Syllabus: BJT as an amplifier, BJT as a Switch, Transistor switch circuit to switch ON/OFF an LED and a lamp in a power circuit using a relay. Feedback Amplifiers- Principle, Properties and advantages of negative Feedback, Types of Feedback, Voltage Series feedback, Gain stability with feedback. Oscillators- Barkhaunsen's criteria for Oscillation, RC phase Shift Oscillator, Wein Bridge Oscillator, IC 555 Timer and Astable Oscillator using IC555.

Module-4

BJT Applications, Feedback Amplifiers and Oscillator

BJT as an amplifier

- **Amplification** is the process of linearly increasing the amplitude of an electrical signal and is one of the major properties of a transistor. When a BJT is biased in the active (or linear) region, as the Base Emitter junction has a low resistance due to forward bias and the BC junction has a high resistance due to reverse bias.

DC and AC Quantities

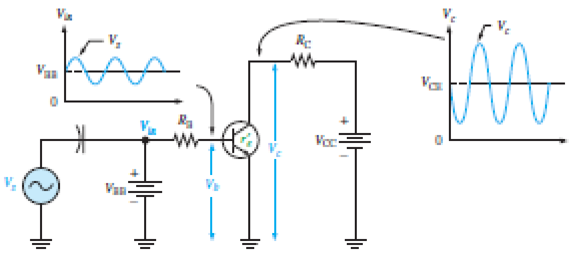
- Before discussing the concept of transistor amplification, the designations that we will use for the circuit quantities of current, voltage, and resistance must be explained because amplifier circuits have both dc and ac quantities.
- The italic capital letters are used for both dc and ac currents (*I*) and voltages (*V*). This rule applies to rms, average, peak, and peak-to-peak ac values. AC current and voltage values are always rms unless stated otherwise.
- Although some texts use lowercase *I* and *v* for ac current and voltage, we reserve the use of lowercase *i* and *v* only for instantaneous values.DC quantities always carry an uppercase roman (nonitalic) subscript. For example, *I*B, *I*C, and *I*E are the dc transistor currents. *V*BE, *V*CB, and *V*CE are the dc voltages from one transistor terminal to another. Single subscripted voltages such as *V*B, *V*C, and *V*E are dc voltages from the transistor terminals to ground. AC and all time-varying quantities always carry a lowercase italic subscript.

For example,

- *Ib*, *Ic*, and *Ie* are the ac transistor currents. *Vbe*, *Vcb*, and *Vce* are the ac voltages from one transistor terminal to another. Single subscripted voltages such as *Vb*, *Vc*, and *Ve* are ac voltages from the transistor terminals to ground.
- The rule is different for *internal* transistor resistances. As you will see later, transistors have internal ac resistances that are designated by lowercase with an appropriate subscript. For example *R*E is an external dc emitter resistance and *Re* is an external ac emitter resistance.

Voltage Amplification

- As a transistor amplifies current because the collector current is equal to the base current multiplied by the current gain, b. The base current in a transistor is very small compared to the collector and emitter currents.
- Because of this, the collector current is approximately equal to the emitter current. An ac voltage, *Vs*, is superimposed on the dc bias voltage *V*BB by capacitive coupling as shown. The dc bias voltage *V*CC is connected to the collector through the collector resistor, *R*C. The ac input voltage produces an ac base current, which results in a much larger ac collector current.
- The ac collector current produces an ac voltage across *R*C, thus producing an amplified, but inverted, reproduction of the ac input voltage in the active region of operation
- The forward-biased base-emitter junction presents a very low resistance to the ac signal. This internal ac emitter resistance is designated in Figure and appears in series with *R*B. The ac base voltage is



$$V_b = I_e r'_e$$

The ac collector voltage, V_c, equals the ac voltage drop across R_C.

$$V_c = I_c R_C$$

Since $I_c \cong I_e$, the ac collector voltage is

$$V_c \cong I_e R_C$$

Vb can be considered the transistor ac input voltage where *Vb Vs IbR*B. *Vc* can be considered the transistor ac output voltage. Since *voltage gain* is defined as the ratio of the output. voltage to the input voltage, the ratio of *Vc* to *Vb* is the ac voltage gain, *Av*, of the transistor.

$$A_v = \frac{V_c}{V_b}$$

Substituting $I_e R_C$ for V_c and $I_e r'_e$ for V_b yields

$$A_v = \frac{V_c}{V_b} \cong \frac{I_e R_C}{I_e r'_e}$$

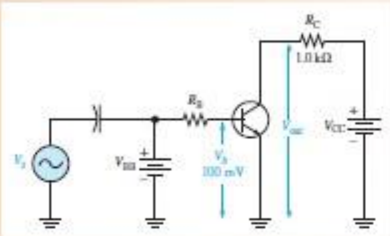
The I_e terms cancel; therefore,

$$A_v \cong \frac{R_C}{r'_e}$$

Since *R*C is always considerably larger in value than , the output voltage for this configuration is greater than the input voltage

EXAMPLE 4–9 Determine the voltage gain and the ac output voltage in Figure 4–22 if $r'_e = 50\ \Omega$.

FIGURE 4–22



Solution The voltage gain is

$$A_v \cong \frac{R_C}{r'_e} = \frac{1.0\ \text{k}\Omega}{50\ \Omega} = \mathbf{20}$$

Therefore, the ac output voltage is

$$V_{out} = A_v V_b = (20)(100\ \text{mV}) = \mathbf{2\ V\ rms}$$

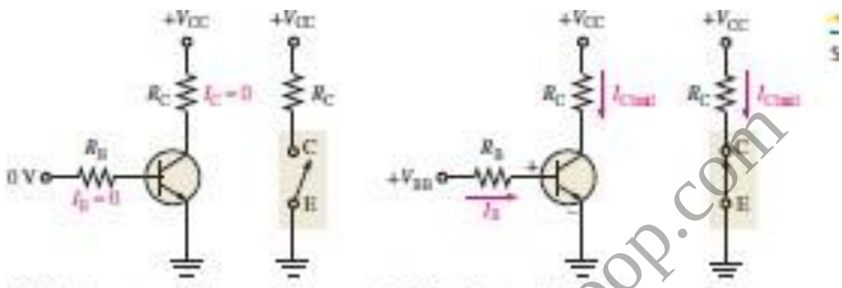
Related Problem What value of R_C in Figure 4–22 will it take to have a voltage gain of 50?

BJT as a Switch

The second major application area is switching applications. When used as an electronic switch, a BJT is normally operated alternately in cutoff and saturation. Many digital circuits use the BJT as a switch

Switching Operation

- In part (a), the transistor is in the **cutoff region** because the base-emitter junction is not forward-biased. In this condition, there is, ideally, an *open* between collector and emitter, as indicated by theswitch equivalent.
- In part (b), the transistor is in the **saturation region** because the base emitter junction and the base-collector junction are forward-biased and the base current is made large enough to cause the collector current to reach its saturation value.
- In this condition, there is, ideally, a *short* between collector and emitter, as indicated by the switch equivalent. Actually, a small voltage drop across the transistor of up to a few tenths of a volt normally occurs, which is the saturation voltage, $V_{CE(sat)}$



(a) Cutoff — open switch (b) Saturation — closed switch

Conditions in Cutoff

As mentioned before, a transistor is in the cutoff region when the base-emitter junction is not forward-biased. Neglecting leakage current, all of the currents are zero, and V_{CE} is equal to V_{CC}.

$$V_{CE(cutoff)} = V_{CC}$$

Conditions in Saturation

As you have learned, when the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated. The formula for collector saturation current is

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C}$$

Since $V_{CE(sat)}$ is very small compared to V_{CC}, it can usually be neglected.

