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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMMUNICATION ENGINEERING

UNIT - I
ELECTRONIC CIRCUITS II – SECA1401

1. FEEDBACK AMPLIFIER

INTRODUCTION

An ideal amplifier will provide a stable output which is in an amplified version of the input signal. But the gain and stability of practical amplifiers is not very good because of device parameter variation or due to changes in ambient temperature and nonlinearity of the device. This problem can be avoided by the technique of feedback wherein a portion of the output signal is feedback to the input and combined with the input signal to produce the desired output. The feedback can be either negative (degenerative) or positive (regenerative).In negative feedback a portion of the output signal is subtracted from the input signal and in positive feedback a portion of the output signal is added to the input signal to produce desired output. Negative feedback plays a very important role in almost all the amplifier stabilization of biasing circuits, it causes the location of the quiescent point to become stable. Thus it maintain a constant value of amplifier gain against temperature variation, supply voltage etc. The feedback may be classified into two types.

Types of feedback

(i) Positive feedback. When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called positive feedback. This is illustrated in Fig. 1.1. Both amplifier and feedback network introduce a phase shift of 180°. The result is a 360° phase shift around the loop, causing the feedback voltage Vf to be in phase with the input signal Vin.

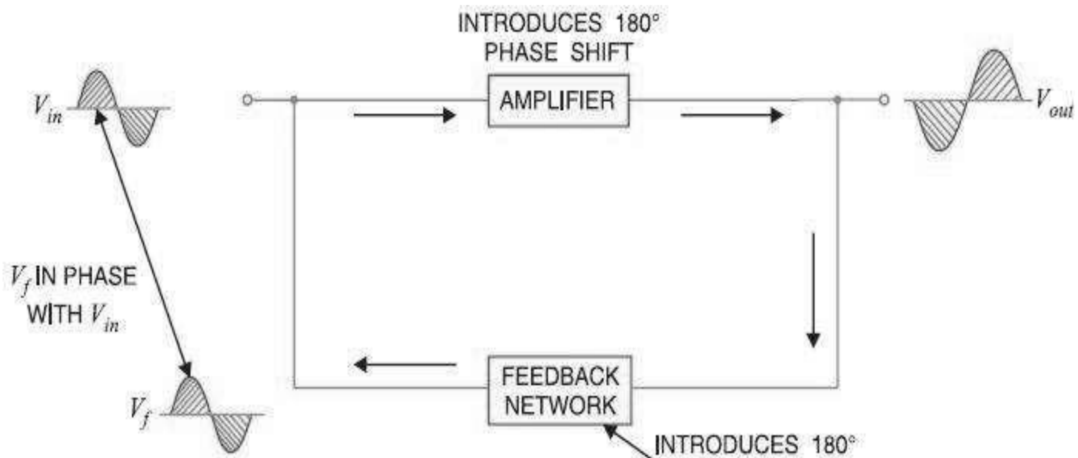


Figure 1.1

The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability. Therefore, positive feedback is seldom employed in amplifiers. One important use of positive feedback is in oscillators. As we shall see in the next chapter, if positive feedback is sufficiently large, it leads to oscillations. As a matter of fact, an oscillator is a device that converts d.c. power into a.c. power of any desired frequency.

(ii) Negative feedback. When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called negative feedback. This is illustrated in Fig. 1.2. As you can see, the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (i.e., 0° phase shift). The result is that the feedback voltage Vf is 180° out of phase with the input signal Vin.

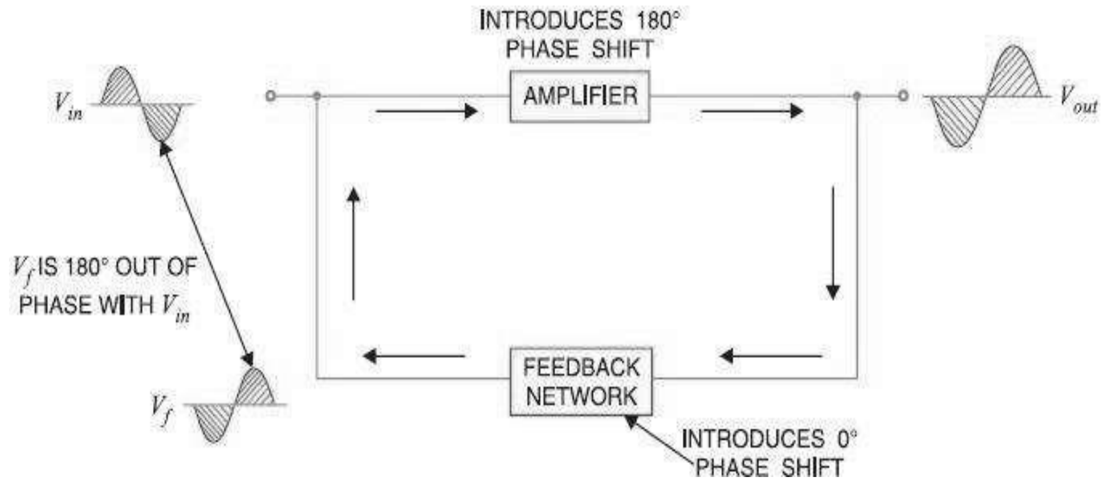


Figure 1.2

Negative feedback reduces the gain of the amplifier. However, the advantages of negative feedback are: reduction in distortion, stability in gain, increased bandwidth and improved input and output impedances. It is due to these advantages that negative feedback is frequently employed in amplifiers.

Principles of Negative Voltage Feedback in Amplifiers

A feedback amplifier has two parts viz an amplifier and a feedback circuit. The feedback circuit usually consists of resistors and returns a fraction of output energy back to the input. Fig. 1.3 *shows the principles of negative voltage feedback in an amplifier. Typical values have been assumed to make the treatment more illustrative. The output of the amplifier is 10 V. The fraction mv of this output i.e. 100 mV is fedback to the input where it is applied in series with the input signal of 101 mV. As the feedback is negative, therefore, only 1 mV appears at the input terminals of the amplifier. Referring to Fig. 1.3, we have, Gain of amplifier without feedback,

$$A_v = \frac{10\text{ V}}{1\text{ mV}} = 10,000$$

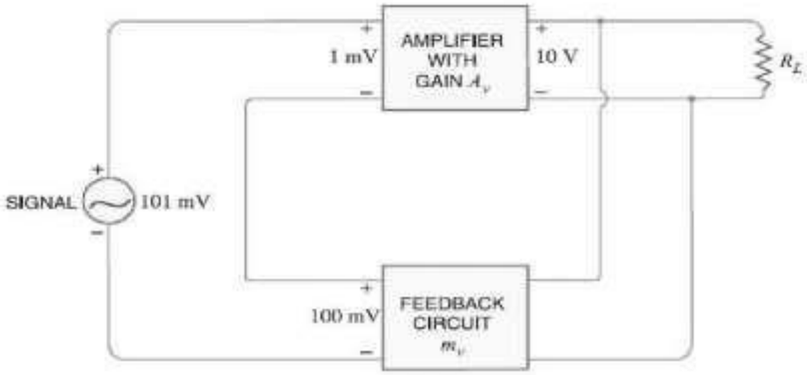


Figure 1.3

$$\text{Fraction of output voltage fedback, } m_v = \frac{100\text{ mV}}{10\text{ V}} = 0.01$$

$$\text{Gain of amplifier with negative feedback, } A_{vf} = \frac{10\text{ V}}{101\text{ mV}} = 100$$

The following points are worth noting:

- **When negative voltage feedback is applied, the gain of the amplifier is reduced. Thus, the gain of above amplifier without feedback is 10,000 whereas with negative feedback, it is only 100.**
- **When negative voltage feedback is employed, the voltage actually applied to the amplifier is extremely small. In this case, the signal voltage is 101 mV and the negative feedback is 100 mV so that voltage applied at the input of the amplifier is only 1 mV.**
- **In a negative voltage feedback circuit, the feedback fraction mv is always between 0 and 1.**
- **The gain with feedback is sometimes called closed-loop gain while the gain without feedback is called open-loop gain. These terms come from the fact that amplifier and feedback circuits form a "loop". When the loop is "opened" by disconnecting the feedback circuit from the input, the amplifier's gain is Av, the "open-loop" gain. When the loop is "closed" by connecting the feedback circuit, the gain decreases to Avf , the "closed-loop" gain.**

Gain of Negative Voltage Feedback Amplifier

Consider the negative voltage feedback amplifier shown in Fig. 1.4. The gain of the amplifier without Feedback is Av. Negative feedback is then applied by feeding a fraction mv

of the output voltage e0 back to amplifier input. Therefore, the actual input to the amplifier is the signal voltage e_g minus feedback voltage $m_v e_0$ i.e.,

Actual input to amplifier = $e_g - m_v e_0$

The output e0 must be equal to the input voltage $e_g - m_v e_0$ multiplied by gain Av of the amplifier i.e.,

$$(e_g - m_v e_0) A_v = e_0$$

$$\text{or} \quad A_v e_g - A_v m_v e_0 = e_0$$

$$\text{or} \quad e_0 (1 + A_v m_v) = A_v e_g$$

$$\text{or} \quad \frac{e_0}{e_g} = \frac{A_v}{1 + A_v m_v}$$

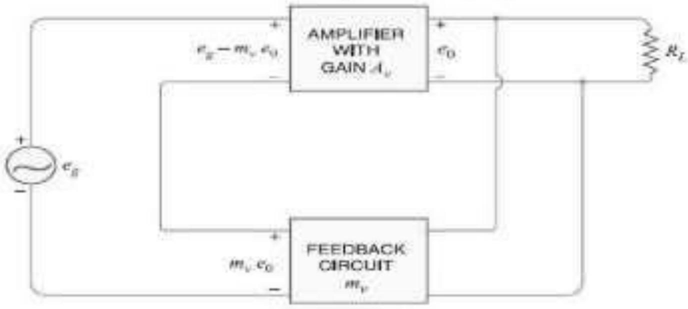


Figure 1.4

But e_0/eg is the voltage gain of the amplifier with

feedback. Voltage gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v m_v}$$

It may be seen that the gain of the amplifier without feedback is Av. However, when negative voltage feedback is applied, the gain is reduced by a factor 1 + Av mv. It may be noted that negative voltage feedback does not affect the current gain of the circuit.

Advantages of Negative Voltage Feedback

The following are the advantages of negative voltage feedback in amplifiers:

(i) Gain stability. An important advantage of negative voltage feedback is that the resultant gain of the amplifier can be made independent of transistor parameters or the supply voltage variations.

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

For negative voltage feedback in an amplifier to be effective, the designer deliberately makes the product Av mv much greater than unity. Therefore, in the above relation, 1 can be neglected as compared to Av mv and the expression become :

$$A_{vf} = \frac{A_v}{A_v\, m_v} = \frac{1}{m_v}$$

It may be seen that the gain now depends only upon feedback fraction mv i.e., on the characteristics of feedback circuit. As feedback circuit is usually a voltage divider (a resistive network), therefore, it is unaffected by changes in temperature, variations in transistor parameters and frequency. Hence, the gain of the amplifier is extremely stable.

