pick up random signals from the surroundings and give an unpredictable output.

The resistor value is not very important, so we pick something fairly big to make the current small.

Question: What is the current in the resistor when the switch is pressed?

Task 3.11 – Prototype and test a bump sensor



Build this sensor on breadboard.

You should connect to the **common (C)** and **normally open (NO)** terminals.

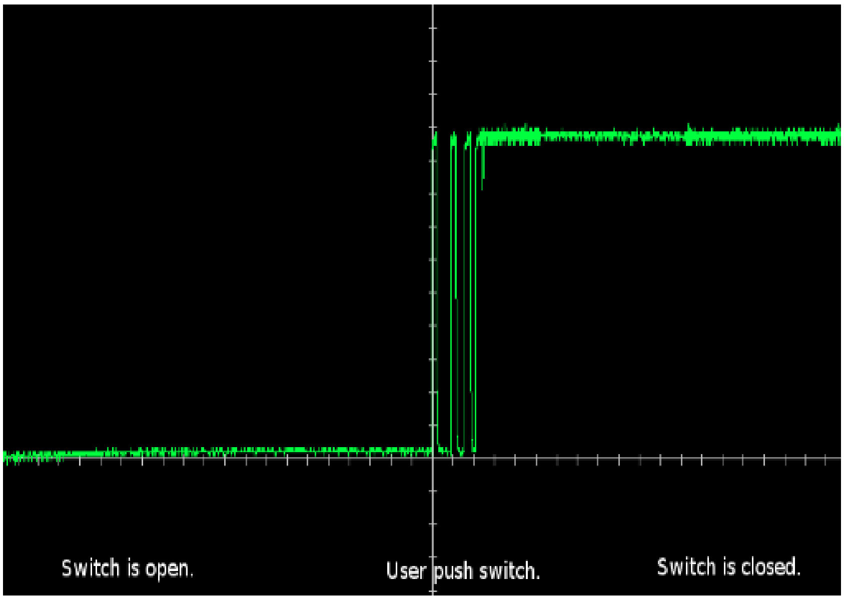
Connect the output to the multimeter and test it.

Show your mentor when it works.

Mentor Checked	

3.2 Improving the sensor

The Arduino board in your kit will read the sensor very quickly, so **switch bounce** will be a problem.



When the switch is pressed the contacts will very quickly connect and disconnect a random number of times, so your sensor will detect several presses.

We could fix this in software by adding a delay of a few milliseconds, but a delay is a "blocking" command, so we can't check other sensors while delaying.

To fix it in circuit, we can add a **capacitor** in parallel with the resistor.

The capacitor will charge almost instantly when the switch is pressed as it is connected to the 5V line with only the resistance of the wire, then discharge more slowly through the resistor.

The time for a capacitor to charge or discharge to half the power supply is calculated by:

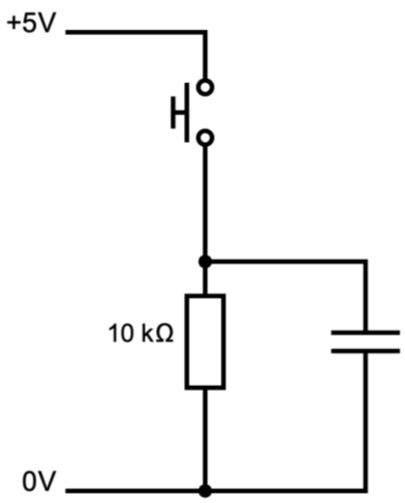
$$T_{1/2} = 0.7RC$$

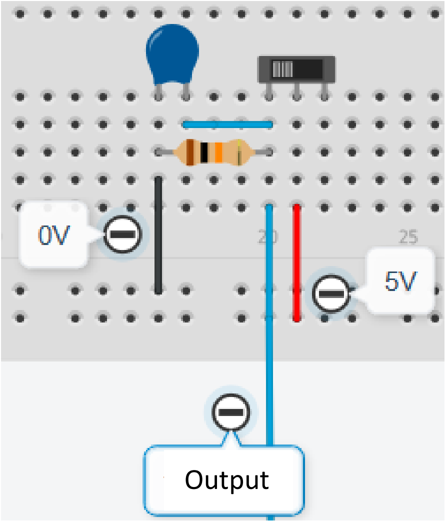
Where R is the resistor value and C is the capacitor value.
A time **> 1ms** should be suitable for debouncing.

