4.6 Oscillators – Barkhaunsen's criteria for oscillation

An oscillator is a circuit that produces a periodic waveform on its output with only the dc supply voltage as an input. A repetitive input signal is not required except to synchronize oscillations in some applications. The output voltage can be either sinusoidal or nonsinusoidal, depending on the type of oscillator. Two major classifications for oscillators **are feedback oscillators and relaxation oscillators.**

Principles of Oscillator

With exception such as relaxation oscillator, the operation of oscillator is based on principle of positive feedback where portion of the output signal is feedback into input without phase change. Thus, it reinforces the input and sustains the continuous sinusoidal output. Beside this, the phase shift of feedback signal must be either 0o or 360o. The last requirement is the loop gain T of amplifier must be equal to one, which is also named as Barkhausen criterion. Thus mathematically, the loop gain T is

T =AVb = 1

where A_V is the voltage gain of the amplifier and $\beta = \frac{V_f}{V_{out}}$ is the feedback portion of output voltage. If A_V is equal to 10 then the feedback portion β should be 1/10. The principles of the oscillator are illustrated in Fig. 16.1. The transfer function of the circuit shall be $A_f = \frac{A_V}{1 - A_V\beta}$.

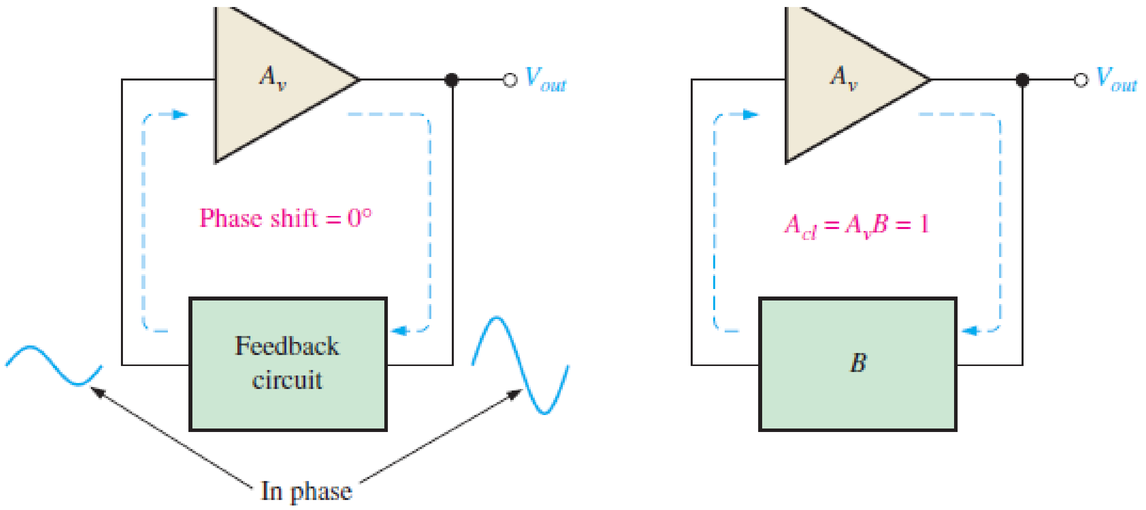
Conditions for Oscillation

Two conditions, illustrated in Figure 4, are required for a sustained state of oscillation:

1. The phase shift around the feedback loop must be effectively

2. The voltage gain, Acl, around the closed feedback loop (loop gain) must equal 1 (unity).

The voltage gain around the closed feedback loop, is the product of the amplifier gain, and the attenuation, B, of the feedback circuit. If a sinusoidal wave is the desired output, a loop gain greater than 1 will rapidly cause the output to saturate at both peaks of the waveform, producing unacceptable distortion. To avoid this, some form of gain control must be used to keep the loop gain at exactly 1 once oscillations have started. For example, if the attenuation of the feedback circuit is 0.01, the amplifier must have a gain of exactly 100 to overcome this attenuation and not create unacceptable distortion An amplifier gain of greater than 100 will cause the oscillator to limit both peaks of the waveform.



