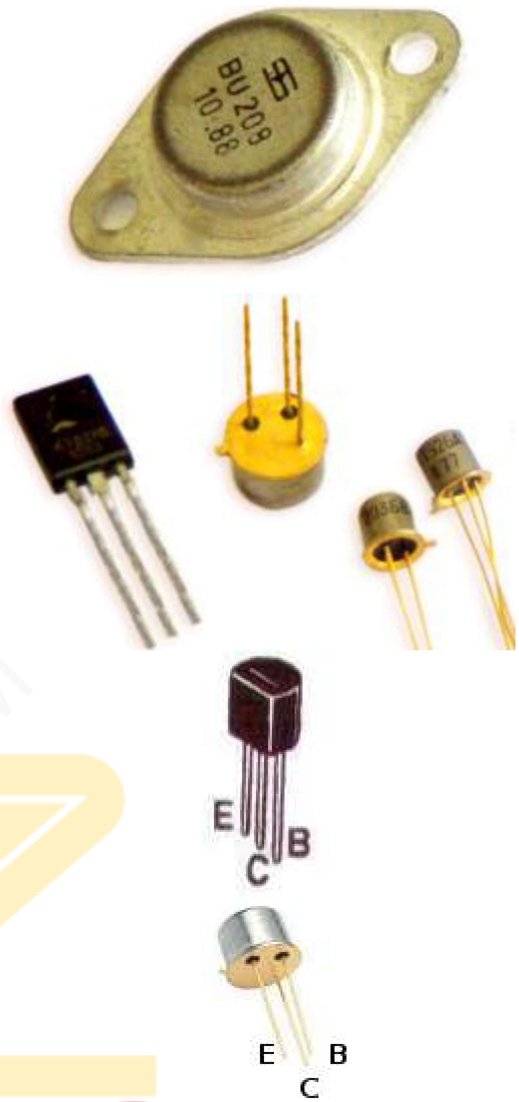
Module – 4 BJT Applications, Feedback Amplifiers and Oscillators

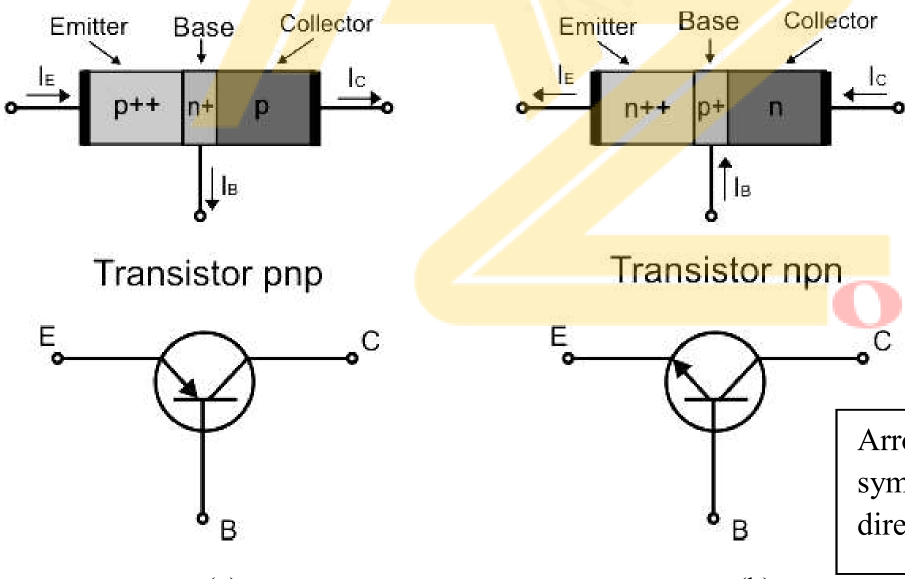


4.1 Introduction

Transistor means, transfer resistor. So, named because it transfers the signal from the region of low resistance to the region of high resistance. Transistor is a three layered - two PN junction semiconductor device. The three layers are called the emitter (E), base (B) and collector (C). It is also called as Bipolar Junction Transistor (BJT): because, both electrons and holes contribute to current in the device. This current controlled device is invented in 1948 by Shockley, Bardeen, and Brattain at Bell Laboratories.
BJT can act as an electrically controlled switch, or a current amplifier depending upon junction biasing condition. There are two types of BJT: NPN and PNP. The NPN type consists of two N-regions separated by a P-region. The PNP type consists of two P-regions separated by an N-region. The details of three regions of the transistor can be summarized as below.

Region	Function	Doping level	Physical Area
Emitter (E)	Emits or injects the majority carriers	high	Moderate
Base (B)	Controls the flow of the majority carriers	light	Thin
Collector (C)	Collects the majority carriers	Moderate	Large

Doping level of the Emitter is made high because its function is to emit the majority carriers. Base is thin and lightly doped because it has to control the flow of majority carriers with least recombination. Physical area of the collector is large because it must dissipate more heat while collecting the majority carriers. Structure and circuit symbol of PNP and NPN transistors are shown in the fig. 4.1.



Arrow head in the circuit symbol shows the conventional direction of current flow

(a) (b)

Fig. 4.1 (a) Structure and circuit symbol of PNP (b) Structure and circuit symbol of NPN transistor

4.2 BJT in CE mode: As a voltage Amplifier

The CE amplifier is designed so that a small change in input voltage, results large changes at the output due to small current in the Base (ΔI_B) of the transistor made large changes in the Collector current (ΔI_C). That means, the small swings in the input produce large changes in the output.

Amplifier is the circuit that increases the strength of a weak signal, is as shown in fig. 4.2.

Let V_{in} be a small AC input voltage signal applied to the Base of the NPN transistor connected in the CE mode in series with the bias source V_{BB}.

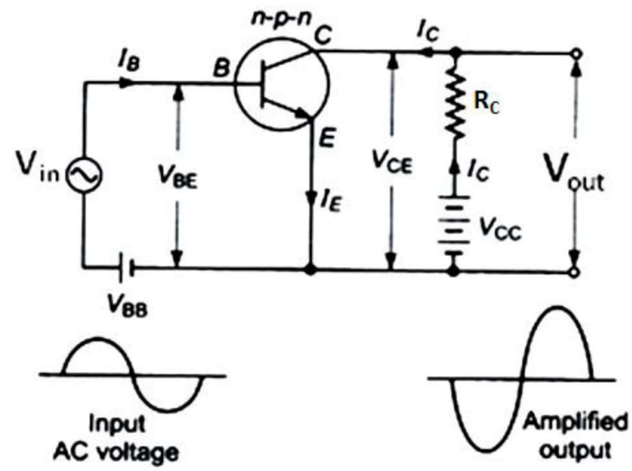


Fig. 4.2 Biased NPN transistor in CE mode as a voltage Amplifier

- **During positive half cycle of V_{in}:** Input voltage to the transistor is (V_{BB} + V_{in}). This makes input more forward bias. Increasing I_B, causes exponential increase in I_C and it is $I_C = \beta I_B$.
- As I_C rises, voltage drop across R_C increases and V_{CE} drops toward ground ($V_{CE} = V_o = V_{CC} - I_C R_C$). As a result, output voltage V_o (= V_{CE}) is a negative swing.
- **During negative half cycle of V_{in}:** Input voltage to the transistor is (V_{BB} - V_{in}). This makes input less forward bias. Decreasing I_B, causes decrease in I_C.
- As I_C drops, voltage drops across R_C also decreases and V_{CE} rises toward V_{CC} ($V_{CE} = V_o = V_{CC} - I_C R_C$). As a result, output voltage V_o (= V_{CE}) is a positive swing.
- In this way small swings in the input produce large changes in the output. Since the output signal goes negative when the input is positive, input and output signals are 180^o out of phase.
- **β** is *current gain* defined as the ratio of the Collector current I_C to the Emitter current I_B. $\beta \approx \frac{I_C}{I_B}$

  Voltage gain is given by, $A_V = \frac{V_{out}}{V_{in}}$

Characteristics:

1. Large current gain, voltage gain and power gain
2. Voltage phase shift is about 180^0
3. Moderate input and output impedance

Transistor Voltages and currents

PNP and NPN Transistor voltages and currents are described in the fig.4.3.

