Auto-Lamppost Workshop

UCAS visit day – 2018/19

1 Introduction

In this workshop you will implement a system which detects a car as it drives by and switches on a lamppost ahead of it.
The systems comprises of

- A Proximity detector, based on an LED-photodiode pair, which produces a voltage when a car is detected
- A threshold comparator, based on an op-amp, which turns on the lamppost when a set voltage threshold is exceeded.
- A 555 timer which keeps the lamppost on for a set time (optional).

In the following sections we will be looking at the implementation of each of these sub-systems.

Your first task is to implement a system which makes LEDs flash as the car drives by.

Your second task will entail the design and implementation of a timer which keeps the LEDs on for a set time. There may not be enough time for you to do this.

Once the overall system is up and running we can test it "in the field" with our Scalextric set!

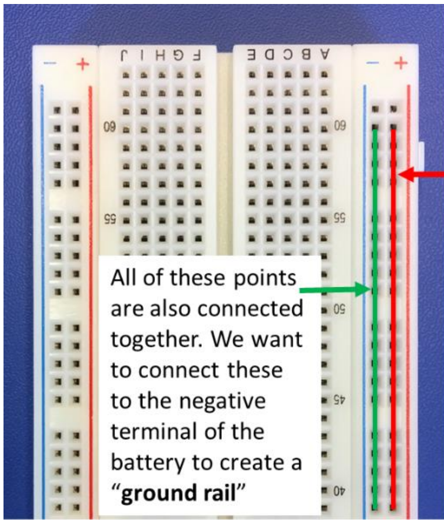
Note that the lampposts are made up of a bespoke frame, 3D printed in Bristol, and two white LEDs.

Lastly, you may work on improving your detection range or on enhancing the circuit in any way you like!

Dr Francesco Fornetti – University of Bristol

2 The Prototyping board (breadboard)

In this exercise you will use solderless “breadboards” to construct your circuits. The figures below explain how these work but feel free to ask a demonstrator if you are not sure.



All of these points are connected together. We want to connect these to the positive terminal of the battery to create a “**positive voltage rail**”

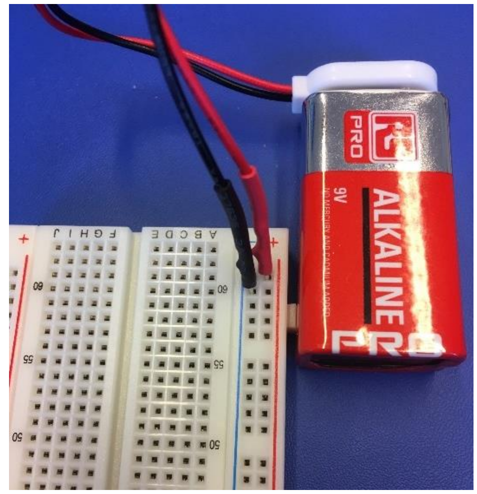
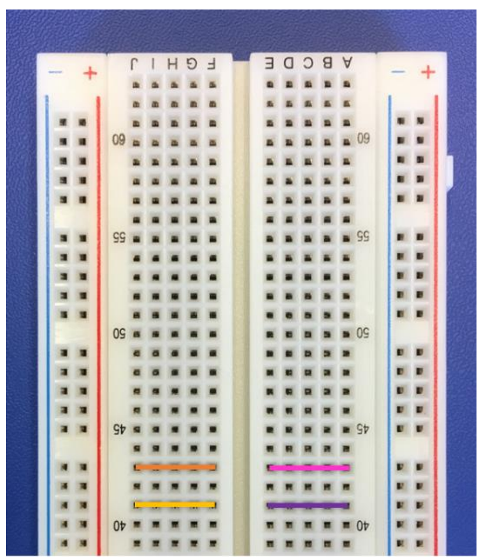


Figure 2-1 Breadboard Power rails



The 5 points in each row are also connected together

Figure 2-2 Breadboard connections

3 Auto-lamppost system

3.1 Proximity detector

Below is the list of components which we will need to construct our proximity detector:

- One IR LED
- One Photodiode
- One 390Ω resistor
- One 10kΩ resistor
- One Bipolar Junction Transistor (BC549B)
- One 9V battery and respective connector

Let’s gather the bits and get started!