(ii) Reduces distortion. A large signal stage has non-linear distortion because its voltage gain changes at various points in the cycle. The negative voltage feedback reduces the nonlinear distortion in large signal amplifiers. It can be proved mathematically that :

$$D_{vf} = \frac{D}{1 + A_v\, m_v}$$

where D = distortion in amplifier without feedback

D_{vf} = distortion in amplifier with negative feedback

It is clear that by applying negative voltage feedback to an amplifier, distortion is reduced by a factor 1 + Av mv.

(iii) Improves frequency response. As feedback is usually obtained through a resistive network, therefore, voltage gain of the amplifier is *independent of signal frequency. The result is that voltage gain of the amplifier will be substantially constant over a wide range of signal frequency. The negative voltage feedback, therefore, improves the frequency response of the amplifier.

(iv) Increases circuit stability. The output of an ordinary amplifier is easily changed due to variations in ambient temperature, frequency and signal amplitude. This changes the gain of the amplifier, resulting in distortion. However, by applying negative voltage feedback, voltage gain of the amplifier is stabilised or accurately fixed in value. This can be easily explained. Suppose the output of a negative voltage feedback amplifier has increased because of temperature change or due to some other reason. This means more negative feedback since feedback is being given from the output. This tends to oppose the increase in amplification and maintains it stable. The same is true should the output voltage decrease. Consequently, the circuit stability is considerably increased.

(v) Increases input impedance and decreases output impedance. The negative voltage feedback increases the input impedance and decreases the output impedance of amplifier. Such a change is profitable in practice as the amplifier can then serve the purpose of impedance matching.

a) Input impedance. The increase in input impedance with negative voltage feedback can be explained by referring to Fig. 1.4. Suppose the input impedance of the amplifier is Z_{in} without feedback and Z 'in with negative feedback. Let us further assume that input current is i1. Referring to Fig. 1.5, we have,

$$e_g - m_v e_0 = i_1 Z_{in}$$

Now

$$\begin{aligned} e_g &= (e_g - m_v e_0) + m_v e_0 \\ &= (e_g - m_v e_0) + A_v m_v (e_g - m_v e_0) \qquad [\because e_0 = A_v (e_g - m_v e_0)] \\ &= (e_g - m_v e_0)(1 + A_v m_v) \\ &= i_1 Z_{in} (1 + A_v m_v) \qquad [\because e_g - m_v e_0 = i_1 Z_{in}] \end{aligned}$$

or

$$\frac{e_g}{i_1} = Z_{in}(1 + A_v m_v)$$

But eg/i1 = Z 'i n , the input impedance of the amplifier with negative voltage feedback.

$$Z'_{in} = Z_{in}(1 + A_v m_v)$$

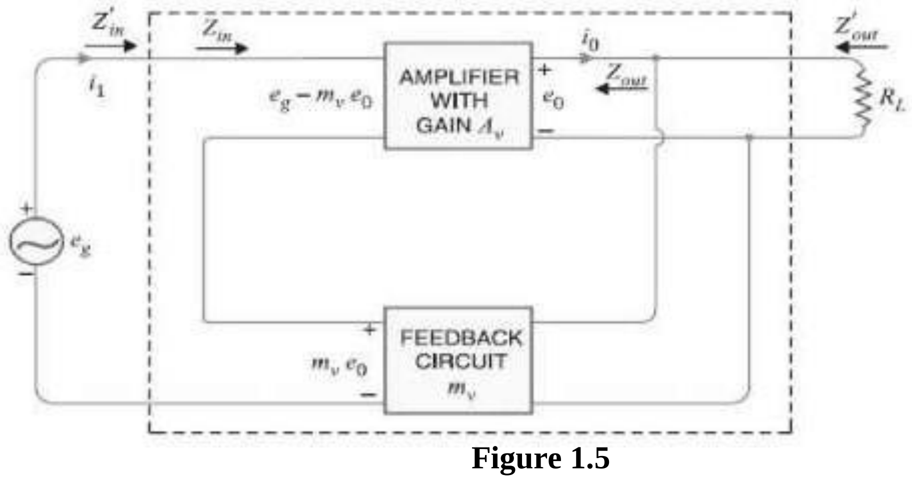


Figure 1.5

It is clear that by applying negative voltage feedback, the input impedance of the amplifier is increased by a factor 1 + Av mv. As Av mv is much greater than unity, therefore, input impedance is increased considerably. This is an advantage, since the amplifier will now present less of a load to its source circuit.

(b) Output impedance. Following similar line, we can show that output impedance with negative voltage feedback is given by

$$Z'_{out} = \frac{Z_{out}}{1 + A_v\, m_v}$$

where Z'_{out} = output impedance with negative voltage feedback

Z_{out} = output impedance without feedback

It is clear that by applying negative feedback, the output impedance of the amplifier is decreased by a factor 1 + Av mv. This is an added benefit of using negative voltage feedback. With lower value of output impedance, the amplifier is much better suited to drive low impedance loads.

Disadvantages of negative feedback amplifier

- **Reduced circuit overall gain**
- **Reduced stability at high frequency**

Feedback Circuit

The function of the feedback circuit is to return a fraction of the output voltage to the input of the amplifier. Fig. 1.6 shows the feedback circuit of negative voltage feedback amplifier. It is essentially a potential divider consisting of resistances R1 and R2. The output voltage of the amplifier is fed to this potential divider which gives the feedback voltage to the input. Referring to Fig. 1.6, it is clear that:

$$\text{Voltage across } R_1 = \left(\frac{R_1}{R_1 + R_2}\right) e_0$$

$$\text{Feedback fraction, } m_v = \frac{\text{Voltage across } R_1}{e_0} = \frac{R_1}{R_1 + R_2}$$

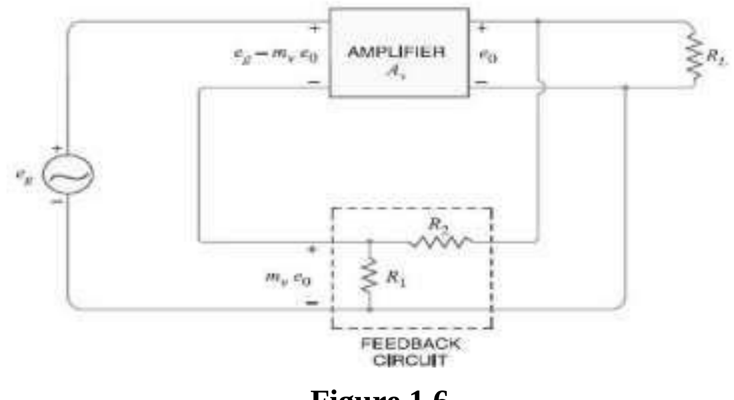


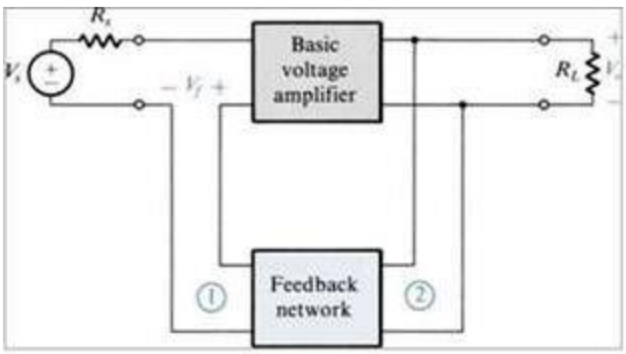
Figure 1.6

Basic Feedback Topologies

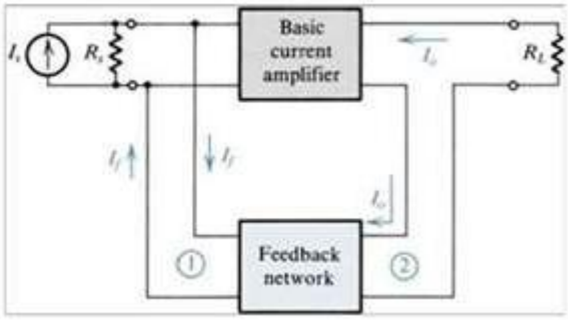
Depending on the input signal (voltage or current) to be amplified and form of the output (voltage or current), amplifiers can be classified into four categories. Depending on the amplifier category, one of four types of feedback structures should be used.

Voltage series feedback (*Af = Vo/Vs)* – Voltage amplifier
Voltage shunt feedback (*Af = Vo/Is)* – Trans-resistance amplifier
Current series feedback (*Af = Io /Vs)* - Trans-conductance amplifier
Current shunt feedback (*Af = Io/Is)* - Current amplifier

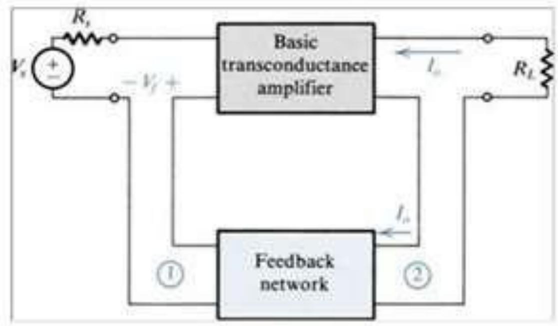
Here voltage refers to connecting the output voltage as input to the feedback network. Similarly current refers to connecting the output current as input to the feedback network. Series refers to connecting the feedback signal in series with the input voltage; Shunt refers to connecting the feedback signal in shunt (parallel) with an input current source.



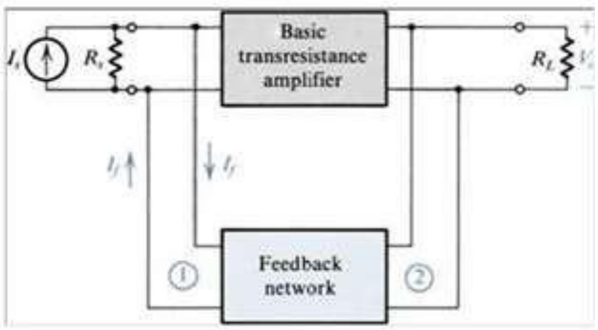
(a)



(b)



(c)



(d)

The four basic feedback topologies: (a) voltage-sampling series-mixing (series-shunt) topology; (b) current-sampling shunt-mixing (shunt-series) topology; (c) current-sampling series-mixing (series-series) topology; (d) voltage-sampling shunt-mixing (shunt-shunt) topology.