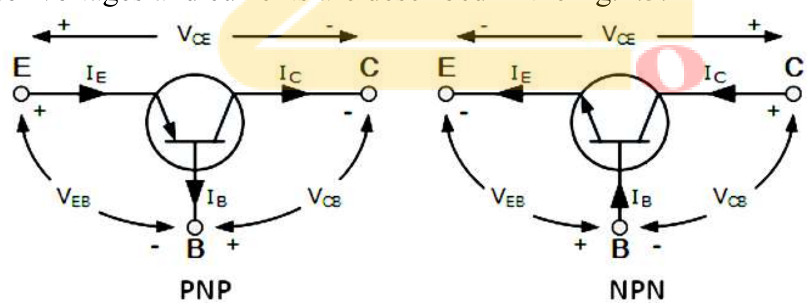


Fig. 4.3 PNP and NPN Transistor Voltages and currents

Table 2 Notations and meanings of PNP and NPN Transistor Voltages and currents

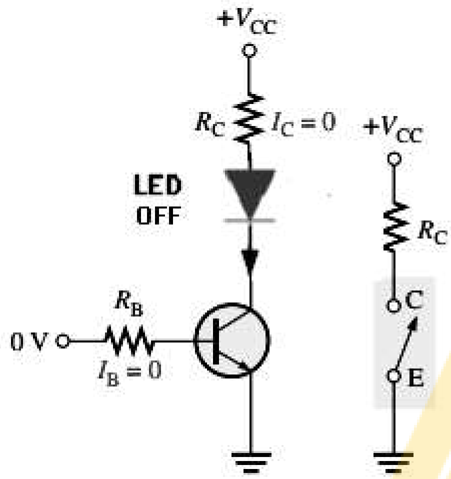
Transistor voltages		Transistor Currents
Between transistor terminals	**Between terminal and ground**	**Through terminals**
V_{CE} = Voltage between Collector-Emitter	V_E = Emitter Voltage	I_E = Emitter Current
V_{CB}= Voltage between Collector-Base	V_B = Base Voltage	I_B = Base Current
V_{EB}= Voltage between Emitter-Base	V_C = Collector Voltage	I_C = Collector Current

4.3 Transistor as a switch

A BJT works as a switch when it is alternately driven between the *saturation region* and *cutoff regions*. A simple version of the switch is shown in fig. 4.4(a) and (b).

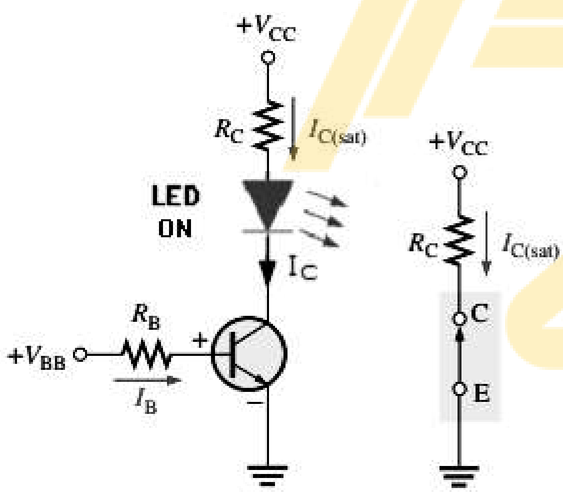
Cut-off Characteristics: When the input equals 0V, the BE junction is reverse biased (OFF), so no current flows in the circuit; hence transistor works as open switch.

Saturation Characteristics: When the input equals $+V_{BB}$, the BE junction is forward biased (ON), so current flows in the circuit; hence transistor works as closed switch.



(a) Cutoff — open switch

- The input = 0V, hence $I_B = 0$, in turn $I_C = 0$
- Base-Emitter voltage $V_{BE} < 0.7V$
- BE and BC junctions are reverse biased
- $I_C = 0$, thus $V_{CE} = V_{CC}$
- Transistor is "fully-OFF" (Cut-off region) and operates as a "**open switch**"



(b) Saturation — closed switch

- The input is $+V_{in} = V_{BB}$, Base current I_B flows
- Base-Emitter voltage $V_{BE} > 0.7V$
- BE and BC junctions are forward biased
- Maximum Collector current flows ($I_C = Vcc/R_L$) and $V_{CE} = 0$, (No voltage drop)
- Transistor is "fully-ON" (saturation region) and operates as a "**closed switch**"

Fig4.4. Transistor as a switch (a) open switch (b) Closed switch

4.4 Transistor Switch Circuit Using Relay

Electromechanical relays are switches used to control high power electrical devices or load (electric lamp, motor, etc). It is possible to control the relay operation using a transistor as a switch. When a transistor is able to energize a coil of the relay, so that the external load connected to it is controlled. The fig.4.5, illustrates transistor switch circuit to switch ON/OFF an LED and a LAMP in a power circuit using a relay.

Consider the fig.4.5 (a) illustrates a transistor switch circuit used to switch ON/OFF an LED using the relay coil. The input (+ V) applied at the Base causes to drive the transistor into *saturation region*, which further results the circuit becomes short circuit. So the relay coil gets energized and relay contacts get operated and LED turned ON. Similarly, fig.4.5 (b) illustrates a transistor switch circuit used to switch ON/OFF a *lamp* using the relay coil.

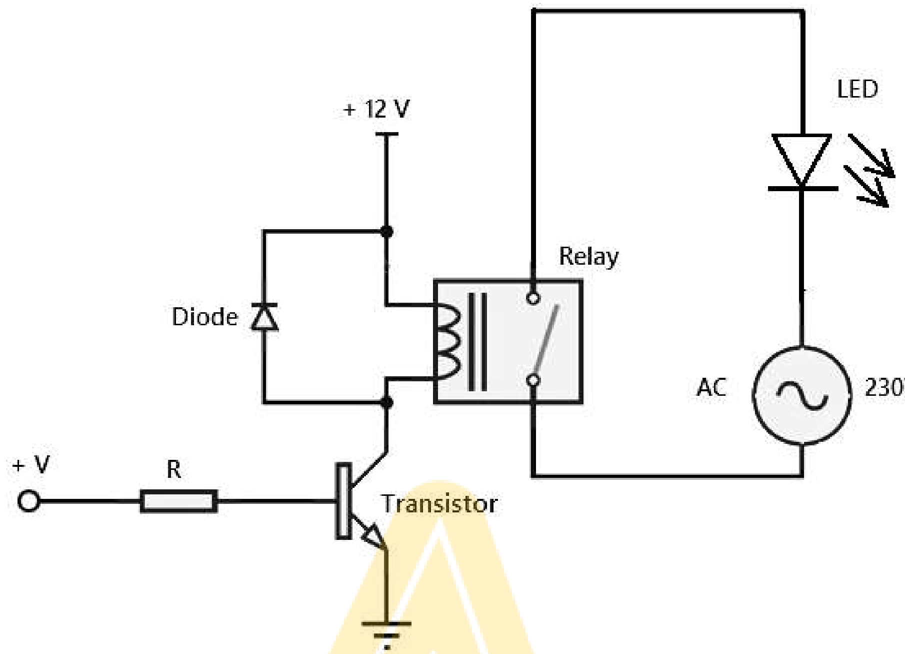


Fig.4.5 (a) illustrates a transistor switch circuit used to switch ON/OFF an LED using the relay

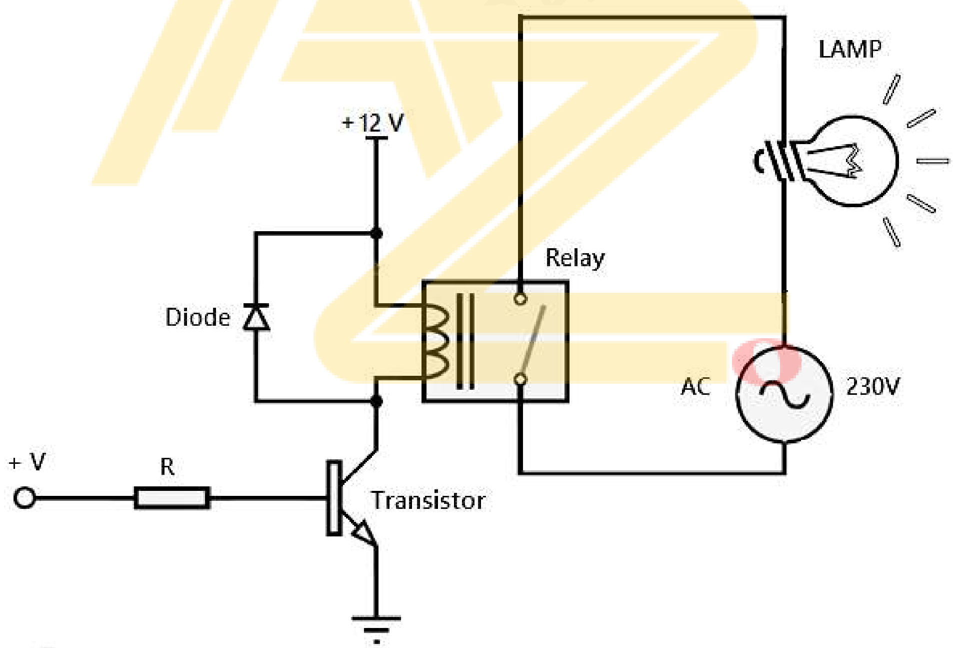


Fig. 4.5(b) illustrates a transistor switch circuit used to switch ON/OFF an LAMP using the relay

In inductive loads, particularly switching of motors and inductors, sudden removal of power can induce a high potential across the coil. This high voltage can cause considerable damage to the rest circuit. Therefore, the diode is connected in parallel with inductive load to protect the circuit from induced voltages.