3.1.1 Infrared LED

Firstly we need to forward bias our IR LED so that it emits some Infrared light.
Remember that forward biasing a diode means applying a voltage to it which is higher on the p-side then it is on the n-side.
In circuit terms, the terminal of the diode connected to the p-side is called the anode (or positive terminal).
The terminal connected to the n-side is called the cathode (or negative terminal).

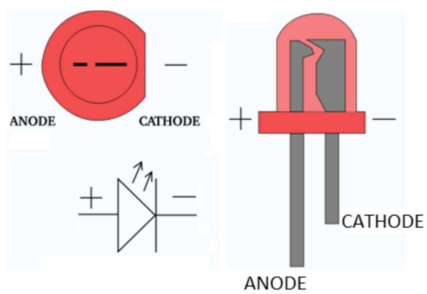


Figure 3-1 Physical LED

You can identify the anode and cathode of an LED quite easily. The cathode (negative) is the shorter leg, the anode (positive) is the longer leg. In addition, the base of the plastic case is flat on the cathode side and round on the anode side.
You can also look inside the head. The cathode is connected to the largest of the two bits of metal inside the head of the LED.
Now we want to apply a voltage to the LED which is higher at the anode than it is at the cathode. This is because our LED needs to be forward-biased to emit light.
To this end, we *could* simply connect a battery across our diode. However, if we apply too big a voltage i.e. if we try to shove too many charges in, we may break our LED!
To regulate the flow of charge into the LED we can simply use a resistor between the battery and the anode.
Note that we could use a resistor whose resistance can be easily varied by means of a dial. This would allow us to regulate how many charges flow into our LEDs and hence how much light it emits! We can see our variable resistor as a sort of “charge tap”.

However is this exercise we will simple use a fixed value resistor of 390Ω as shown in the figure below.

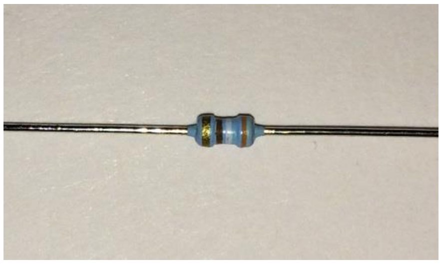


Figure 3-2 A 390Ω resistor is places in series with the IR LED

We then connect one side of this resistor to the anode of the LED and the other side to the battery. Make sure that the cathode is connected to ground which, in our case, is also the negative terminal of the battery. The whole arrangement is shown below.

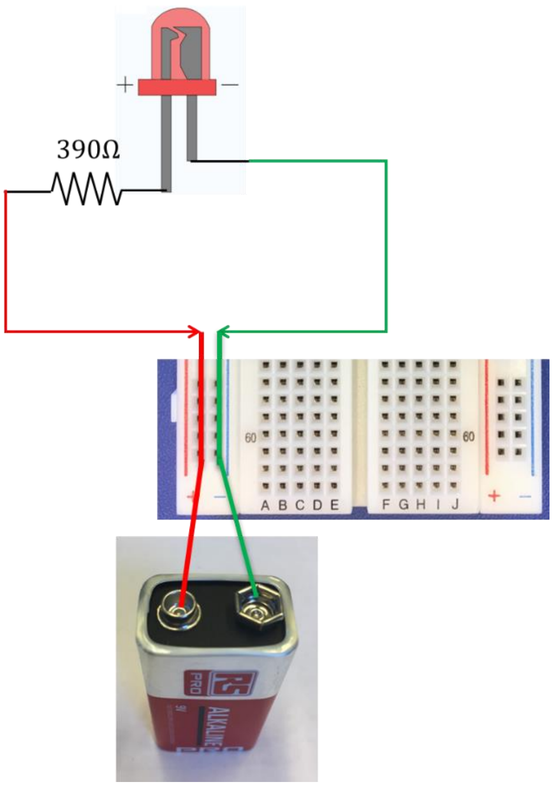


Figure 3-3 Infrared LED setup

Make sure that you have connected the LED the right way around before you connect the battery. Get one of the demonstrators to check if you are not sure.

The problem is, we can't actually see if the LED is or isn't working because the light that it emits is not visible to the human eye.

So let's put together our light detector and check!