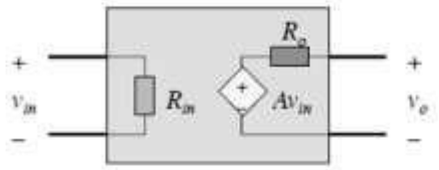
Table Effects of Feedback[a]

Feedback Type	x_s	x_o	Gain Stabilized	Input Impedance	Output Impedance	Ideal Amplifier
Series voltage	v_s	v_o	$A_{vf} = \frac{A_v}{1 + A_v\beta}$	$R_i(1 + A_v\beta)$	$\frac{R_o}{1 + \beta A_{voc}}$	Voltage
Series current	v_s	i_o	$G_{mf} = \frac{G_m}{1 + G_m\beta}$	$R_i(1 + G_m\beta)$	$R_o(1 + \beta G_{msc})$	Transconductance
Parallel voltage	i_s	v_o	$R_{mf} = \frac{R_m}{1 + R_m\beta}$	$\frac{R_i}{1 + R_m\beta}$	$\frac{R_o}{1 + \beta R_{moc}}$	Transresistance
Parallel current	i_s	i_o	$A_{if} = \frac{A_i}{1 + A_i\beta}$	$\frac{R_i}{1 + A_i\beta}$	$R_o(1 + \beta A_{isc})$	Current

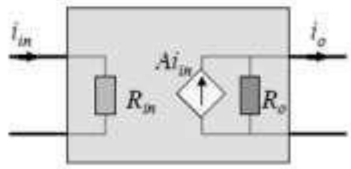
[a] Formulas given assume an ideal controlled source for the feedback network (as shown in Figure 9.14), zero source impedance for series feedback, and infinite source impedance for parallel feedback. Gains with subscripts sc and oc are for short-circuit and open-circuit loads, respectively. The gains A_v, G_m, R_m, and A_i are for the actual load.

1.6 Types of Negative Feedback Connection

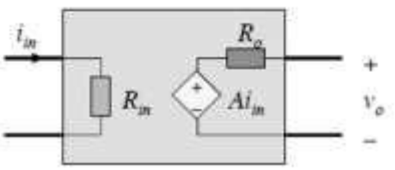
Models of Amplifier



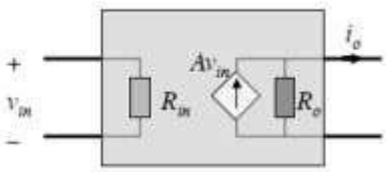
voltage amplifier



current amplifier



transresistance amplifier

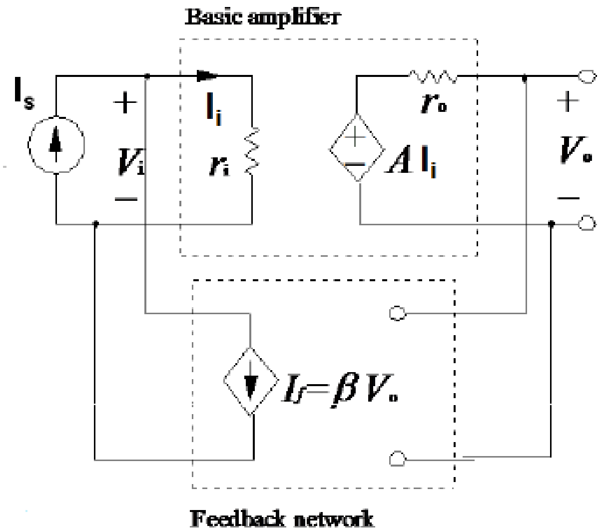


transconductance amplifier

1.7. Feedback topologies

Voltage shunt feedback

Voltage gain



$$V_o = A \cdot I_i = A(I_S - I_f)$$
$$I_f = \beta \cdot V_o$$
$$A(I_S - \beta V_o) = V_o$$
$$AI_S = (1 + \beta A)V_o$$
$$A_f = \frac{V_o}{I_S} = (\frac{A}{1+\beta A})$$

Input impedance

$$Z_{in} = \frac{V_i}{I_S} = \frac{V_i}{I_i + I_f}$$
$$= \frac{I_i \cdot r_i}{I_i + \beta V_o)} = \frac{I_i \cdot r_i}{I_i + \beta A I_i}$$
$$Z_{in} = \frac{r_i}{(1+\beta A)}$$

Output impedance

$$Z_{out}\,|_{V_S=0} = \frac{V_o}{I_o}$$

from input port,

$$I_i = -I_f = -\beta V_o$$

from output port,

$$I_o = \frac{V_o - AI_i}{r_o} = \frac{V_o + \beta A V_o}{r_o}$$

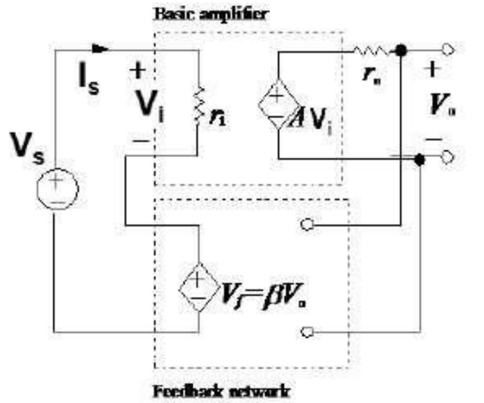
$$Z_{out} = \frac{V_o}{I_o} = \frac{r_o}{(1+\beta A)}$$

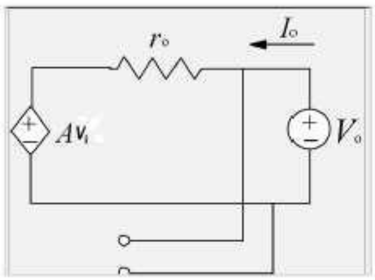
Voltage series feedback

$$V_o = A \cdot V_i = A(V_S - V_f)$$
$$V_f = \beta \cdot V_o$$
$$A(V_S - \beta V_o) = V_o$$
$$AV_S = (1+\beta A)V_o$$
$$A_f = \frac{V_o}{V_S} = (\frac{A}{1+\beta A})$$

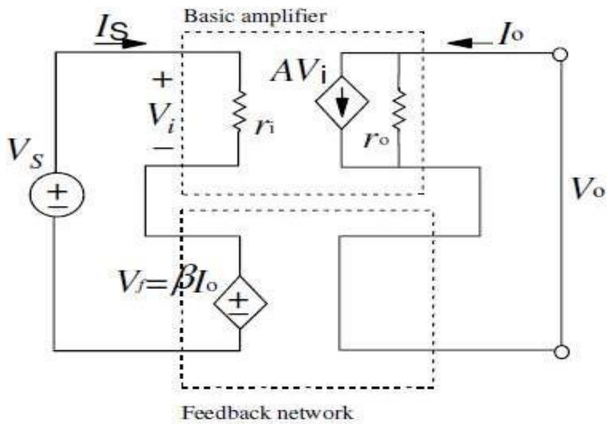
$$Z_{\text{in}} = \frac{V_S}{I_S} = \frac{V_i + V_f}{I_S}$$
$$= \frac{V_i + \beta V_o}{I_S} = \frac{V_i + \beta A V_i}{I_S}$$
$$Z_{\text{in}} = \frac{V_i(1+\beta A)}{I_S} = r_i(1+\beta A)$$

$$Z_{\text{out}}\,|_{V_s=0} = \frac{V_o}{I_o}$$
$$I_o = \frac{V_o - A \cdot V_i}{r_o}$$
$$V_i + \beta \cdot V_o = V_S = 0$$
$$V_i = -\beta \cdot V_o$$
$$I_o = \frac{V_o + A \cdot \beta \cdot V_o}{r_o}$$
$$Z_{\text{out}} = \frac{V_o}{I_o} = \frac{r_o}{1 + A \cdot \beta}$$





Current series feedback



Voltage Gain

$$I_o = A \cdot V_i = A(V_S - V_f)$$
$$V_f = \beta \cdot I_o$$
$$A(V_S - \beta I_o) = I_o$$
$$AV_S = (1+\beta A)I_o$$
$$A_f = \frac{I_o}{V_S} = (\frac{A}{1+\beta A})$$

Input Impedance

$$Z_{\text{in}} = \frac{V_S}{I_S} = \frac{V_i + V_f}{I_S}$$
$$= \frac{V_i + \beta V_o}{I_S} = \frac{V_i + \beta A V_i}{I_S}$$
$$Z_{\text{in}} = \frac{V_i(1+\beta A)}{I_S} = r_i(1+\beta A)$$

Output Impedance

$$Z_{\text{out}}\big|_{V_S=0} = \frac{V_o}{I_o}; I_o = \frac{V_o - A \cdot V_i}{r_o}$$

$$V_i + V_f = V_S = 0$$
$$I_o = \frac{V_o + A \cdot \beta \cdot I_o}{r_o}$$

$$\boxed{Z_{\text{out}} = \frac{V_o}{I_o} = \frac{r_o}{1 + A \cdot \beta}}$$

Analysis of Emitter Follower

It is a negative current feedback circuit. The emitter follower is a current amplifier that has no voltage gain. Its most important characteristic is that it has high input impedance and low output impedance. This makes it an ideal circuit for impedance matching.

Circuit details. Fig.1.8 shows the circuit of an emitter follower. As you can see, it differs from the circuitry of a conventional CE amplifier by the absence of collector load and emitter bypass capacitor. The emitter resistance RE itself acts as the load and a.c. output voltage (Vout) is taken across RE. The biasing is generally provided by voltage-divider method or by base resistor method. The following points are worth noting about the emitter follower :

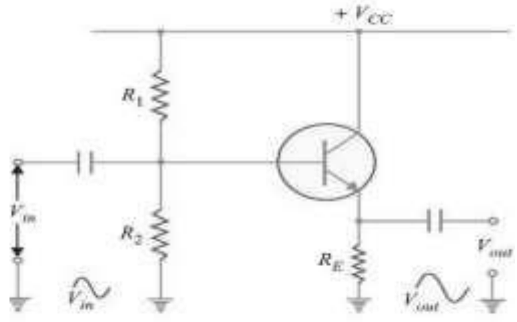


Figure. 1.8

(i) There is neither collector resistor in the circuit nor there is emitter bypass capacitor. These are the two circuit recognition features of the emitter follower.

(ii) Since the collector is at ac ground, this circuit is also known as common collector (CC) amplifier.

Operation. The input voltage is applied between base and emitter and the resulting a.c. emitter current produces an output voltage ie RE across the emitter resistance. This voltage opposes the input voltage, thus providing negative feedback. Clearly, it is a negative current feedback circuit since the voltage feedback is proportional to the emitter current i.e., output current. It is called emitter follower because the output voltage follows the input voltage.

Characteristics.

The major characteristics of the emitter follower are:

(i) No voltage gain. In fact, the voltage gain of an emitter follower is close to 1.
(ii) Relatively high current gain and power gain.
(iii) High input impedance and low output impedance.
(iv) Input and output ac voltages are in phase.

D.C. Analysis of Emitter Follower

The d.c. analysis of an emitter follower is made in the same way as the voltage divider bias circuit of a CE amplifier. Thus referring to Fig. 1.8.4 emitter follower above, we have,

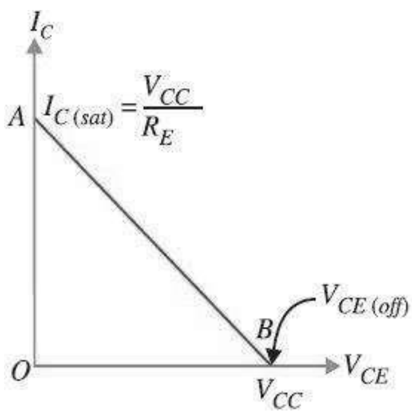


Figure 1.8.4

$$\text{Voltage across } R_2,\ V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2$$

$$\text{Emitter current, } I_E = \frac{V_E}{R_E} = \frac{V_2 - V_{BE}}{R_E}$$

Collector-emitter voltage, $V_{CE} = V_{CC} - V_E$

D.C. Load Line. The d.c. load line of emitter follower can be constructed by locating the two end points viz., IC(sat) and VCE(off).