The minimum value of base current needed to produce saturation is

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}}$$

Normally, I_B should be significantly greater than $I_{B(min)}$ to ensure that the transistor is saturated.

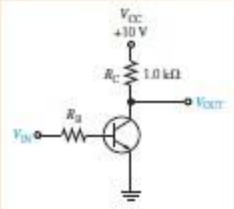
EXAMPLE 4–10

(a) For the transistor circuit in Figure 4–24, what is V_{CE} when $V_{IN} = 0$ V?

(b) What minimum value of I_B is required to saturate this transistor if β_{DC} is 200? Neglect $V_{CE(sat)}$.

(c) Calculate the maximum value of R_B when $V_{IN} = 5$ V.

FIGURE 4–24



Solution

(a) When $V_{IN} = 0$ V, the transistor is in cutoff (acts like an open switch) and

$$V_{CE} = V_{CC} = \mathbf{10\ V}$$

(b) Since $V_{CE(sat)}$ is neglected (assumed to be 0 V),

$$I_{C(sat)} = \frac{V_{CC}}{R_C} = \frac{10\ \text{V}}{1.0\ \text{k}\Omega} = 10\ \text{mA}$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} = \frac{10\ \text{mA}}{200} = \mathbf{50\ \mu A}$$

This is the value of I_B necessary to drive the transistor to the point of saturation. Any further increase in I_B will ensure the transistor remains in saturation but there cannot be any further increase in I_C.

(c) When the transistor is on, $V_{BE} \cong 0.7$ V. The voltage across R_B is

$$V_{R_B} = V_{IN} - V_{BE} \cong 5\ \text{V} - 0.7\ \text{V} = 4.3\ \text{V}$$

Calculate the maximum value of R_B needed to allow a minimum I_B of 50 μA using Ohm's law as follows:

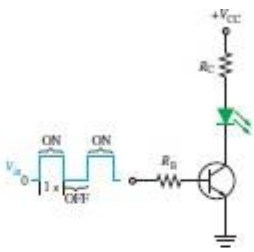
$$R_{B(max)} = \frac{V_{R_B}}{I_{B(min)}} = \frac{4.3\ \text{V}}{50\ \mu\text{A}} = \mathbf{86\ k\Omega}$$

A Simple Application of a Transistor Switch

- The transistor in Figure 4–25 is used as a switch to turn the LED on and off.
- For example, a square wave input voltage with a period of 2 s is applied to the input as indicated. When the square wave is at 0 V, the transistor is in cutoff; and since there is no collector current, the LED does not emit light.
- When the square wave goes to its high level, the transistor saturates. These forward-biases the LED, and the resulting collector current through the LED causes it to emit light. Thus, the LED is on for 1 second and off for 1 second.

FIGURE 4–25

A transistor used to switch an LED on and off.



EXAMPLE 4–11

The LED in Figure 4–25 requires 30 mA to emit a sufficient level of light. Therefore, the collector current should be approximately 30 mA. For the following circuit values, determine the amplitude of the square wave input voltage necessary to make sure that the transistor saturates. Use double the minimum value of base current as a safety margin to ensure saturation. $V_{CC} = 9$ V, $V_{CE(sat)} = 0.3$ V, $R_C = 220\ \Omega$, $R_B = 3.3$ kΩ, $\beta_{DC} = 50$, and $V_{LED} = 1.6$ V.

Solution

$$I_{C(sat)} = \frac{V_{CC} - V_{LED} - V_{CE(sat)}}{R_C} = \frac{9\ \text{V} - 1.6\ \text{V} - 0.3\ \text{V}}{220\ \Omega} = 32.3\ \text{mA}$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} = \frac{32.3\ \text{mA}}{50} = 646\ \mu\text{A}$$

To ensure saturation, use twice the value of $I_{B(min)}$, which is 1.29 mA. Use Ohm's law to solve for V_{in}.

$$I_B = \frac{V_{R_B}}{R_B} = \frac{V_{in} - V_{BE}}{R_B} = \frac{V_{in} - 0.7\ \text{V}}{3.3\ \text{k}\Omega}$$

$$V_{in} - 0.7\ \text{V} = 2I_{B(min)}R_B = (1.29\ \text{mA})(3.3\ \text{k}\Omega)$$

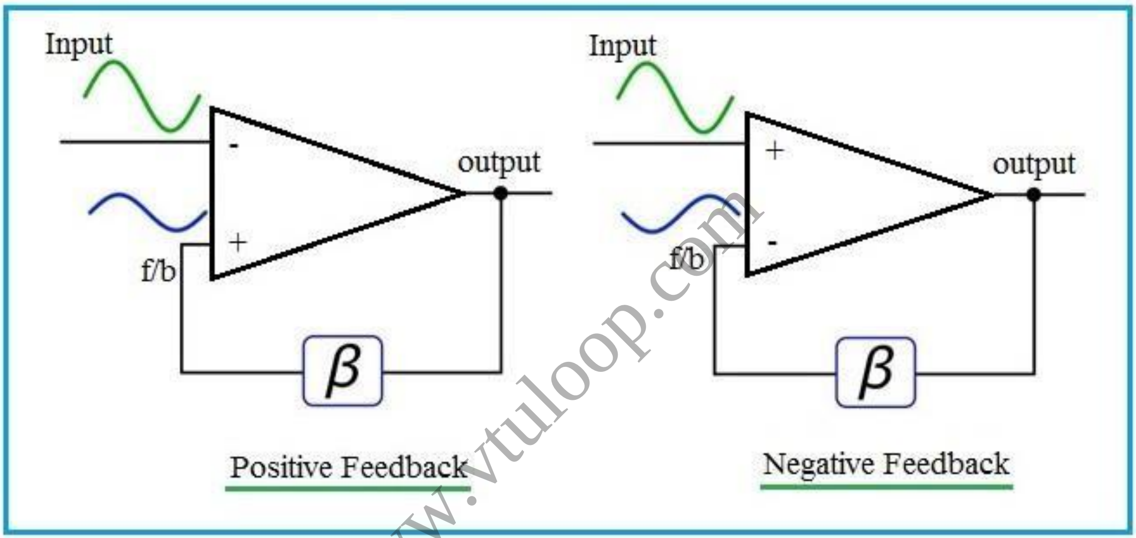
$$V_{in} = (1.29\ \text{mA})(3.3\ \text{k}\Omega) + 0.7\ \text{V} = \mathbf{4.96\ V}$$

