Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 22: Electronic Circuits and Devices

Unit Workbook 3

in a series of 4 for this unit

Learning Outcome 3

Oscillators

3.1 Oscillators

Oscillators systems that will output a repeating A.C signal with only a D.C supply. The output of the oscillator (shape and amplitude) are determined by the design and component choices. The amplitude is typically constant, but frequency can be altered through the use of variable resistors.

Oscillators are classed into three different types, dependent on their wave output:

- Sine wave oscillators produce sine waves
- Relaxation oscillators produces rectangular waves.
- Sweep Oscillators produce "sawtooth" waves.

Fig.3.1 shows a graphic output of each oscillator type.

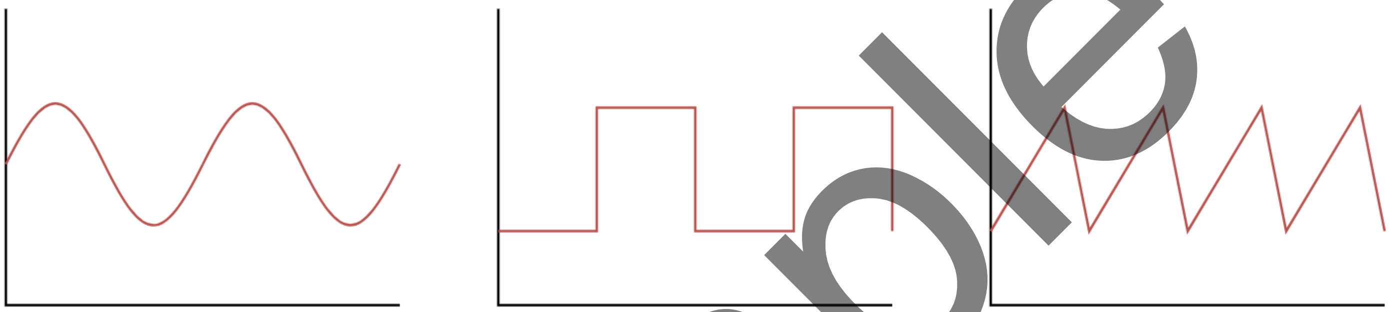

Fig.3.1: Different oscillation outputs: sine wave (left), rectangular wave (centre), sawtooth wave (right)

3.2 Sine Wave Oscillators

Sine wave oscillators are used to generate radio or audio frequencies from a DC supply. These can be classified further:

- Hartley oscillator,
- Colpitts oscillator,
- RC ladder oscillator,
- Crystal sine wave oscillator.

3.2.1 LC Coupling Oscillator

The design can either incorporate two inductors and one capacitor (Hartley), or two capacitors and one inductor (Colpitts). The defining feature of LC coupling oscillators are the "tank" circuits. The two oscillators have different resonant frequencies, which are discussed later. These types of oscillators are however, prone to drifting when there are small changes in the supply voltage.

Hartley Oscillators incorporate a tank circuit that consists of two coils and a capacitor, shown in more detail in Fig.3.2. It is difficult to tune the oscillator to the required frequency, as if the coupling between $\mathrm{L_1}$ and $\mathrm{L_2}$ is too small, the feedback will drop to zero, if the coupling is too great the oscillations will continue to grow and distort. Tuning the feedback loop accurately, however, produces constant amplitude oscillations.

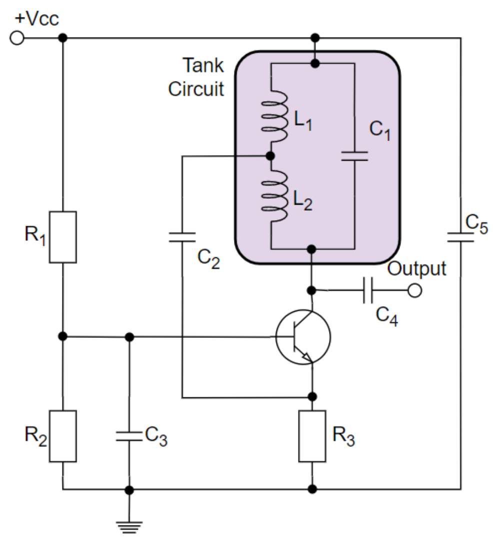

Fig.3.2: Hartley oscillator

Hartley oscillators resonant frequency is calculated using Eq.3.1, where L and C are the inductance and capacitance of the tank circuit, respectively.