(i) When the transistor is saturated, VCE = 0.

$$I_{C(sat)} = \frac{V_{CC}}{R_E}$$

This locates the point A (OA = VCC÷ RE) of the d.c. load line as shown in Fig.1.8.4

(ii) When the transistor is cut off, IC = 0. Therefore, VCE(off) = VCC. This locates the point B (OB = VCC) of the d.c. load line.

By joining points A and B, d.c. load line AB is constructed.

Voltage Gain of Emitter Follower

Fig.1.8.6.1 shows the emitter follower circuit. Since the emitter resistor is not bypassed by a capacitor, the a.c. equivalent circuit of emitter follower will be as shown in Fig. 1.8.6.2. The ac resistance rE of the emitter circuit is given by

$$r_E = r'_e + R_E \qquad \text{where } r'_e = \frac{25 \text{ mV}}{I_E}$$

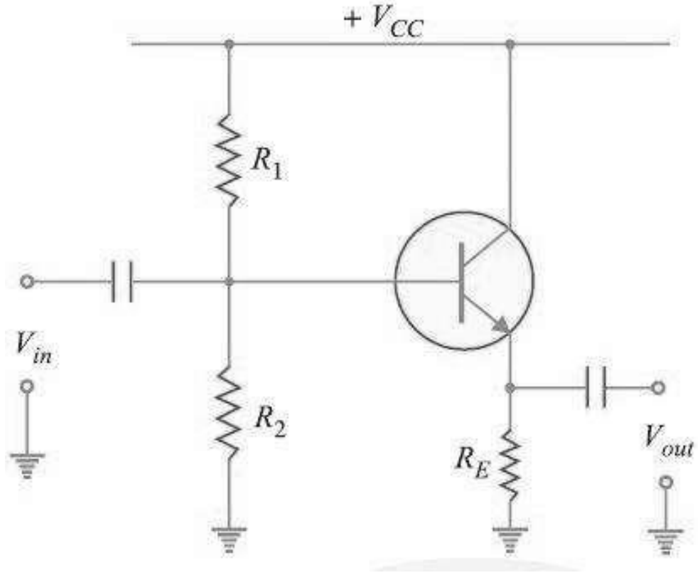


Figure 1.8.6.1

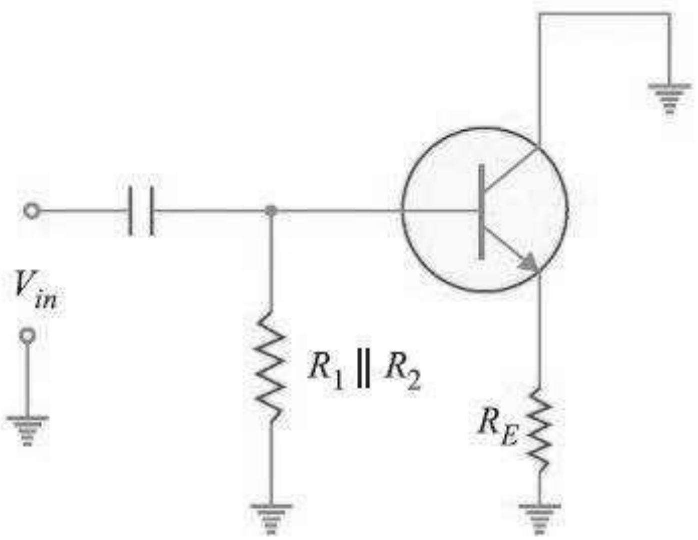


Figure 1.8.6.2

In order to find the voltage gain of the emitter follower, let us replace the transistor in Fig. 1.8.6.2 by its equivalent circuit. The circuit then becomes as shown in Fig. 1.8.6.3 Note that input voltage is applied across the ac resistance of the emitter circuit i.e., (r'e + RE). Assuming the emitter diode to be ideal,

Output voltage, Vout = ie RE

Input voltage, Vin = ie (r'e + RE)

Voltage gain of emitter follower is

$$A_v = \frac{V_{out}}{V_{in}} = \frac{i_e R_E}{i_e (r'_e + R_E)} = \frac{R_E}{r'_e + R_E}$$

or $$A_v = \frac{R_E}{r'_e + R_E}$$

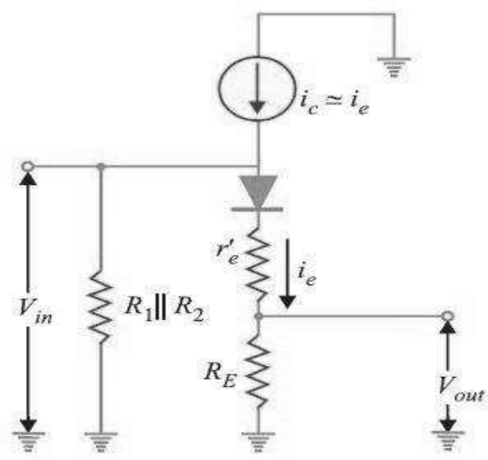


Figure 1.8.6.3

In most practical applications, RE >> r'e so that Av =1.

In practice, the voltage gain of an emitter follower is between 0.8 and 0.999.

Input Impedance of Emitter Follower

Fig. 1.8.7. (i) shows the circuit of a loaded emitter follower. The a.c. equivalent circuit with T model is shown in Fig. 1.8.7. (ii).

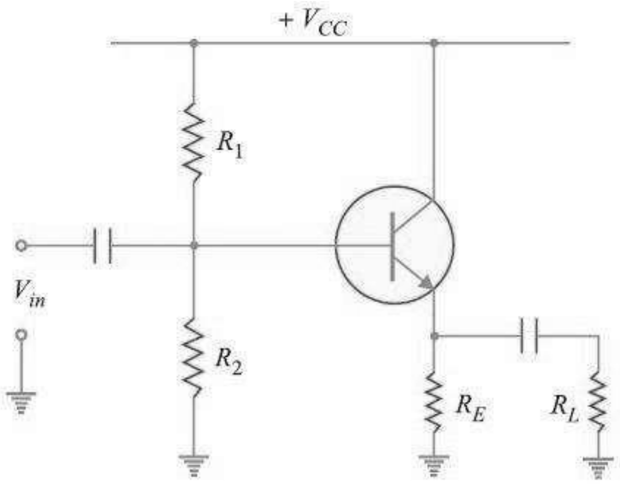


Figure 1.8.7 (i)

As for CE amplifier, the input impedance of emitter follower is the combined effect of biasing resistors (R1 and R2) and the input impedance of transistor base [Zin (base)]. Since these resistances are in parallel to the ac signal, the input impedance Zin of the emitter follower is given by:

$$Z_{in} = R_1 \,||\, R_2 \,||\, Z_{in(\text{base})}$$

where $$Z_{in\,(base)} = \beta\,(r'_e + R'_E)$$

Now $$r'_e = \frac{25\text{ mV}}{I_E} \quad \text{and} \quad R'_E = R_E \,||\, R_L$$

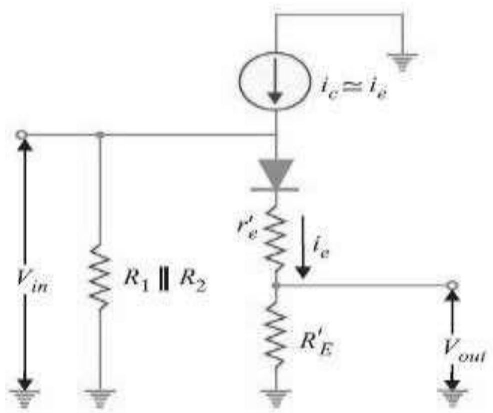


Figure 1.8.7 (ii)

Output Impedance of Emitter Follower

The output impedance of a circuit is the impedance that the circuit offers to the load. When load is connected to the circuit, the output impedance acts as the source impedance for the load. Fig.1.8.8 shows the circuit of emitter follower. Here Rs is the output resistance of amplifier voltage source. It can be proved that the output impedance

Zout of the emitter follower is given by:

$$Z_{out} = R_E \parallel \left(r'_e + \frac{R'_{in}}{\beta} \right)$$

In practical circuits, the value of RE is large enough to be ignored. For this reason, the output impedance of emitter follower is approximately given by :

$$Z_{out} = r'_e + \frac{R'_{in}}{\beta}$$

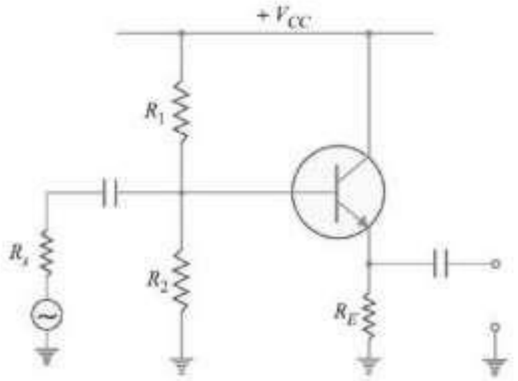


Figure 1.8.8

Applications of Emitter Follower

The emitter follower has the following principal applications:

(i) To provide current amplification with no voltage gain.

(ii) Impedance matching.

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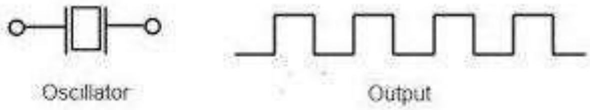
UNIT - II

ELECTRONIC CIRCUITS II – SECA1401

2. OSCILLATORS

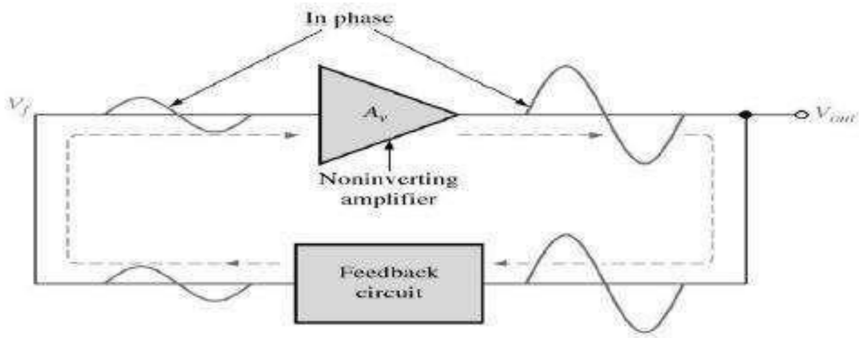
Introduction

An oscillator is a circuit that produces a repetitive signal from a dc voltage. The feedback type oscillator which rely on a positive feedback of the output to maintain the oscillations. The relaxation oscillator makes use of an RC timing circuit to generate a non-sinusoidal signal such as square wave.



