Timing Circuits

Learners should be able to:

(a) describe how a RC network can produce a time delay

(b) describe how the voltage across a charging or discharging capacitor in a RC circuit varies with time, including the interpretation of decay graphs for RC networks

(c) describe how the time delay may be changed by varying R and/or C, including interpretation of the voltage–time graph for monostable and astable timers

(d) describe the action of a 555 monostable timer and then use the equation T = 1.1 RC, where T is the pulse duration

(e) describe the action of a 555 astable timer in terms of period and mark–space ratio

(f) use an oscilloscope (or a computer configured as an oscilloscope) to measure the amplitude and period of the output of an astable timer

(g) select and apply equations for the frequency and mark–space ratio of a 555 astable timer

$$f = \frac{1}{T} \quad \text{frequency, period relationship}$$

$$f = \frac{1.44}{(R_1 + 2R_2)\,C} \quad \text{frequency of an astable}$$

$$\frac{T_{ON}}{T_{OFF}} = \frac{R_1 + R_2}{R_2} \quad \text{mark – space ratio of an astable}$$

(h) draw and analyse the circuit diagrams for a monostable and/or astable timer based on a 555 IC

Timing Circuits

In Component 1, we used several different types of timing circuit to produce effects such as holding an output on for a set period of time, making an output flash on/off continuously, or delaying an output from coming on for a short time period even though an input had been activated. All of these applications would not be possible without the use of a **timing circuit**.

We will now investigate how these circuits work in more detail. By the end of this Chapter you should be able to design these circuits for yourself to produce any of the functions described above.

Resistor–Capacitor (RC) Network

We can all think of situations in which an electronic timer controls for how long or when something should happen. A microwave oven has a timer to control how long food is cooked for. A Pelican crossing has a timer which activates a sequence of traffic lights for a predetermined time when a pedestrian presses a switch.

These timer circuits make use of a component called a capacitor. Capacitors have many applications in electronic circuits. At this stage we will only be concerned with their use in timing circuits.

Types and symbols of capacitors

There are two main types of capacitors, **polarised** and **non-polarised**. Polarised capacitors include **electrolytic capacitors**.

In the practical work you will be using electrolytic capacitors. They are used because they have a much larger capacity than non-electrolytic capacitors of the same physical size.
The symbols used for the two types are shown below.

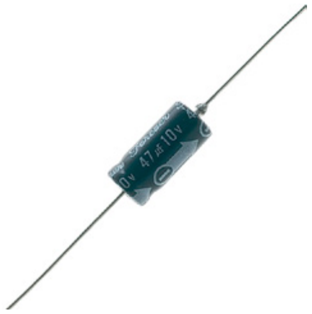
Polarised Capacitor

Non-Polarised Capacitor

Considerable care is required when using electrolytic capacitors. Their positive terminal must be nearer the positive supply rail than their negative terminal.

Identifying the leads on electrolytic capacitors

The ‘+’ and ‘–’ leads are always clearly marked on electrolytic capacitors. The following illustrate some conventions in common use.



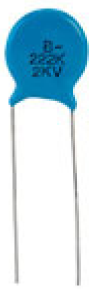
Axial Lead – Positive lead is on left, next to indent on case. Negative is shown by white stripe down side of case.

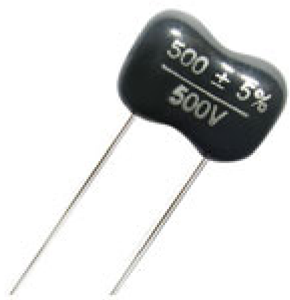
Radial Lead – Positive is the longer lead. Negative is also marked by the white stripe just visible on the left.

Care must be taken **not** to exceed the working voltage of the capacitor. This is clearly marked on the capacitor, 40 V and 25 V respectively.

Non-polarised capacitors

The following pictures show a variety of non-polarised capacitors which can be connected either way around in a circuit, but notice that they still have a maximum working voltage.





Units of capacitance

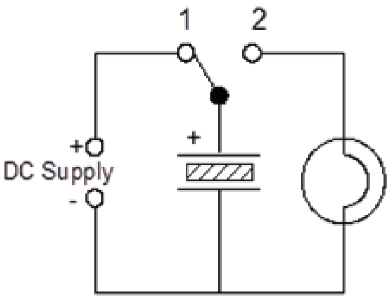
The charge storage capability of a capacitor is measured in units called farads. The farad (F) is a very large unit and is not normally used in electronics. Capacitor values are usually given in microfarads (μF).

$$1 \text{ Farad} = 1{,}000{,}000\ \mu\text{F or } 1\ \mu\text{F} = \frac{1}{1{,}000{,}000}\ \text{F} = 1\times10^{-6}\ \text{F}$$

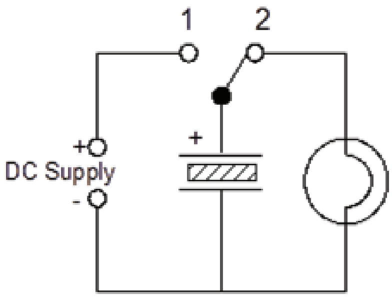
We will now consider how capacitors can be charged and discharged.

Charging and discharging a capacitor

We can think of a capacitor as being two metal plates separated by an insulator. The insulator is called the **dielectric**.



Charging Capacitor



Discharging Capacitor

When the switch is set to position 1, the power supply draws electrons off the top plate and transfers them onto the bottom plate. As a result, the bottom plate carries a negative charge and the top plate a positive charge. Transfer of charge continues until the voltage across the capacitor is equal to the supply voltage. The capacitor is then fully charged.

The amount of charge stored, and hence the energy stored within the capacitor, will depend upon the size of the capacitor and the supply voltage used.

When the switch is moved to position 2, the capacitor provides a voltage across the lamp. Electrons flow through the lamp and the capacitor will rapidly discharge. The lamp will initially glow brightly then dim as the voltage across the capacitor falls. After a short while the capacitor becomes fully discharged and no voltage will be present across its terminals.

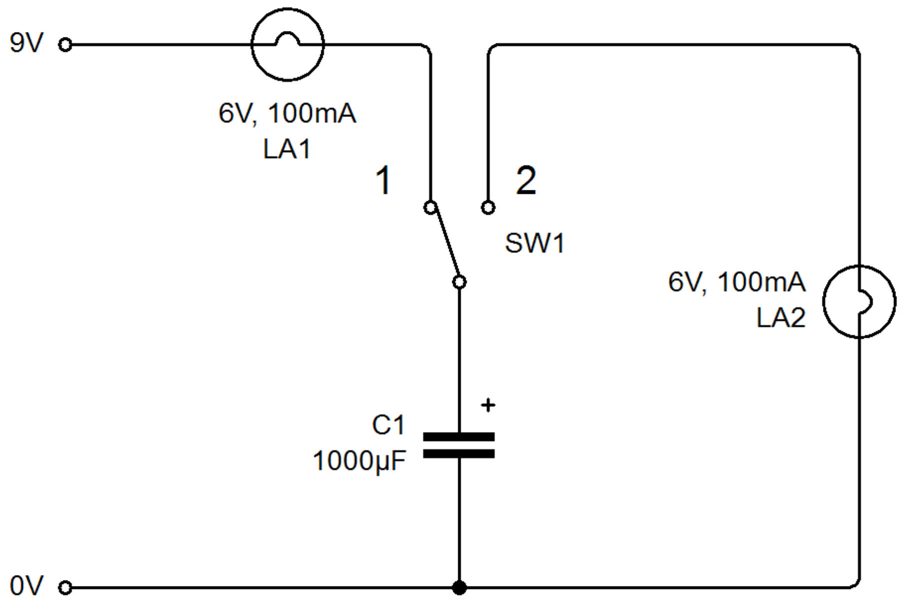
The action can be repeated by moving the switch to position 1 then back to position 2. When used in this way the capacitor behaves like a small rechargeable battery.

CAUTION:

Be very careful to observe polarity when using electrolytic capacitors.
The positive terminal must be connected to the positive side of the supply. Failure to do this may result in the capacitor heating up and exploding.
The voltage applied across it must not exceed the working voltage. The working voltage of the capacitor is shown on its body.

Investigation 1.1

a) Set up the following circuit either on breadboard or a simulation program. Lamps are 6 V, 100 mA.



b) Change the switch over to position 2. Describe and explain what you observe.

....

c) Change the switch back to position 1. Describe and explain what you observe.

....

d) Replace the 1000 µF capacitor with a 4700 µF capacitor and repeat parts b) and c) above. Observe the difference and complete the sentence below:

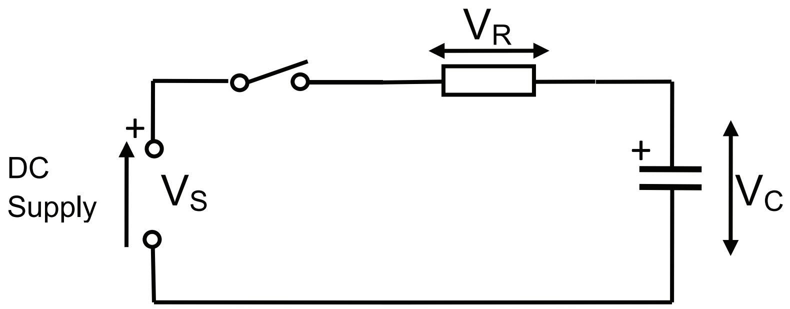
The amount of charge energy a capacitor can store .... when the value of capacitance ....