4.5 Feedback Amplifiers

Feedback Systems are very useful and widely used in amplifier circuits, oscillators, process control systems as well as other types of electronic systems. A feedback system is one in which a fraction of the output signal is sampled and then fed back to the input to form an error signal that drives the system.

4.5.1 Principle of Feedback Amplifier

A feedback amplifier generally consists of two parts. They are the **amplifier** and the **feedback circuit**. The Feedback circuit is essentially a potential divider consisting of resistances R_1 and R_2. The purpose of feedback circuit is to return a fraction of the output voltage to the input of the amplifier circuit. The concept of feedback amplifier can be understood from the following fig.4.6.

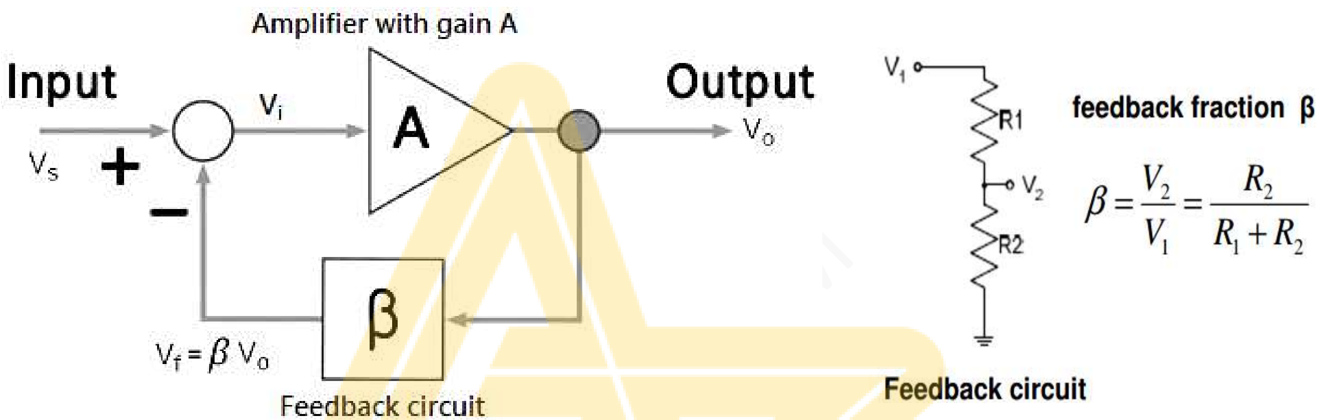


Fig. 4.6 Principle of Feedback Amplifier

From the fig.4.6 the gain of the amplifier is represented as A and defined as the ratio of output voltage V_o to the input voltage V_i. The gain of the feedback circuit is represented as β and extracts a voltage $V_f = \beta\ V_o$ from the output V_o of the amplifier. The quantity $\beta = V_f/V_o$ is called as feedback ratio (fraction).

This voltage is added for positive feedback and subtracted for negative feedback, from the signal voltage Vs. Now,

$$Vi = Vs + V_f = Vs + \beta Vo \text{ (positive feedback)}$$

$$Vi = Vs - V_f = Vs - \beta Vo \text{ (negative feedback)}$$

4. 5. 2 Types of Feedbacks

Depending upon whether the feedback signal **aids** or **opposes** the input signal, there are two types of feedbacks used.

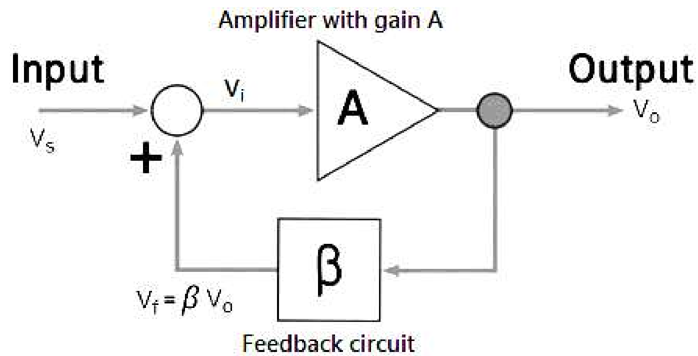
1) Positive Feedback

Positive feedback is when output is *added* to the input (via feedback) and amplified again. In this case, the feedback signal (voltage or current) is in phase with the input signal. Both the input signal and feedback signal introduces a phase shift of 180° thus making a 360° resultant phase shift around the loop, to be finally in phase with the input signal.

Though the positive feedback **increases the gain** of the amplifier, it has the disadvantages such as Increasing distortion and instability

Though the positive feedback **increases the gain** of the amplifier, it has the disadvantages such as

- Increasing distortion and
- instability



It is because of these disadvantages the positive feedback is not recommended for the *amplifiers*. If the positive feedback is sufficiently large, it leads to oscillations, by which *oscillator circuits* are formed. Let A_f be the overall gain (gain with the feedback) of the amplifier. This is defined as the ratio of output voltage V_o to the applied signal voltage V_s, i.e.,

$$A_f = \frac{Output\ voltage}{Input\ signal\ voltage} = \frac{V_o}{V_s}$$

The equation of gain of the feedback amplifier, with positive feedback is given by

$$(Vs + \beta Vo)\ A = Vo\ (Vs + \beta Vo)\ A = Vo$$

Or

$$AVs + A\ \beta Vo = Vo\ AVs + A\ \beta Vo = Vo$$

Or

$$AVs = Vo\ (1\text{-}A\beta)\ AVs = Vo\ (1\text{-}A\beta)$$

$$\frac{V_o}{V_s} = A_f = \frac{A}{1 - A\beta}$$

2) Negative Feedback

Negative feedback is when the output is subtracted from the input. In this case, the feedback signal (voltage or current) is out of phase with the input signal. In negative feedback, the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it produces no phase shift or zero phase shift. Thus the resultant feedback voltage V_f is 180° out of phase with the input signal V_{in}. The output V_o must be equal to the input voltage (V_s - βV_o) multiplied by the gain A of the amplifier. Hence,

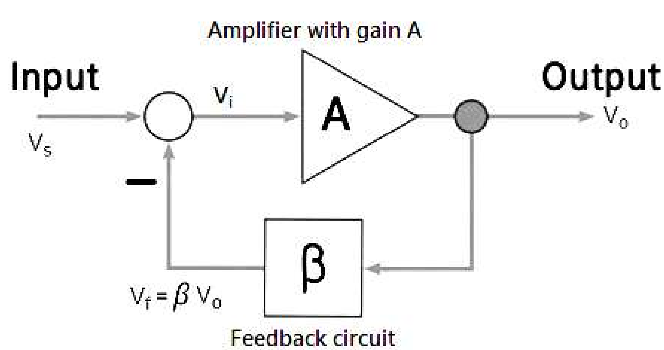
$$(Vs - \beta Vo)\ A = Vo\ (Vs - \beta Vo)\ A = Vo$$

Or

$$AVs - A\ \beta Vo = Vo\ AVs - A\ \beta Vo = Vo$$

Or

$$AVs = Vo\ (1+A\beta)\ AVs = Vo\ (1+A\beta)$$



Therefore, the equation of gain of the feedback amplifier, with negative feedback is given by

$$\frac{V_o}{V_s} = A_f = \frac{A}{1 + A\beta}$$

Though the gain of negative feedback amplifier is reduced, there are many ***advantages.***

Advantages of negative feedback

- Stability of gain is improved
- Reduction in distortion
- Reduction in noise
- Bandwidth increases
- Non linear distortion decreases – improves higher fidelity
- Increase in input impedance
- Decrease in output impedance

It is because of these advantages negative feedback is frequently employed in ***amplifiers***.