The requirements for oscillation are described by the Baukhausen criterion:

- **The magnitude of the loop gain Aβ must be 1**
- **The phase shift of the loop gain A β must be 0^o or 360^o or integer multiple of 2pi**



Amplitude stabilization:

- **In both the oscillators above, the loop gain is set by component values**
- **In practice the gain of the active components is very variable**
- **If the gain of the circuit is too high it will saturate**
- **If the gain of the circuit is too low the oscillation will die**

Real circuits need some means of stabilizing the magnitude of the oscillation to cope with variability in the gain of the circuit

Barkhausan criterion

The conditions for oscillator to produce oscillation are given by Barkhausan criterion. They are:

- **The total phase shift produced by the circuit should be 360^o or 0^o**

- **The Magnitude of loop gain must be greater than or equal to 1 (ie)$|A\beta| \geq 1$**

In practice loop gain is kept slightly greater than unity to ensure that oscillator work even if there is a slight change in the circuit parameters

Mechanism of start of oscillation

The starting voltage is provided by noise, which is produced due to random motion of electrons in resistors used in the circuit. The noise voltage contains almost all the sinusoidal frequencies. This low amplitude noise voltage gets amplified and appears at the output terminals. The amplified noise drives the feedback network which is the phase shift network. Because of this the feedback voltage is maximum at a particular frequency, which in turn represents the frequency of oscillation.

LC Oscillator:

Oscillators are used in many electronic circuits and systems providing the central "clock" signal that controls that controls the sequential operation of the entire system. Oscillators convert a DC input (the supply voltage) into an AC output (the waveform), which can have a wide range of different wave shapes and frequencies that can be either complicated in nature or simple sine waves depending upon the application.

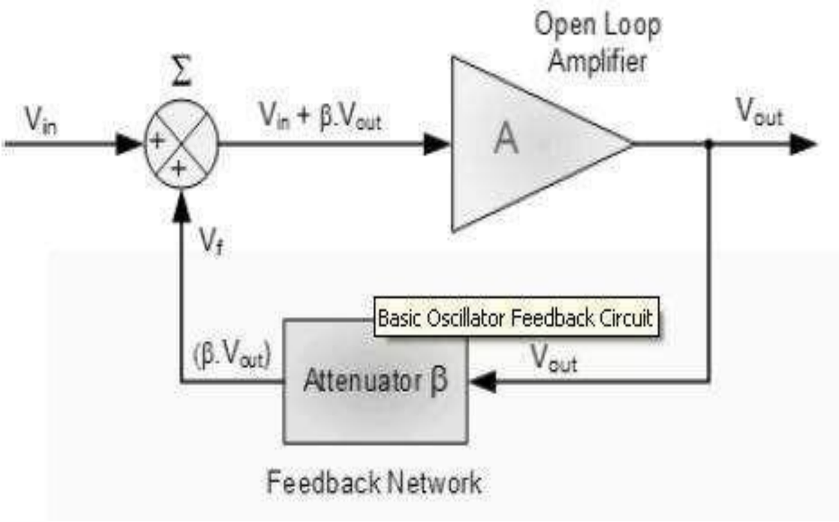
Oscillators are also used in many pieces of test equipment producing either sinusoidal sine wave, square, saw tooth or triangular shaped waveforms or just a train of pulse of a variable or constant width. LC Oscillators are commonly used in radio-frequency circuits because of their good phase noise characteristics and their ease of implementation.

An Oscillator is basically an Amplifier with "Positive Feedback", or regenerative feedback (in-phase) and one of the many problems in electronic circuit design is stooping amplifiers from oscillating while trying to get oscillators to oscillate. Oscillators work because they overcome the losses of their feedback resonator circuit either in the form of a capacitor or both in the same circuit by applying DC energy at the required frequency into this resonator circuit.

In other words, an oscillator is an amplifier which uses positive feedback that generates an output frequency without the use of an input signal.

It is self-sustaining. Then an oscillator has a small signal feedback amplifier with an open-loop gain equal to or slightly greater than one for oscillations to start but to continue oscillations the average loop gain must return to unity. In addition to these reactive components, an amplifying device such as an Operational Amplifier or Bipolar Transistors required. Unlike an amplifier there is no external AC input required to cause the Oscillator to work as the DC supply energy is converted by the oscillator into AC energy at the required frequency.

Basic Oscillator Feedback Circuit



Where: β is a feedback fraction.

$$\text{Gain, } Av = \frac{Vout}{Vin} \qquad A = \text{open loop voltage gain}$$

$$Av \times Vin = Vout$$

Basic Oscillator Feedback Circuit with Feedback

$$Av(Vin - \beta Vout) = Vout \qquad \beta \text{ is the feedback fraction}$$

$$Av.Vin - Av.\beta.Vout = Vout \qquad A\beta = \text{the loop gain}$$

$$Av.Vin = Vout(1 + A\beta) \qquad 1 + A\beta = \text{the feedback factor}$$

$$\therefore \frac{Vout}{Vin} = Gv = \frac{A}{1 + A\beta} \qquad Gv = \text{the closed loop gain}$$

Oscillators are circuits that generate a continuous voltage output waveform at a required frequency with the values of the inductors, capacitors or resistors forming a frequency selective LC resonant tank circuit and feedback network. This feedback network is an attenuation network which has a gain of less than one (β<1) and starts oscillations when A β>1 which returns to unity (A β=1) once Oscillations commence. The LC oscillator's frequency is controlled using a tuned or resonant inductive/capacitive (LC) circuit with the resulting output frequency being known as the Oscillation Frequency.

By making the oscillators feedback a reactive network the phase angle of the feedback will vary as a function of frequency and this is called Phase-shift.

There are basically types of Oscillators:

- **Sinusoidal Oscillators - these are known as Harmonic Oscillators and are generally a: LC Tuned-feedback" or "RC tuned-feedback" type Oscillator that generates a purely sinusoidal waveform which is of constant amplitude and frequency.**
- **Non-Sinusoidal Oscillators – these are known as Relaxation Oscillators and generate complex non-sinusoidal waveforms that changes very quickly from one condition of stability to another such as "Square-wave", "Triangular-wave" or "Saw toothed-wave" type waveforms.**

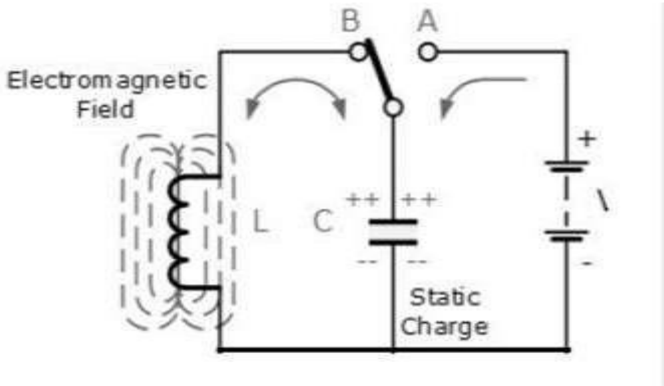
Resonance

When a constant voltage but of varying frequency is applied to a circuit consisting of an inductor, capacitor and resistor the reactance of both the Capacitor/Resistor and Inductor/Resistor circuits is to change both the amplitude and the phase of the output signal due to the reactance of the components used.

At high frequencies the reactance of a capacitor is very low acting as a short circuit while the reactance of the inductor is high acting as an open circuit. At low frequencies the reverse is true, the reactance of the capacitor acts as an open circuit and the reactance of the inductor acts as a short circuit.

Between these two extremes the combination of the inductor and capacitor produces a "Tuned" or "Resonant" circuit that has a Resonant Frequency, (fr) in which the capacitive and inductive reactance's are equal and cancel out each other, leaving only the resistance of the circuit to oppose the flow of current. This means that there is no phase shift as the current is in phase with the voltage. Consider the circuit below.

Basic LC Oscillator Tank Circuit



The circuit consists of an inductive coil, L and a capacitor, C. The capacitor stores energy in the form of an electrostatic field and which produces a potential (static voltage) across its plates, while the inductive coil stores its energy in the form of an electromagnetic field.

The capacitor is charged up to the DC supply voltage, V by putting the switch in position
A. When the capacitor is fully charged the switch changes to position B. The charged capacitor is now connected in parallel across the inductive coil so the capacitor begins to discharge itself through the coil.

The voltage across C starts falling as the current through the coil begins to rise. This rising current sets up an electromagnetic field around the coil which resists this flow of current. When the capacitor, C is completely discharged the energy that was originally stored in the capacitor, C as an electrostatic filed is now stored in the inductive coil, L as an electromagnetic field around the coils windings.

As there is now no external voltage in the circuit to maintain the current within the coil, it starts to fall as the electromagnetic field begins to collapse. A back emf is induced in the coil (e=
-Ldi/dt) keeping the current flowing in the original direction. This current now charges up the capacitor, c with the opposite polarity to its original charge.

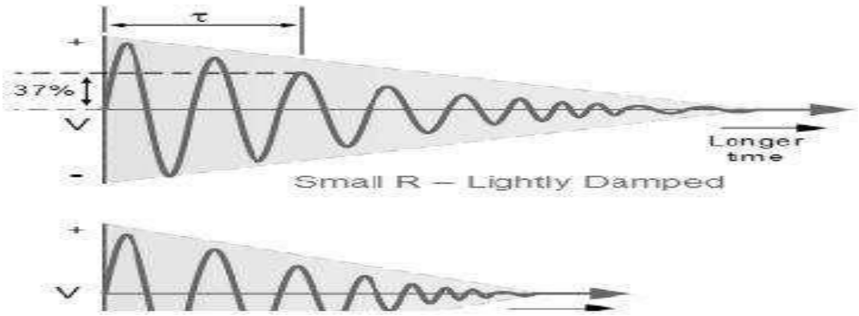
C continues to charge up until the current reduces to zero and the electromagnetic field of the coil has collapsed completely. The energy originally introduced into the circuit through the switch, has been returned to the capacitor which again has an electrostatic voltage potential across it, although it is now of the opposite polarity. The capacitor now starts to discharge again back through the coil and the whole process os repeated. The polarity of the voltage changes as the energy is passed back and forth between the capacitor and inductor producing an AC type sinusoidal voltage and current waveform.

This then forms the basis of an LC oscillator's tank circuit and theoretically this cycling back and forth will continue indefinitely. However, every time energy is transferred from C to L or from L to C losses occur which decay the oscillations.

This oscillatory action of passing energy back and forth between the capacitor, C to the inductor, L would continue indefinitely if it was not for energy losses within the circuit. Electrical energy is lost in the DC or real resistance of the inductors coil, in the dielectric of the capacitor, and in radiation from the circuit so the oscillation steadily decreases until they die away completely and the process stops.