Using Capacitors as Timing Elements

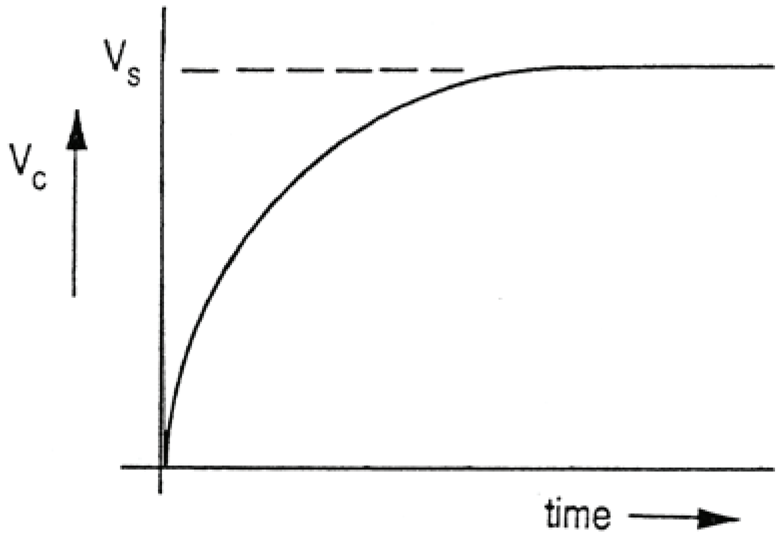
1. Charging capacitor

When a capacitor is charged directly from a voltage supply it very quickly becomes fully charged. We can slow down the charging process by including a series resistor in the circuit.

Consider the following circuit.

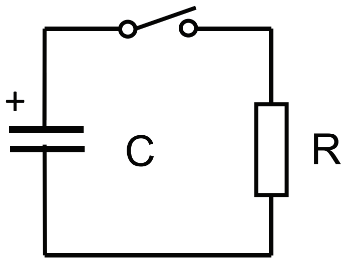


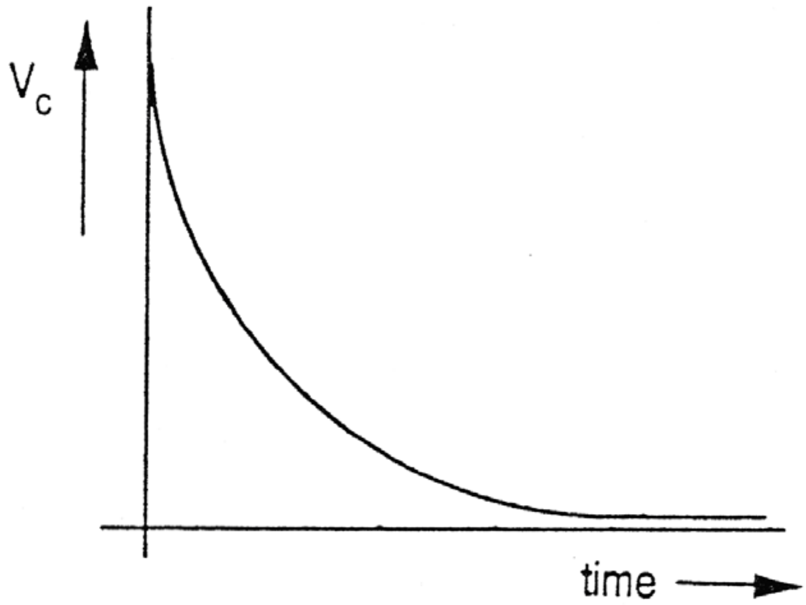
The capacitor will always charge up in a predictable way in a fixed length of time until it approximately reaches the power supply voltage V_S. The way the capacitor charges up is shown in the graph below. The time taken is dependent on both the value of capacitor and value of resistor used.



2. Discharging capacitor

The discharging process can also be slowed down by discharging the capacitor through a large resistance.



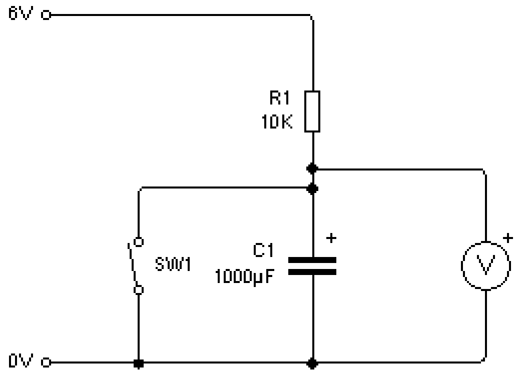


In the following Investigation you will see how the predictable way in which capacitors charge and discharge can be used to our advantage.

Investigation 1.2

1. Charging a capacitor through a resistor

a) Set up the following circuit with the supply voltage set to 6 V.



b) Connect a digital voltmeter across the output terminals to monitor the output voltage.

c) Open the switch 'SW1' to allow the capacitor to charge up. Comment on the speed at which the voltage changes when the switch is first opened compared to the speed later.

....

d) Repeat the procedure and measure the time taken for the capacitor to charge up to 3 V.

....

e) Replace the 10 kΩ resistor with a 20 kΩ resistor. Measure the time taken for the voltage across the capacitor to change from 0 V to 3 V.

....

f) Replace the 1000 μF capacitor with a 2200 μF capacitor. Measure the time taken for the capacitor to charge up from 0 V to +3 V.

....

g) Look at your results for the time taken in parts d), e) and f) to help you complete the following statements:

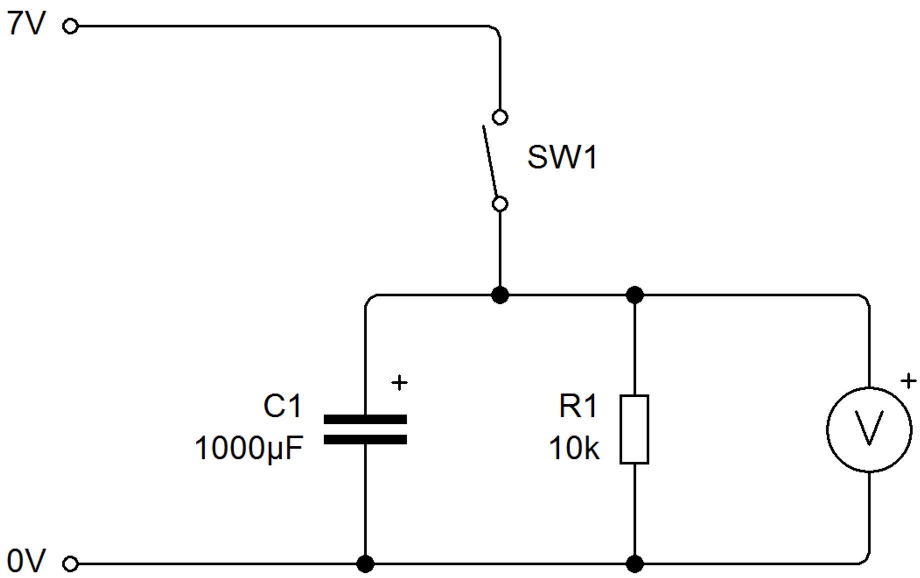
The larger the value of **capacitor** used in a resistor-capacitor network the .... the time taken for the capacitor to charge.

The larger the value of **resistor** used in a resistor-capacitor network the .... the time taken for the capacitor to charge.

2. Discharging a capacitor through a resistor

a) Set up the following circuit with the supply voltage set to 7 V.

b) Close the switch 'SW1' to charge up the capacitor.



c) Open the switch 'SW1' and comment on the speed at which the voltage changes when the switch is first opened compared to the speed later.

....

d) Repeat the procedure but this time measure the time taken for the capacitor to discharge to 3 V.

....

e) Replace the 10 kΩ resistor with a 20 kΩ resistor. Measure the time taken for the capacitor to discharge to 3 V.

....

f) Replace the 1000 μF capacitor with a 2200 μF capacitor. Measure the time taken for the capacitor to discharge to 3 V.

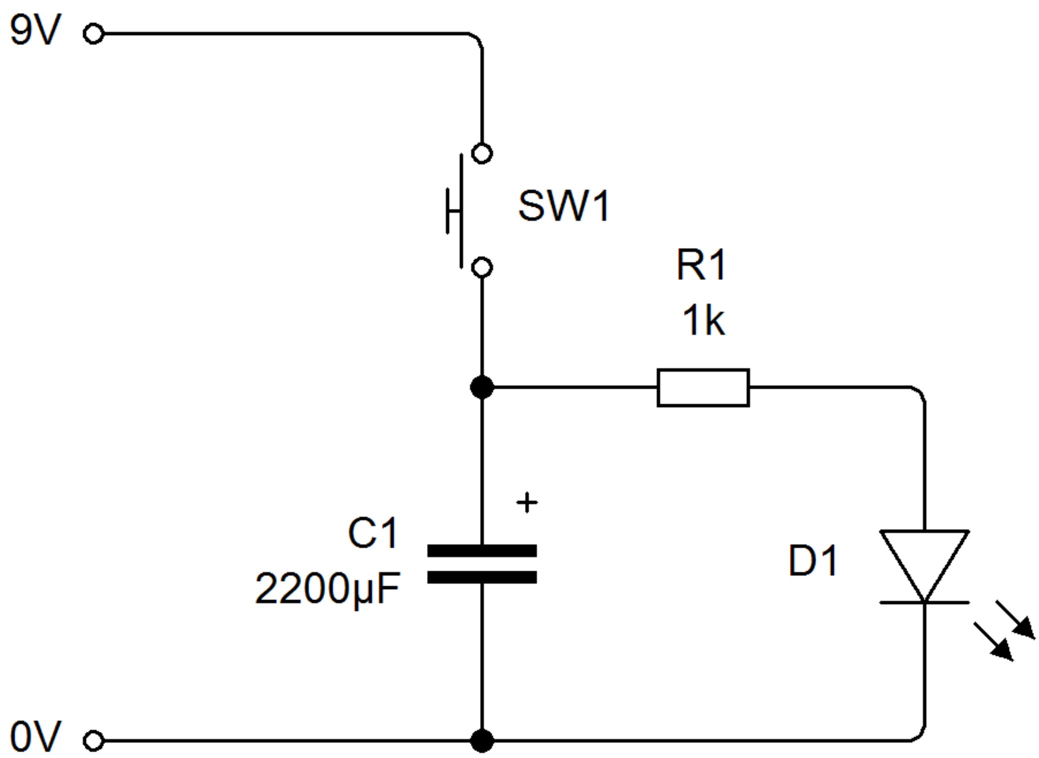
....

g) Look at your results for the time taken in d), e) and f) to help you complete the following statements:

The larger the value of **capacitor** used in a resistor-capacitor network the .... the time taken for the capacitor to discharge.
The larger the value of **resistor** used in a resistor-capacitor network the .... the time taken for the capacitor to discharge.