Disadvantages of negative feedback

- Overall amplifier gain is reduced.
- Unstable and oscillate at high frequencies.

4.6 Properties of Feedback amplifiers

1. Reduced gain
2. Increased bandwidth
3. Increased stability
4. Decreased Noise
5. Modified Input impedance and Output Impedance

4.7 Classification of Feedback Systems (types of feedback topologies)

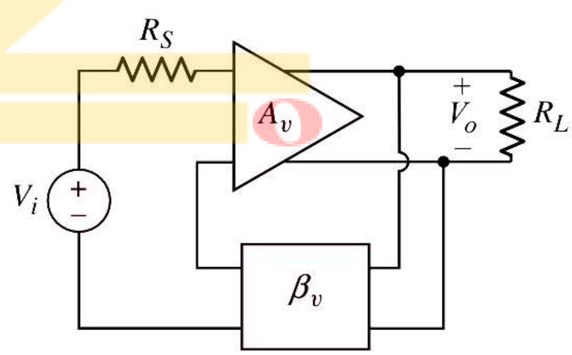
There are four different types of feedback topologies based on type of output signal and feedback signal (voltage or current signal). Voltage feedback is taken in series with the load and current feedback is taken in shunt with the load.

1. Voltage-series or series-shunt feedback

Voltage in and Voltage out or *Voltage Controlled Voltage Source* (VCVS).

Works as a voltage amplifier as the input signal is a voltage and the output signal is a voltage, so the transfer gain is given *as:*

$$Av = Vo / Vi.$$

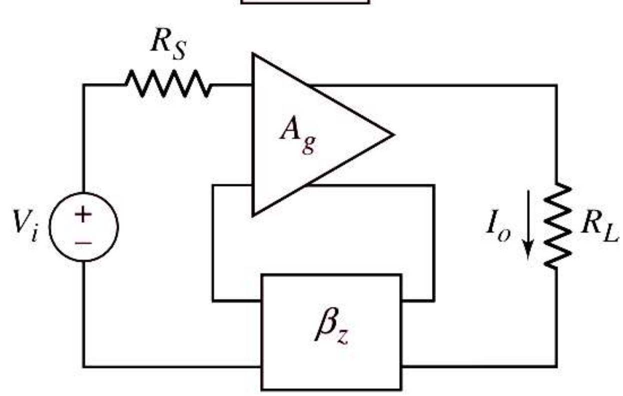


2. Current-series or series-series feedback

Voltage in and Current out or *Voltage Controlled Current Source* (VCCS).

Works as trans-conductance type amplifier system as the input signal is a voltage and the output signal is a current. then for a series-series feedback circuit the transfer gain is given as:

$$Gm = Io / Vi.$$

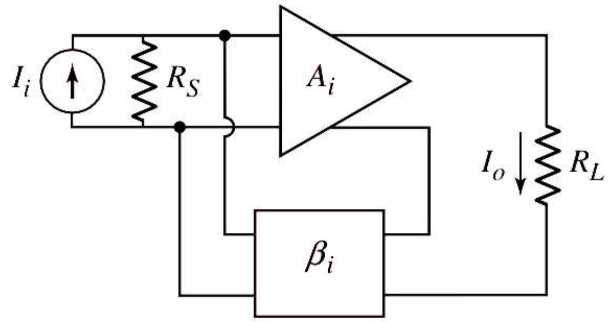


3. Current-shunt or shunt-series feedback

Current in and Current out or *Current Controlled Current Source* (CCCS).

Works as a true current amplifier as the input signal is a current and the output signal is a current, so the transfer gain is given as:

Ai = Io / Ii.

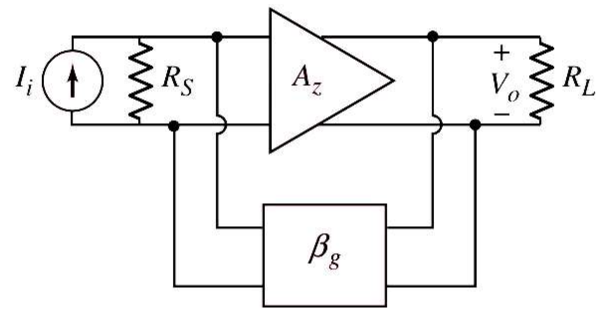


4. Voltage-shunt or shunt-shunt feedback

Current in and Voltage out or *Current Controlled Voltage Source* (CCVS).

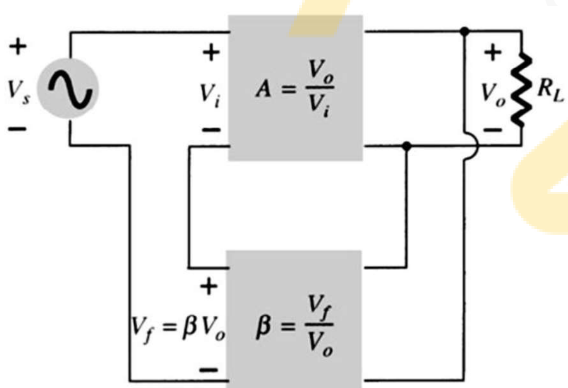
Works as trans-resistance type voltage amplifier as the input signal is a current and the output signal is a voltage, so the transfer gain is given as:

Rm = Vo / Ii.



4.8 Voltage-Series Feedback

The input voltage Vi of the basic amplifier is the algebraic sum of input signal Vs and the feedback signal Vo , where Vo is the output voltage. In this case, feedback connection with a part of the output voltage V_0 fed back in series with the input signal V_s.



If there is no feedback ($V_f = 0$), the voltage gain of the amplifier is

$$A = \frac{V_o}{V_s} = \frac{V_o}{V_i}$$

If a feedback signal V_f is connected with the input in series, the overall voltage gain is

$$A_f = \frac{V_o}{V_s} = \frac{A}{1+\beta A}$$

Input Impedance with the feedback is: $z_{if} = \frac{V_s}{I_i}$

$V_S = I_i Z_i + V_f = I_i Z_i + \beta Vo$

Using voltage divider rule, we get: $V_o = A_v V_i \frac{Z_i}{Z_o + Z_L}$

Let, $I_i =$

Now, $Vo = A_V I_i Z_L = A_V V_i$

Gain, $A_V = \frac{V_o}{I_i}$ *Input impedance,* $Z_i = \frac{V_i}{I_i}$

4.9 Gain Stability with feedback

The gain, A of the basic amplifier depends generally on certain factors (temperature, parameters of active devices, OP, etc.).

$$A_f = \frac{A}{1 + \beta A}$$

Differentiating,

$$\frac{dA_f}{dA} = \frac{(1 + \beta A) - \beta A}{(1 + \beta A)^2} = \frac{1}{(1 + \beta A)^2}$$

$$\frac{dA_f}{dA} = \frac{A}{1 + \beta A} \cdot \frac{1}{A} \cdot \frac{1}{1 + \beta A}$$

$$\frac{dA_f}{dA} = A_f \cdot \frac{1}{A} \cdot \frac{1}{1 + \beta A}$$

$$\frac{dA_f}{A_f} = \frac{1}{1 + \beta A} \cdot \frac{dA}{A}$$

Where, *dAf /Af = fractional change in gain with the feedback;*
dA/A = fractional change in gain without the feedback.

$$If\ \beta A \gg 1, \qquad \frac{dA_f}{A_f} = \frac{1}{\beta A} \cdot \frac{dA}{A}$$

$(1 + \beta A)$ = de-sensitivity (reciprocal of sensitivity*) indicates the fraction* by *which the voltage gain has been* reduced due to feedback.

4.10 Oscillators – Barkhausen's criteria for oscillation

An **oscillator** is a circuit that produces a periodic waveform on its output using only the DC supply voltage (V_{CC}) as an input.
A transistor amplifier with *proper* positive feedback can act as an oscillator. That means, it can generate oscillations without any external signal source. The necessary conditions for oscillations is shown in the fig. 4.7.