$$f_r = \frac{1}{2\pi\sqrt{LC}}, \text{ where } L = L_1 + L_2 \qquad \text{(Eq.3.1)}$$

Colpitts Oscillators are a very similar design to the Hartley oscillator design but could be considered to be its exact opposite. In this case, the tank circuit uses two capacitors and one inductor, by eliminating some of the self-inductance within the tank circuit, the Colpitts has an improved stability, as well as a simpler design. At higher frequencies, the lower impedance path of the capacitors will produce a more accurate sine wave. A schematic of the Colpitts oscillator is shown in Fig.3.3 below.

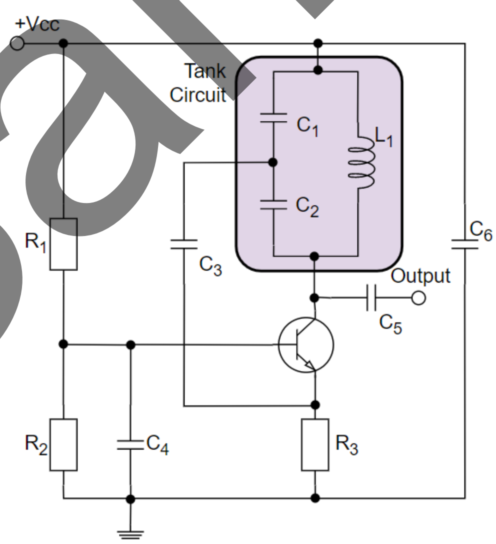

Fig.3.3: Colpitts oscillator

Colpitts oscillators resonant frequency is calculated using Eq.3.2, Colpitts oscillators are much better at maintaining high frequency stability.

$$f_r = \frac{1}{2\pi\sqrt{LC}}, \text{ where } C = \frac{C_1 \times C_2}{C_1 + C_2} \qquad \text{(Eq.3.2)}$$

3.2.3 Crystal Oscillator

Crystal oscillators are also LC oscillators but use a crystal in the system to promote frequency stability. The crystal is normally quartz, which is a piezo-electric device. A piezo-electric device will bend and produce a mechanical stress when it is subjected to a voltage, and so when the quartz is stressed, it will produce a voltage. Therefore, by inducing a voltage in pulses, the piezo-electric device will reinforce the pulses and oscillate in phase with the pulses. The equivalent circuit of a quartz crystal can be shown in Fig.3.4.

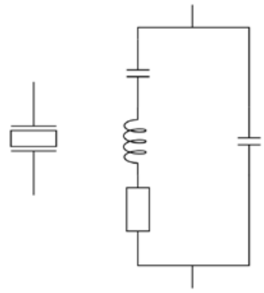

Fig.3.4: The symbol for a piezo-crystal (left) and it's equivalent circuit (right)

The frequency at which the reinforcing effect occurs is also the resonant frequency of the crystal, which is dependent on the size of the crystal and the atomic structure. A well-prepared crystal will act oscillate in an underdamped fashion (the oscillations will take a long time to die out). Fig.3.5 shows both a Hartley and Colpitts oscillator with a crystal configuration incorporated.