3.1.2 Photodiode and Current amplifier

As you saw in the introductory presentation, a photodiode is the opposite of an LED.
An LED generates light from an electrical current whereas a photodiode generates an electrical current from light.
Whereas in an LED we are sending charges into the device, in a photodiode we are trying to get them out. We therefore need to apply an opposite voltage to our device.
That is to say that a photodiode must be reverse-biased i.e. the voltage at the cathode must be greater than the voltage at the anode.
As we have seen in the introduction however, the current that comes out of a photodiode is quite small so we want to use a BJT to amplify it, as shown in Figure 3-4. We can then let this amplified current flow through a resistor to establish a voltage. Note that the transistor also needs to be connected to the battery. The battery has enough charges for both transistor and photodiode. The whole arrangement is shown below.

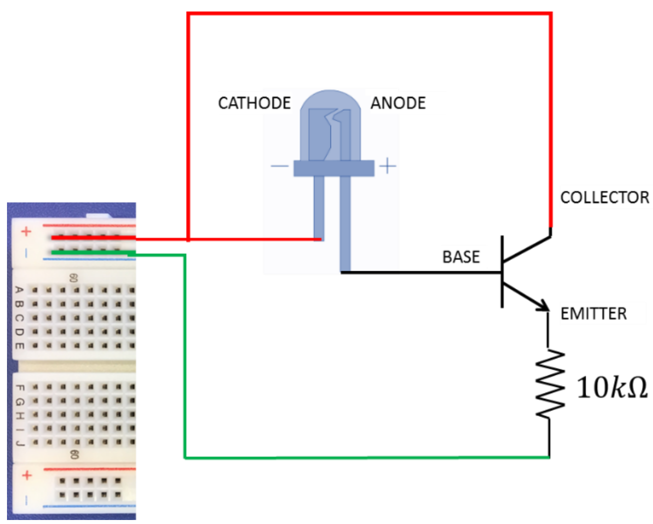


Figure 3-4 Photodiode and Current amplifier

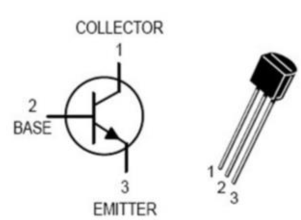


Figure 3-5 BJT pin configuration

As in the previous case, the resistor which we connect to the emitter of the BJT could be variable. However is this case we will simple use a 10 kΩ resistor.

3.1.3 Testing and tuning the proximity sensor

Now the moment of truth!
Connect one of the probes of the oscilloscope to the emitter of the transistor as shown in Figure 3-6. Theoretically you should see no voltage since no current should be produced by the photodiode. However you do see a small one!
Now put a reflective surface between the LED ad the photodiode. Does the voltage decrease?

There are two factors that contribute to this “baseline” voltage.
Firstly there will be some ambient infrared light and we can do very little about this.
Secondly, although the LED has a relatively narrow beam, some light will leak from its side into the photodiode. This problem can be mitigated by interposing a surface between the two.
However in our system, since we can set a specific threshold for detection, all we need to do is adjust the threshold to take into account this baseline voltage. More about this later.