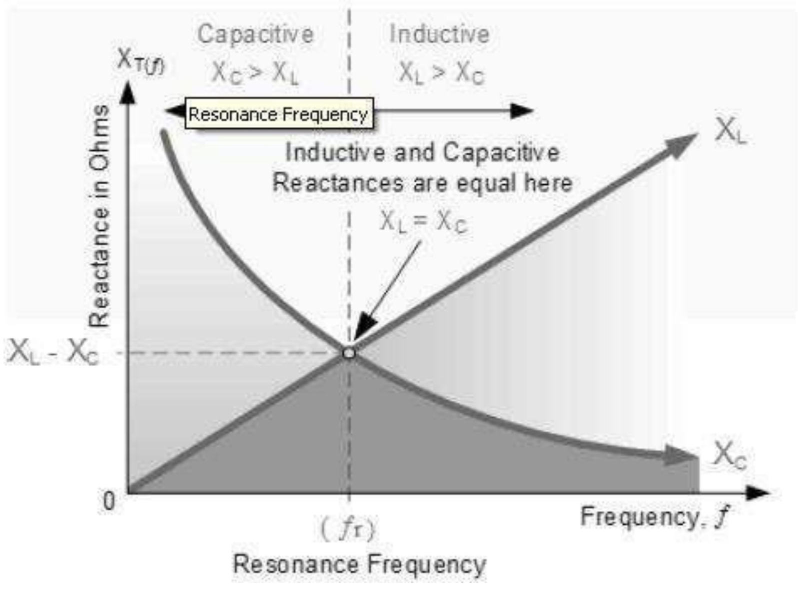
Then in a practical LC circuit the amplitude of the oscillatory voltage decreases at each half cycle of oscillation and will eventually die away to zero. The oscillations are then said to be "damped" with the amount of damping being determined by the quality or Q-factor of the circuit.

Damped Oscillations



The frequency of the oscillatory voltage depends upon the value of the inductance and capacitance in the LC tank circuit. We now know that for resonance to occur in the tank circuit, there must be a frequency point were the value of X_C, the capacitive reactance is the same as the value of X_L, the inductive reactance ($X_L = X_C$) and which will therefore cancel out each other out leaving only the DC resistance in the circuit to oppose the flow of current.
If we now place the curve for inductive reactance on top of the curve for capacitive reactance so that both curves are on the same axes, the point of intersection will give us the resonance frequency point, (fr or ωr) as shown below.

Resonance Frequency



Where: f_r is in Hertz, L is in Henries and C is in Farads.

Then the frequency at which this will happen is given as:

$$X_L = 2\pi f L \quad \text{and} \quad X_C = \frac{1}{2\pi f C}$$

$$\text{at resonance:} \quad X_L = X_C$$

$$\therefore \; 2\pi f L = \frac{1}{2\pi f C}$$

$$2\pi f^2 L = \frac{1}{2\pi C}$$

$$\therefore \; f^2 = \frac{1}{(2\pi)^2 LC}$$

$$f = \frac{\sqrt{1}}{\sqrt{(2\pi)^2 LC}}$$

Then by simplifying the above equation we get the final equation for Resonant

Frequency, fr in a tuned LC circuit as:

Resonant Frequency of a LC Oscillator

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Where:

L is the Inductance in

Henries C is the

Capacitance in Farads

fr is the Output Frequency in Hertz

This equation shows that if either L or C are decreased, the frequency increases. This output frequency is commonly given the abbreviation of (fr) to identify it as the "resonant frequency". To keep the oscillations going in an LC tank circuit, we have to replace all the energy lost in each oscillation and also maintain the amplitude of these oscillations at a constant level.

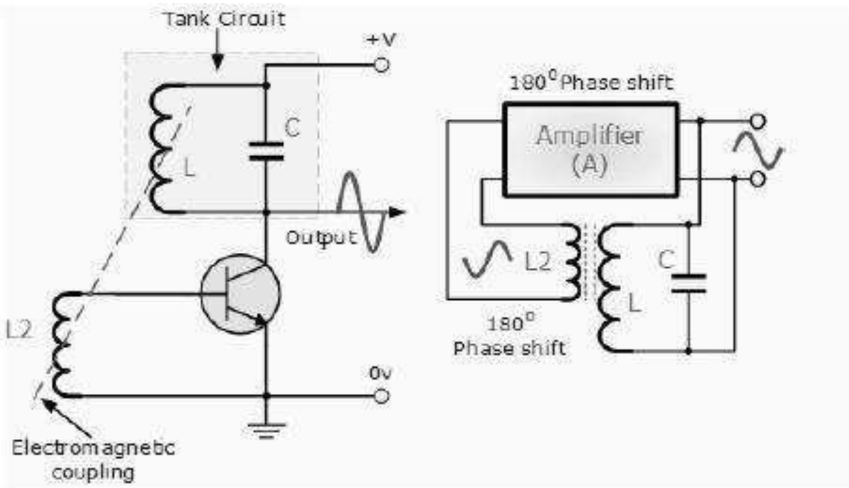
The amount of energy replaced must therefore be equal to the energy lost during each cycle. If the energy replaced is too large the amplitude would increase until clipping of the supply rails occurs. Alternatively, if the amount of energy replaced is too small the amplitude would eventually decrease to zero over time and the oscillations would stop.

The simplest way of replacing this lost energy is to take part of the output from the LC tank circuit, amplify it and then feed it back into the LC circuit again. This process can be achieved using a voltage amplifier using an op-amp, FET or bipolar transistor as its active device.

However, if the loop gain of the feedback amplifier is too small, the desired oscillation decays to zero and if it is too large, the waveform becomes distorted. To produce a constant oscillation, the level of the energy fed back to the LC network must be accurately controlled.

Then there must be some form of automatic amplitude or gain control when the amplitude tries to vary from a reference voltage either up or down. To maintain a stable oscillation the overall gain of the circuit must be equal to one or unity. Any less and the oscillations will not start or die away to zero, any more the oscillations will occur but the amplitude will become clipped by the supply rails causing distortion. Consider the circuit below.

Basic Transistor LC Oscillator Circuit



A Bipolar Transistor is used as the LC oscillator's amplifier with the tuned LC tank circuit acts as the collector load. Another coil L2 is connected between the base and the emitter of the transistor whose electromagnetic field is "mutually" coupled with that of coil L. Mutual inductance exists between the two circuits.

The changing current flowing in one coil circuit induces, by electromagnetic induction, a potential voltage in the other (transformer effect) so as the oscillations occur in

the tuned circuit, electromagnetic energy is transferred from coil L to coil L2 and a voltage of the same frequency as that in the tuned circuit is applied between the base and emitter of the transistor.

In this way the necessary automatic feedback voltage is applied to the amplifying transistor. The amount of feedback can be increased or decreased by altering the coupling between the two coils L and L2. When the circuit is oscillating its impedance is resistive and the collector and base voltages are 180 out of phase. In order to maintain oscillations (called frequency stability) the voltage applied to the tuned circuit must be "in-phase" with the oscillations occurring in the tuned circuit.

Therefore, we must introduce an additional 180^o phase shift into the feedback path between the collector and the base. This is achieved by winding the coil of L2 in the correct direction relative to coil L giving us the correct amplitude and phase relationships for the Oscillators circuit or by connecting a phase shift network between the output and input of the amplifier.

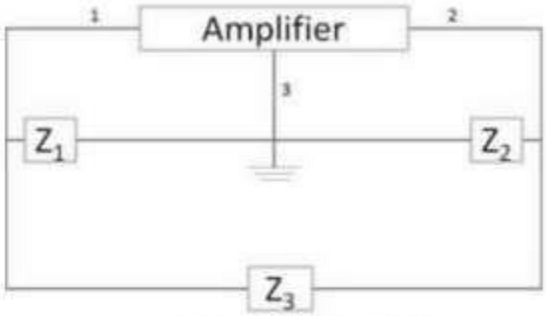
The LC Oscillator is therefore a "Sinusoidal Oscillator" or a "Harmonic Oscillator" as it is more commonly called. LC oscillators can generate high frequency sine waves for use in radio frequency (RF) type applications with the transistor amplifier being of a Bipolar Transistor or FET.

Harmonic Oscillators come in many different forms because there are many different ways to construct an LC filter network and amplifier with the most common being the Hartley LC Oscillator, Colpitts LC Oscillator, Armstrong Oscillator and Clapp Oscillator to name a few.

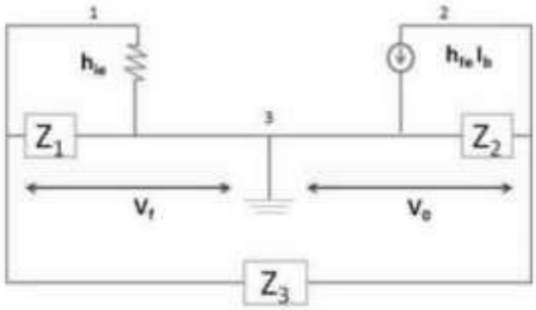
Types of LC Oscillators

- **Hartley oscillator.**
- **Colpitts oscillator.**
- **Clapp oscillator.**
- **Armstrong oscillator.**

General Form of LC Oscillators



General Form of LC Oscillator



Equivalent Circuit of LC Oscillator

In the general form of LC oscillator any of the active devices such as Vacuum tube, Transistor, FET, Op-Amp may be used in the amplifier section.

$$Z' = z_1 \parallel h_{ie} = \frac{z_1 h_{ie}}{z_1 + h_{ie}}$$

$$Z_L = z' + z_3 \parallel z_2$$

$$Z_L = \frac{z_1 z_3 h_{ie}}{z_3 z_1 + z_3 h_{ie}} \parallel z_2 \qquad Z_L = \frac{\dfrac{z1 z2 z3 hie}{z3 z1 + z3 hie}}{\dfrac{z1 z2 z3 + z2 z3 hie + z1 z3 hie}{z3 z1 + z3 hie}}$$

$$Z_L = \frac{z_1 h_{ie}}{z_1 + h_{ie}} + z_3 \parallel z_2$$

$$\boxed{Z_L = \frac{z2\,[h_{ie}(z_1 + z_3) + z_1 z_3]}{h_{ie}(z_1 + z_2 + z_3) + z_1 z_3 + z_1 z_2}}$$

$$V_o = -I_1(Z^1+Z_3) = -I_1 \frac{h_{ie} z_3 + h_{ie} z_1 + z_1 z_3}{h_{ie} + z_1}$$

$$v_f = -I_1 Z^1 = -I_1 \frac{z_1 h_{ie}}{z_1 + h_{ie}} \qquad v_f = \frac{Z' V_o}{z' + z3}$$

$$\beta = \frac{v_f}{V_o} = \frac{z_1 h_{ie}}{h_{ie}(z1 + z3) + z1z3}$$

$$A_v = \frac{-h_{fe}}{h_{ie}} Z_L$$

$$A_v \ \beta = 1$$

$$\frac{-h_{fe}}{h_{ie}} \quad \frac{z2 \, [\, h_{ie} (z_1 + z_3) + z_1 z_3]}{h_{ie}(z_1 + z_2 + z_3) + z_1 z_3 + z_1 z_2} \quad \frac{z_1 h_{ie}}{h_{ie}(z1 + z3) + z1z3} = 1$$

General Equation of LC Oscillator:

$$\boxed{h_{ie} (z_1+z_2+z_3) + z_1 z_2 (1+h_{fe}) z_1 z_3 = 0}$$

The Hartley Oscillator

The main disadvantages of the basic LC Oscillator circuit we looked at in the previous tutorial is that they have no means of controlling the amplitude of the oscillations and also, it is difficult to tune the oscillator to the required frequency.