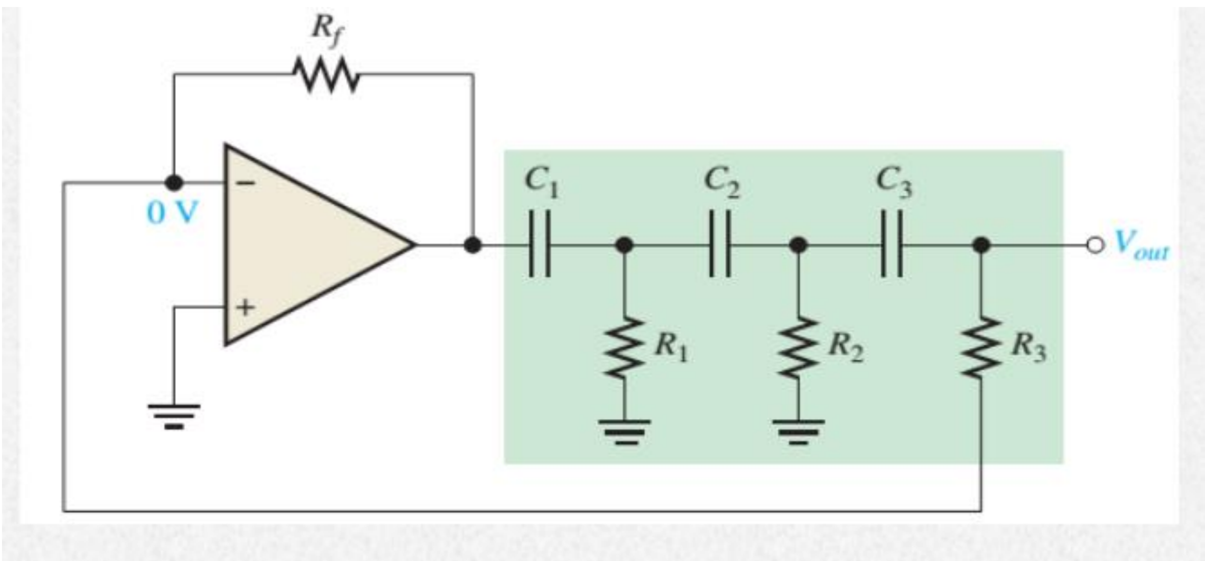
(a) The phase shift around the loop is 0°. (b) The closed loop gain is 1.

Figure 4: General conditions to sustain oscillation.

4.7 RC Phase Shift oscillator, Wien Bridge oscillator

RC Phase Shift oscillator

Three types of feedback oscillators that use RC circuits to produce sinusoidal outputs are the Wien-bridge oscillator, the phase-shift oscillator, and the twin-T oscillator. Generally, RC feedback oscillators are used for frequencies up to about 1 MHz. The Wien-bridge is by far the most widely used type of RC feedback oscillator for this range of frequencies.



$$f_r \cong \frac{1}{2\pi\sqrt{6}RC}$$

Wien-Bridge Oscillator

Wien-Bridge oscillator is an oscillator that meets the principle of oscillator. Its circuit is shown in Figure 5

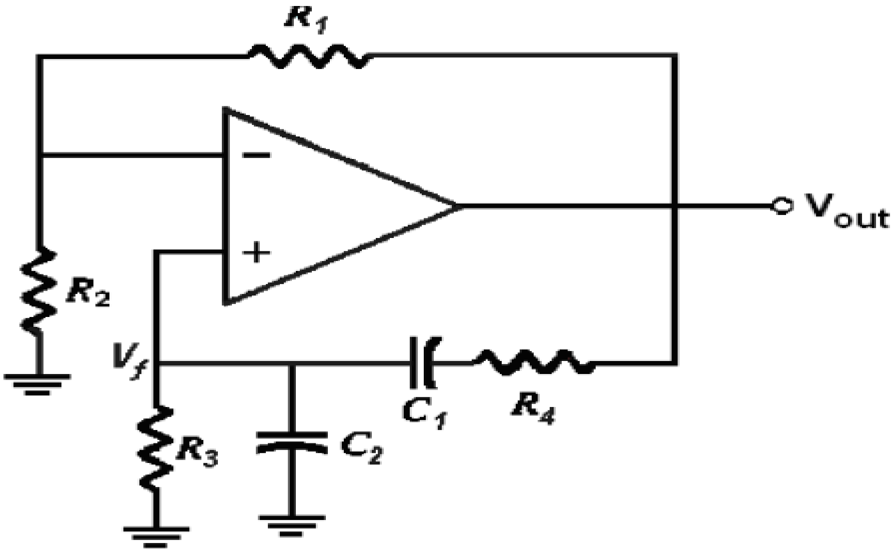
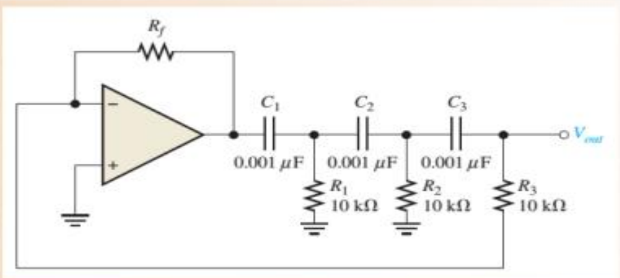