Question: Calculate a suitable capacitor value for debouncing the switch.

Task 3.21 – Switch Debounce

Add a suitable capacitor in parallel with your resistor.





Connect to the oscilloscope and check that you only see **one state change**.

Show your mentor the completed circuit and demonstrate it working.

Ask your mentor to show you how to use the oscilloscope

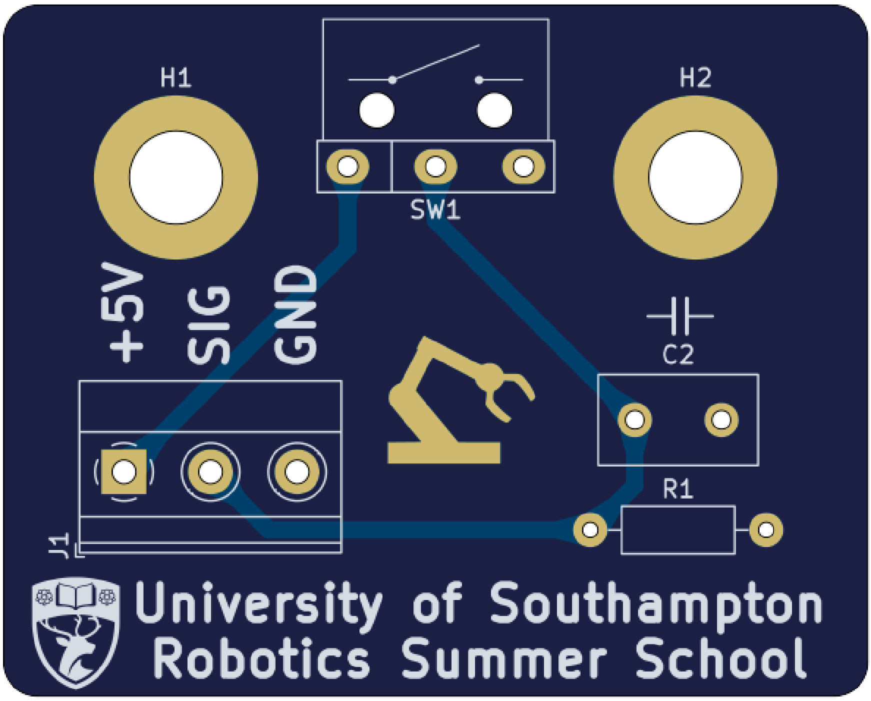
Mentor Checked	

Task 3.22 – Building a permanent sensor

Breadboard is great for prototyping but falls apart easily.

For a permanent sensor we have made printed circuit boards (PCBs). You can also keep the completed board as a souvenir!

The PCB design is:



H1 and H2 are mounting holes to attach the board to extrusion.

Solder the components in the correct places.

If you are not completely sure how to solder, go to a Soldering Mentor for a demonstration

Test your completed circuit and demonstrate it to your mentor.

Mentor Checked	

4. Infrared reflective sensors

To make navigation easier there is a line of white tape with a black line in the centre. It's not the most efficient route, but you could follow the black line around the course.

To do this you can use infrared reflectors to detect the white and black lines.