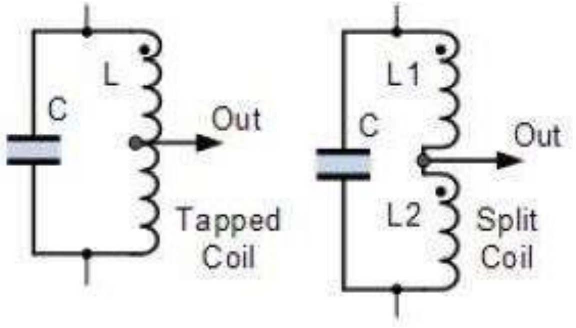
However, it is possible to feedback exactly the right amount of voltage for constant amplitude oscillations. If we feed back more than is necessary the amplitude of the oscillations can be controlled by biasing the amplifier in such a way that if the oscillations increase in amplitude, the bias is increased and the gain of the amplifier is reduced.

If the amplitude of the oscillations decreases the bias decreases and the gain of the amplifier increases, thus increasing the feedback. In this way the amplitude of the oscillations are kept constant using a process known as Automatic Base Bias.

One big advantage of automatic base bias in a voltage controlled oscillator, is that the oscillator can be made more efficient by providing a Class-B bias or even a Class-C bias condition of the transistor. This has the advantage that the collector current only flows during part of the oscillation cycle so the quiescent collector current is very small.

Then this "self-tuning" base oscillator circuit forms one of the most common types

of LC parallel resonant feedback oscillator configurations called the Hartley Oscillator circuit.



Hartley Oscillator Tuned Circuit

In the Hartley Oscillator the tuned LC circuit is connected between the collector and the base of the transistor amplifier. As far as the oscillatory voltage is concerned, the emitter is connected to a tapping point on the tuned circuit coil.

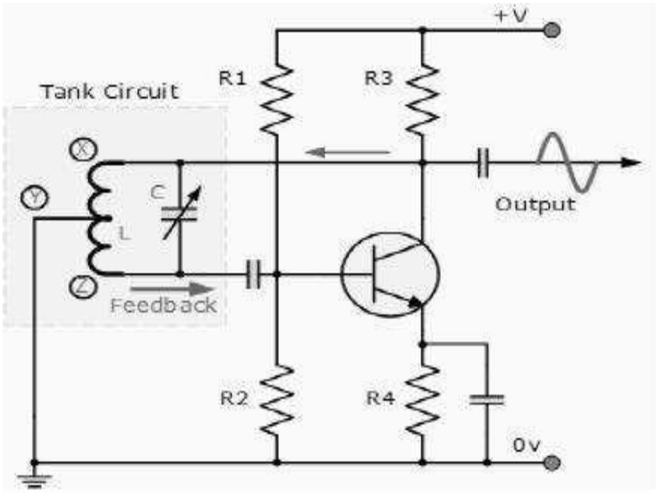
The feedback of the tuned tank circuit is taken from the centre tap of the inductor coil or even two separate coils in series which are in parallel with a variable capacitor, C as shown.

The Hartley circuit is often referred to as a split-inductance oscillator because coil L is centre-tapped. In effect, inductance L acts like two separate coils in very close proximity with the current flowing through coil section XY induces a signal into coil section YZ below.

A Hartley Oscillator circuit can be made from any configuration that uses either a single tapped coil (similar to an autotransformer) or a pair of series connected coils in parallel with a single capacitor as shown below.

Basic Hartley Oscillator Circuit

When the circuit is oscillating, the voltage at point X (collector), relative to point Y (emitter), is 180^o out-of-phase with the voltage at point Z (base) relative to point Y. At the frequency of oscillation, the impedance of the Collector load is resistive and an increase in Base voltage causes a decrease in the Collector voltage. Then there is a 180 phase change in the voltage between the Base and Collector and this along with the original 180 phase shift in the feedback loop provides the correct phase relationship of positive feedback for oscillations to be maintained.



The amount of feedback depends upon the position of the "tapping point" of the inductor. If this is moved nearer to the collector the amount of feedback is increased, but the output taken between the Collector and earth is reduced and vice versa.

Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the capacitors act as DC-blocking capacitors.

In this Hartley Oscillator circuit, the DC Collector current flows through part of the coil and for this reason the circuit is said to be "Series-fed" with the frequency of oscillation of the Hartley Oscillator being given as.

$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

where: $L_T = L_1 + L_2 + 2M$

The frequency of oscillations can be adjusted by varying the "tuning" capacitor, C or by varying the position of the iron-dust core inside the coil (inductive tuning) giving an output over

a wide range of frequencies making it very easy to tune. Also the Hartley Oscillator produces an output amplitude which is constant over the entire frequency range.

As well as the Series-fed Hartley Oscillator above, it is also possible to connect the tuned Tank circuit across the amplifier as a shunt-fed oscillator as shown below.

Armstrong oscillator

The Armstrong oscillator (also known as Meissner oscillator) is named after the electrical engineer Edwin Armstrong, its inventor. It is sometimes called a tickler oscillator because the feedback needed to produce oscillations is provided using a tickler coil via magnetic coupling between coil L and coil T.

Assuming the coupling is weak, but sufficient to sustain oscillation, the frequency is determined primarily by the tank circuit (L and C in the illustration) and is approximately given by. In a practical circuit, the actual oscillation frequency will be slightly different from the value provided by this formula because of stray capacitance and inductance, internal losses (resistance), and the loading of the tank circuit by the tickler coil.

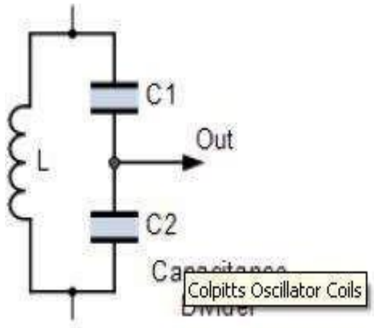
This circuit is the basis of the regenerative receiver for amplitude modulated radio signals. In that application, an antenna is attached to an additional tickler coil, and the feedback is reduced, for example, by slightly increasing the distance between coils T and L, so the circuit is just short of oscillation.

The result is a narrow-band radio-frequency filter and amplifier. The non- linear characteristic of the transistor or tube provides the demodulated audio signal.

Colpitts Oscillator

The Colpitts Oscillator, named after its inventor Edwin Colpitts is another type of LC oscillator design. In many ways, the Colpitts oscillator is the exact opposite of the Hartley Oscillator we looked at in the previous tutorial. Just like the Hartley oscillator, the tuned tank circuit consists of an LC resonance sub-circuit connected between the collector and the base of a single stage transistor amplifier producing a sinusoidal output waveform.

The basic configuration of the Colpitts Oscillator resembles that of the Hartley Oscillator but the difference this time is that the centre tapping of the tank sub-circuit is now made at the junction of a "capacitive voltage divider" network instead of a tapped autotransformer type inductor as in the Hartley oscillator.

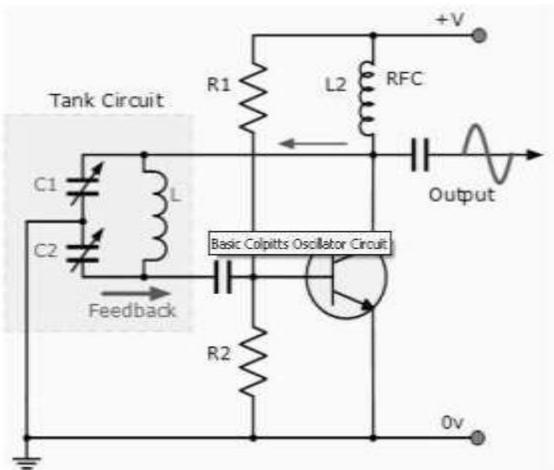


2.9.1 Colpitts Oscillator Circuit

The Colpitts oscillator uses a capacitor voltage divider as its feedback source. The two capacitors, C1 and C2 are placed across a common inductor, L as shown so that C1, C2 and L forms the tuned tank circuit the same as for the Hartley oscillator circuit.

The advantage of this type of tank circuit configuration is that with less self and mutual inductance in the tank circuit, frequency stability is improved along with a more simple design. As with the Hartley oscillator, the Colpitts oscillator uses a single stage bipolar transistor amplifier as the gain element which produces a sinusoidal output. Consider the circuit below.

2.9.1 Basic Colpitts Oscillator Circuit



The transistor amplifiers emitter is connected to the junction of capacitors, C1 and C2 which are connected in series and act as a simple voltage divider. When the power supply is firstly applied, capacitors C1 and C2 charge up and then discharge through the coil L. The oscillations across the capacitors are applied to the base-emitter junction and appear in the amplified at the collector output. The amount of feedback depends on the values of C1 and C2 with the smaller the values of C the greater will be the feedback.

The required external phase shift is obtained in a similar manner to that in the Hartley oscillator circuit with the required positive feedback obtained for sustained un-damped oscillations. The amount of feedback is determined by the ratio of C1 and C2 which are generally "ganged" together to provide a constant amount of feedback so as one is adjusted the other automatically follows.

The frequency of oscillations for a Colpitts oscillator is determined by the resonant frequency of the LC tank circuit and is given as:

$$f_r = \frac{1}{2\pi\sqrt{L\,C_T}}$$

where C_T is the capacitance of C1 and C2 connected in series and is given as:.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{or} \quad C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

The configuration of the transistor amplifier is of a Common Emitter Amplifier with the Output signal 180º out of phase with regards to the input signal. The additional 180º phase shift require for oscillation is achieved by the fact that the two capacitors are connected together in series but in parallel with the inductive coil resulting in overall phase shift of the circuit being zero or 360º. Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the capacitor acts as a DC-blocking capacitors. The radio- frequency choke (RFC) is used to provide a high reactance (ideally open circuit) at the frequency of oscillation, (fr) and a low resistance at DC.

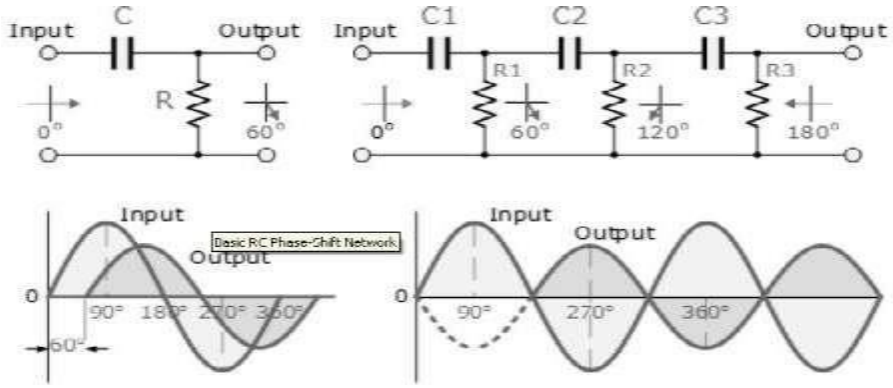
RC Phase-Shift Oscillator

In a RC Oscillator the input is shifted 180º through the amplifier stage and180º again through a second inverting stage giving us "180º + 180º = 360º" of phase shift which is the same as 0º thereby giving us the required positive feedback. In other words, the phase shift of the feedback loop should be "0".

In a Resistance-Capacitance Oscillator or simply an RC Oscillator, we make use of the fact that a phase shift occurs between the input to a RC network and the output from the same

network by using RC elements in the feedback branch, for example.