3. A simple time-delay circuit

a) Set up the following circuit.



b) Momentarily close the switch ‘SW1’ and comment on what you observe.

LED stays on for ………………………………….. seconds

c) Replace the 2200 µF capacitor with a 1000 µF one and repeat the above procedure.

LED stays on for ………………………………….. seconds

Compare this with the time you obtained in b).

……

d) Replace the LED with a 6 V lamp and repeat the above procedure. What happens?

……

e) Replace the lamp with a buzzer and repeat one more time. What happens?

……

Practical Timer Circuits

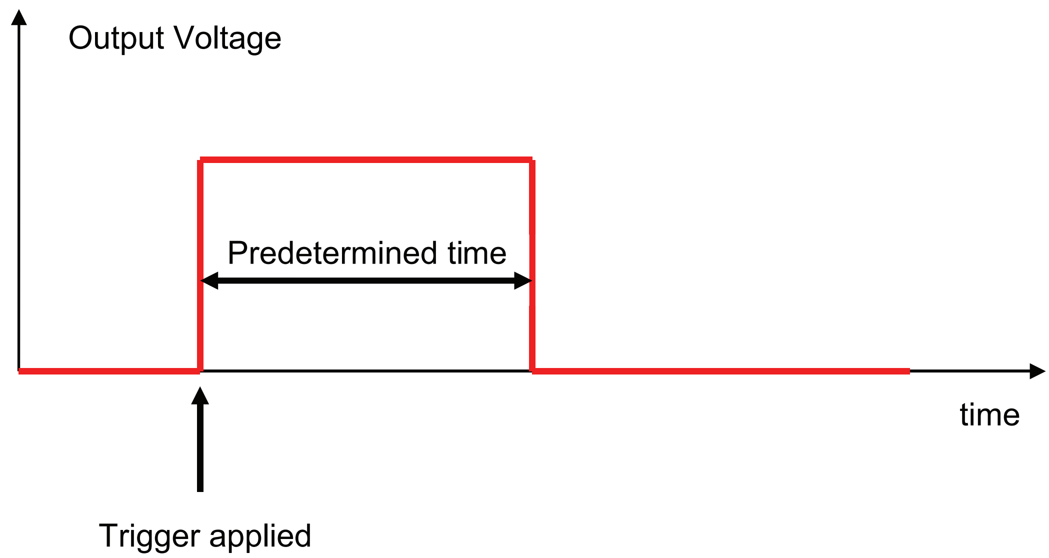
The simple timer circuit investigated in question 3 of Investigation 1.2 is satisfactory for demonstrating the idea of a timer circuit, but it is of little use for practical circuits since it has three main limitations:

i) The output changes gradually as the capacitor gradually discharges from 9 V to 0 V, resulting in a poorly defined timing period.

ii) The circuit can only supply a very small current which is barely sufficient to drive a LED.

iii) The timing circuit has to supply the current to drive the load which affects the predictability of the timing.

We require a timer that produces a single, square wave pulse as shown in the graph below. Its output will usually start off in a **LOW** state. When its input is triggered the output will then go **HIGH** for a predetermined length of time before returning to its low state. The output will then remain indefinitely in its low state until triggered again.



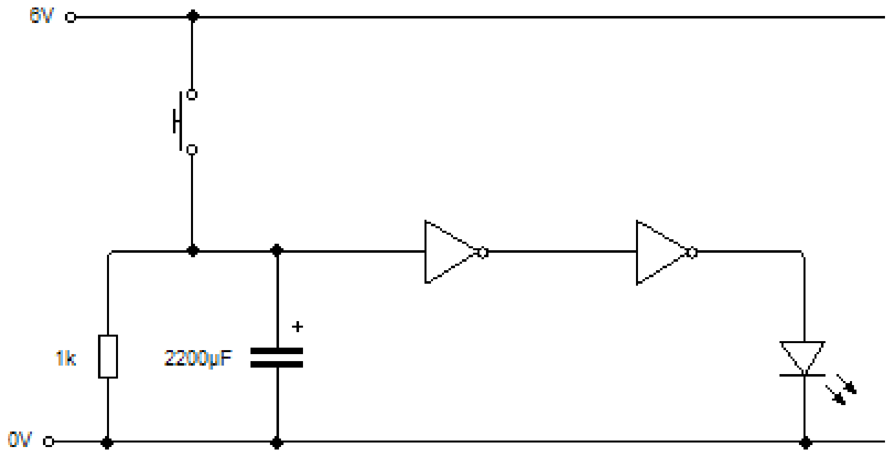
The signal produced by the RC network has to be processed to overcome the limitations stated above.

A processing sub-system is required between the timing unit and the load. It must draw very little current from the timing unit and supply sufficient current to drive a load. Such a sub-system is often referred to as a **buffer**.

A buffer is, in fact, any sub-system connected between two other sub-systems in order to strengthen a signal.

Investigation 1.3: A buffered time-delay circuit

a) Set up the following circuit.



b) Two inverters (NOT gates) have been added to the simple time delay circuit investigated in our previous task to act as a buffer. Why are two inverters needed?

....

c) Momentarily close the switch.

(i) Record the time the LED stays on after the switch is released

....

(ii) Compare the way in which the LED switches off with what you observed previously in Investigation 1.2, question 3 b).

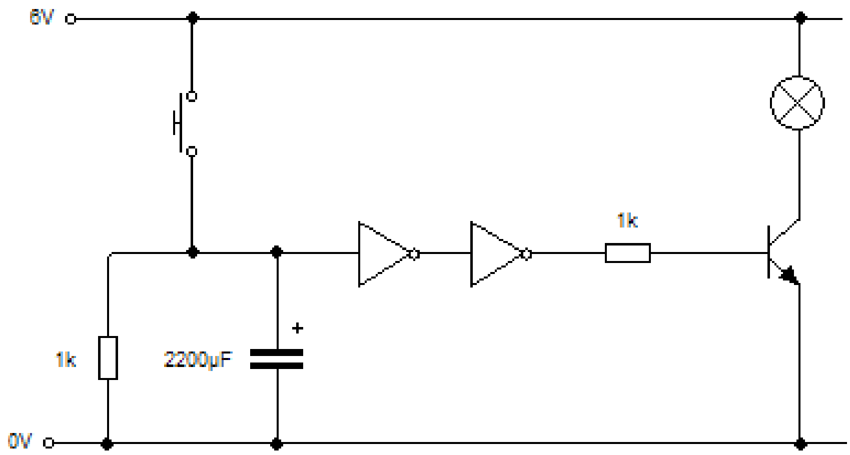
....

d) Replace the LED with a 6 V, 60 mA lamp and comment on what you observe. Can you give a reason for this?

....

An improved buffered time-delay circuit

You probably realised that, although the buffered time delay examined in investigation 1.3 gave a much sharper switching action, it still suffered from the problem of being unable to provide sufficient current to light the lamp. We can add a transistor to overcome this.



If you have time, try setting up and testing this circuit.

Summary

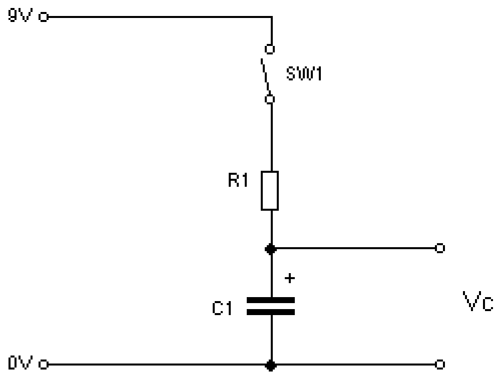
The timer circuits considered so far have several limitations. Many electronic systems require a more sophisticated timer to control their operation.

The popular 555 timer IC overcomes the limitations of the simple timers and is very versatile as it can be used to produce two different types of timed output:

1. A single pulse of a fixed period of time. This type of circuit is called a **monostable**.
2. A continuous train of on/off pulses. This type of circuit is called a square **wave oscillator** or **astable**.

Exercise 1.1

1. In the following circuit:



What will be the value of Vc:

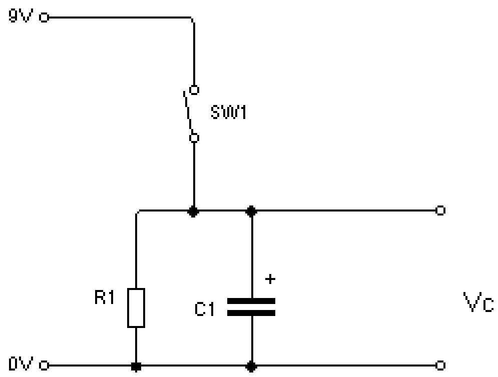
a) at the instant switch SW1 is closed;

....

b) after a long period of time?