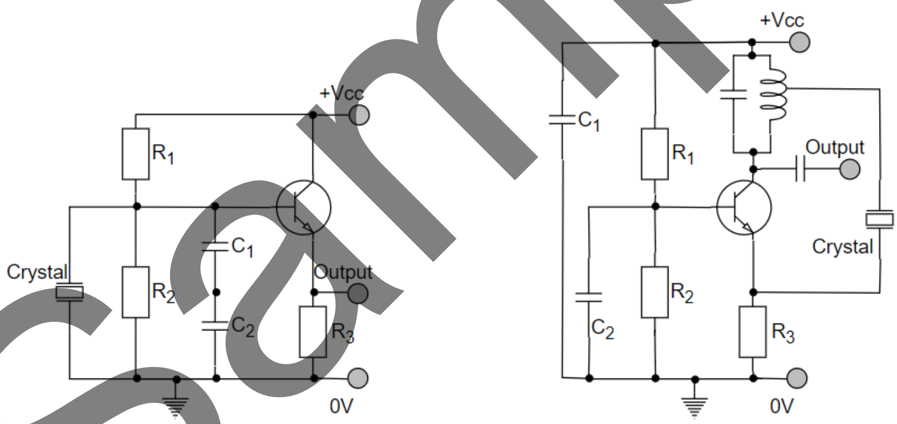

Fig.3.5: A crystal incorporated Colpitts (left) and Hartley (right) oscillator

3.2.4 RC Ladder

RC ladders are a method used to develop a sine wave, with each RC point developing $60°$ phase the sine wave, so the initial amplified stage ($180°$) is generated, and the inverted signal is also developed (giving the whole $360°$ of the sine wave). Fig.3.3 shows an RC ladder circuit, it is important that the capacitors and resistors in the ladder are equal, otherwise the amplification will not be even across the wave, which will cause a signal distortion.

systems will use RC systems. The advantage being that both variable capacitors and resistors are available, but realistically varying the capacitors is undesirable because of the size of the capacitor that would be required.

The Wien bridge is the typical oscillator system used in audio testing and fault analysis. By using multiple RC configurations in the system, it is possible to produce a given phase shift to the input, as well as controlling the frequency and gain with the use of variable components. A basic Wien bridge oscillator can be seen in Fig.3.5. You will also notice that there is no input signal in the system, just a potential across the Op-Amp, this is another advantage of the Wien bridge, the system will continue to oscillate even without an input signal.

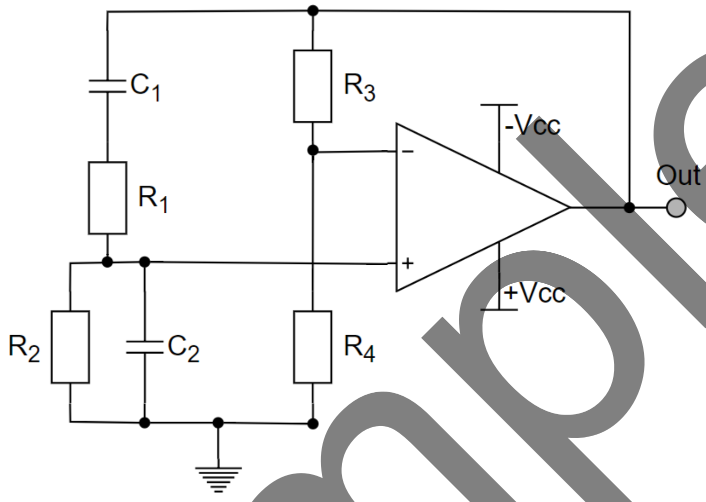

Fig.3.5: A basic Wien bridge amplifier

By altering R_1 and R_2, the frequency of the system will change, and the gain is controlled with R_4. For the system to produce self-sustaining oscillations, the voltage gain of the amplifier must be greater than 3.

3.3 Rectangular Wave Oscillators

Rectangular wave oscillators are used to produce oscillators with less variation in the signal. They can typically be used in clock signals and to generate a tone. Binary signals, the form of communication in electronics are dependent on rectangular waves. An example of a rectangular wave generator is flashing lights on emergency service vehicles. Rectangular wave oscillators can be categorised as:

- Astable (no stable states)
- Monostable (one stable state)

Rectangular waves are generated using either Op-Amps or 555 timer circuits.

3.3.1 Op-Amp Astable

Op-Amps are systems that are better suited to low frequency applications, as the slew rate of the Op-Amp (the maximum rate of voltage change) will become a considerable limiting factor at higher frequencies. A schematic of an Op-Amp Astable circuit can be seen in Fig.3.6.