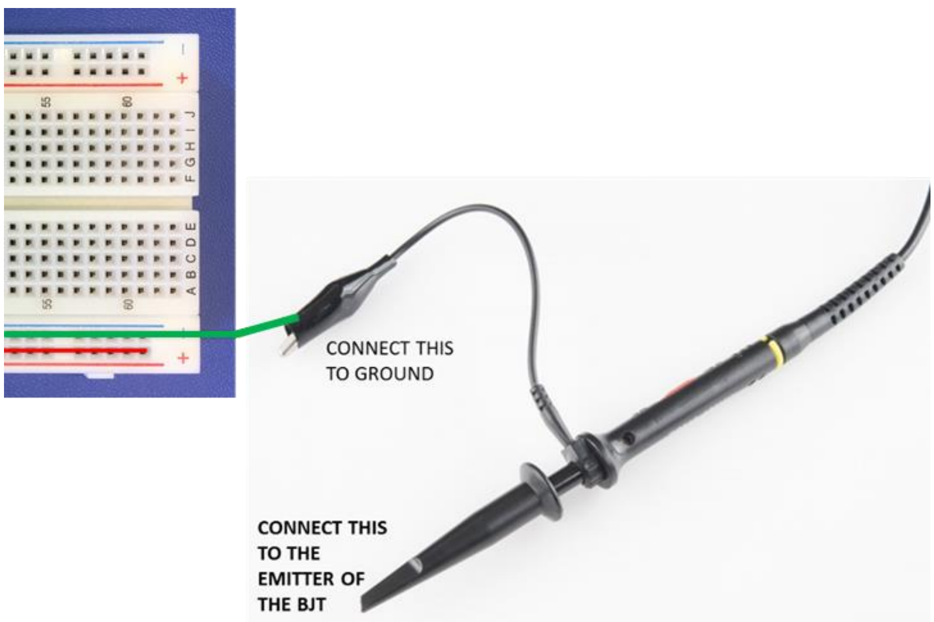


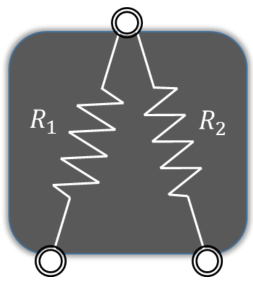
Figure 3-6 Oscilloscope Probe is used to measure the voltage at the emitter of the BJT

Now put a reflective surface in front of the diode pair and observe how the emitter voltage changes as the object is brought closer to the detector.
Now move the object away, until you are very close to the fixed voltage level which you observed earlier.

Now we have a circuit which allow us to produce a voltage proportional to the distance of an object from the detector.

3.2 Threshold Comparator

What we need to do now is establish a voltage threshold. This will enable us to decide if our object is close enough to switch on the lamppost.
To establish the threshold we can use a 10kΩ potentiometer or pot.
The figure below shows what a potentiometer looks like on the inside. It comprises of two resistors in series, R_1 and R_2, whose values may be varied. However the overall resistance of the series $(R_1 + R_2)$ remains constant and is equal to R_T. This is shown in Figure 3-7.



$$R_1 = \mathrm{k}R_T$$

$$R_2 = (1-\mathrm{k})R_T$$

$$0 < \mathrm{k} < 1$$

Figure 3-7 A potentiometer inner workings

This device is perfect to achieve what we explained in the introductory lecture, as shown below.

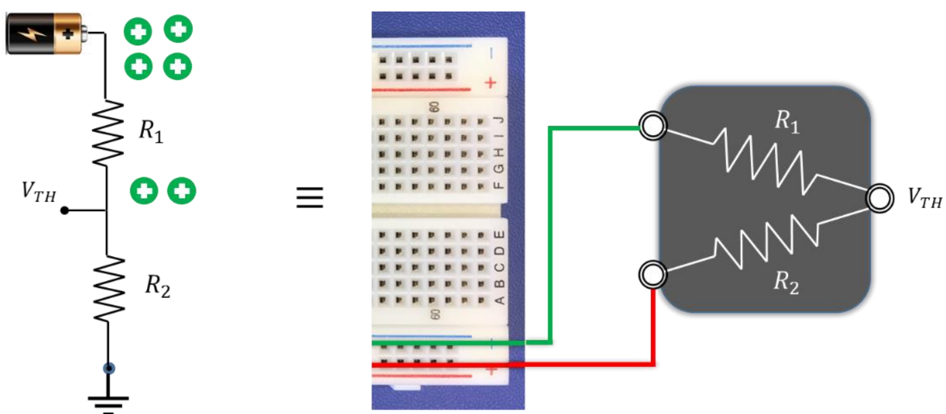


Figure 3-8 A potentiometer may be used to establish our threshold

Of the two terminals **which are on the same side**, connect one to the positive rail and one to the ground rail, as shown above.
Now use the oscilloscope to observe the threshold voltage established at the terminal on the other side (V_{TH}).

Now turn the dial of the pot until you get a voltage between 1.5 and 2 V. This is our initial threshold but we can increase it or decrease it anytime by simply turning the dial.

Next we need to set up our op-amp to act as a comparator. The chip that we will be using is an LM 741. Place the chip across the gap in the breadboard as shown below.

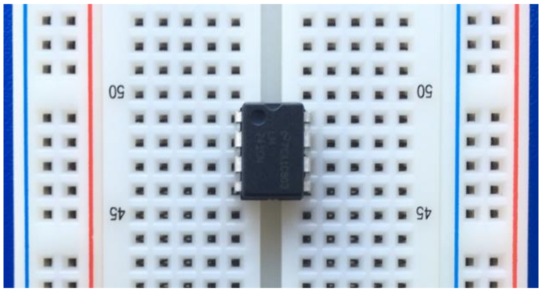


Figure 3-9 Op-amp placement

Its pin configuration is shown below.