....

2. In the following circuit:



What will be the value of Vc :

a) at the instant switch SW1 is closed;

....

b) after a long period of time?

....

3. A 100 µF capacitor is connected in series with a 100 kΩ resistor across a power supply. The capacitor takes 16 s to charge up to 5 V.

   a) The value of the resistor is kept at 100 kΩ and the value of capacitor changed to 200 µF. Roughly how long will it take now for the capacitor to charge to 5 V?

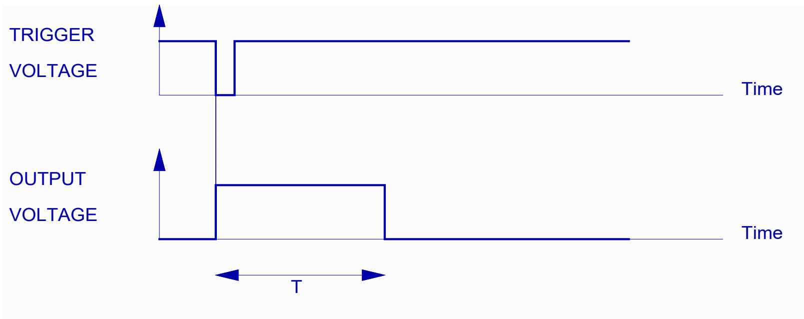
   ....

   b) The value of the capacitor is kept at 200 µF and the value of resistor is changed to 200 kΩ. Roughly how long will it take now for the capacitor to charge to 5 V?

   ....

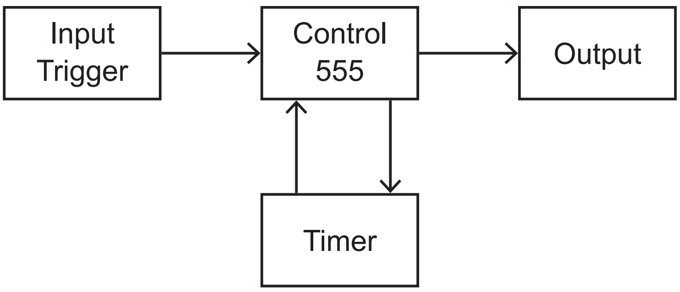
Monostable Circuits

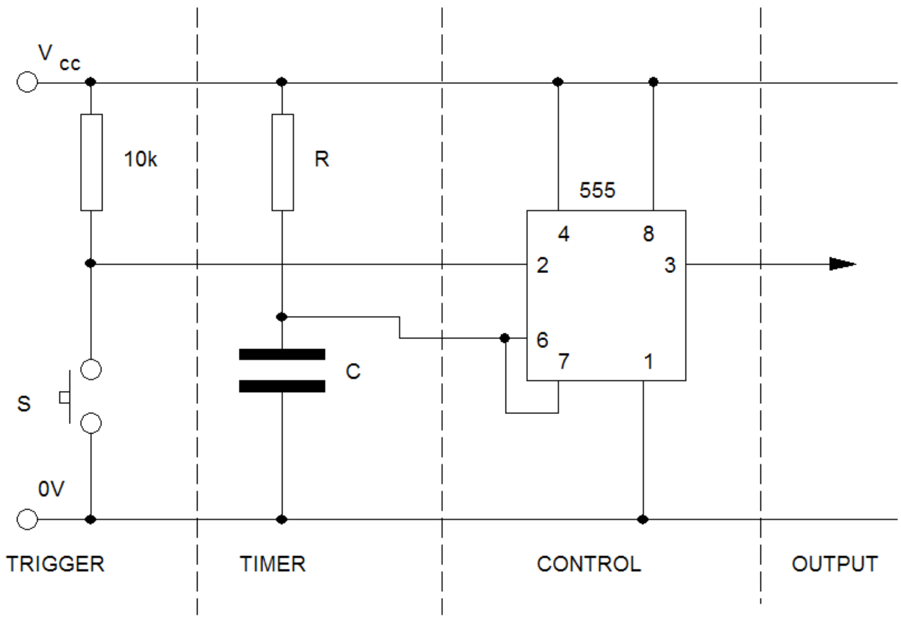
In this application of timer circuits we are trying to produce a single pulse of fixed duration when the circuit is provided with a trigger pulse, as illustrated in the following diagram.



Monostable Timer

A monostable has only one stable output state. Normally it is in this stable state (output 0 V), but can be triggered into the other state (output approximately equal to supply voltage) where it stays for a predetermined time. This time is determined by two external components, a resistor and a capacitor. Both a block diagram and a circuit diagram for a 555 monostable are shown below.





When switch S is pressed momentarily, the monostable is triggered by the falling edge of the trigger pulse produced. The output of the 555 timer (pin 3) goes high and remains high for a time given by the formula:

$$T = 1.1 \times R \times C$$

Where: **T** is in seconds, if **R** is in Ohms, and **C** is in farads.

In practice the capacitor value will usually be in μF and the resistor values in either kΩ or MΩ, which allows us to use one of the following rules:

- If **R** is in kΩ, and **C** is in μF then **T** will be in ms (milliseconds)
- If **R** is in MΩ, and **C** is in μF then **T** will be in seconds

Example 1a: For each of the following values of **R** and **C** in a 555 monostable circuit, calculate for how long the output remains high after the circuit has been triggered:

a) **R** = 10 kΩ and **C** = 220 μF

$T = 1.1 \times R \times C = 1.1 \times 10 \times 220 = 2420$ ms = 2.420 s

b) **R** = 1.2 MΩ and **C** = 47 μF

$T = 1.1 \times R \times C = 1.1 \times 1.2 \times 47 = 62.04$ s

Alternatively, these calculations can be performed using **powers** and the **rules of indices**.
Remember that 1 kΩ = 1×10^3 Ω,1 MΩ = 1×10^6 Ω, 1 μF = 1×10^{-6} F

Example 1b: For each of the following values of **R** and **C** in a 555 monostable circuit, calculate for how long the output remains high after the circuit has been triggered:

a) **R** = 10 kΩ and **C** = 220 μF

$$\begin{aligned} T &= 1.1 \times R \times C \\ &= 1.1 \times 10 \times 10^3 \times 220 \times 10^{-6} \\ &= 2420 \times 10^{-3} \\ &= 2420 \text{ ms} = 2.420 \text{ s} \end{aligned}$$

b) **R** = 1.2 MΩ and **C** = 47 μF

$$\begin{aligned} T &= 1.1 \times R \times C \\ &= 1.1 \times 1.2 \times 10^6 \times 47 \times 10^{-6} \\ &= 62.04 \text{ s} \end{aligned}$$

Exercise 1.2

For each of the following values of **R** and **C** in a 555 monostable circuit, calculate how long the output remains high after the circuit has been triggered:

1. **R** = 10 kΩ, **C** = 2200 μF

   ....

2. **R** = 8.2 MΩ, **C** = 330 μF

   ....

3. **R** = 3.9 kΩ, **C** = 680 μF

   ....

4. **R** = 100 kΩ, **C** = 33 μF

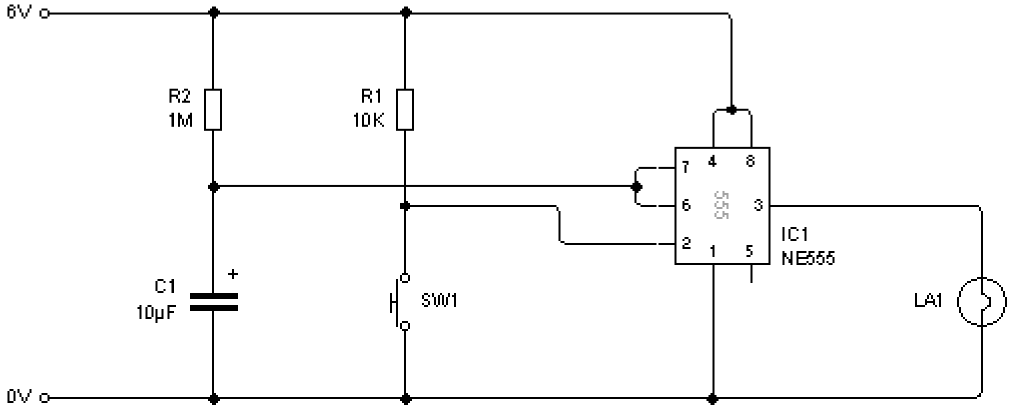
   ....

5. **R** = 1 MΩ, **C** = 150 μF

   ....

Investigation 1.4

a) Set up the 555 monostable circuit as shown below.



b) Run the simulation and operate the switch SW1. Describe what you observe.

....

c) The theoretical duration of the output pulse is given by:

$$T = 1.1 \times R_2 \times C_1$$

Calculate its value from the value of the components, and then measure its value using a stop watch.

Theoretical duration = ...

Measured value = ...

Suggest a practical application for this circuit.

....

d) Investigate whether the pulse duration depends upon the supply voltage by changing the supply voltage to 9 V and then to 12 V. Comment on your findings.

....

e) Connect the lamp between the output pin and the positive supply rail and momentarily take the trigger output low by flicking the switch on.

Compare the result with that obtained in b) above.

....

Varying the time delay

In the previous activity, you will probably have found that the actual and theoretical times were within one or two seconds of each other, which is usually acceptable. For some applications we need very accurate timings, and for other applications we need adjustable timings.

The 1 MΩ fixed resistor could be replaced with a 1 MΩ variable resistor in series with a 1 kΩ fixed resistor. The fixed resistor is required to limit the current flowing into pin 7 when the variable resistor is set to zero.