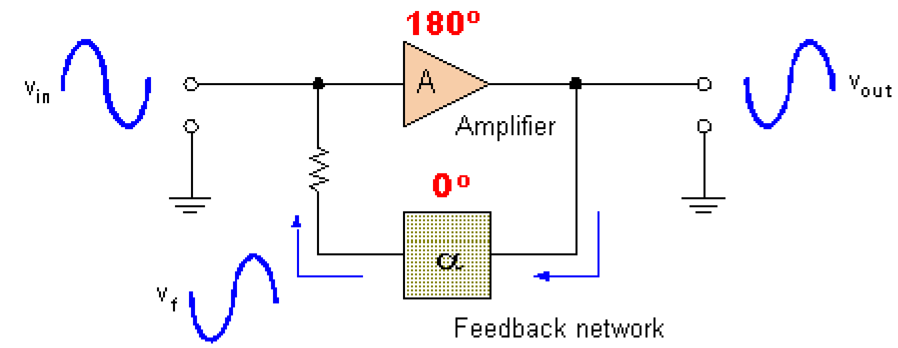
Feedback Amplifiers

- The voltage or current output is fed back to the input through a modifying network which determines the magnitude and phase
- There are two types of feedback in amplifier.
  - Positive feedback
  - Negative feedback

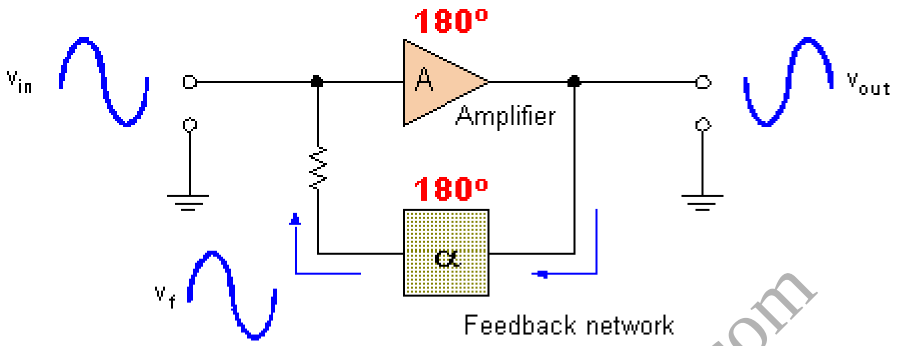
1. **Positive Feedback:** In positive feedback, the feedback energy (voltage or currents), is in phase with the input signal and thus aids it. Positive feedback increases gain of the amplifier also increases distortion, noise and instability. Because of these disadvantages, positive feedback is seldom employed in amplifiers. But the positive feedback is used in oscillators.

2. **Negative Feedback:** In negative feedback, the feedback energy (voltage or current), is out of phase with the input signal and thus opposes it. Negative feedback reduces gain of the amplifier. It also reduce distortion, noise and instability. This feedback increases bandwidth and improves input and output impedances. Due to these advantages, the negative feedback is frequently used in amplifiers.





(a) Negative Feedback



(b) Positive Feedback

The important advantage of negative feedback is that the resultant gain of the amplifier can be made independent of transistor parameters or the supply voltage variations.

$A_f = (A) / (1 + A\beta)$

The voltage gain with positive feedback amplifier

$A_f = (A) / (1 - A\beta)$

Properties of Negative Feedback Amplifier

1. Desensitize the gain

It brings the stability to amplifier by making gain less sensitive to all kind of variations

2. Reduce Non Linear Distortion

The negative feedback makes the output proportional to the input

3. Reduce the Effect of Noise

It minimize the un wanted contribution of electric signals. this noise may be generated by the circuit components or by external interference

4. Control the input and output impedance

It increases or decreases the input and output impedance .this is done by choosing appropriate feed back topology

5. Extend the bandwidth of amplifier

By incorporating negative feedback the bandwidth can be increased

Advantages of Negative Feedback

1.Gain Stability

2.Significant extension of bandwidth

3.very less distortions

4.Decreased output Resistance

5. Stable operating point
6. Reduces Noise and other interference in Amplifier

All the advantages are on cost of reduced gain of an amplifier and hence in negative feedback there is always tradeoff between amplifier gain and other desirable properties

Comparisons between positive and negative feedback Amplifier

S.No.	Negative Feedback	Positive Feedback
1.	Feedback energy is out phase with their input signal	Feedback energy is in phase with the input signal.
2.	Gain of the amplifier decreases	Gain of the amplifier increases
3.	Gain stability increases	Gain stability decreases
4.	Noise and distortion decreases.	Noise and distribution increases.
5.	Increase the band width	Decreases bandwidth
6.	Used in amplifiers	Used in Oscillators

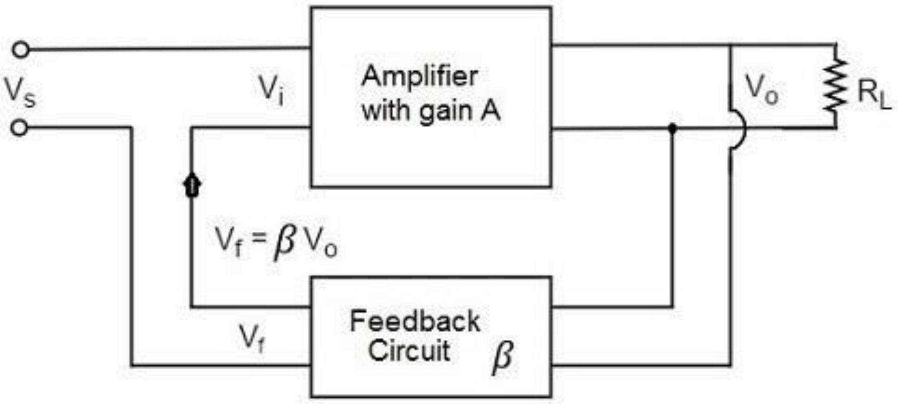
Types of feed back

The feedback amplifiers can be classified according to mixing and sampling employed to it as follows:

1. Voltage series feedback amplifier
2. Current series feedback amplifier
3. Current shunt feedback amplifier
4. Voltage shunt feedback amplifier

Voltage Series Feedback Amplifier: This uses output voltage sampling and series mixing.
Current Series Feedback Amplifier: This uses output current sampling and series mixing.
Current Shunt Feedback Amplifier: This uses output current sampling and shunt mixing.
Voltage Shunt Feedback Amplifier: This uses output voltage sampling and shunt mixing

Voltage series feedback amplifier



From the above figure, the gain of the amplifier is represented as A. the gain of the amplifier is the ratio of output voltage V_o to the input voltage V_i. the feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier.