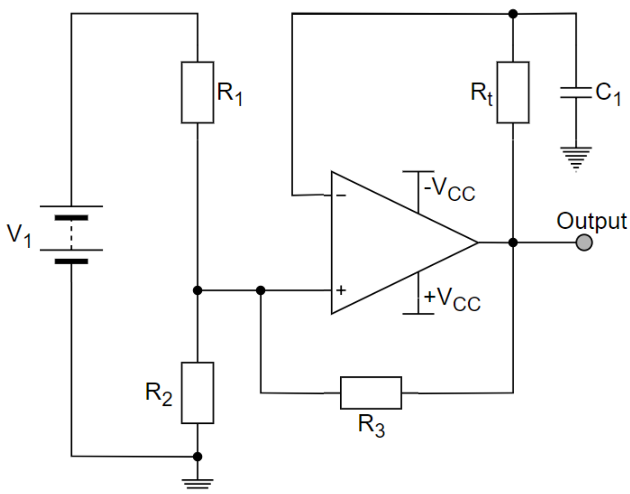

Fig.3.6: Op-Amp Astable

The frequency of the oscillation is determined by the capacitor C_1 and the resistor R_3, and the output of the system is shown in Fig.3.7. The frequency of the system is calculated using Eq.3.3.

$$f = \frac{1}{2ln(2) \cdot R_t C} \qquad \text{(Eq.3.3)}$$

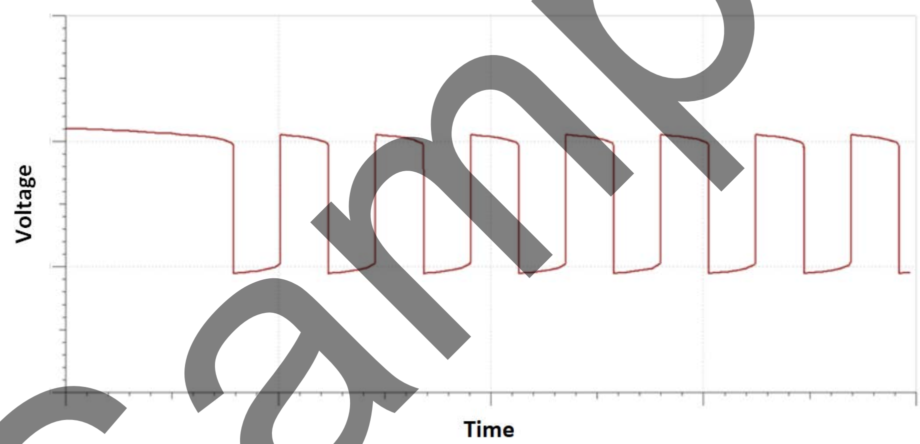

Fig.3.7: Op-Amp Astable output

3.3.2 555 Astable

555 ICs are timing chips and one of the most commonly used Astable systems in electronics, due to their simplistic design. The 555 timer is an eight-pinned IC that is used as a simple and cheap timing mechanism. The pin layout is shown below in Fig.3.8, because of the small size of the chips it would be impossible to display the numbers for someone to see (a typical 555 timer is roughly $10\text{mm} \times 10\text{mm}$ – smaller than a 5p coin). So small notches are cut into the casing, the semicircle indicates where pins 1 and 8 are, and the small circle indicates pin 1.

The change of state is determined by the capacitor, whether it is charging or discharging. The voltage of the output V_{out} and the voltage of the capacitor V_{cap} of the circuit is shown in Fig.3.10.

