OSCILLATORS AND MULTIVIBRATORS

INTRODUCTION

In the discussion about op-amp, negative feedback concept was introduced. The disadvantage of negative feedback is a reduction in gain. In this chapter, a positive feedback is introduced to such extent that the gain increases and the amplifier will produce an output without having an input signal. With different conditions, the output can be made to oscillate at certain frequencies producing a sinusoidal waveform or becomes saturated and producing rectangular waveform.

2.1 Oscillator Principles and Operation

An oscillator is a circuit which produces a sinusoidal waveform without having an input signal. Figure 2.1 is a block diagram of a positive feedback system where A_V is the gain without feedback, V_O/V_i and β is the feedback factor, V_f/V_O. The feedback voltage V_f is in phase with V_S.

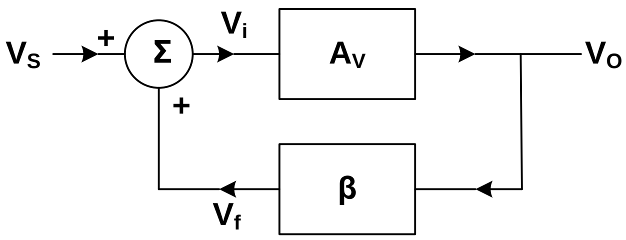


Figure 2.1: Positive feedback system

$$V_i = V_S + V_f$$

$$V_S = V_i - V_f = \frac{V_O}{A_V} - \beta V_O = V_O\left(\frac{1}{A_V} - \beta\right) = V_O\left(\frac{1-\beta A_V}{A_V}\right)$$

$$\text{Hence, } \frac{V_O}{V_S} = \frac{A_V}{(1-\beta A_V)}$$

If $\beta A_V = 1$, then $A_{Vf} = V_O/V_S = \infty$ which means V_S is 0 and that the amplifier produces an output with no input. Figure 2.2 shows that there is no external input signal applied to the amplifier. How does the circuit works? There is always a very small electrical noise in the circuit at V_i. This noise will be amplified and the feedback signal will appear at V_i with much larger amplitude. The signals builds up and the circuit will burst into oscillation when the condition $\beta A_V = 1$ occurs. This condition is known as Barkhausen criterion. As the oscillator circuits involve capacitors and inductors, βA_V is in complex form and can be written in polar coordinates as $\beta A_V = 1\angle 0°$.

$|\beta A_V| = 1$ (the magnitude) and Arg $\beta A_V = 0$ or 2π (the phase)

There will be a frequency at which $\beta A_V = 1$ and this frequency is called the frequency of oscillation.

Analysis of an oscillator circuit involves determining of frequency of oscillation f_O and the component values of the feedback network and the amplifier circuit which will result in the oscillation to take place.

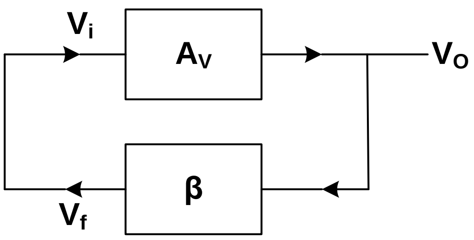


Figure 2.2 : The equivalent circuit when $\beta A_V = 1$

2.2 Wien-Bridge Oscillator

Low frequency oscillators generally consist of RC networks with op-amp as the active device. The two most common RC oscillators are the Wien-bridge oscillator and the ladder network RC oscillator. Figure 2.3 is the Wien-bridge oscillator. The resistors R_1 and R_2 with feedback voltage V_f forms a non-inverting amplifier discussed previously. The RC network forms the feedback network. Take note that the op-amp has both negative and positive feedback. Since the output is a sinusoid, the op-amp works in the linear region.

For the amplifier, $A_V = \frac{V_O}{V_f} = 1 + \frac{R_B}{R_A}$.

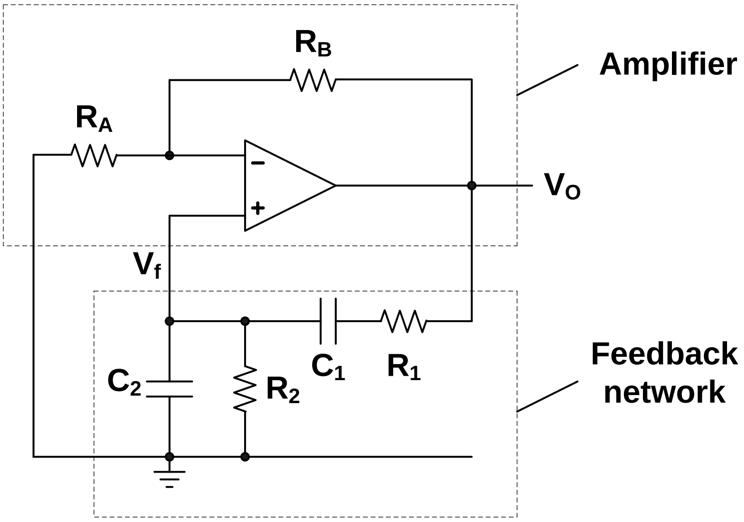


Figure 2.3 : Wien-bridge oscillator

For the feedback network, β can be expressed as

$$\beta = \frac{V_f}{V_O} = \frac{1}{1 + \frac{R_1}{R_2} + \frac{C_2}{C_1} + j(\omega C_2 R_1 - \frac{1}{\omega C_1 R_2})}$$