This voltage is added for negative feedback, from the signal voltage V_s. Now,

$V_i = V_{in} - \beta V_o$

$V_0 = AV_i = AV_{in} - A\beta V_0$

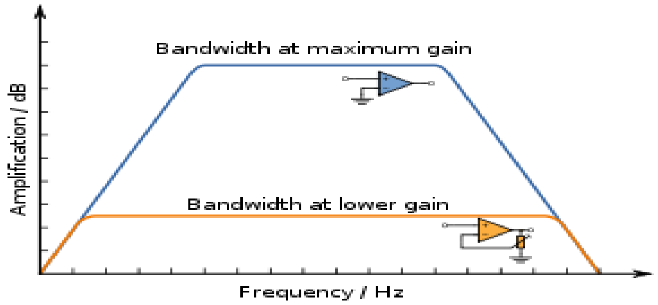
Re orgranising ,we get
$Af = (A) / (1+ A\beta)$
The input impedance with feedback $Z_{if} = Z_i(1+\beta A)$,Increases
The output impedance with feedback $Z_{of} = Z_o / (1+\beta A)$,decreases

The product of Aβ is much greater than unity. Therefore in above relation can be neglected as compared to Aβ. Then, the expression becomes.
$Af = (A / A\beta) = (1 / \beta)$
It may see that the gain now depends only upon feedback fraction β. The Feedback circuit is usually resistive network.

Gain and bandwidth of feedback Amplifier

In RC Coupled Amplifiers ,the gain reduces at low frequency and high frequency end.So Aβ is no longer much more than unity.as a result the percent reduction in gain is less at the two frequency ends compare to the mid band.

$f1 << f2$ and $f_{1f} << f_{2f}$ therefore
$BW = f_2$
$BW_f = f_{2f}$
It can be shown that
$A_0 f_2 = A_{0f} f_{2f} =$ Constant product of gain bandwidth



Gain stability with feedback

The over all gain with negative feedback is given by

$Af = (A) / (1+ A\beta)$

Differentiation of above equation leads to

$dAf / Af = (dA/A) * 1/(1+ A\beta)$

$dAf / Af = (dA/A)*1 / (A\beta)$ for $\beta A >>1$

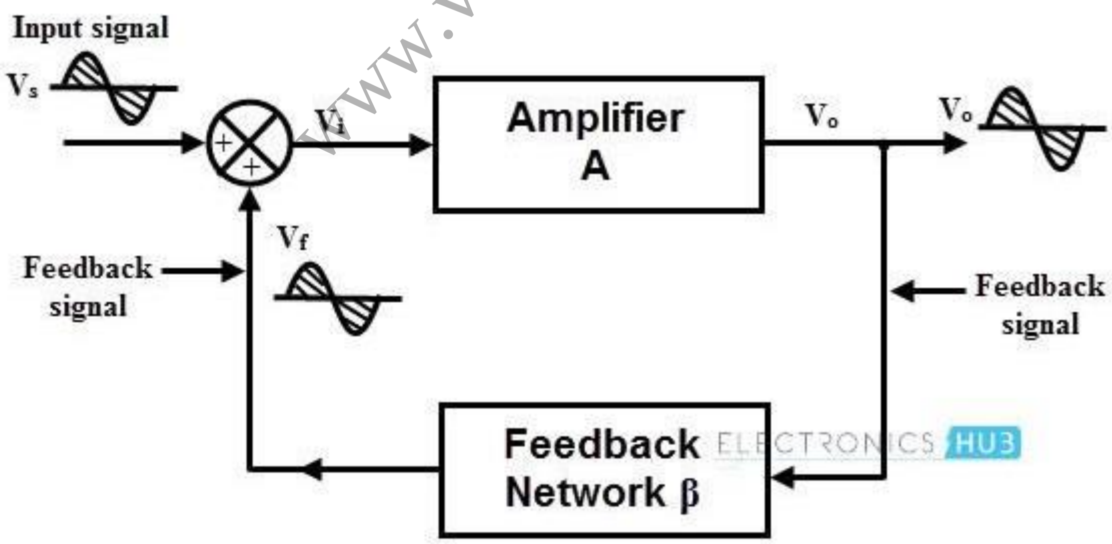
this shows the relative change(dA / A)in the basic amplifier gain is reduced by the factor βA in the relative change (dAf / Af)in the overall gain of the feedback amplifier.

Oscillators

Introduction to Oscillators

- the main statement of the oscillator is that the oscillation is achieved through positive feedback which generates the output signal without input signal. Also, the voltage gain of the amplifier increases with the increase in the amount of positive feedback.

- In order to understand this concept, let us consider a non-inverting amplifier with a voltage gain 'A' and a positive feedback network with feedback gain of β as shown in figure.



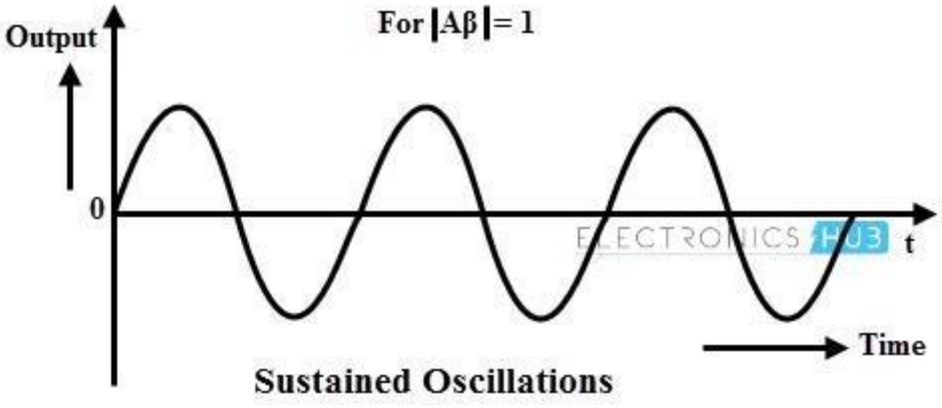
Amplifier gain = $Af = (A) / (1+ A\beta)$

If β is adjusted such that $\beta A = -1 = 1 < -180^0$

The gain tends to become infinity for modulus of Aβ slightly more than unity.the circuit become self oscillatory with no input $V_{in} = 0$

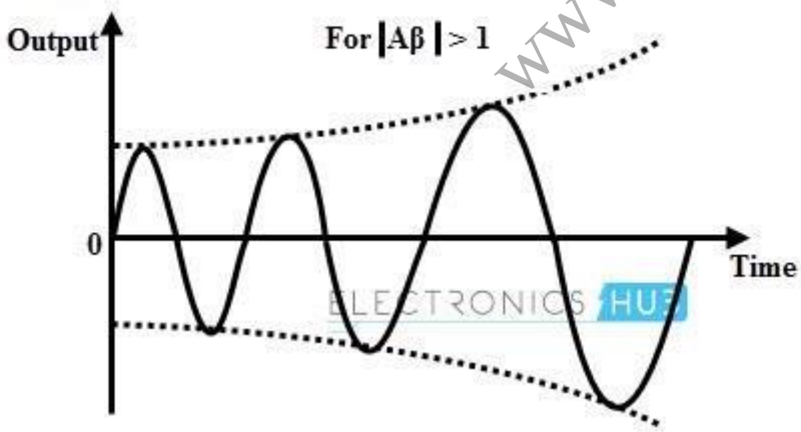
Sustained Oscillations

Sustained oscillations are nothing but oscillations which oscillate with constant amplitude and frequency. Based on the Barkhausen criterion sustained oscillations are produced when the magnitude of loop gain or modulus of A β is equal to one and total phase shift around the loop is 0 degrees or 360 ensuring positive feedback.