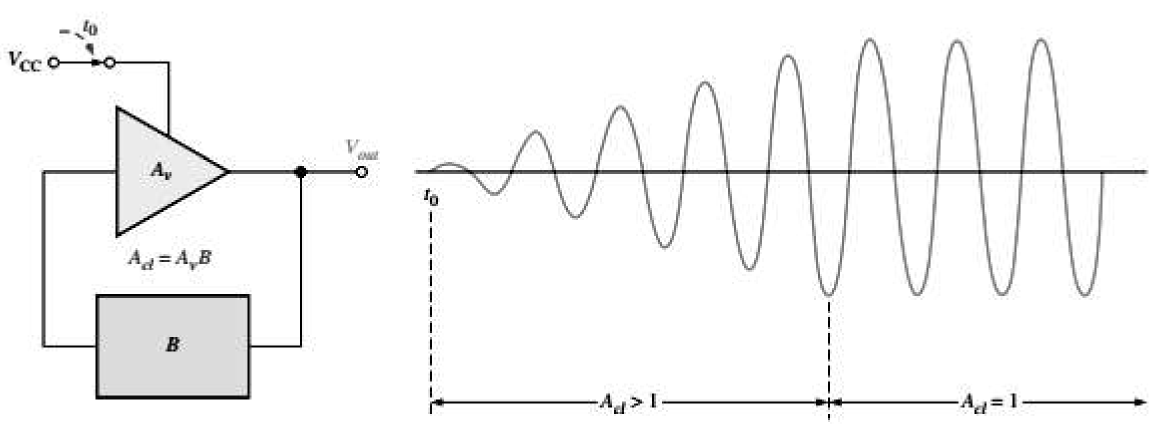


Fig. 4.7Conditions for Oscillation

Barkhausen Criterion or Conditions for Oscillation

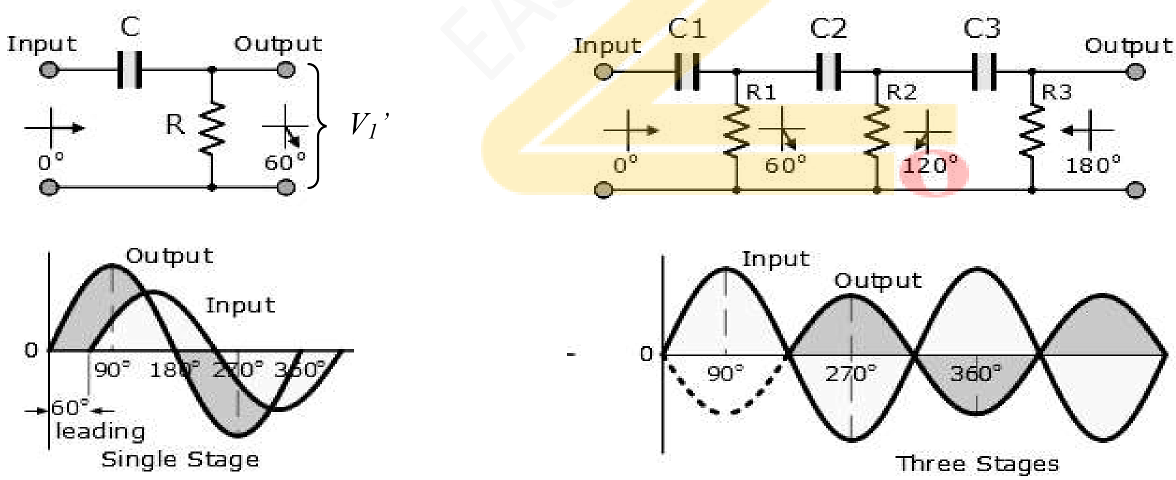
Two conditions are required for a sustained state of oscillation:

1. The phase shift around the feedback loop must be 0° or 360°.
2. The voltage gain, $A_{cl,}$ around the closed feedback loop must be unity (i.e, loop gain, $A_v \beta = 1$).

The voltage gain around the closed feedback loop, is the product of the amplifier gain, and the feedback factor, β, of the feedback circuit. $A_{cl} = A_v \beta$
As illustrated in the fig.4.7, when oscillation starts at t_0, the condition $A_{cl} > 1$ causes the sinusoidal output voltage amplitude to build up to a desired level. Then A_{cl} decreases to 1 and maintains the desired amplitude.

4.11 R-C phase shift oscillator

Good frequency stability and waveform can be obtained from oscillators employing resistive and capacitive elements. Such amplifiers are called *R-C* or *phase shift oscillators* and have the additional advantage that they can be used for very low frequencies. In a phase shift oscillator, a phase shift of 180° is obtained with a phase shift circuit instead of inductive or capacitive coupling. A further phase shift of 180° is introduced due to the transistor properties.
Fig.4.8 (a) shows a single section of *RC* network. From the elementary theory of electrical engineering, it can be shown that alternating voltage V_1' across R *leads* the applied voltage V_1 by ø°. The value of ø depends upon the values of R and C. If resistance R is varied, the value of ø also changes. If R were reduced to zero, V_1' will lead *input voltage* by 90° *i.e.* ø = 90°. However, adjusting R to zero would be impracticable because it would lead to no voltage across R. Therefore, in practice, R is varied to such a value that makes V'_1 to lead *input voltage* by 60°. Similarly as shown in fig.4.8 (b) for three RC stages output lead the *input voltage* by 180°.



(a) (b)

Fig. 4.8 RC phase shift network. (a) *RC single* section producing 60° phase shift (b) RC three sections producing 180° phase shift.

As shown in the fig. 4.9, RC Phase shift oscillator consists of an opamp and a *RC* phase shift network. The phase shift network consists of three *RC* sections. At some particular frequency f_0, the phase shift in each *RC* section is 60° so that the total phase-shift produced by the *RC* network is 180°.

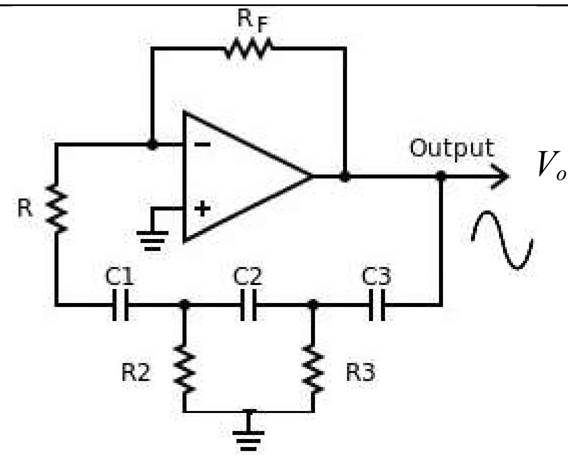


Fig.4.9 R-C phase shift oscillator

The frequency of oscillations is given by:

$$\text{Frequency of oscillation, } f_o = \frac{1}{2\pi RC\sqrt{2N}} = \frac{1}{2\pi RC\sqrt{2X3}} = \frac{1}{2\pi RC\sqrt{6}}$$

N = number of RC stages,
$R_1 = R_2 = R_3 = R$
$C_1 = C_2 = C_3 = C$ ………………(i)

Circuit operation:

When the circuit is switched on, it produces oscillations of frequency determined by eqn. (i). The output V_0 of the OPAMP is fed back to RC feedback network. A phase shift of 180º is produced by OPAMP. A further phase shift of 180º is produced by the RC network. As a result, the phase shift around the entire loop is 360º. This satisfies one of the Barkhausen's criteria. Another criterion is *loop gain*, $|A\beta| \geq -1$.

$$Frequency\ of\ oscillation\quad \omega_o \quad f_o = \frac{1}{2\pi RC\sqrt{6}}\ ; \quad \omega_o = \frac{1}{RC\sqrt{6}}$$

$$\text{For oscillations to occur,} \quad |\beta| > \frac{1}{29}\ ; or\ \beta = -\frac{1}{29}\ (-ve\ indicates\ 180^o\ phase\ shift)$$

$$Gain\ of\ OPAMP\ is, \quad A = -\frac{R_F}{R}$$

$$A\beta = -\frac{1}{29}\left(-\frac{R_F}{R}\right) = \frac{R_F}{29R} > 1$$

$$R_F > 29R$$

RC Oscillators are constant and provide a well shaped sine wave output with the frequency being proportional to 1/RC and therefore, when we are using a variable capacitor a wide frequency range is possible.

Advantages

(i) It does not require transformers or inductors.
(ii) It can be used to produce very low frequencies (starting at a few Hertz and up to about 100 kHz).
(iii) The circuit provides good frequency stability.

Disadvantages

(*i*) It is difficult for the circuit to start oscillations as the feedback is generally small.

(*ii*) The circuit gives small output.

4.12 Wien Bridge oscillator

A Wien bridge oscillator is an oscillator that generates sine waves with a wide range of frequencies. The bridge comprises four resistors and two capacitors. Wien bridge oscillator using RC bridge and OPAMP is shown in the fig.4.10.