For β to have a phase shift of 0°, the imaginary part must be equal to 0.

$$\omega C_2 R_1 - \frac{1}{\omega C_1 R_2} = 0 \Rightarrow \omega^2 = \frac{1}{C_1 C_2 R_1 R_2}$$

$\omega = 2\pi f$, hence the frequency of oscillation, $f_O = \frac{1}{2\pi\sqrt{C_1 C_2 R_1 R_2}}$.

At this frequency, the imaginary part is 0.

$$|\beta| = \frac{1}{1 + \frac{R_1}{R_2} + \frac{C_2}{C_1}}$$

For the circuit to oscillate, $|\beta A_V| = 1$. Therefore the gain of the amplifier

$|A_V| = 1 + \frac{R_1}{R_2} + \frac{C_2}{C_1}$.

Hence, $1 + \frac{R_1}{R_2} + \frac{C_2}{C_1} = 1 + \frac{R_B}{R_A} \Rightarrow \frac{R_B}{R_A} = \frac{R_1}{R_2} + \frac{C_2}{C_1}$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$, then $f_O = \frac{1}{2\pi RC}$, $|\beta| = 1/3$ and the gain of the amplifier $|A_V|$ must be 3.

$$A_V = 3 = 1 + \frac{R_B}{R_A}, \quad \frac{R_B}{R_A} = 2.$$

Exercise

2.1 If $R_1 = 2\ k\Omega$, $R_2 = 1\ k\Omega$, $C_1 = 1\ \mu F$, $C_2 = 2\ \mu F$, $R_B = 5\ k\Omega$ and $R_A = 1\ k\Omega$, determine the frequency of oscillation f_O.

2.2 A 10 kΩ variable resistor (R_P) is connected in series with R_1 in Figure 2.3. What is the range of frequency of oscillation the circuit can produce and the corresponding value of R_B. $R_1 = 2\ k\Omega$, $R_2 = 1\ k\Omega$, $C_1 = 1\ \mu F$, $C_2 = 2\ \mu F$ and $R_A = 1\ k\Omega$.

2.3 Multivibrators

A multivibrator circuit has a significant input voltage as compared to oscillator circuit. The amplification will result in the output becomes saturated at both ends (negative and positive) which results in a rectangular waveforms. The two saturated output levels are called the states which can be classified as stable and unstable states. The output state is called stable state if it does not switch to the other state unless triggered externally. It is called unstable state if it switches to the other state after a period of time determined by the circuit parameters. There are three types of multivibrators;

(i) Bistable multivibrators : Both states are stable. This is a flip-flop used in digital system. To change state, the circuit must be triggered externally.

(ii) Monostable multivibrators : One state is stable while the other is unstable. If the output is not stable initially, after a certain period of time the circuit will switch to the stable state and remains in that state.

(iii) Astable multivibrators : Both states are unstable. The output will switch between the two states after a certain period of time. It is also called a free-running multivibrator as it does not require external triggering signal.

Bistable and monostable multivibrators will not be discussed. Analysis of an astable multivibrator circuit deals with determining the times the circuit are in the high (t_1) and the low states (t_2). Once these are known, the frequency of the output and the duty cycle can be determined.

The output frequency, $f = \frac{1}{T} = \frac{1}{t_1 + t_2}$ while

the duty cycle $= \frac{t_1}{t_1 + t_2} \times 100\%$

Figure 2.4 is an astable multivibrator using op-amp as the active device. There are both negative and positive feedbacks at the inputs of the op-amp. As the outputs are rectangular, the op-amp works in the non-linear region. Hence the output state can be determined by comparing the voltages at inverting (V^-) and non-inverting (V^+) inputs.

$$V^+ = \frac{R_2}{R_2 + R_1} \times V_O = \lambda V_O$$

V^- is the voltage drop across the capacitor, V_C.

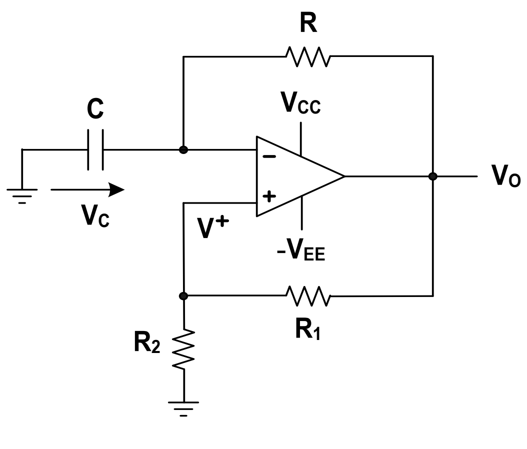


Figure 2.4 : Astable multivibrator

Assume that $V_{CC} = V_{EE} = 15$ V, $R_1 = R_2$ and initially $V_O = 15$ V ($\therefore V^+ = 7.5$ V) and $V_C = 0$ V, the V^+, V_C and V_O waveforms obtained are shown in Figure 2.5.