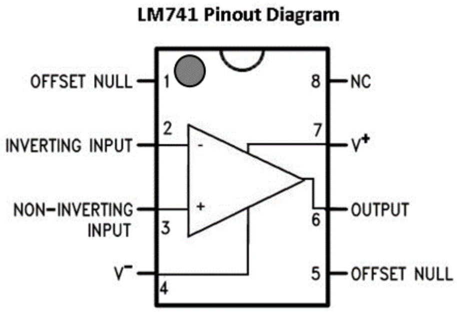


Figure 3-10 Op-amp pin configuration

This is a little tricky if you are not familiar with chips since this one has 8 and we need to know which one is which! The key is figuring out which one is pin 1! You should be able to see a little circle on one of the corners of your chip. This is pin 1.
Now, of these 8 pins we will only be using only 5, these are pins 2, 3, 4, 6 and 7. The rest of the pins are unconnected. The connections to the circuits which we developed in previous sections are shown below.

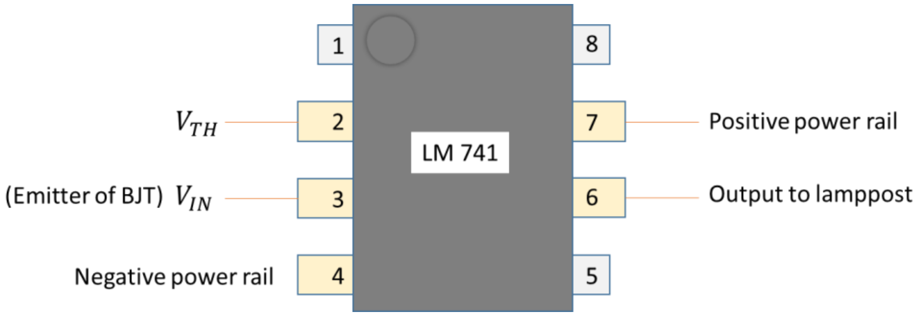


Figure 3-11 Connections between op-amp and rest of the circuitry

The negative power rail is something which is necessary in order for an op-amp to operate correctly. Figure 3-12 and Figure 3-13 illustrate how to create a negative power rail and to connect the op-amp to both positive and negative rails.