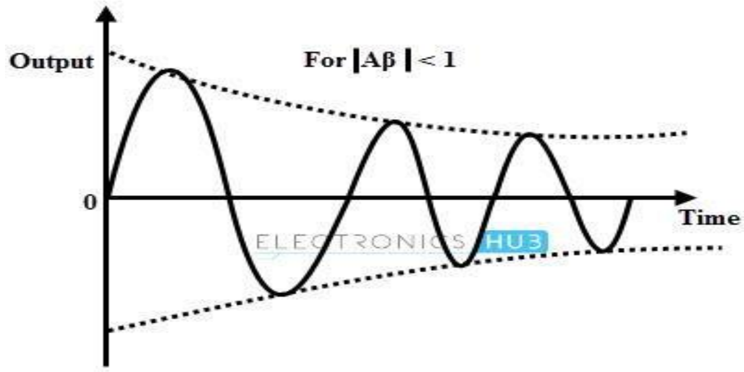


Growing Type of Oscillations

If modulus of A β or the magnitude of loop gain is greater than unity and total phase shift around the loop is 0 or 360 degrees, then the oscillations produced by the oscillator are of growing type. The below figure shows the oscillator output with increasing amplitude of oscillations.



Exponentially Decaying Oscillations: If modulus of A β or the magnitude of loop gain is less than unity and total phase shift around the loop is 0 or 360 degrees, then the amplitude of the oscillations decreases exponentially and finally these oscillations will cease.



Barkhausen Criterion:

1. Sustained oscillations are produced in a sinusoidal oscillators at a frequency for which the total phase shift introduced, as the signal travels from the input terminal through the basic amplifier, feedback network and mixing network back to the input terminals its precisely zero or a integral multiple of 2π radians.
2. Sustained oscillations are not produced if at the oscillation frequency the magnitude of the loop gain i.e., the product of the transfer gain A, of amplifer and magnitude of the feedback factor β of the feedback network is less than unity.

Requisites of an Oscillator

1.Tank Circuit:

It consists of inductor connected in parallel with capacitor C. The frequency of oscillations in the circuit depends upon the values of inductance (L) and capacitace (C). In RC oscillators inductor replaced by resistor(R).

2. Transistor Amplifier:

The transistor amplifier receives d.c power from the battery and changes it into a.c. power for supplying to the tank circuit. The oscillations occurring in the tank circuit are applied to the input of the transistor amplifier. The amplified output of oscillations is due to the d.c. power supplied by the battery. The output of the transistor can be supplied the tank circuit to meet the losses.

3. Feedback Circuit:

The feedback circuit supplies a part of collector energy to the tank circuit in correct phase to aid the oscillations i.e., it provides positive feedback. In oscillator is to satisfy Barkhausen criteria has to get sustained oscillations.

Classification of Oscillator

1.Based on Operating Principle
- Negative Resistance Effect Oscillations
- Feedback Oscillations

2.Based on wave forms
- Sinusoidal Oscillations
- Relaxation Oscillations

3.Based on frequency generation
- AF Oscillations
- RF Oscillations
- UHF Oscillations
- Microwave Oscillations

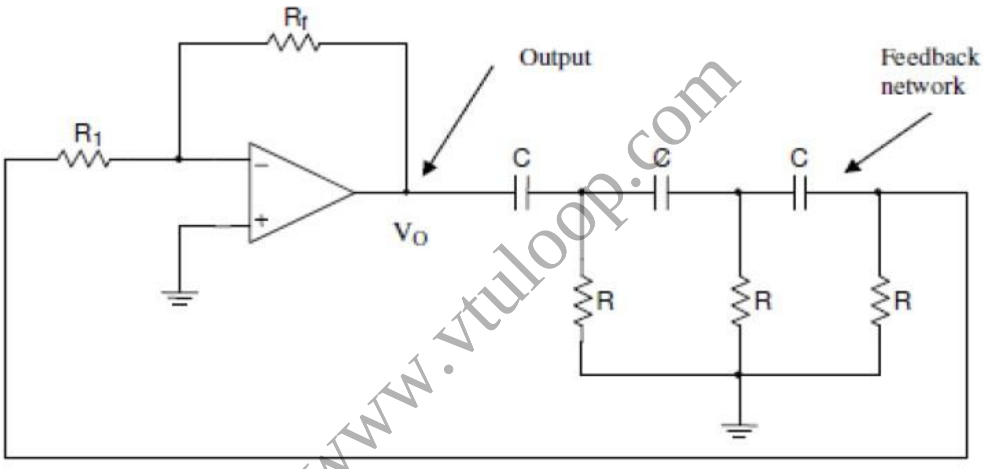
4.According to Circuit employed.
- LC Oscillations
- RC Oscillations

Phase Shift Oscillator

It is achieved by RC network .

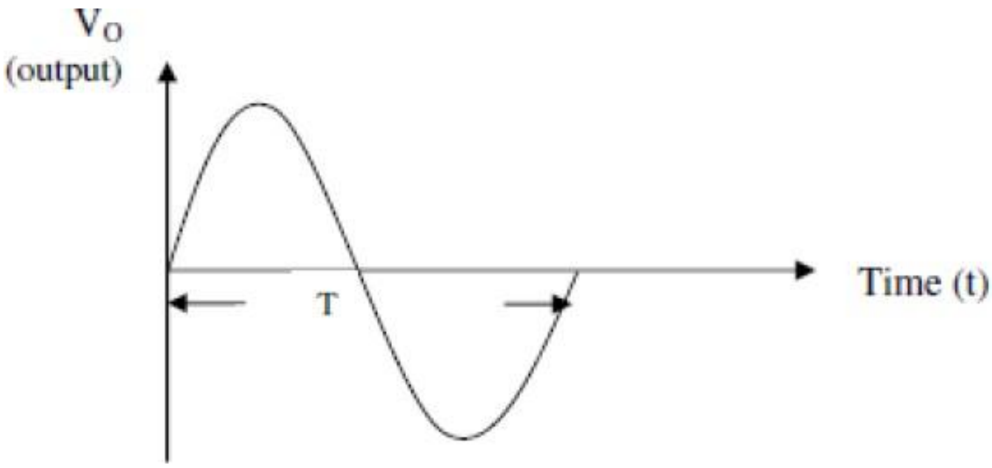
RC Phase Shift Oscillator

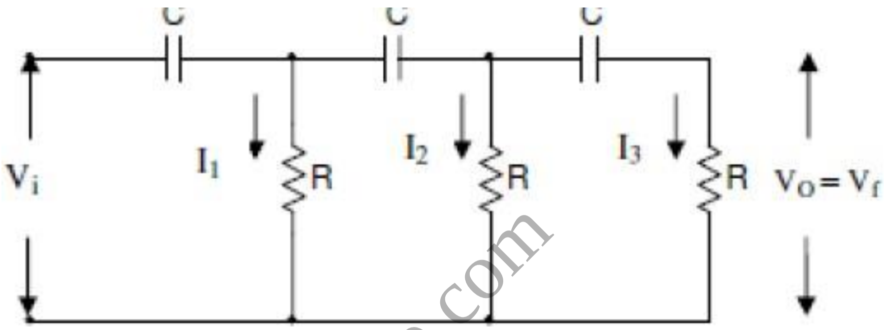
- The RC phase shift oscillator consists of an amplifier and a feedback network consisting of resistors and capacitors arranged in ladder fashion. RC network forms the basis whose phase angle is adjusted in practice equal to 60º. RC network is used in the feedback path.
- In oscillators feedback must introduce a phase shift of 180º to obtain a total phase shift around a loop as 360º.
- As one RC network produces a phase shift of 60º, it is necessary to use to three such RC networks in cascade to get a phase shift of 180º. Op-amp used in inverting mode introduces a phase shift of 180º and these RC networks together produce 180º to get a total phase shift of 360º. Figure shows the circuit of a RC phase shift oscillator using op-amp.