It can be shown that $t_1 = RC \ln 3$ and $t_2 = RC \ln 3$.

If $t_1 = t_2$, the output waveform is symmetrical with a duty cycle of 50% and it is called a square wave.

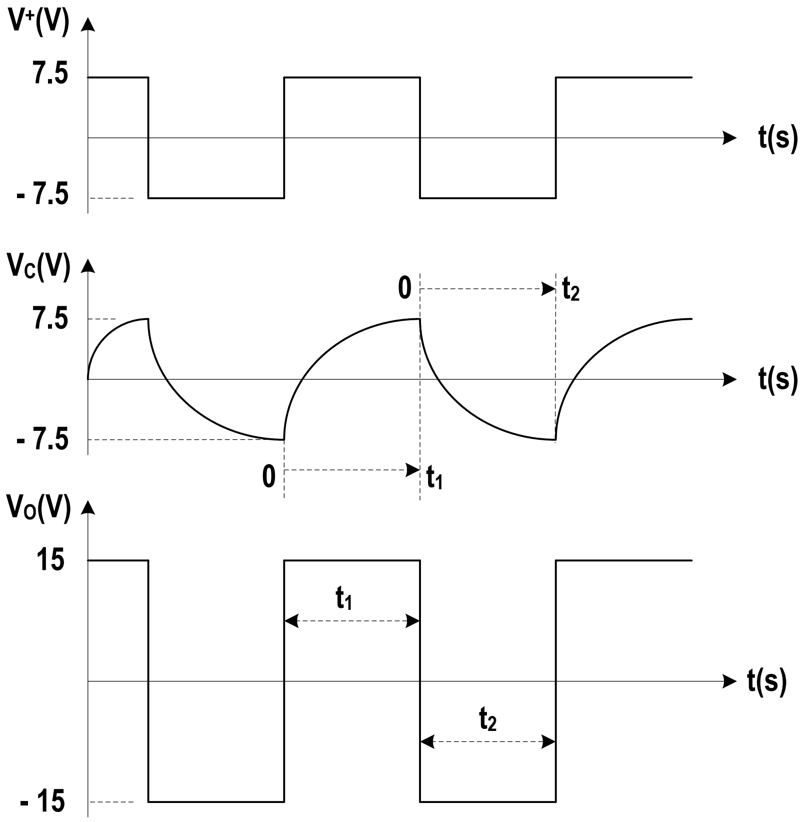
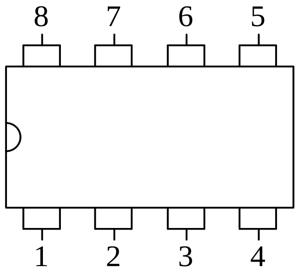


Figure 2.5 : V^+, V_C and V_O waveforms

2.4 555 Timer

555 timer is an integrated circuit chip that can function as an astable multivibrator. The pin diagram and its names are shown in Figure 2.6.



1 - Ground
2 - Trigger
3 - Output
4 - Reset
5 - Control
6 - Threshold
7 - Discahrge
8 - V_{CC}

Figure 2.6 : 555 Timer

To function as an astable multivibrator, the IC is connected as in Figure 2.7.

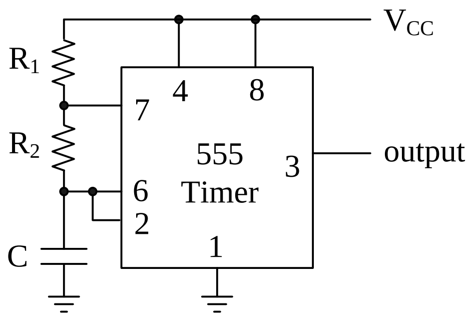


Figure 2.7 : The Astable Multivibrator

The output is a rectangular waveform as shown in Figure 2.8

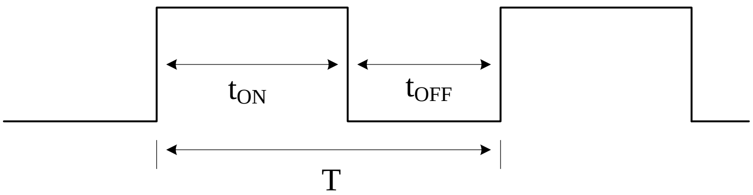


Figure 2.8 : Output Waveform

The period $T = t_{ON} + t_{OFF}$ and the frequency $f = 1/T$.

The time t_{ON} and t_{OFF} are calculated by the following equations ;

$t_{ON} = (R_1+R_2) \times C \times \ln 2$

$t_{OFF} = R_2 \times C \times \ln 2$

Substitute t_{ON} and t_{OFF} into the period equation T gives

$T = (R_1+2R_2) \times C \times \ln 2$

Exercise

2.3 If the output frequency f of the circuit in Figure 2.8 is 1 kHz with t_{OFF} = 0.4 ms, what is the suitable value for R_1 and R_2 if C = 0.1μF?