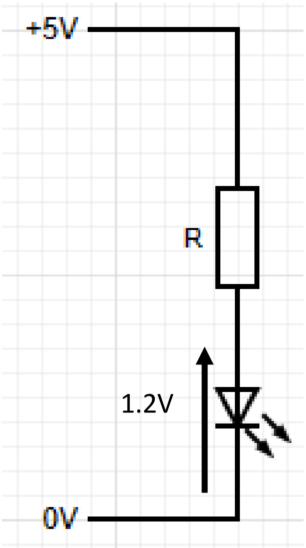
4.1 IR Emitter

The IR emitter circuit is very simple – we just need an IR LED and a resistor.

Our IR LED is an L-53F3C. From the datasheet we can see that the LED has a forward voltage of 1.2V and a forward current of 20mA. So we will need a resistor to limit the current.

Parameter	P/N	Symbol	Typ.	Max.	Units	Test Conditions
Forward Voltage [1]	F3	V_F	1.2	1.6	V	I_F=20mA

The circuit is just the same as our Hello World design.



This time you'll need to calculate the resistor value.

From the datasheet we know the LED will have 1.2V across it.

We need the current to be 20mA.

Task: Calculate the resistor needed in the circuit.

Task 4.11 – Build and test the emitter

Build and test the emitter circuit on breadboard. IR light is invisible to the human eye, but you can see the current on the power supply and you may be able to see the IR light using your phone camera.

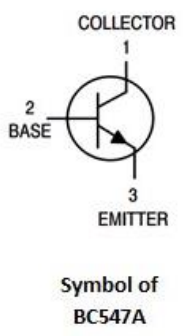
IMPORTANT TIP: The IR LED and the phototransistor are the same shape.
The LED has clear housing.
The phototransistor has black housing.

Breadboard Mentor Checked	

4.2 – Infrared receiver

To build the receiver we are going to use a **phototransistor.**

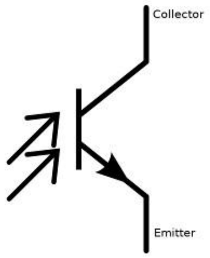
A transistor is a three terminal device. These are called the collector, emitter and base.



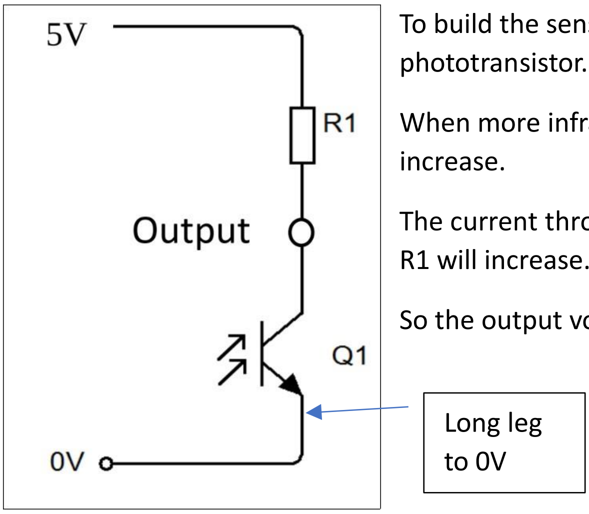
For an NPN transistor (the type we are using), the current in the collector is controlled by the current into the base.

$$I_{Collector} = \text{Gain} \times I_{Base}$$

For a typical transistor the gain might be 100 or more. So a small current into the base makes a large current flow into the collector.



A phototransistor works in the same way but uses light as the base. So, more photons hitting the base gives a larger current into the collector.



To build the sensor we just need a resistor in series with the phototransistor.

When more infrared hits the phototransistor the current will increase.

The current through the resistor will increase, so the voltage across R1 will increase.

So the output voltage will fall as more light hits the phototransistor.

Task 4.21 – Building and testing the receiver

For our phototransistor (L-53P3C) the datasheet gives the following useful information:

I_{CEO}	Collector Dark Current			100	nA	V_{CE}=10V Ee=0mW/c㎡

This tells us the current will be 100nA when no IR hits the phototransistor.