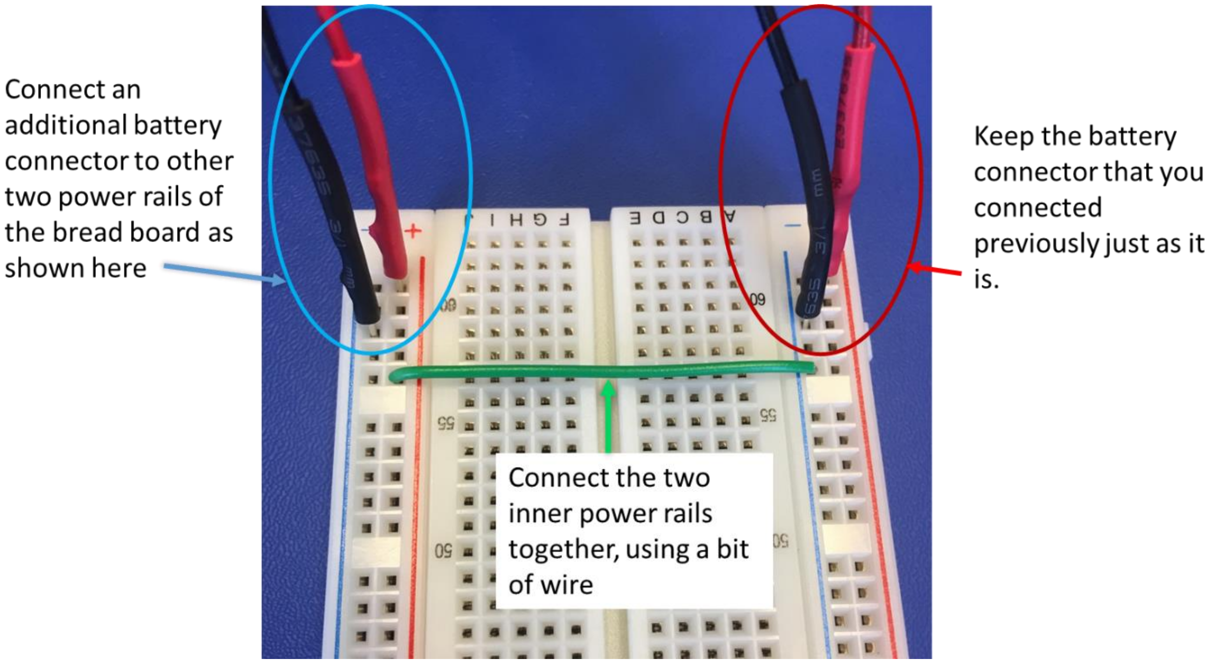


Figure 3-12 Creating positive and negative power rails

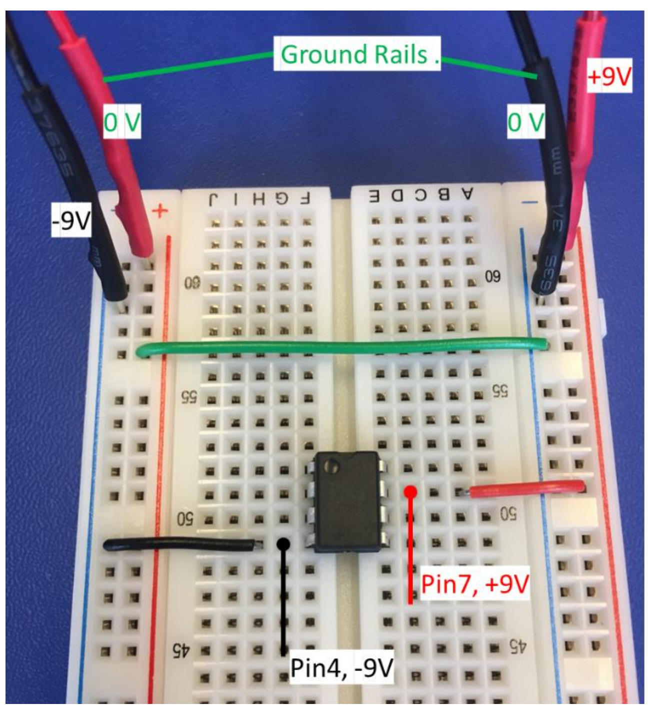


Figure 3-13 Positive and Negative power rails & Op-amp Connections

If the voltage difference between pin 3 and pin 2 is positive then the op-amp will produce a positive voltage at its output. Since the bulbs of our lampposts are also LEDs (white light ones this time!), this positive voltage will forward bias them and hence turn them on.
If the difference between pin 3 and pin 2 is negative then the op-amp will produce a negative voltage at its output. This will make our LEDs reverse biased and hence turn them off.
Before we connect the lamppost, let's check that we get the right voltages according to what we put in front of our LED-photodiode pair.
Check that when we put a reflective surface in front of our detector, the output of the op-amp observed at pin 6 is around 8V.
Also, when there is no reflective object in front of our pair, we should see a negative voltage of about -8V at pin 6.
Once you are satisfied that your comparator is working correctly we can move on the final step of this stage.
Ask a demonstrator for a lamppost. This will consist of two CREE LEDs (C503D) connected in series. Then connect a 270Ω resistor to pin 6 of the op-amp on one side and the positive (red) terminal of the lamppost on the other side. Also, connect the ground terminal of the lamppost to one of the ground rails. This is shown in Figure 3-14.

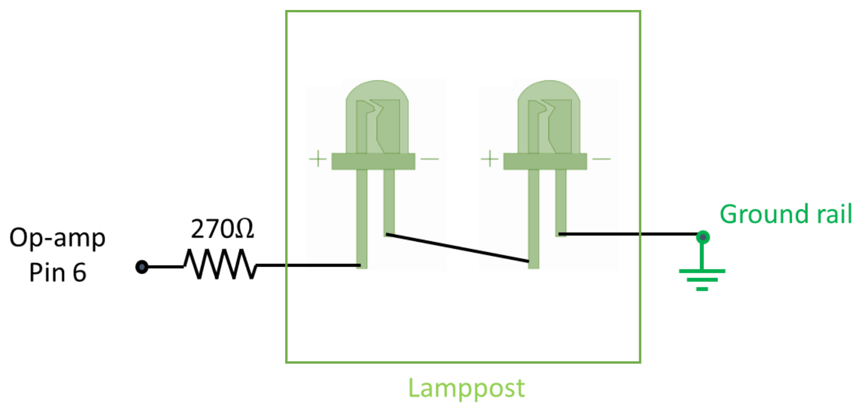


Figure 3-14 Our lamppost is made up of two white LEDs connected in series

Now when your proximity sensor detects an object, the white LEDs should turn on.