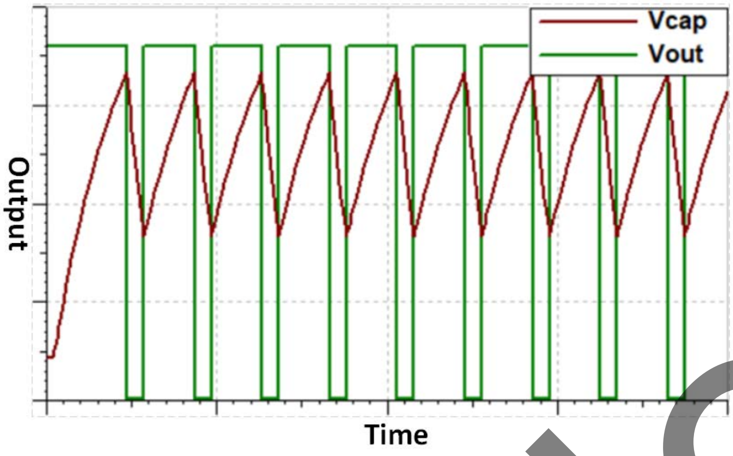

Fig.3.10: 555 Astable output

Example 1

Fig.3.11 is a useful tool when calculating the resistance and capacitance to achieve the desired frequency. Let's say an Astable circuit is to be designed with a frequency of $1kHz$, by consulting Fig.3.11 it is possible to select an appropriate capacitance, by also selecting an appropriate resistance for the circuit.

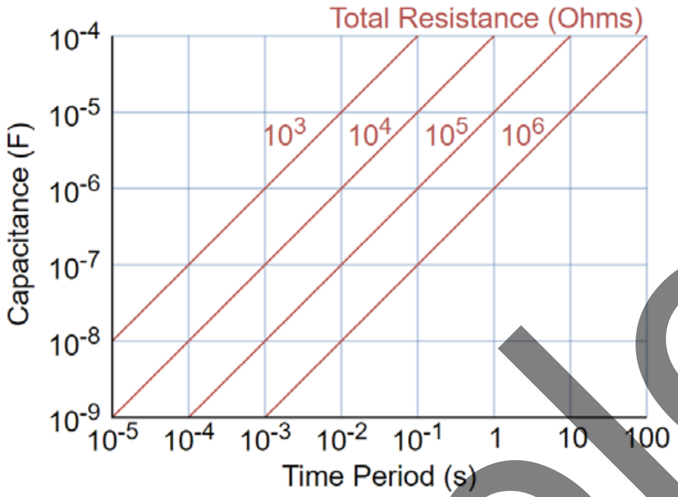

Fig.3.11: Time period vs Capacitance for an Astable Circuit.

The time period is calculated using:

$$t = \frac{1}{f} = \frac{1}{1000} = 10^{-3}s$$

There is now an option of selecting the resistance and capacitance (the total resistance is given by $R_1 + R_2$):

1. $1\mathrm{nF}$ Capacitor and $1M\Omega$ resistance
2. $10\mathrm{nF}$ Capacitor and $100\mathrm{k}\Omega$ resistance
3. $100\mathrm{nF}$ Capacitor and $10\mathrm{k}\Omega$ resistance

For this example, the selected capacitor will be $100\mathrm{nF}$, so the resistance should equal $10\mathrm{k}\Omega$.

The mark: space ratio will also need to be defined, this ratio is the time that the system will be in the two different states, either in the "high" state (mark) or the "low" state (space), this ratio is defined in more detail in Fig.3.12 below.

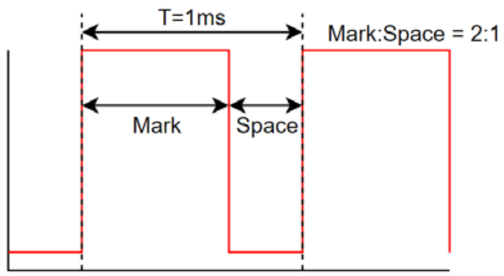

Fig.3.12: Mark: space ratio

In this example, the desired mark: space ratio will be set as 3:1. For a 555 Astable circuit, the capacitor will be either charging or discharging. The charging period is the mark, and discharge is the space, or:

$$t_c = \frac{3t}{4} = 750\mu s$$

$$t_d = \frac{t}{4} = 250\mu s$$

The following relationships in Eq.3.4 and Eq.3.5 are used to find the discharge and charge time, respectively.

$$t_d = 0.7C_1(R_2) \qquad \text{(Eq.3.4)}$$

$$t_c = 0.7C_1(R_1 + R_2) \qquad \text{(Eq.3.5)}$$

Rearranging Eq.3.4 gives:

$$R_2 = \frac{t_d}{0.7C_1} = \frac{0.25 \cdot 10^{-3}}{0.7(100 \cdot 10^{-9})} = 3571\Omega$$