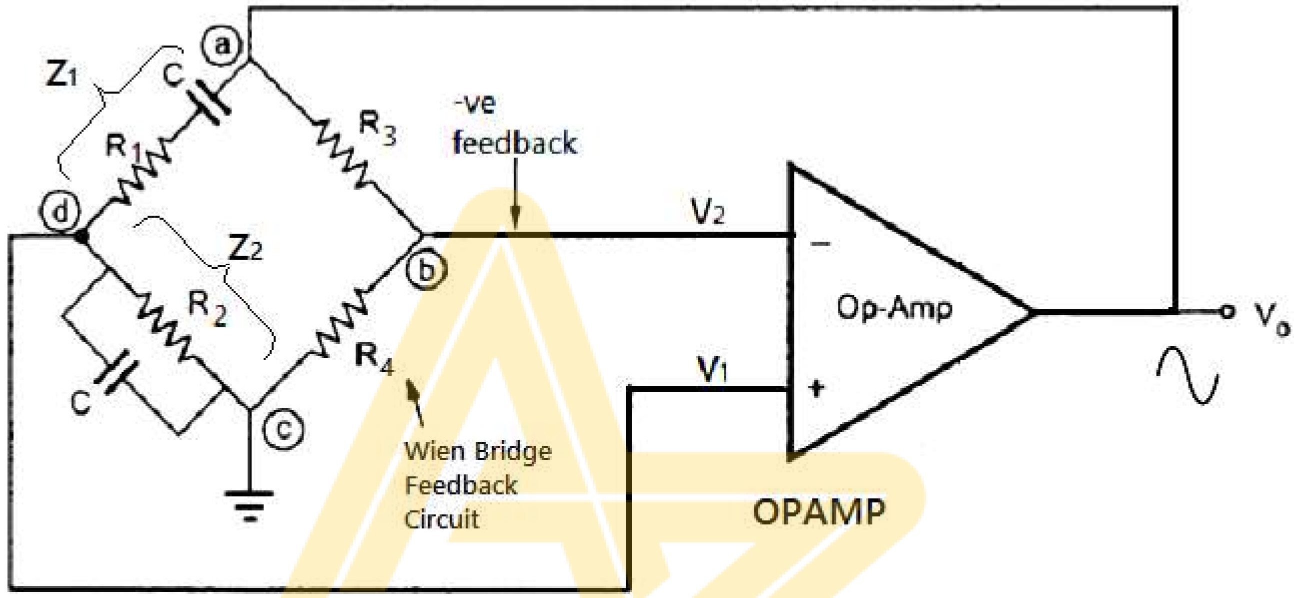


Fig.4.10 Wien bridge oscillator using RC bridge and OPAMP

Circuit operation

When the circuit is switched on, there exists a particular frequency at which the values of the resistance and the capacitive reactance will become equal to each other, producing maximum output voltage. This frequency is referred to as resonant frequency which is given as

$$f_o = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}} = \frac{1}{2\pi\sqrt{RC}}\ ; if\ \ R_1 = R_2 = R\ and\ C_1 = C_2 = C \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

The output V_0 of the OPAMP is fed back to *Wien* bridge feedback circuit with respect to points ***a*** and ***c***. Points ***b*** and ***d*** provide – ve and + ve inputs to the OPAMP. A phase shift of 180º is produced by inverting OPAMP. A further phase shift of 180º is produced by the *RC* feedback bridge circuit. As a result, the phase shift around the entire loop is 360º. This satisfies one of the Barkhausen's criteria.

For oscillations, Barkhausen's other criterion: loop gain, is $A\beta = -1$.

$$\text{Forward gain at inverting terminal of OPAMP is,} \qquad A = -\frac{V_o}{V_2} = -\left[1 + \frac{R_3}{R_4}\right]$$

$$\text{Feedback gain at non} - \text{inverting terminal of OPAMP is,} \qquad \beta = \frac{V_o}{V_i} = \left[\frac{Z_2}{Z_1 + Z_2}\right]$$

Let, $\qquad | A\beta | = 1$

$$\left[1+\frac{R_3}{R_4}\right]\left[\frac{Z_2}{Z_1+Z_2}\right]=1$$

From the Wien bridge $Z_1 = R + \frac{1}{j\omega C}, Z_2 = \frac{1}{\frac{1}{R}+j\omega C}$

Also, $\omega = \omega_o = \frac{1}{RC}$

We get condition, $\frac{1}{3}\left[1+\frac{R_3}{R_4}\right]=1$

Solving, $\boldsymbol{R_3 = 2R_4}$

Thus ratio of resistances will provide sufficient loop gain for the circuit to oscillate at the frequency of Eqn. (ii).

Applications of Wien Bridge Oscillators

- To measure the audio frequency
- As a band-pass filter to amplify the 19KHz pilot carrier from FM audio
- To produce sine wave
- For finding the exact value of the capacitor
- For generating 0^o phase

Advantages

- By varying capacitances the frequency of oscillation can be easily varied
- Excitation for AC Bridge
- To fabricate pure tune
- Useful audio frequency range (20 Hz to 100 kHz)

Disadvantages

- Maximum frequency output is limited because of amplitude and phase shift characteristics of the amplifier
- The design is bulky

4.13 IC 555 Timer

IC 555 timer mainly consists three sections: (see fig. 4.11(b)).

1. **Comparator:**

The two OPAMP Comparators are compare the two input voltages i.e. between the inverting (-) and the non-inverting (+) input and if the non-inverting input is more than the inverting input then the output of the comparator is high.

2. **A resistive network:**

It is formed by three equal resistors (5 KΩ - the IC bears its name as 555 timer). These are arranged in voltage divider configuration and as a result provide the voltage values of 2⁄3 V_{CC} and 1⁄3 V_{CC}.

3. **Flip/Flop (FF):**

FF is a memory element that operates as

R = 1, S = 0, output = 0 and R = 0, S = 1, output = 1.

The output of comparators is directly given to the inputs of SR Flip Flop. Thus the output of the SR Flip Flop will be set according to the outputs of the comparator which in turn depends on the Trigger and Threshold inputs.

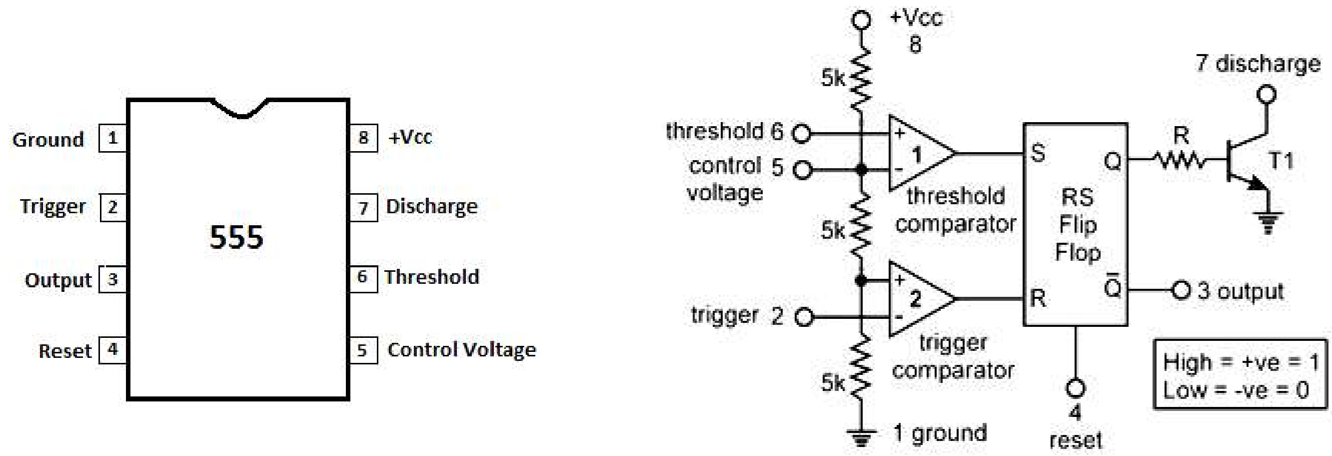


Fig.4.11 (a) IC 555 timer (b) internal circuitary

Table: Function of different Pins

Pin No.	Name	Function
1	Ground	Used to provide a zero voltage.
2	Trigger	A low voltage (less than 1/3 the supply voltage) applied momentarily to the Trigger input causes the output (pin 3) to go high. The output will remain high until a high voltage is applied to the Threshold input (pin 6).
3	Output	This is the output pin of the timer. It can source or sink 200 mA of current.
4	Reset	A low voltage (< 0.7V) applied to this pin will cause the output (pin 3) to go LOW. This input should remain connected to +Vcc when not used.
5	Control Voltage	This pin can be used to change the reference voltages of the comparators through this we can vary the timing.
6	Threshold	When the voltage at this input rises above the threshold value (V_{th}) the output will go from high to low.
7	Discharge	When the voltage across the timing capacitor exceeds the threshold value. The timing capacitor is discharged through this input.
8	Supply Voltage	Positive supply voltage terminal is usually between +5V and +15V.