Figure 5 : **Wien-Bridge Oscillator**

There is a lead-lag RC network whereby C_1 and R_3 leads and R_4 and C_2 lags. Reactance χ_{C_1} of capacitance C_1 is significantly affecting the V_{IN+} at low frequency, whilst reactance χ_{C_2} of capacitor C_2 equal to $1/j\omega C_2$ is significant affecting at high frequency. If $C_1 = C_2$ and $R_4 = R_3$, there will be no phase-shift because the phase lead is compensated by phase lag. From the analysis of the circuit, the portion of the output feedback to input

(a) Determine the value of R_f necessary for the circuit in Figure 16–14 to operate as an oscillator.

(b) Determine the frequency of oscillation.



Solution **(a)** $A_{cl} = 29$, and $B = 1/29 = R_3/R_f$. Therefore,

$$\frac{R_f}{R_3} = 29$$

$$R_f = 29R_3 = 29(10\,\text{k}\Omega) = \mathbf{290\,k\Omega}$$

(b) $R_1 = R_2 = R_3 = R$ and $C_1 = C_2 = C_3 = C$. Therefore,

$$f_r = \frac{1}{2\pi\sqrt{6}RC} = \frac{1}{2\pi\sqrt{6}(10\,\text{k}\Omega)(0.001\,\mu\text{F})} \cong \mathbf{6.5\,kHz}$$

4.8 IC 555 Timer and Astable Oscillator using IC 555

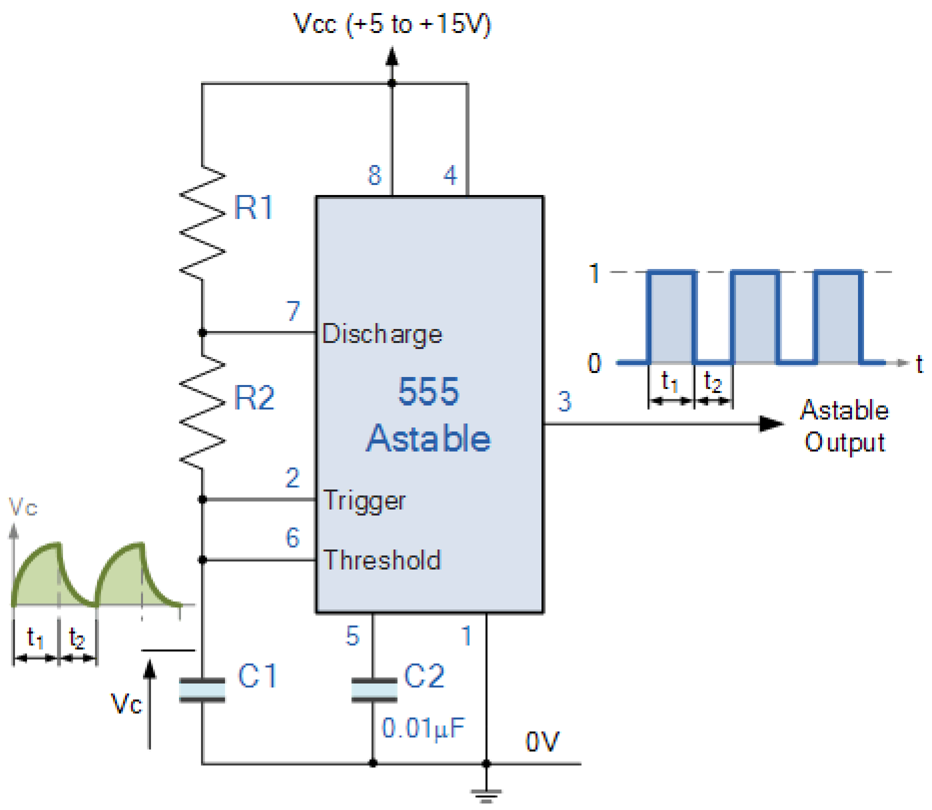
The **555 Timer IC** can be connected either in its Monostable mode thereby producing a precision timer of a fixed time duration, or in its Bistable mode to produce a flip-flop type switching action. But we can also connect the 555 timer IC in an Astable mode to produce a very stable **555 Oscillator** circuit for generating highly accurate free running waveforms whose output frequency can be adjusted by means of an externally connected RC tank circuit consisting of just two resistors and a capacitor.