In fact, a wide range of 'timings' may be obtained by using a 1 kΩ fixed resistor in series with a 1 MΩ variable resistor and one of the capacitor values, as shown in the table below.

Required timing period	Capacitor
11 ms to 11 seconds	10 μF
52 ms to 52 seconds	47 μF
0.11 to 110 seconds	100 μF
0.52 to 520 seconds	470 μF
1.1 to 1100 seconds	1000 μF

Choosing component values for a monostable

Sometimes we are required to design a monostable to a specification, rather than have to analyse a given circuit with set values.

For example: Design a monostable to keep an outside light on for a period of approximately 90 seconds.

The formula for a monostable delay is $T = 1.1 \times R \times C$ so in this case this becomes:

$$90 = 1.1 \times R \times C$$

There are two unknowns in this equation, so as it stands it cannot be solved. We have to 'guess' one of the values for **R** or **C**, and then work out what the corresponding value required is to make the formula correct. It is usually easier to find a resistor of different values than a capacitor because there are more of them and variable resistors are very common. Finding a variable capacitor is not so easy (and they are very expensive).

So, for our problem, we will try a capacitor value of 100 μF. This gives us the following:

$$90 = 1.1 \times R \times C$$
$$90 = 1.1 \times R \times 100$$
$$90 = 110 \times R$$

$$R = \frac{90}{110} = 0.818\ \text{M}\Omega$$

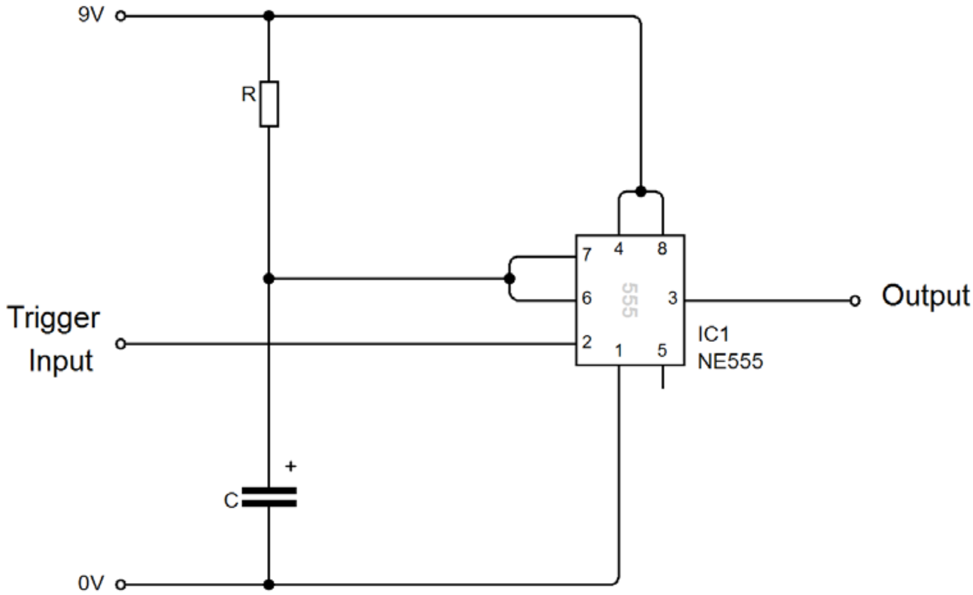
$$R = 818\ \text{K}\Omega \approx 820\ \text{K}\Omega$$

Had we chosen **C** to be 1000 μF, then **R** would be 82 kΩ.

In design problems like these, there is no single correct answer. However we always try to ensure that **R** is greater than 1 kΩ, to minimise the current flowing in the timing circuit. In an exercise or examination you will be given either the value of **R** or **C**, and will be asked to calculate the missing one.

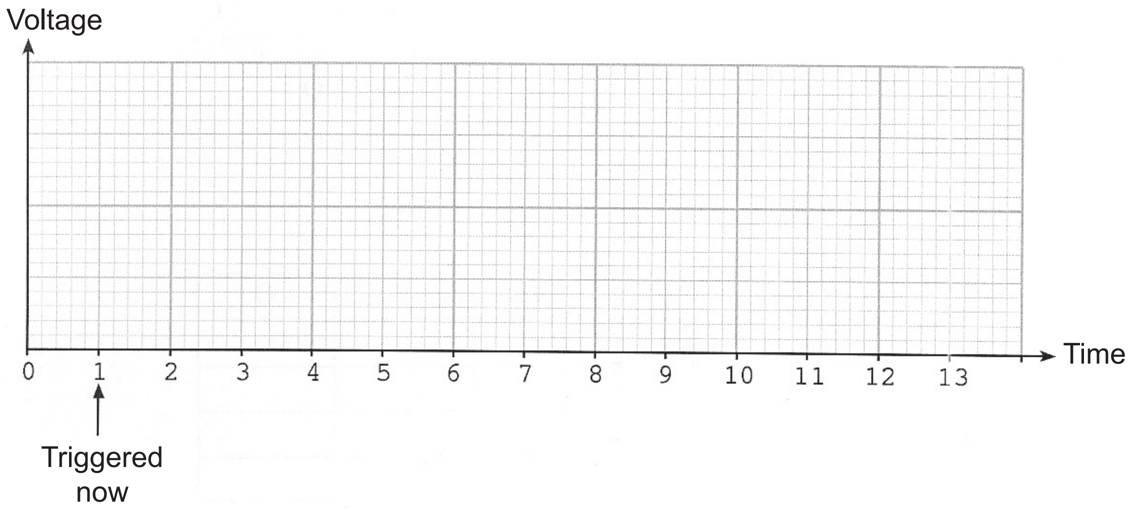
Exercise 1.3

1. The circuit diagram shows a monostable circuit using a 555 timer.



a) Add suitable components to the circuit diagram to provide a falling edge trigger pulse.

b) Using the axes provided to sketch the output signal produced by a 10 second monostable circuit, which is triggered at the time shown.



c) The monostable time delay can be found from the formula:

T = 1.1 RC (where T is in seconds, R is in MΩ, and C is in μF)

Here are four resistor/capacitor sets.

Set	Resistor	Capacitor
A	47 kΩ	100 μF
B	82 kΩ	100 μF
C	47 kΩ	220 μF
D	82 kΩ	220 μF

Which one will produce a time delay nearest to 10 seconds?
Show how you obtained your answer.

....

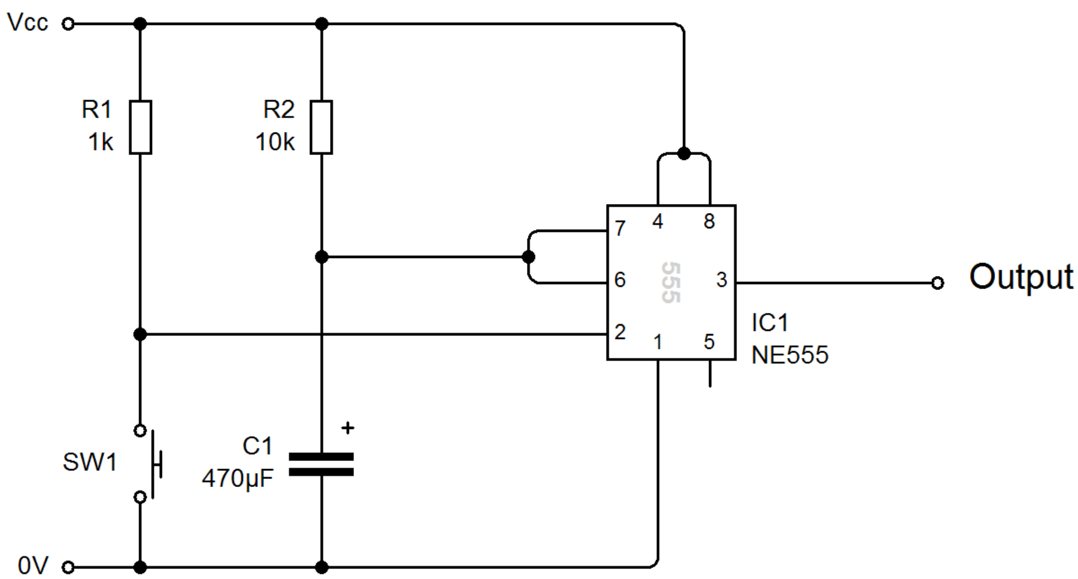
....

....

....

The answer is set ....

2. The following circuit diagram shows a 555 timer connected as a monostable.



a) Calculate the theoretical time duration of the output pulse for the circuit. (T=1.1RC)

....

....

....

b) The circuit needs to be modified to provide a delay of approximately 2 minutes. The capacitor is replaced with a 2200 μF one. Calculate the value of resistance required to provide a 2-minute delay and suggest a suitable preferred value from the E24 series.

....

....

....

....

....

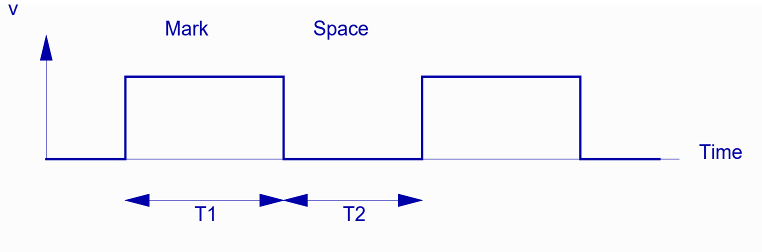
....

....

....

Astable Circuits

An astable has no stable output state.
The output will continually switch between 0 V ('low') and the supply voltage, ('high') producing a 'square' wave output. The diagram on the right shows a typical output waveform. The astable is sometimes called a **pulse generator** as we did in Component 1.