3.3 Timer (OPTIONAL)

What we may want to do next is add some circuitry which will keep our lamppost on for a set number of seconds.
We can do this by using a device called a 555 Timer, a resistor and a capacitor. The circuit configuration is shown below.

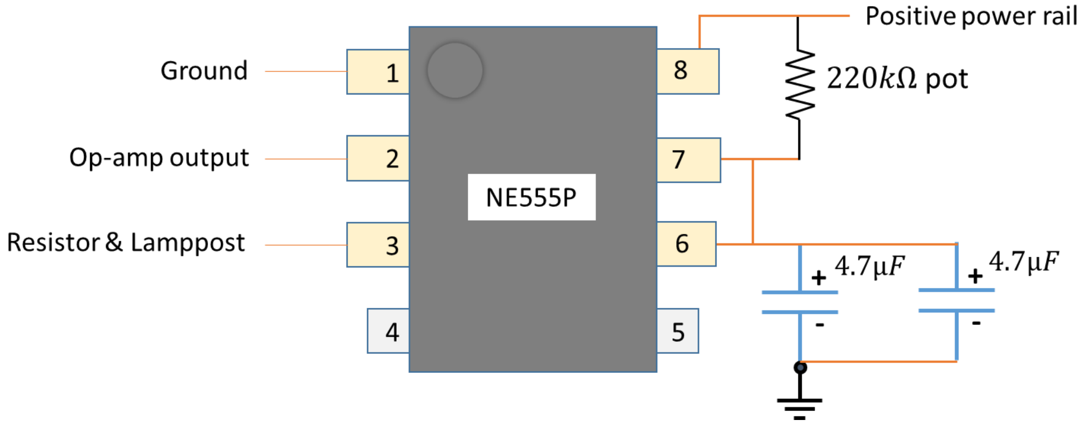


Figure 3-15 Configuration of the 555 Timer

Notice that the capacitor connected between pin 6 and ground is a polarised one and must be connected the right way around! The negative lead is always shorter than the positive lead so we can easily get this right.

Figure 3-16 Polarised capacitor

Also the 220kΩ pot is used as a variable resistor in this case, so you will need to bend (Figure 3-17 (a)) or cut off (Figure 3-17 (b)) one of the two legs which are on the same side of the pot, as shown below.

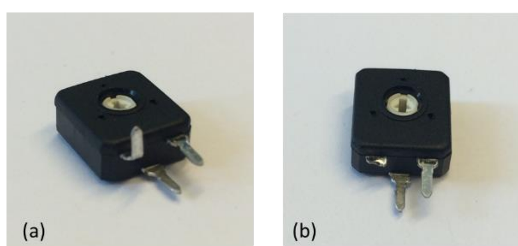


Figure 3-17 Turning a pot into a variable resistor

How long the Timer will keep the voltage on is related to the values of the capacitor and resistor through the equation shown below

$$t = 1.1 \times R \times C$$

Before we test the circuit however there is one last thing we need to do.
The timer starts when the voltage at pin 2 goes negative. At the moment, when a car is detected, the output voltage of the op-amp goes positive.
We can easily flip things over however and set up the op-amp in such a way that, when a car is detected, its output voltage goes negative.
All we need to do is swap over the connections of pins 2 and 3, as shown below.

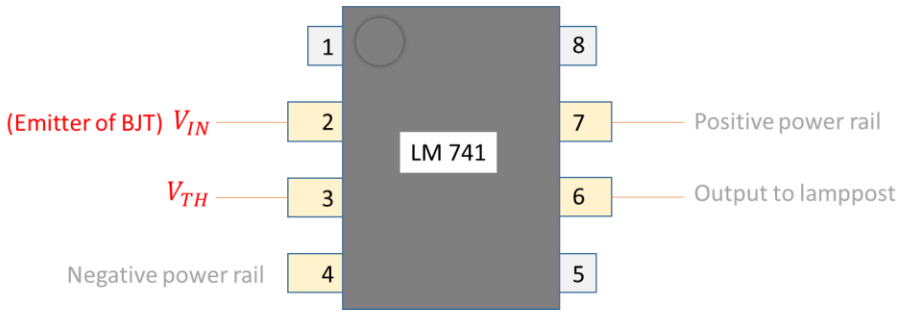


Figure 3-18 Modified op-amp comparator

Hopefully all is working swimmingly well now!

Feel free to play around with your circuit!

Can you enhance its range?