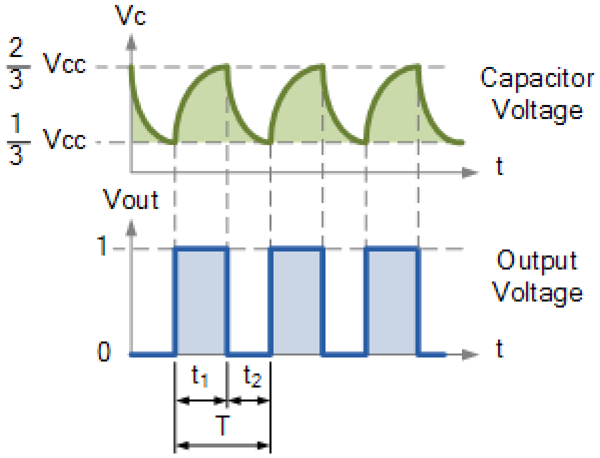
The **555 Oscillator** is another type of relaxation oscillator for generating stabilized square wave output waveforms of either a fixed frequency of up to 500kHz or of varying duty cycles from 50 to 100%. In the previous 555 Timer tutorial we saw that the Monostable circuit produces a single output one-shot pulse when triggered on its pin 2 trigger input.

Whereas the 555 monostable circuit stopped after a preset time waiting for the next trigger pulse to start over again, in order to get the 555 Oscillator to operate as an astable multivibrator it is necessary to continuously re-trigger the 555 IC after each and every timing cycle.

This re-triggering is basically achieved by connecting the *trigger* input (pin 2) and the *threshold* input (pin 6) together, thereby allowing the device to act as an astable oscillator. Then the 555 Oscillator has no stable states as it continuously switches from one state to the other. Also the single timing resistor of the previous monostable multivibrator circuit has been split into two separate resistors, R1 and R2 with their junction connected to the *discharge* input (pin 7) as shown below.

Basic Astable 555 Oscillator Circuit





In the **555 Oscillator** circuit above, pin 2 and pin 6 are connected together allowing the circuit to re-trigger itself on each and every cycle allowing it to operate as a free running oscillator. During each cycle capacitor, C charges up through both timing resistors, R1 and R2 but discharges itself only through resistor, R2 as the other side of R2 is connected to the *discharge* terminal, pin 7.

Then the capacitor charges up to 2/3Vcc (the upper comparator limit) which is determined by the 0.693(R1+R2)C combination and discharges itself down to 1/3Vcc (the lower comparator limit) determined by the 0.693(R2*C) combination. This results in an output waveform whose voltage level is approximately equal to Vcc – 1.5V and whose output "ON" and "OFF" time periods are determined by the capacitor and resistors combinations. The individual times required to complete one charge and discharge cycle of the output is therefore given as:

Astable 555 Oscillator Charge and Discharge Times

$$t_1 = 0.693(R_1 + R_2).C$$

and

$$t_2 = 0.693 \times R_2 \times C$$

Where, R is in Ω and C in Farads.

When connected as an astable multivibrator, the output from the **555 Oscillator** will continue indefinitely charging and discharging between 2/3Vcc and 1/3Vcc until the power supply is removed. As with the monostable multivibrator these charge and discharge times and therefore the frequency are independent on the supply voltage.

The duration of one full timing cycle is therefore equal to the sum of the two individual times that the capacitor charges and discharges added together and is given as:

555 Oscillator Cycle Time

$$T = t_1 + t_2 = 0.693(R_1 + 2R_2).C$$

The output frequency of oscillations can be found by inverting the equation above for the total cycle time giving a final equation for the output frequency of an Astable 555 Oscillator as:

555 Oscillator Frequency Equation

$$f = \frac{1}{T} = \frac{1.44}{(R_1 + 2R_2).C}$$

By altering the time constant of just one of the RC combinations, the **Duty Cycle** better known as the "Mark-to-Space" ratio of the output waveform can be accurately set and is given as the ratio of resistor R2 to resistor R1. The Duty Cycle for the 555 Oscillator, which is the ratio of the "ON" time divided by the "OFF" time is given by:

555 Oscillator Duty Cycle

$$\text{Duty Cycle} = \frac{T_{ON}}{T_{OFF} + T_{ON}} = \frac{R_1 + R_2}{(R_1 + 2R_2)}\ \%$$

The duty cycle has no units as it is a ratio but can be expressed as a percentage (%). If both timing resistors, R1 and R2 are equal in value, then the output duty cycle will be 2:1 that is, 66% ON time and 33% OFF time with respect to the period.