The op-amp is in inverting mode and its output is given to the feedback network. The output of

The op-amp is in inverting mode and its output is given to the feedback network. The output of feedback network drives the amplifier. It is not necessary that all the three RC sections are identical so long the total phase shift is 180º. However if non- identical stages are used it is possible that the total phase shift is 180º for more than one frequency. This may lead to undesirable inter-modal oscillations. The output waveform is shown in figure.





By KVL to the loops we get,

$$I_1\left(R + \frac{1}{j\omega C}\right) - I_2 R = V_1$$

$$-I_1 R + I_2\left(2R + \frac{1}{j\omega C}\right) - I_3 R = 0$$

$$0 - I_2 R + I_3\left(2R + \frac{1}{j\omega C}\right) = 0$$

solving the equations

$$I_3 = \frac{V_i s^3 R^2 C^3}{1 + 5sRC + 6s^2C^2R^2 + s^3R^3C^3}$$

From the figure we get $V_0 = V_f = I_3 R$

Hence $V_O = \dfrac{V_i s^3 R^3 C^3}{1 + 5sRC + 6s^2C^2R^2 + s^3R^3C^3}$

As $\beta = V_O / V_i$ we can write

$$\beta = \frac{s^3 R^3 C^3}{1 + 5sRC + 6s^2C^2R^2 + s^3R^3C^3}$$

Replace s by jω, s^2 by $-\omega^2$ and so on. Simplifying the equation using $\alpha = \frac{1}{\omega RC}$

We get $\beta = \frac{1}{1 + j6\alpha - 5\alpha^2 - j\alpha^3} = \frac{1}{(1-5\alpha^2) + j\alpha(6-\alpha^2)}$

To have 180º phase shift, the imaginary part of the denominator in the above must be zero. Hence we get,

$\alpha(6 - \alpha^2) = 0$ and upon simplification,

$\omega = \frac{1}{RC\sqrt{6}}$ - after substituting for $\alpha = \frac{1}{\omega RC}$

$\therefore\ f = \frac{1}{2\pi RC\sqrt{6}}$

Above equation shows the expression for frequency of oscillations with which the circuit oscillates. At this frequency

$\beta = \frac{1}{1-5(\sqrt{6})^2} = -\frac{1}{29}$ as $\alpha = \sqrt{6}$

The negative sign is due to the phase shift and $|\beta| = \frac{1}{29}$

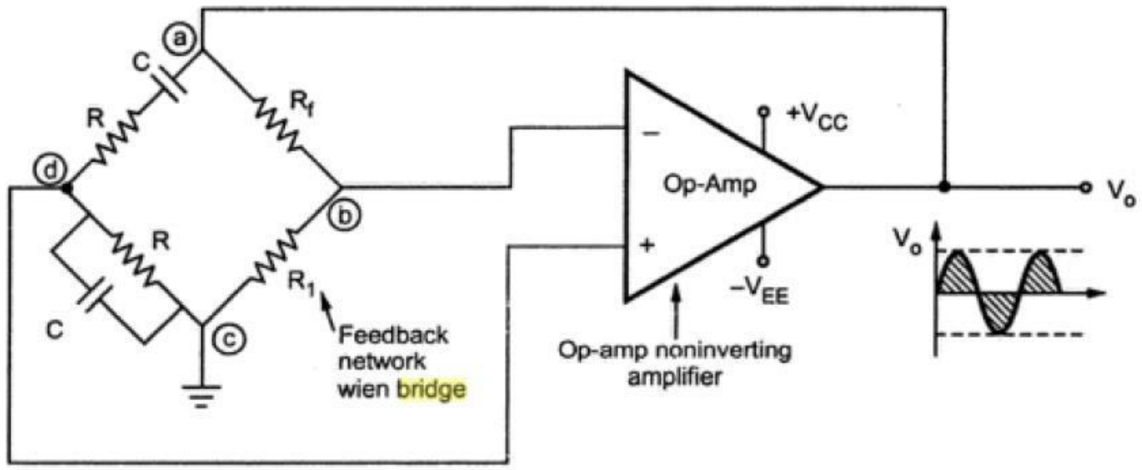
Now for oscillations to start, $|A\beta| \geq 1$. Hence we can write, $|A| \geq 29$

For oscillations to occur the gain of the op-amp must be equal to or greater than 29, which can be adjusted using the resistances R_f and R_1.

The oscillator poses certain merits like simple design, produce sine output in the audio frequency range and can be used as a fixed frequency oscillator.

Wien Bridge Oscillator

One of the most commonly used audio oscillators is the Wien Bridge Oscillator. Op-amp is used in the non-inverting mode. No phase shift is produced during amplifier stage. As the total phase shift required is 0º or 2nπ radians, in Wien bridge type no phase shift is needed through feedback. Figure shows the basic circuit of a Wien bridge oscillator connected between the amplifier input and the output terminal.



The oscillator consists of a Wien bridge having four arms, connected to the non-inverting terminal of the op-amp. The amplifier input is supplied from the feedback network. The resistors in inverting path account for the gain. The Wien Bridge has a series RC network in one arm and a parallel RC network in the adjoining arm. In the remaining two arms of the bridge, resistors R_1 and R_f are connected. The essential conditions of oscillations are satisfied only when the bridge gets balanced (at resonance). The output of the amplifier is applied between terminals 1 and 3 which is the input to the feedback network. While the amplifier input is supplied from the diagonal terminals, which is the output from the feedback network. Thus the amplifier supplies its own input.