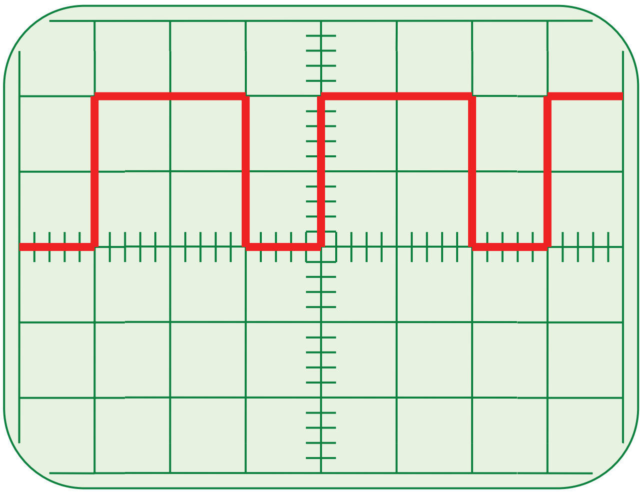


The time when the output **on** is referred to as the '**Mark**' and the **off** time is usually referred to as the '**Space**'. The frequency of the output pulse can be calculated using the formula:

$$f = \frac{1}{(T1 + T2)}$$

Interpreting an oscilloscope trace

You will need to be able to calculate the period and amplitude of the output of an astable (or pulse generator) from an oscilloscope trace. Here are a couple of examples to show you how this can be carried out.



Oscilloscope Settings

Time Base = 2 ms / cm

Voltage Gain = 5 V / cm

The squares on an oscilloscope screen are 1cm x 1cm.

The amplitude is the vertical distance from the lowest to highest point, which in this case is 2 cm. The voltage gain is set to 5 V / cm, making the amplitude of this astable output 2 × 5 =10 V.

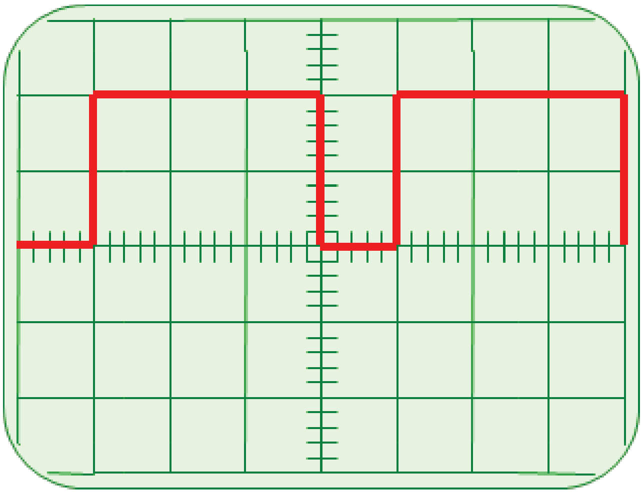
The frequency is calculated from finding the sum of mark and space, i.e. the time for one complete cycle.

In this example the mark is 2 cm which is 2 × 2 ms = 4 ms, and the space is 1 cm which is 1 × 2 ms = 2 ms, giving the complete cycle time to be 6 ms.

The frequency can then be calculated from $f = \frac{1}{T} = \frac{1}{6\text{ ms}} = 166.6\text{ Hz}$

Exercise 1.4

1.



Oscilloscope Settings

Time Base = 5 ms / cm

Voltage Gain = 2 V / cm

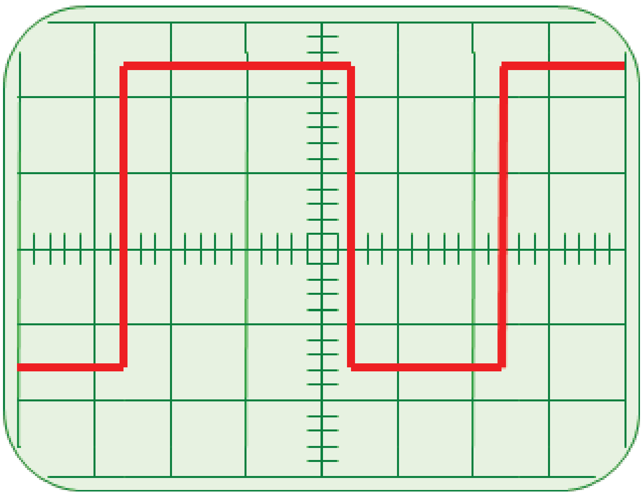
a) Amplitude = ...

b) Mark = ...

c) Space = ...

d) Frequency = ...

2.



Oscilloscope Settings

Time Base = 10 ms / cm

Voltage Gain = 1 V / cm

a) Amplitude = ...

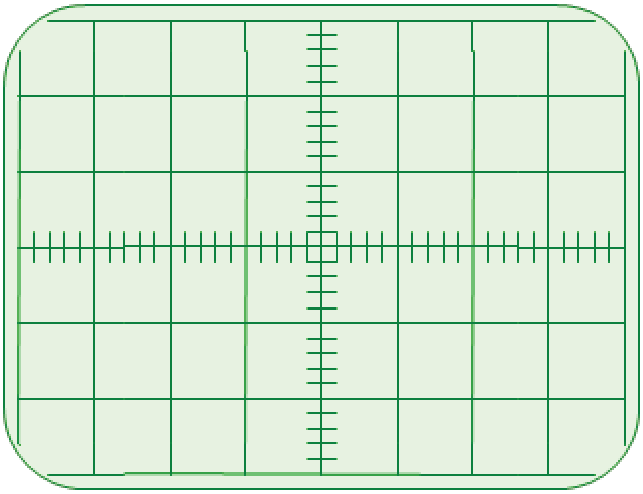
b) Mark = ...

c) Space = ...

d) Frequency = ...

3. On the oscilloscope screen below, draw the waveform that you would expect to see if an astable was operating with the following specification.

Amplitude = 6 V Mark = 10 ms Space = 5 ms



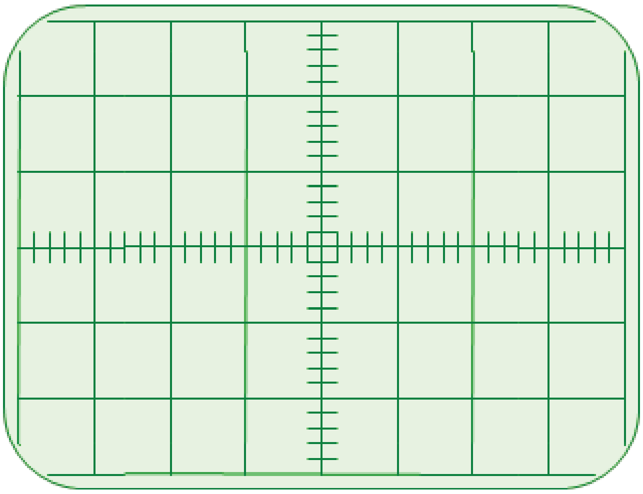
Oscilloscope Settings

Time Base = 5 ms / cm

Voltage Gain = 2 V / cm

4. On the oscilloscope screen below, draw the waveform that you would expect to see if a pulse generator was working with the following specification.

Amplitude = 9 V Mark = 4 ms Space = 8 ms



Oscilloscope Settings

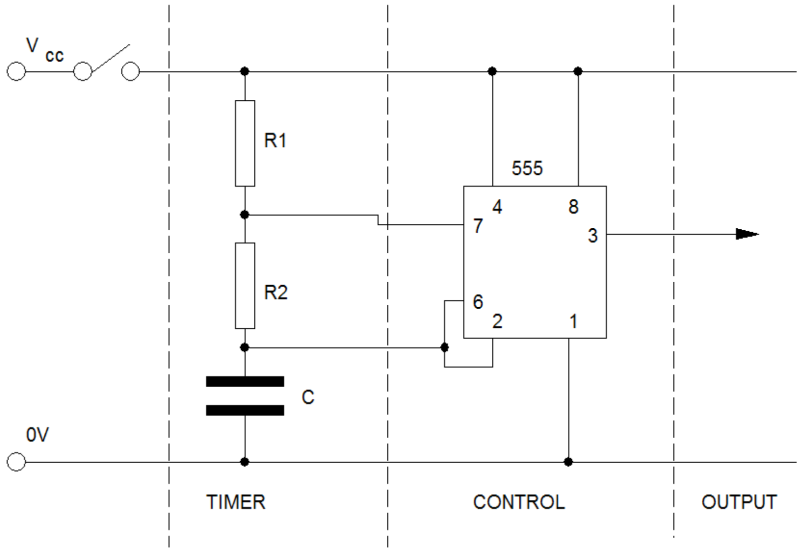
Time Base = 2 ms / cm

Voltage Gain = 5 V / cm

Astable circuit based on a 555 timer

The circuit diagram for a 555 astable is shown opposite.

The mark and space timings, and therefore the frequency of the output are determined by three external components – a capacitor and two resistors.



The theoretical values for the Mark, Space, Period and Frequency are given by the following equations:

$$\text{Mark } T1 = 0.7 \times (R_1 + R_2) \times C$$
$$\text{Space } T2 = 0.7 \times R_2 \times C$$
$$\text{Period} = T1 + T2$$

$$\text{Frequency } f = \frac{1}{\text{Period}} = \frac{1}{T1 + T2}$$

We can use similar rules as for the monostable:

- If $\mathbf{R_1}$ & $\mathbf{R_2}$ are in kΩ, and **C** is in μF then **T**1 and **T**2 will be in ms (milliseconds)
- If $\mathbf{R_1}$ & $\mathbf{R_2}$ are in MΩ, and **C** is in μF then **T**1 and **T**2 will be in seconds
- If the Period is in seconds, the frequency will be in Hertz (Hz)
- If the Period is in ms (milliseconds), the frequency will be in kilohertz (kHz)

OR we can use indices

Note: The mark and space timings of the output waveform can be altered by varying $\mathbf{R_1}$ or $\mathbf{R_2}$. As the timing equation shows, the mark will always be greater than the space. An approximately square waveform may be obtained (i.e. mark = space) if $\mathbf{R_2}$ is much larger than $\mathbf{R_1}$.