Applications

As an Oscillator (Mono-stable, Astable or in Bistable mode to produce a flip/flop type action)

In Pulse Amplitude Modulation (PAM),

Pulse Width Modulation (PWM) etc.

4.14 Astable Oscillator using IC 555

The astable multi-vibrator is a free running oscillator that generates a continuous rectangular ON/OFF pulses that switch between two voltage levels. The frequency of the pulses and their duty cycle are dependent upon the RC values of the circuit.

Working:

From the fig.4.12, assume the Flip Flop is initially cleared, when the power is switched ON, then the output of inverter will be HIGH.

Case -1: When output is HIGH

The capacitor C charges towards V_{cc} through the series resistors R_1 and R_2 (see fig. 4.13). The charging time constant $T_C = 0.693\ (R_1 + R_2)\ C$. Where, R_1 and R_2 are in Ω and C in Farads. As voltage across the capacitor is just greater than 2/3 Vcc, upper comparator sets Flip Flop and output goes LOW.

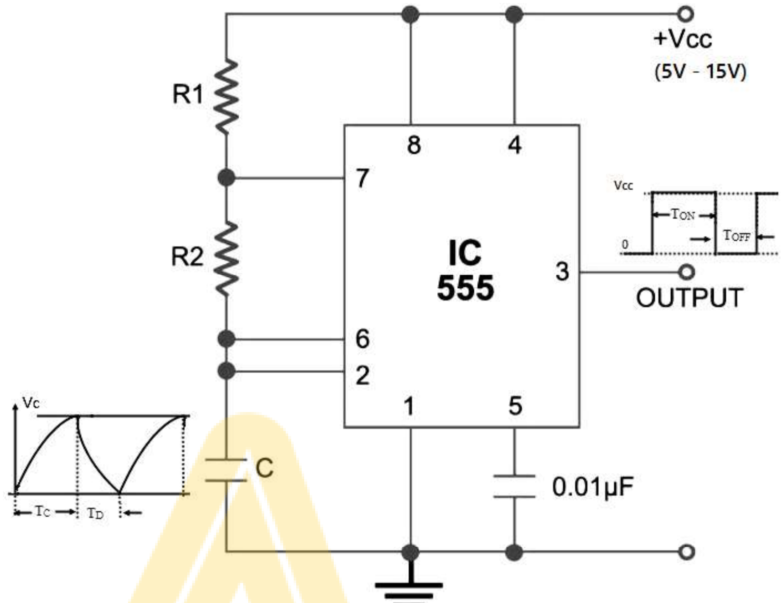


Fig.4.12 Astable Oscillator using IC 555

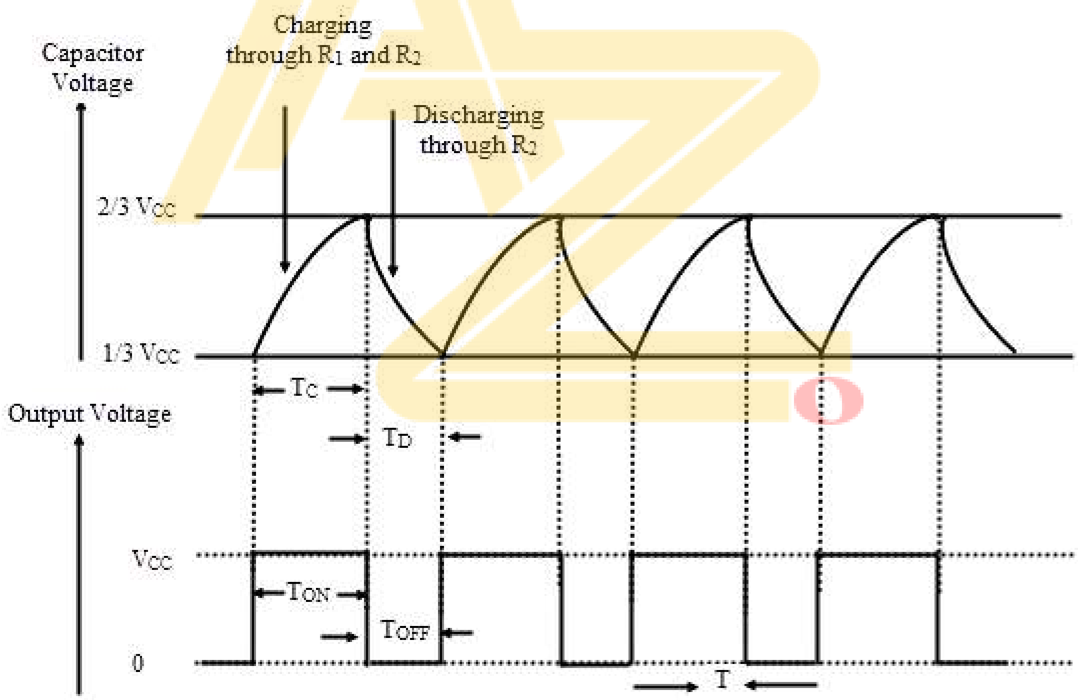


Fig.4.13 Astable Oscillator waveforms using IC 555

Case -2: When output is LOW

The capacitor C discharges through resistors R_2. The discharging time constant $T_C = 0.693\ (R_1 + R_2)\ C$. As voltage across the capacitor is slightly lesser than 1/3 Vcc, lower comparator resets Flip Flop and output goes HIGH.

Since, $T_C > T_D$, output wave form is a rectangular pulse train. Total time period of the waveform shown in the fig.4.13 (b) is

T = $T_C + T_D = 0.693\ (R_1 + R_2)\ C + 0.693\ (R_1 + R_2)\ C = 0.693\ (R_1 + 2R_2)\ C$

Frequency of oscillation, $f_o = \dfrac{1}{T} = \dfrac{1.44}{(R_1 + 2R_2)C}$

Duty cycle, $\dfrac{T_{ON}}{T} = \dfrac{(R_1 + R_2)}{(R_1 + 2R_2)}$

The duty cycle 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.

Design: Astable Multi-vibrator using 555

Case – 1: The time during which the capacitor C charges from 1/3 V_{CC} to 2/3 V_{CC} is equal to the time the output is HIGH and is given as T_C or $T_{HIGH} = 0.693\ (R_1 + R_2)\ C$, which is proved below.
Voltage across the capacitor at any instant during *charging* period is given as,

$$V_c = V_{CC}\,(1 - e^{t/RC})$$

i) Time taken by the capacitor to charge from 0 to +1/3 V_{CC}

$V_c = V_{CC}\,(1 - e^{t/RC})$ where $V_c = 1/3\ V_{CC}$

$1/3\ V_{CC} = V_{CC}\,(1 - e^{t/RC})$

$e^{-t/RC} = (1-1/3)$

$e^{-t/RC} = 2/3$

$t_1 = \log_e (3/2)RC$ where $t = t_1$ (Note: $\ln = \log_e$)

$t_1 = 0.405RC$

ii) Time taken by the capacitor to charge from 0 to +2/3 V_{CC}

$2/3\ V_{CC} = V_{CC}\,(1 - e^{t/RC})$
$e^{-t/RC} = (1-2/3)$
$e^{-t/RC} = 1/3$ where $t = t_2$
$t_2 = RC \log_e 3 = 1.0986\ RC$

iii) Time taken by the capacitor to charge from +1/3 V_{CC} to +2/3 V_{CC}

$T_C = (t_2 - t_1) = (1.0986 - 0.405)\ RC = 0.693\ RC$

Substituting R = $(R_1 + R_2)$ in above equation we have

$$\boxed{T_C = 0.693\ (R_A + R_B)\ C}$$

Case -2: The time during which the capacitor discharges from +2/3 V_{CC} to +1/3 V_{CC} is equal to the time the output is low and is given as

$$V_c = 2/3\ V_{CC}\, e^{-Td/R2C}$$

Substituting $V_c = 1/3\ V_{CC}$ and t = t_d in above equation we have

$1/3\ V_{CC} = 2/3\ V_{CC}\, e^{-(Td/R2C)}$

$2 * e^{-(Td/R2C)} = 1,$ apply log_e on both sides,

$log_e 2 - Td/R_2C = 0$

$$\boxed{T_D = 0.693\ R_2C}$$

Applications

1. Square Generator
2. FSK Generator
3. Pulse Position Modulator

Appendix A – Analysis of RC Phase shift Oscillator

- Let us find transfer function of the RC feedback network :