The gain of the op-amp is given by

$$A = 1 + \frac{R_f}{R_1}.$$

Assuming all the resistors and capacitors are same and equal in the reactive leg of the Wien Bridge,
To satisfy Oscillations criteria, it is necessary that the gain of the non-inverting amplifier be greater than or equal to 3.

$$\text{. Ie., } |A| \geq 3\text{. Hence } \frac{R_f}{R_1} \geq 2\text{.}$$

If in a Wien bridge feedback network, two resistances are not equal i.e. they are R_1 and R_2 while two capacitors are not equal i.e. they are C_1 and C_2 then the frequency of oscillations is given by,

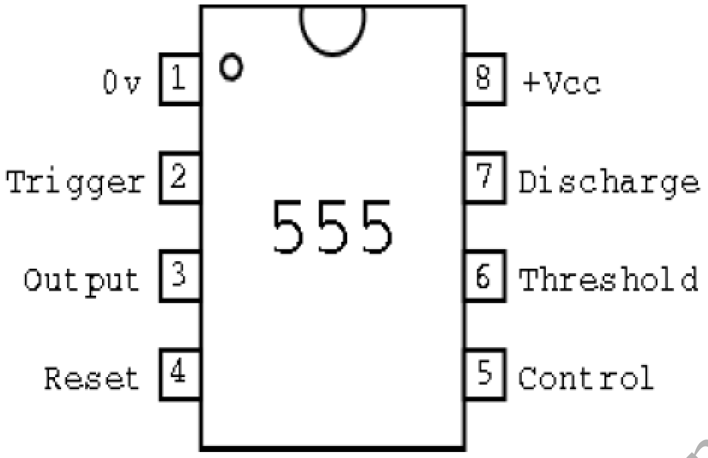
$$\boxed{f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}}$$

Oscillator using IC 555

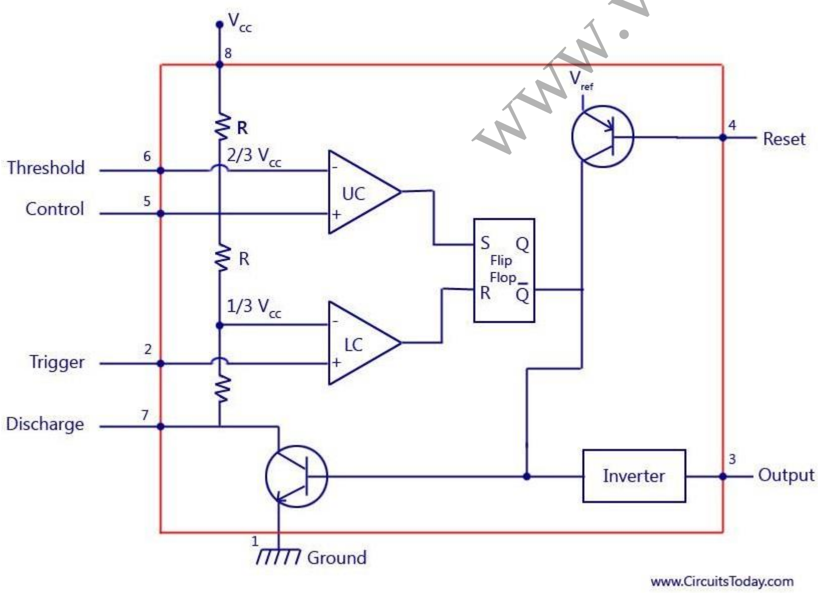
- A popular Analog –Digital Integrator Circuit is the 555 timer
- The 555 timer is an integrated circuit specifically designed to perform signal generation and timing functions.
- IC NE/SE 555 is a highly stable device for generating accurate time delays. Commercially

The salient features of 555 Timer IC's are:

- Compatible with both TTL and CMOS logic families.
- The maximum load current can go up to 200 mA.
- The typical power supply is from +5V to +18 V



555 IC Timer Block Diagram



- The block diagram of a 555 timer is shown in the above figure. A 555 timer has two comparators, which are basically 2 op-amps), an R-S flip-flop, two transistors and a resistive network.
- Resistive network consists of three equal resistors and acts as a voltage divider.

Comparator 1 compares threshold voltage with a reference voltage + 2/3 VCC volts.

Comparator 2 compares the trigger voltage with a reference voltage + 1/3 VCC volts.

- Output of both the comparators is supplied to the flip-flop. Flip-flop assumes its state according to the output of the two comparators. One of the two transistors is a discharge transistor of which collector is connected to pin 7.
- This transistor saturates or cuts-off according to the output state of the flip-flop. The saturated transistor provides a discharge path to a capacitor connected externally. Base of another transistor is connected to a reset terminal. A pulse applied to this terminal resets the whole timer irrespective of any input.

Working principle

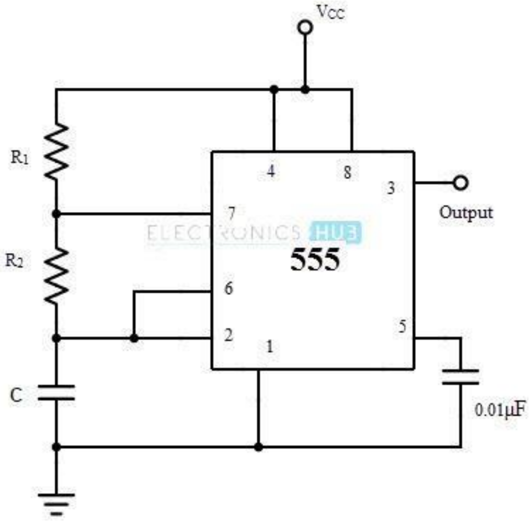
- The internal resistors act as a voltage divider network, providing (2/3)Vcc at the non-inverting terminal of the upper comparator and (1/3)Vcc at the inverting terminal of the lower comparator. In most applications, the control input is not used, so that the control voltage equals +(2/3) VCC.
- Upper comparator has a threshold input (pin 6) and a control input (pin 5). Output of the upper comparator is applied to set (S) input of the flip-flop. Whenever the threshold voltage exceeds the control voltage, the upper comparator will set the flip-flop and its output is high.
- A high output from the flip-flop when given to the base of the discharge transistor saturates it and thus discharges the transistor that is connected externally to the discharge pin 7.
- The complementary signal out of the flip-flop goes to pin 3, the output. The output available at pin 3 is low. These conditions will prevail until lower comparator triggers the flip-flop. Even if the voltage at the threshold input falls below (2/3) VCC, that is upper comparator cannot cause the flip-flop to change again.
- It means that the upper comparator can only force the flip-flop's output high.

To change the output of flip-flop to low, the voltage at the trigger input must fall below + (1/3) Vcc. When this occurs, lower comparator triggers the flip-flop, forcing its output low.

- The low output from the flip-flop turns the discharge transistor off and forces the power amplifier to output a high. These conditions will continue independent of the voltage on the trigger input. Lower comparator can only cause the flip-flop to output low.
- From the above discussion it is concluded that for the having low output from the timer 555, the voltage on the threshold input must exceed the control voltage or + (2/3) VCC. This also turns the discharge transistor on. To force the output from the timer high, the voltage on the trigger input must drop below +(1/3) VCC. This turns the discharge transistor off.
- A voltage may be applied to the control input to change the levels at which the switching occurs. When not in use, a 0.01 nano Farad capacitor should be connected between pin 5 and ground to prevent noise coupled onto this pin from causing false triggering. Connecting the reset (pin 4) to a logic low will place a high on the output of flip-flop.
- The discharge transistor will go on and the power amplifier will output a low. This condition will continue until reset is taken high. This allows synchronization or resetting of the circuit's operation. When not in use, reset should be tied to +VCC.