The Arduino will detect any voltage above 4V as digital 1. This will give 1V across the resistor. So the maximum resistor value is:

$$R = \frac{V}{I} = \frac{1}{100 \times 10^{-9}} = 10M\Omega$$

$I_{(ON)}$	On State Collector Current	0.7	3		mA	V_{CE} = 5V Ee=1mW/c㎡ λ=940nm

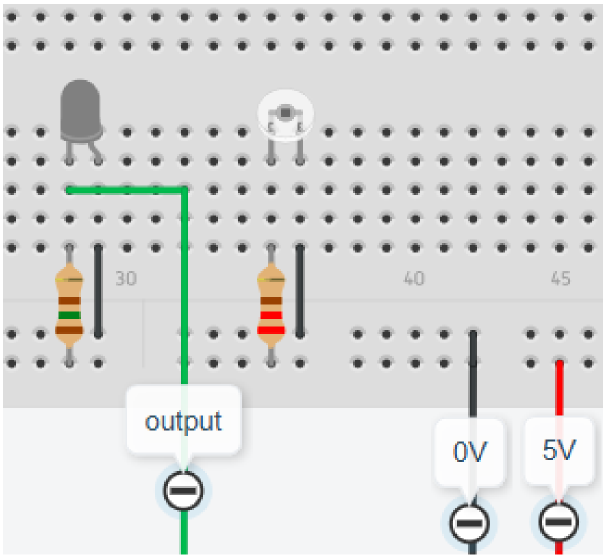
This tells us that when the phototransistor is switched on, it must have **no more than 3mA** of current. So the minimum resistor value is:

$$R = \frac{V}{I} = \frac{1}{3 \times 10^{-3}} = 1.33k\Omega$$

Build the receiver circuit on the same board as your emitter.

Connect the power supply and multimeter.

Experiment with different resistor values to find a sensitivity you are happy with. You will probably need somewhere between 10K and 1M.



Breadboard Mentor Checked	

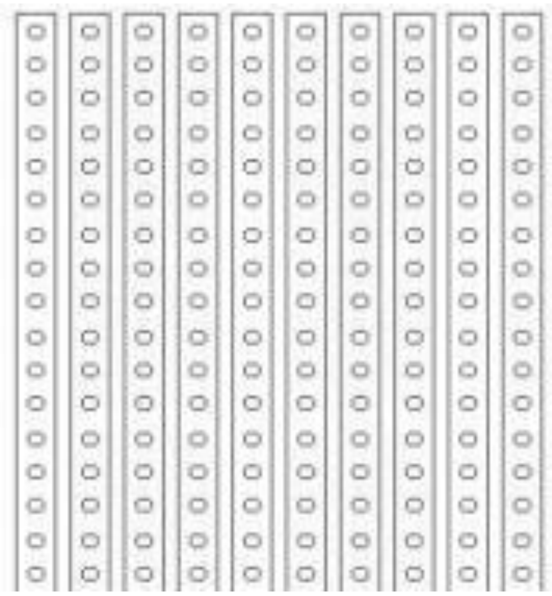
Task 4.22 – Building a permanent circuit

Breadboard is great for testing a circuit design but not very robust.

We can build a permanent circuit by soldering it on **stripboard**.

1. Design your layout on the template below
2. **Get your mentor to check the design**
3. Solder the circuit together and test it.

If you aren't absolutely certain about soldering, go to the Soldering Mentors for a demo and test run



Show your mentor the complete working circuit.

Mentor Checked	

5. Ultrasonic Distance Sensors

Each team has been given two HC-SR04 sensors.

This sensor has four screw terminals labelled Vcc, Trig, Echo, GND.

Vcc is the positive voltage pin and must be connected to 5V.

GND is the ground pin and must be connected to the Arduino GND.

Trig is used to start a measurement. When it is set HIGH(5V) the sensor will send out a pulse of ultrasound.