The frequency equation $f = \dfrac{1.44}{(R_1 + 2R_2)C}$ is derived from the mark and space equations.

Example:

An astable using a 555 timer has: $\mathbf{R}_1$ = 22 kΩ, $\mathbf{R}_2$ = 82 kΩ, **C** = 470 μF

Calculate:
- i) the mark,
- ii) the space,
- iii) the period,
- iv) the frequency of the astable.

Solution: Either

(i) Mark T1 $= 0.7 \times (R_1 + R_2) \times C$
$= 0.7 \times (22 + 82) \times 470$ ms
$= 34216$ ms
$= 34.216$ s ≈ 34 s

(ii) Space T2 $= 0.7 \times R_2 \times C$
$= 0.7 \times 82 \times 470$ ms
$= 26978$ ms
$= 26.978$ s ≈ 27 s

(iii) Period $=$ T1 + T2
$= 34 + 27$
$= 61$s

(iv) Frequency $f = \dfrac{1}{T1 + T2}$
$= \dfrac{1}{34 + 27}$
$= \dfrac{1}{61}$
$= 0.016$ Hz

or

Mark T1 $= 0.7 \times (R_1 + R_2) \times C$
$= 0.7 \times (22 + 10^3 + 82 \times 10^3) \times 470 \times 10^{-6}$ s
$= 34.216$ s ≈ 34 s

Space T2 $= 0.7 \times R_2 \times C$
$= 0.7 \times 82 \times 10^3 \times 470 \times 10^{-6}$ s
$= 26.978$ s ≈ 27 s

Period $=$ T1 + T2
$= 34 + 27$
$= 61$s

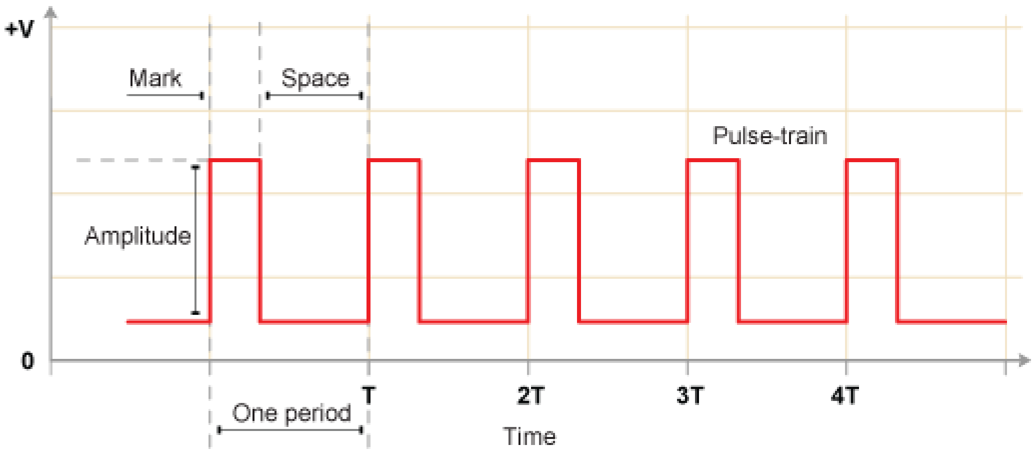
Frequency $f = \dfrac{1}{T1 + T2}$
$= \dfrac{1}{34 + 27}$
$= \dfrac{1}{61}$
$= 0.016$ Hz

or directly from the formula

$$\text{Frequency} = \frac{1.44}{(R_1 + 2R_2)c}$$
$$= \frac{1.44}{(22 \times 10^3 + 82 \times 10^3)\, 470 \times 10^{-6}}$$
$$= 0.0165 \text{ Hz}$$

Mark–space ratio

In the circuit, timing resistors and capacitors control when the time output is high (the mark time) and when the time output is low (the space time).



We can also define a Mark–space ratio of an astable as being the On time (mark) – Off time (space):

$$\frac{T_{ON}}{T_{OFF}} = \frac{0.7 \times (R_1 + R_2) \times C}{0.7 \times R_2 \times C} \text{ simplifies to } \frac{R_1 + R_2}{R_2} = \text{ mark – space ratio of an astable}$$

For the previous example: **R**$_1$ = 22 kΩ, **R**$_2$ = 82 kΩ, T_{ON} = 34.216 s, T_{OFF} = 26.978 s

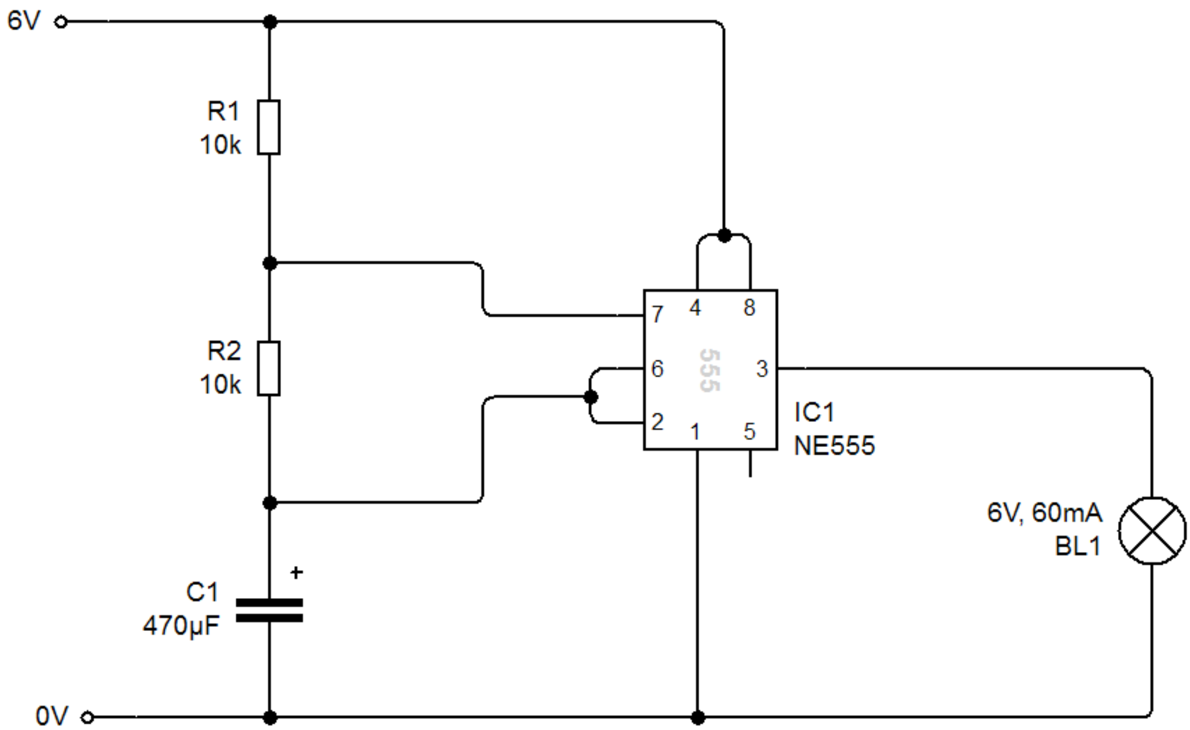
$$\frac{\text{mark}}{\text{space}} = \frac{T_{ON}}{T_{OFF}} = \frac{34.216}{26.978} = 1.268$$

$$\frac{\text{mark}}{\text{space}} = \frac{R_1 + R_2}{R_2} = \frac{22000 + 82000}{82000} = 1.268$$

Either method gives the same answer.

Investigation 1.5

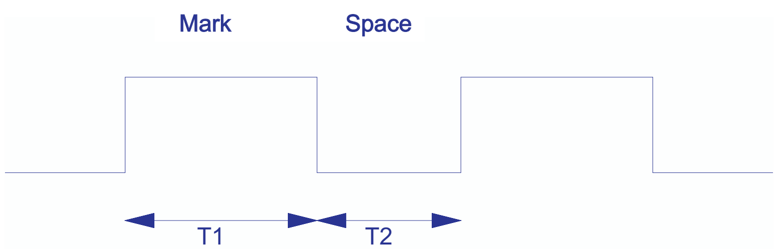
a) Set up the following circuit on either a simulator or breadboard, with the resistors **R**$_1$ and **R**$_2$ both equal to 10 kΩ and **C** = 470 μF.



b) Describe what you observe.

....