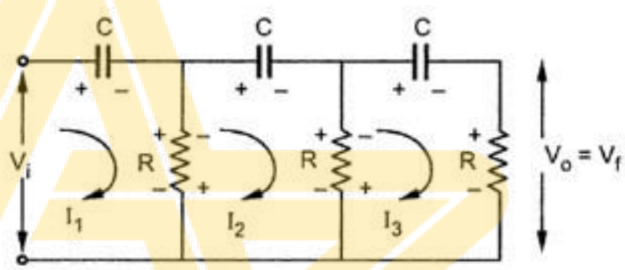


Fig. 2.13

- Applying KVL to various loops we get,

$$I_1\left(R+\frac{1}{j\omega C}\right) - I_2 R = V_i \qquad \ldots (15)$$

$$-I_1 R + I_2\left(2R+\frac{1}{j\omega C}\right) - I_3 R = 0 \qquad \ldots (16)$$

$$0 - I_2 R + I_3\left(2R+\frac{1}{j\omega C}\right) = 0 \qquad \ldots (17)$$

- Replacing jω by s and writing the equations in the matrix form,

$$\begin{vmatrix} R+\frac{1}{sC} & -R & 0 \\ -R & 2R+\frac{1}{sC} & -R \\ 0 & -R & 2R+\frac{1}{sC} \end{vmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_i \\ 0 \\ 0 \end{bmatrix} \qquad \ldots (18)$$

Using the Crammer's rule to obtain I_3

$$D = \begin{vmatrix} \frac{1+sRC}{sC} & -R & 0 \\ -R & \frac{1+2sRC}{sC} & -R \\ 0 & -R & \frac{1+2sRC}{sC} \end{vmatrix}$$

$$= \frac{(1+sRC)(1+2sRC)^2}{s^3 C^3} - \frac{R^2(1+2sRC)}{sC} - \frac{R^2(1+sRC)}{sC}$$

$$= \frac{(1+sRC)(1+4sRC+4s^2C^2R^2) - R^2 s^2 C^2 [1+2sRC+1+sRC]}{s^3 C^3}$$

$$= \frac{1+5sRC+8s^2C^2R^2+4s^3C^3R^3-3s^3R^3C^3-2R^2s^2C^2}{s^3C^3}$$

$$= \frac{1+5sRC+6s^2C^2R^2+s^3C^3R^3}{s^3C^3} \qquad \dots (19)$$

$$D_3 = \begin{vmatrix} \frac{1+sRC}{sC} & -R & V_i \\ -R & \frac{1+2sRC}{sC} & 0 \\ 0 & -R & 0 \end{vmatrix}$$

$$= V_i R^2 \qquad \dots (20)$$

$$\therefore \quad I_3 = \frac{D_3}{D} = \frac{V_i R^2 s^3 C^3}{1+5sRC+6s^2C^2R^2+s^3C^3R^3}$$

Now $$V_o = V_f = I_3 R = \frac{V_i R^2 s^3 C^3}{1+5sRC+6s^2C^2R^2+s^3C^3R^3} \qquad \dots (21)$$

$$\therefore \quad \beta = \frac{V_o}{V_i} = \frac{R^3 s^3 C^3}{1+5sCR+6s^2C^2R^2+s^3C^3R^3} \qquad \dots (22)$$

Replacing s by $j\omega$, s^2 by $-\omega^2$, s^3 by $-j\omega^3$

$$\therefore \quad \beta = \frac{-j\omega^3R^3C^3}{1+5j\omega CR-6\omega^2C^2R^2-j\omega^3C^3R^3}$$

Dividing numerator and denominator by $-j\omega^3R^3C^3$ and replacing $\frac{1}{\omega RC}$ by α we get,

$$\therefore \quad \beta = \frac{1}{1+6j\alpha-5\alpha^2-j\alpha^3}$$

$$\therefore \quad \boxed{\beta = \frac{1}{(1-5\alpha^2)+j\alpha(6-\alpha^2)}} \quad \ldots (23)$$

To have phase shift of 180°, the imaginary part in the denominator must be zero.

$$\therefore \quad \alpha(6-\alpha^2) = 0$$

$$\therefore \quad \alpha^2 = 6 \quad \text{neglecting zero value}$$

$$\boxed{\alpha = \sqrt{6}}$$

$$\therefore \quad \frac{1}{\omega RC} = \sqrt{6}$$

$$\therefore \quad \omega = \frac{1}{RC\sqrt{6}}$$

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

This is the frequency with which circuit oscillates,

$$\beta = \frac{1}{1-5\times\left(\sqrt{6}\right)^2} = -\frac{1}{29}$$

At this frequency,

Negative sign indicates phase shift of **180**°

$$\therefore \quad \boxed{|\beta| = \frac{1}{29}} \quad \ldots (25)$$

Now to have the oscillations, $|A\beta| \geq 1$

$$\therefore \quad |A|\ |\beta| > 1$$

$$|A| \geq \frac{1}{|\beta|} \geq \frac{1}{\left(\frac{1}{29}\right)}$$

Exercise

1. Explain how BJT works as an amplifier and as a switch.
2. Explain how does a transistor used to switch ON/OFF an LED using the relay.
3. Differentiate between oscillator and amplifier.

Oscillators

1. They are self-generating circuits. They generate waveforms like sine, square and triangular waveforms of their own. Without having input signal.
2. They are not self-generating circuits. They need a signal at the input and they just increase the level of the input waveform.
3. It has infinite gain

Amplifiers

1. It has finite gain
2. Oscillator uses positive feedback.
3. Amplifier uses negative feedback.

4. What will happen to the oscillation if the magnitude of the loop gain is greater than unity?
In practice loop gain is kept slightily greater than unity to ensure that oscillator work even if there is a slight change in the circuit parameters.

5. Define feedback. What are the types of it?
6. State the conditions for oscillations.
7. Explain the advantages and disadvantages of negative feedback. State the basic proprerties.
8. A phase shift oscillator has R=220Kohms, C=500pF. Calculate the frequency of oscillation.
9. Draw the block diagram and circuit diagram for Voltage series feedback amplifier.
10. Draw & explain RC phase shift oscillator.
11. Draw block diagram of voltage series -ve feedback amplifier and explain effect on i/p impedance, o/p impedance and gain.
12. Explain the working of Wein bridge oscillator. Derive the expression for sustained oscillations.

Multiple Choice Questions

1. An oscillator converts ……………..

1. dc. power into d.c. power
2. dc. power into a.c. power
3. mechanical power into a.c. power
4. none of the above

2. An oscillator employs ……………… feedback

1. Positive
2. Negative
3. Neither positive nor negative
4. Data insufficient

3. The output waveform of a stable oscillator have

1. Constant frequency at low amplitude only
2. Constant frequency at high amplitude only
3. Variable frequency
4. Constant frequency

Answer: d

4. The output of oscillator will not depend upon
    1. Feedback
    2. Amplifier
    3. Both feedback and amplifier
    4. Input voltage

    Answer: d

5. In a phase shift oscillator, the frequency determining elements are …………

1. L and C
2. R, L and C
3. R and C
4. None of the above

6. A Wien bridge oscillator uses ……………. feedback

1. Only positive
2. Only negative
3. Both positive and negative
4. None of the above

Answer : 3

7. In a Wien-bridge oscillator, if the resistances in the positive feedback circuit are decreased, the frequency……….

1. Remains the same
2. Decreases
3. Increases
4. Insufficient data

Answer : 3

8. An oscillator differs from an amplifier because it ………

1. Has more gain
2. Requires no input signal
3. Requires no d.c. supply
4. Always has the same input

9. One condition for oscillation is …………

1. A phase shift around the feedback loop of 180^o
2. A gain around the feedback loop of one-third
3. A phase shift around the feedback loop of 0^o
4. A gain around the feedback loop of less than 1

Answer : 3

10. A second condition for oscillations is ………………

1. A gain of 1 around the feedback loop
2. No gain around the feedback loop
3. The attention of the feedback circuit must be one-third
4. The feedback circuit must be capacitive

Answer : 1