555 Oscillator Example No1

An **Astable 555 Oscillator** is constructed using the following components, R1 = 1kΩ, R2 = 2kΩ and capacitor C = 10uF. Calculate the output frequency from the 555 oscillator and the duty cycle of the output waveform.

t_1 – capacitor charge "ON" time is calculated as:

$$\begin{aligned} t_1 &= 0.693(R_1 + R_2).C \\ &= 0.693(1000 + 2000) \times 10 \times 10^{-6} \\ &= 0.021s = 21ms \end{aligned}$$

t_2 – capacitor discharge "OFF" time is calculated as:

$$\begin{aligned} t_2 &= 0.693\,R_2.C \\ &= 0.693 \times 2000 \times 10 \times 10^{-6} \\ &= 0.014s = 14ms \end{aligned}$$

Total periodic time (T) is therefore calculated as:

$$T = t_1 + t_2 = 21ms + 14ms = 35ms$$

The output frequency, f is therefore given as:

$$f = \frac{1}{T} = \frac{1}{35ms} = 28.6Hz$$

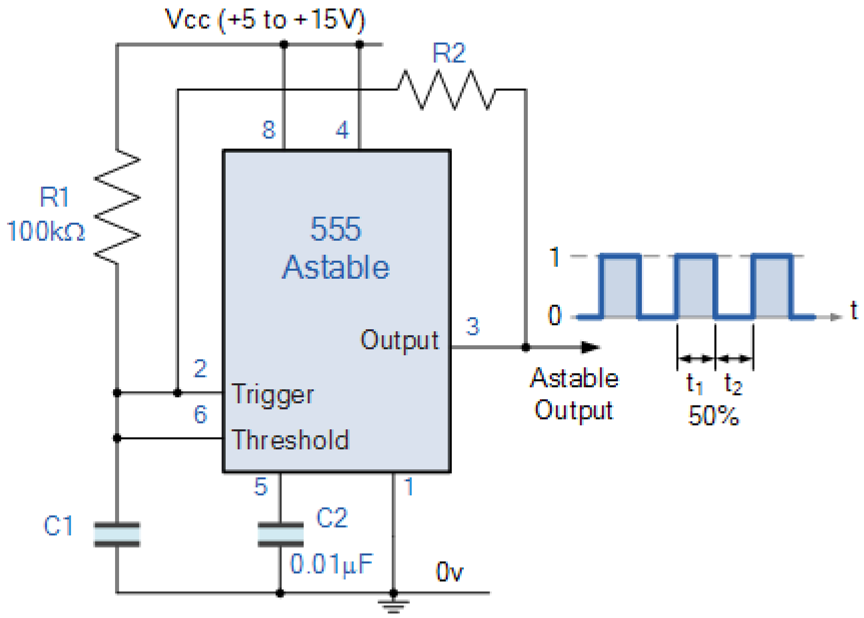
Giving a duty cycle value of:

$$\text{Duty Cycle} = \frac{R_1 + R_2}{(R_1 + 2R_2)} = \frac{1000 + 2000}{(1000 + 2 \times 2000)} = 0.6 \text{ or } 60\%$$

As the timing capacitor, C charges through resistors R1 and R2 but only discharges through resistor R2 the output duty cycle can be varied between 50 and 100% by changing the value of resistor R2. By decreasing the value of R2 the duty cycle increases towards 100% and by increasing R2 the duty cycle reduces towards 50%. If resistor, R2 is very large relative to resistor R1 the output frequency of the 555 astable circuit will determined by R2 x C only.

The problem with this basic astable 555 oscillator configuration is that the duty cycle, the “mark to-space” ratio will never go below 50% as the presence of resistor R2 prevents this. In other words we cannot make the outputs “ON” time shorter than the “OFF” time, as (R1 + R2)C will always be greater than the value of R1 x C. One way to overcome this problem is to connect a signal bypassing diode in parallel with resistor R2 as shown below.

50% Duty Cycle Astable Oscillator



The 555 oscillator now produces a 50% duty cycle as the timing capacitor, C1 is now charging and discharging through the same resistor, R2 rather than discharging through the timers discharge pin 7 as before. When the output from the 555 oscillator is HIGH, the capacitor charges up through R2 and when the output is LOW, it discharges through R2. Resistor R1 is used to ensure that the capacitor charges up fully to the same value as the supply voltage.

However, as the capacitor charges and discharges through the same resistor, the above equation for the output frequency of oscillations has to be modified a little to reflect this circuit change. Then the new equation for the 50% Astable 555 Oscillator is given as:

50% Duty Cycle Frequency Equation

$$f = \frac{1}{0.693(2R_2).C} \text{ Hz}$$

Note that resistor R1 needs to be sufficiently high enough to ensure it does not interfere with the charging of the capacitor to produce the required 50% duty cycle. Also changing the value of the timing capacitor, C1 changes the oscillation frequency of the astable circuit.