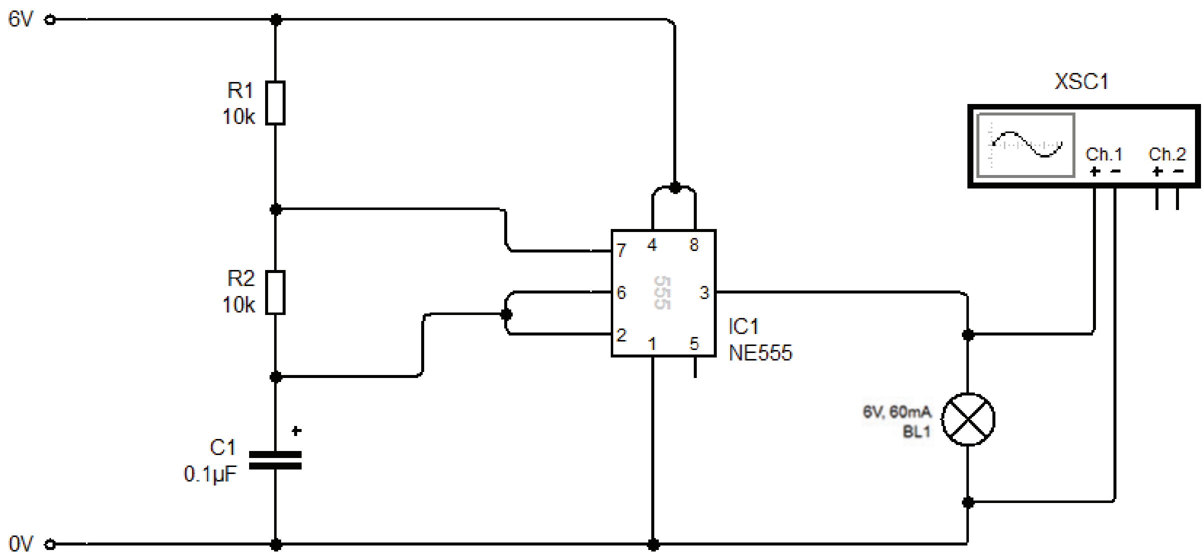
c) Estimate the values of the MARK (T1) and SPACE (T2) and record them on the diagram below.



d) Replace R2 with a 20 kΩ resistor and estimate the new values of the mark and space.

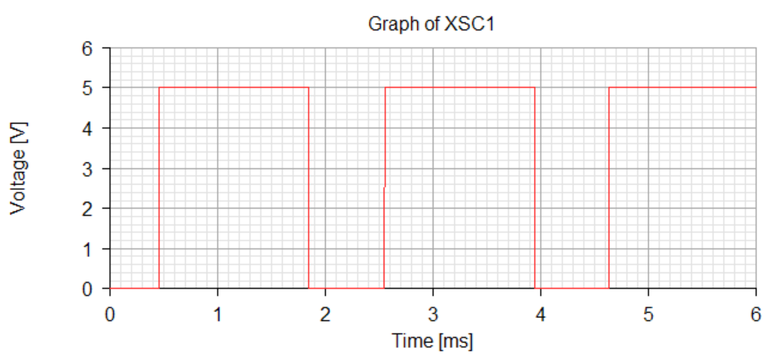
....

e) Replace R2 and C with the values shown in the circuit diagram below.

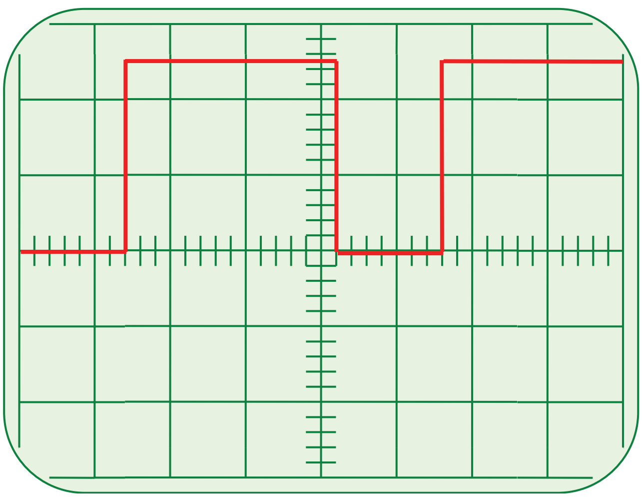


You should observe that the lamp seems to be on all the time.
(In fact it is switching on and off very fast and an oscilloscope is needed to observe the waveform produced.)

Adjust the oscilloscope to obtain a display similar to the following:



This is the waveform displayed on the simulator oscilloscope.



This is the waveform displayed on the oscilloscope connected to the breadboard.

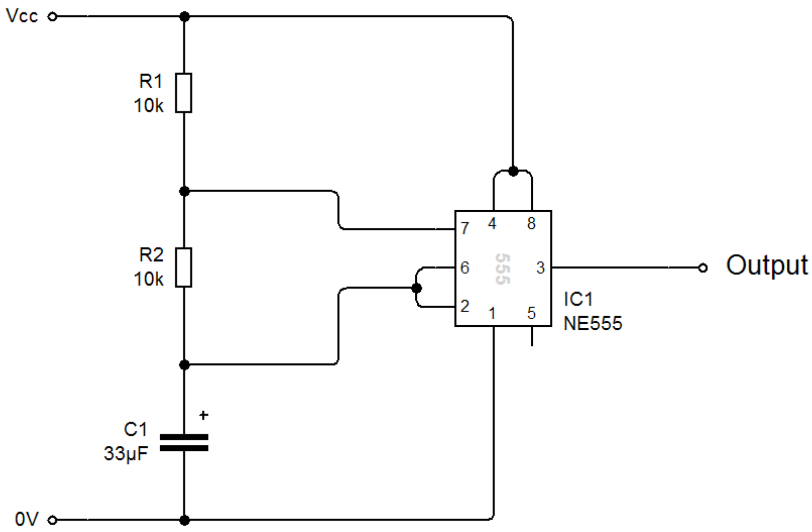
Oscilloscope Settings

Time Base = 0.5 ms / cm

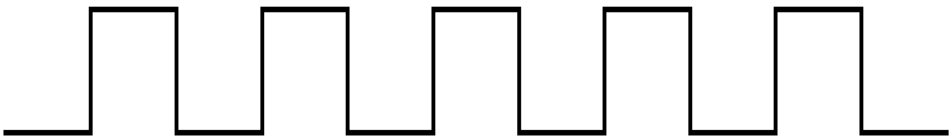
Voltage Gain = 2 V / cm

Exercise 1.5

1. The following circuit shows a 555 timer connected as an *Astable circuit*.



The following graph shows the output observed at pin 3, when viewed on an oscilloscope.



a) What type of wave is this? ....

b) i) On the trace above, label the 'Mark' part of the wave.
ii) On the trace above, label the 'Space' part of the wave

c) The theoretical value of the 'Mark' time is given by: Mark Time = $0.7 \times (R_1 + R_2) \times C$

Calculate the 'Mark' Time for the above circuit.

....

....

d) The theoretical value of the 'Space' time is given by: Space Time = $0.7 \times (R_2) \times C$

Calculate the 'Space' Time for the above circuit.

....

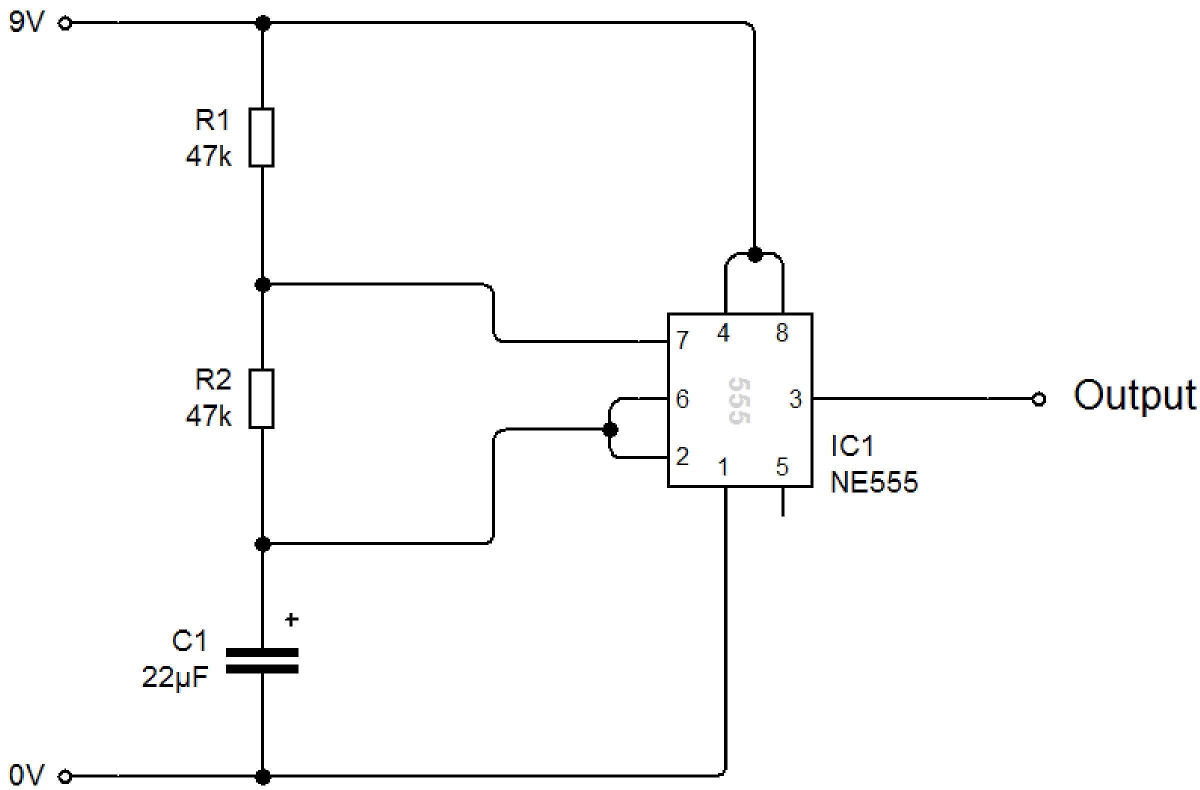
....

e) Finally calculate the frequency of the output wave.

....

....

2. A pulse generator is made from a 555 timer circuit, shown below.



a) Determine the mark–space ratio of the output waveform.

....

....

....

b) Calculate the frequency of the output waveform.

....

....

....