With $\mathrm{R_2}$ calculated, $\mathrm{R_1}$ can be calculated by rearranging Eq.3.5:

$$R_1 = \frac{t_c}{0.7C_1} - R_2 = \frac{0.75 \cdot 10^{-3}}{0.7(100 \cdot 10^{-9})} - 3571 = 7143\Omega$$

So, the values obtained are:

$R_1 = 7143\Omega \; and \; R_2 = 3571\Omega$

Using more realistic values gives,

$R_1 = 7.15k\Omega \; and \; R_2 = 3.57k\Omega$

If we put the realistic values back into the equations, the charge and discharge times are:

$$t_d = 0.7(100 \cdot 10^{-9})(3570) = 249\mu s$$

$$t_c = 0.7(100 \cdot 10^{-9})(7150 + 3570) = 750\mu s$$

Which means the total time period for the oscillation is:

$$249 \times 10^{-6} + 750 \times 10^{-6} = 0.999ms$$

And so, the frequency is:

$$\frac{1}{0.999 \times 10^{-3}} = 1001Hz$$

The output of this system is shown as Fig.3.13.

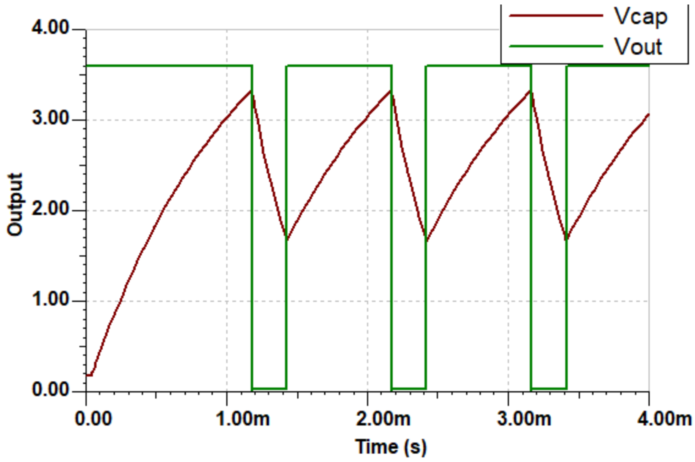

Fig.3.13: Example 1 voltage output

It is also worth noting that the first state will not match the calculated time, this is simply because the capacitor has not reached the necessary charge.

3.4.1 BJT Astable Multivibrators

BJT Astable multivibrators have two outputs in the system, produced by two timing circuits with two BJTs. The system will bounce back and forth between two states "T_1 on and T_2 off" or "T_2 on and T_1 off", hence the "multivibrator" term. The circuit diagram for a BJT Astable mutlivibrator is shown in Fig.3.14.