Echo will send out a pulse of the same time as the total travel time of the ultrasound.

The robot library will automatically send the trigger signal, measure the time of the echo signal, and calculate the distance.

Task 5.1 – Connecting the sensor

Connect the Vcc pin to 5V on the bench supply.

Connect the GND pin to the 0V terminal on the bench supply.

Connect the trigger to the red wire on the signal generator. Connect the signal generator black wire to 0V on the power supply.

Connect one oscilloscope channel to the trigger pin.

Connect the other oscilloscope channel to the echo pin.

Connect both oscilloscope ground connections to GND on the sensor.

Ask your mentor to show you how to use the signal generator and oscilloscope

Task 5.2 – Checking the sensor and estimating the speed of sound

Set the signal generator to produce a square with a frequency of 20Hz. Set to 5V amplitude, 2.5V offset.

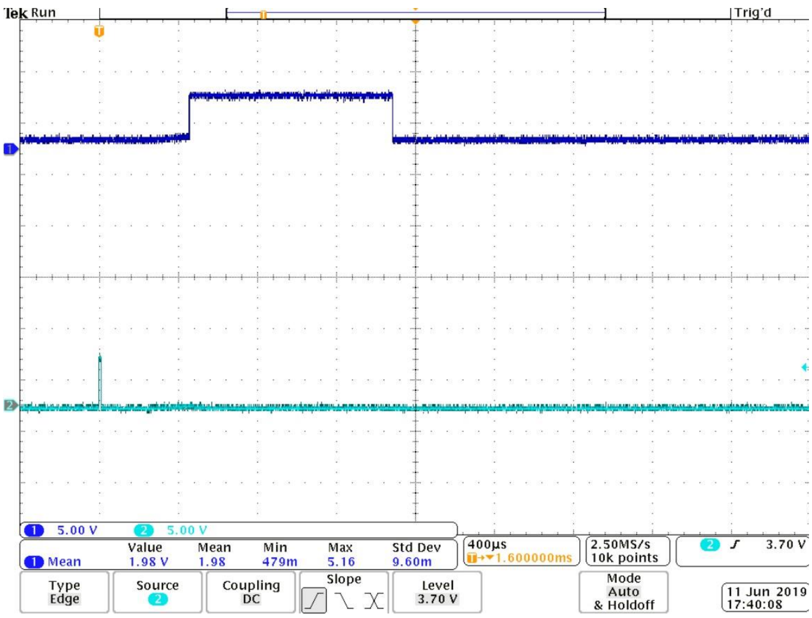
Adjust the duty cycle until the mark (on time) is about 10μS (duty cycle 0.05%). This will cause the sensor to send out an ultrasound pulse.

Turn the output of the channel on by pressing the yellow button.

Press the trigger menu button towards the right of the oscilloscope and set your triggering to the same channel as the trigger pin of your ultrasound sensor. Set the coupling to DC and the trigger type to edge.

You can also adjust the trigger level, which is the threshold that will cause your oscilloscope to take a reading. See if you can find a section where the echo signal goes high.

You should see something like this:



Measure the time of the echo pulse. This is the time from pulse emission to detection so you will need to halve the value.

You can calculate the speed of sound using:

$$speed = \frac{distance\ to\ object}{time}$$

Try moving the target object to different distances and rotating it to see the effect.

Using the sensor on your robot

The Arduino board in your robot kit includes code to automatically calculate the distance measured by the sensor.

To use the sensor, you will need to do some wiring.

1. Cut and strip 4 wires (one red, one black, 2 in other colours of your choice)
2. Screw the red wire into VCC
3. Screw the black wire into GND
4. Screw the other two wires into Trig and Echo.
5. Connect the red wire to 5V on the Arduino and the black wire to GND on the Arduino.
6. Connect the Trig and Echo wires to any digital IO lines on the Arduino.
7. See the docs for information on using the sensor.

Appendix – Resistor Colour Code