Astable multivibrator

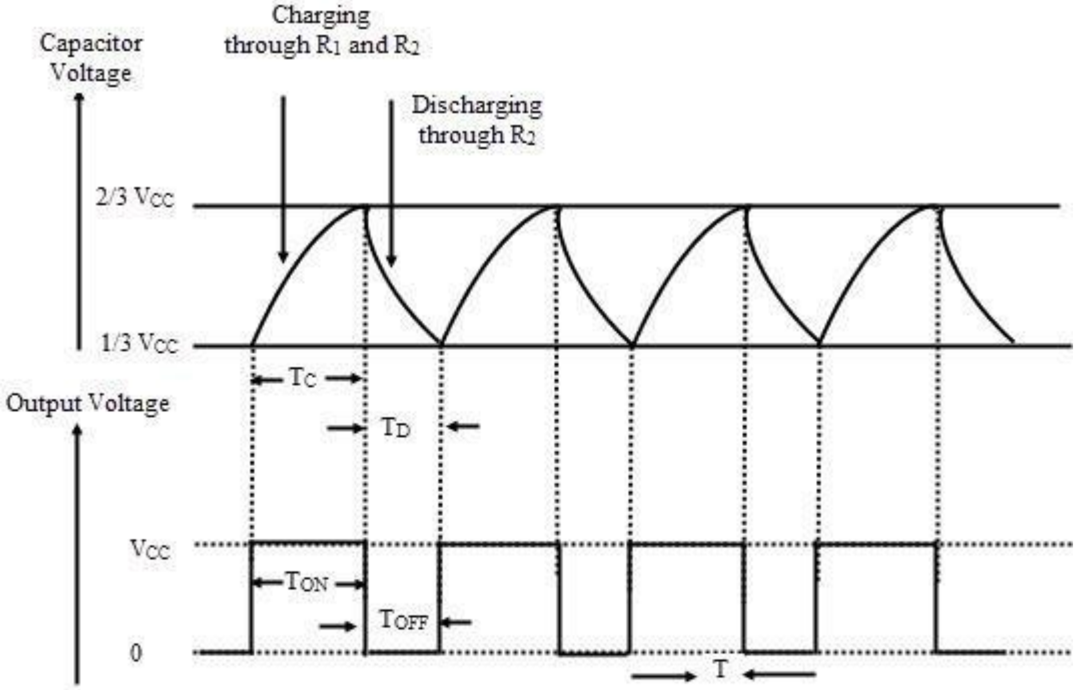
- Astable multivibrator is also called as Free Running Multivibrator. It has no stable states and continuously switches between the two states without application of any external trigger. The IC 555 can be made to work as an astable multivibrator with the addition of three external components: two resistors (R1 and R2) and a capacitor (C).



- the pins 2 and 6 are connected and hence there is no need for an external trigger pulse. It will self trigger and act as a free running multivibrator.
- The rest of the connections are as follows: pin 8 is connected to supply voltage (VCC). Pin 3 is the output terminal and hence the output is available at this pin. Pin 4 is the external reset pin. A momentary low on this pin will reset the timer. Hence when not in use, pin 4 is usually tied to VCC.
- The control voltage applied at pin 5 will change the threshold voltage level. But for normal use, pin 5 is connected to ground via a capacitor (usually 0.01µF), so the external noise from the terminal is filtered out. Pin 1 is ground terminal. The timing circuit that determines the width of the output pulse is made up of R1, R2 and C.

Operation

- initially, on power-up, the flip-flop is RESET (and hence the output of the timer is low). As a result, the discharge transistor is driven to saturation (as it is connected to Q'). The capacitor C of the timing circuit is connected at Pin 7 of the IC 555 and will discharge through the transistor. The output of the timer at this point is low.
- The voltage across the capacitor is nothing but the trigger voltage. So while discharging, if the capacitor voltage becomes less than 1/3 VCC, which is the reference voltage to trigger comparator (comparator 2), the output of the comparator 2 will become high.
- This will SET the flip-flop and hence the output of the timer at pin 3 goes to HIGH. This high output will turn OFF the transistor. As a result, the capacitor C starts charging through the resistors R1 and R2. Now, the capacitor voltage is same as the threshold voltage (as pin 6 is connected to the capacitor resistor junction).
- While charging, the capacitor voltage increases exponentially towards VCC and the moment it crosses 2/3 VCC, which is the reference voltage to threshold comparator (comparator 1), its output becomes high.
- As a result, the flip-flop is RESET. The output of the timer falls to LOW. This low output will once again turn on the transistor which provides a discharge path to the capacitor. Hence the capacitor C will discharge through the resistor R2. And hence the cycle continues.
- Thus, when the capacitor is charging, the voltage across the capacitor rises exponentially and the output voltage at pin 3 is high. Similarly, when the capacitor is discharging, the voltage across the capacitor falls exponentially and the output voltage at pin 3 is low.
- The shape of the output waveform is a train of rectangular pulses. The waveforms of capacitor voltage and the output in the astable mode are shown below.



- While charging, the capacitor charges through the resistors R1 and R2. Therefore the charging time constant is (R1 + R2) C as the total resistance in the charging path is R1 + R2.
- While discharging, the capacitor discharges through the resistor R2 only. Hence the discharge time constant is R2C.

If TON is the time for high output and T is the time period of one cycle, then the duty cycle D is given by

D = TON/ T

Therefore, percentage Duty Cycle is given by

%D = (TON / T) * 100

T is sum of TON (charge time) and TOFF (discharge time). The value of TON or the charge time (for high output) TC is given by

TC = 0.693 * (R1 + R2) C

The value of TOFF or the discharge time (for low output) TD is given by

TD = 0.693 * R2C

Therefore, the time period for one cycle T is given by

T = TON + TOFF = TC + TD

T = 0.693 * (R1 + R2) C + 0.693 * R2C

T = 0.693 * (R1 + 2R2) C

Therefore, %D = (TON/ T) * 100

%D = (0.693 * (R1 + R2) C)/(0.693 * (R1 + 2R2) C) * 100

%D = ((R1 + 2R2))/((R1 + 2R2)) * 100

If T = 0.693 * (R1 + R2) C, then the frequency f is given by

f = 1 / T = 1 / 0.693 * (R1 + 2R2) C

f = 1.44/((R1 + 2R2) C) Hz

Selection R1, R2 and C1 for different ferquency range are as follow:

R1 and R2 should be in the range 1k to 1M . It is best to Choose C1 first (because capacitors are available in just a few values) as per the frequency range from the following table. Choose R2 to give the frequency (f) you require.

R2 = 0.7 /(f × C1)

Choose R1 to be about a tenth of R2 (1k min.)

C1	R2 = 10kΩ R1 = 1kΩ	R2 = 100kΩ R1 = 10kΩ	R2 = 1MΩ R1 = 100kΩ
0.001μF	68kHz	6.8kHz	680Hz
0.01μF	6.8kHz	680Hz	68Hz
0.1μF	680Hz	68Hz	6.8Hz
1μF	68Hz	6.8Hz	0.68Hz
10μF	6.8Hz	0.68Hz (41 per min.)	0.068Hz (4 per min.)