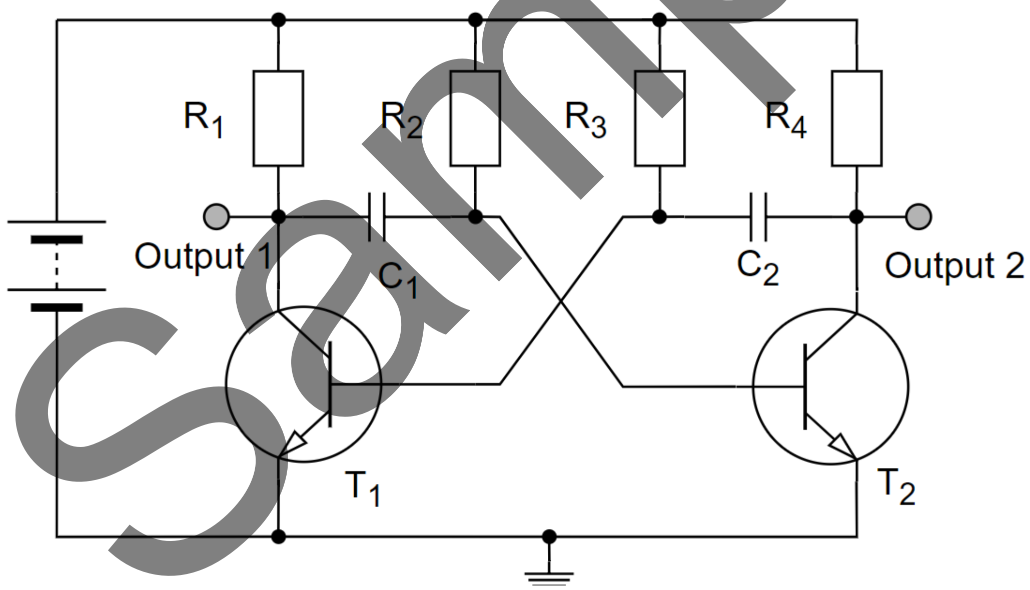

Fig.3.14 BJT Astable multivibrator

The frequency of the system is calculated using Eq.3.6.

$$T = 1.4(C_1R_2 + C_2R_3) \qquad \text{(Eq.3.6)}$$

If $C_1 = C_2$ and $R_2 = R_3$, then the mark: space ratio is 1:1 then the frequency is given as Eq.3.7.

$$f = \frac{1}{1.4CR} \qquad \text{(Eq.3.6)}$$

3.4 Sawtooth Oscillators

Sawtooth oscillators are used in Pulse Width Modulation (PWM) which is used in motor control, the change in voltage is linear, allowing a more controllable system.

3.4.2 Op-Amp Astable

Recalling from Section 3.3.1, an Op-Amp Astable produces a rectangular wave when the output is connected from the Op-Amp output. However, a sawtooth oscillator can be produced by putting the output between C_1 and R_3, shown in Fig.3.14.

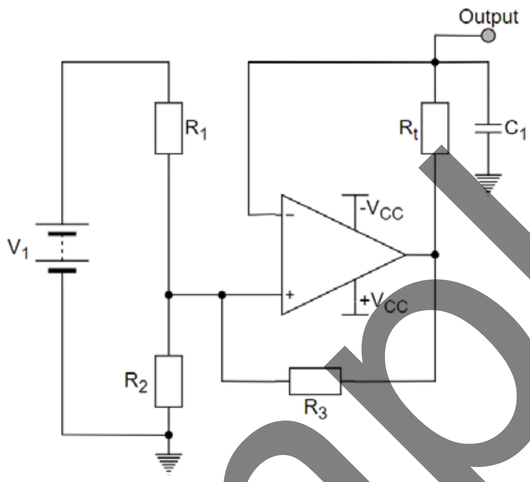

Fig.3.14: Op-Amp Astable sawtooth

By placing the output here, the output will look as Fig.3.15.

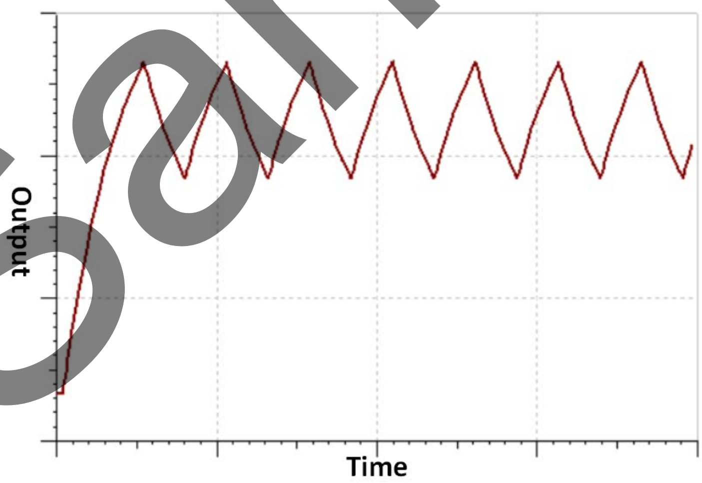

Fig.3.15: Op-Amp sawtooth output

3.4.3 555 Astable

The 555 Astable sawtooth oscillator is the same idea as the Op-Amp sawtooth, simply move the output to somewhere else in the circuit, in this case, the output is connected to the trigger and threshold of the 555 IC, demonstrated by Fig.3.16. The output pin on the 555 timer is then grounded. The result of moving the output is a readout vary similar to that in Fig.3.15.