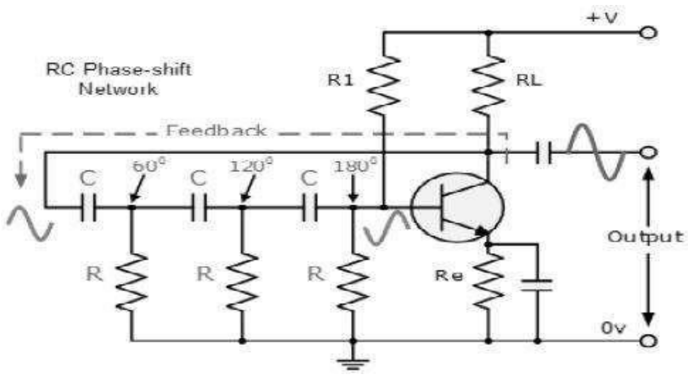
RC Phase-Shift Network



The circuit on the left shows a single resistor -capacitor network and whose output voltage "leads" the input voltage by some angle less than 90 º. An ideal RC circuit would produce a phase shift of exactly 90º.The amount of actual phase shift in the circuit depends upon the values of the resistor and the capacitor, and the chosen frequency of oscillations with the phase angle (Φ) being given as:

$$\phi = \tan^{-1}\frac{X_C}{R}$$

RC Oscillator Circuit



The RC Oscillator which is also called a Phase Shift Oscillator, produces a sine wave output signal using regenerative feedback from the resistor- capacitor combination. This regenerative feedback from the RC network is due to the ability of the capacitor to store an electric charge, (similar to the LC tank circuit).
This resistor-capacitor feedback network can be connected as shown above to produce a leading phase shift (phase advance network) or interchanged to produce a lagging phase shift (phase retard network) the outcome is still the same as the sine wave oscillations only occur at the frequency at which the overall phase-shift is 360^o. By varying one or more of the resistors or capacitors in the phase-shift network, the frequency can be varied and generally this is done using a 3-ganged variable capacitor
If all the resistors, R and the capacitors, C in the phase shift network are equal in value, then the frequency of oscillations produced by the RC oscillator is given as:

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

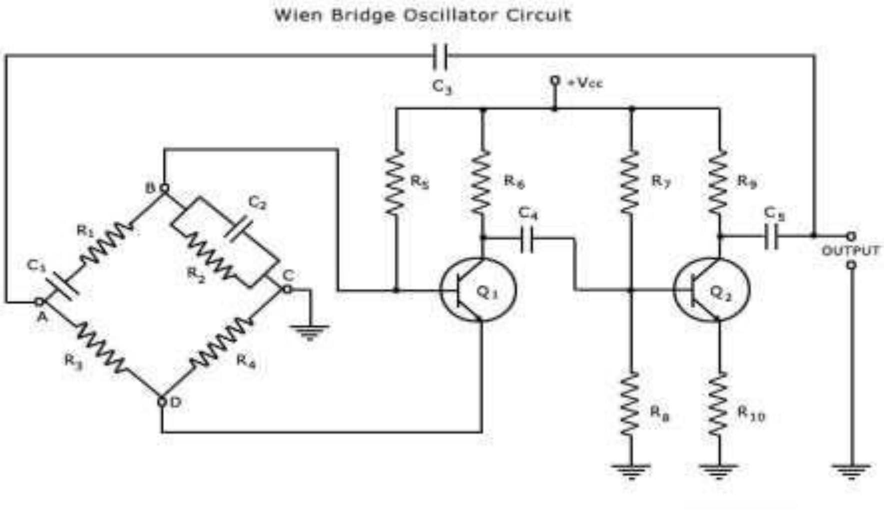
WIEN BRIDGE OSCILLATOR

One of the simplest sine wave oscillators which uses a RC network in place of the conventional LC tuned tank circuit to produce a sinusoidal output waveform, is the Wien Bridge Oscillator.

The Wien Bridge Oscillator is so called because the circuit is based on a frequency-selective form of the Whetstone bridge circuit. The Wien Bridge oscillator is a two-stage RC coupled amplifier circuit that has good stability at its resonant frequency, low distortion and is very easy to tune making it a popular circuit as an audio frequency oscillator

Wein Bridge Oscillator is used in audio and sub-audio frequency ranges (20 – 20 kHz). This type of oscillator is simple in design, compact in size, and remarkably stable in its frequency output. Furthermore, its output is relatively free from distortion and its fre•quency can be varied easily. However, the maximum frequency output of a typical Wien bridge oscillator is only about 1 MHz. This is also, in fact, a phase-shift oscillator. It employs two transistors, each producing a phase shift of 180°, and thus producing a total phase-shift of 360° or 0°.

Wien Bridge Oscillator



It is essentially a two-stage amplifier with an R-C bridge circuit. R-C bridge circuit (Wien bridge) is a lead-lag network. The phase'-shift across the network lags with increasing frequency and leads with decreasing frequency. By adding Wien-bridge feedback network, the oscillator becomes sensitive to a signal of only one particular frequency. This particular frequency is that at which Wien bridge is balanced and for which the phase shift is 0°.If the Wien-bridge feedback network is not employed and output of transistor Q_2 is feedback to transistor Q_1 for providing regeneration required for producing oscillations, the transistor Q_1 will amplify signals over a wide range of frequencies and thus direct coupling would result in poor frequency stability. Thus by employing Wien-bridge feedback network frequency stability is increased.

In the bridge circuit R_1 in series with C_1, R_3, R_4 and R_2 in parallel with C_2 form the four arms. This bridge circuit can be used as feedback network for an oscillator, provided that the phase shift through the amplifier is zero. This requisite condition is achieved by using a two stage amplifier, as illustrated in the figure. In this arrangement the output of the second stage is supplied back to the feedback network and the voltage across the parallel combination C_2 R_2 is fed to the input of the first stage. Transistor Q_1 serves as an oscillator and amplifier whereas the transistor Q_2 as an inverter to cause a phase shift of 180°. The circuit uses positive and negative feedbacks. The positive feedback is through R_1 C_1 R_2, C_2 to transistor Q_1 and negative feedback is through the voltage divider to the input of transistor Q_1. Resistors R_3 and R_4 are used to stabilize the amplitude of the output.

The two transistors Q_1 and Q_2 thus cause a total phase shift of 360° and ensure proper positive feedback. The negative feedback is provided in the circuit to ensure constant output over a range of frequencies. This is achieved by taking resistor R_4 in the form of a temperature sensitive lamp, whose resistance increases with the increase in current. In case the amplitude of the output tends to increase, more current would provide more negative feedback. Thus the output would regain its original value. A reverse action would take place in case the output tends to fall.

The amplifier voltage gain, A $R_3 + R_4 / R_4 = R_3 / R_4 + 1 = 3$

Since $R_3 = 2 R_4$, The above corresponds with the feedback network attenuation of 1/3. Thus,

in this case, voltage gain A, must be equal to or greater than 3, to sustain oscillations. To have a voltage gain of 3 is not difficult. On the other hand, to have a gain as low as 3 may be difficult. For this reason also negative feedback is essential.

Wien Bridge Oscillator – Working

The circuit is set in oscillation by any random change in base current of transistor Q1, that may be due to noise inherent in the transistor or variation in voltage of dc supply. This variation in base current is amplified in collector circuit of transistor Q1 but with a phase-shift of 180°. the output of transistor Q1 is fed to the base of second transistor Q2 through capacitor C4. Now a still further amplified and twice phase-reversed signal appears at the collector of the transistor Q2. Having been inverted twice, the output signal will be in phase with the signal input to the base of transistor Q1 A part of the output signal at transistor Q2 is fedback to the input points of the bridge circuit (point A-C). A part of this feedback signal is applied to emitter resistor R4 where it produces degenerative effect (or negative feedback). Similarly, a part of the feedback signal is applied across the base-bias resistor R2 where it produces regenerative effect (or positive feedback). At the rated frequency, effect of regeneration is made slightly more than that of degeneration so as to obtain sustained oscillations.

The continuous frequency variation in this oscillator can be had by varying the two capacitors C1 and C2 simultaneously. These capacitors are variable air-gang capacitors. We can change the frequency range of the oscillator by switching into the circuit different values of resistors R1 and R2. The advantages and disadvantages of Wien bridge oscillators are given below:

Advantages

- **Provides a stable low distortion sinusoidal output over a wide range of frequency.**
- **The frequency range can be selected simply by using decade resistance boxes.**
- **The frequency of oscillation can be easily varied by varying capacitances C1 and C2 simultaneously. The overall gain is high because of two transistors.**

Disadvantages

- **The circuit needs two transistors and a large number of other components.**
- **The maximum frequency output is limited because of amplitude and the phase-shift characteristics of amplifier.**

Quartz Crystal Oscillators

One of the most important features of any oscillator is its frequency stability, or in other words its ability to provide a constant frequency output under varying load conditions. Some of the factors that affect the frequency stability of an oscillator include: temperature, variations in the load and changes in the DC power supply.

Frequency stability of the output signal can be improved by the proper selection of the components used for the resonant feedback circuit including the amplifier but there is a limit to the stability that can be obtained from normal LC and RC tank circuits.

To obtain a very high level of oscillator stability a Quartz Crystal is generally used as the frequency determining device to produce another types of oscillator circuit known generally as a Quartz Crystal Oscillator, (X_O).

Crystal Oscillator

When a voltage source is applied to a small thin piece of quartz crystal, it begins to change shape producing a characteristic known as the Piezo-electric effect.

This piezo-electric effect is the property of a crystal by which an electrical charge produces a mechanical force by changing the shape of the crystal and vice versa, a mechanical force applied to the crystal produces an electrical charge.

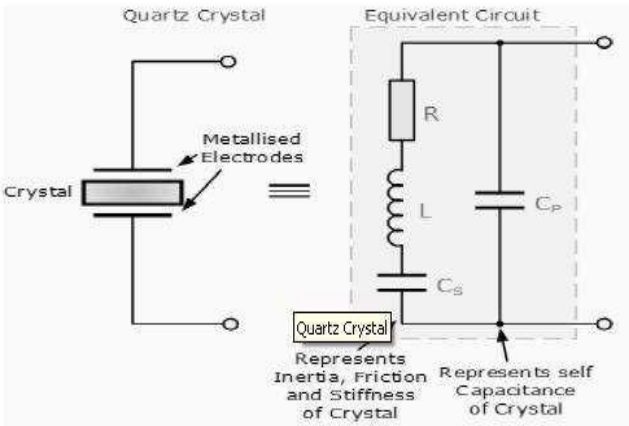
Then, piezo-electric devices can be classed as Transducers as they convert energy of one kind into energy of another (electrical to mechanical or mechanical to electrical).

This piezo-electric effect produces mechanical vibrations or oscillations which are used to replace the LC tank circuit in the previous oscillators.

There are many different types of crystal substances which can be used as oscillators with the most important of these for electronic circuits being the quartz minerals because of their greater mechanical strength. The quartz crystal used in a Quartz Crystal Oscillator is a very small, thin piece or wafer of cut quartz with the two parallel surfaces metallised to make the required electrical connections. The physical size and thickness of a piece of quartz crystal is tightly controlled since it affects the final frequency of oscillations and is called the crystals "characteristic frequency". Then once cut and shaped, the crystal cannot be used at any other frequency. In other words, its size and shape determines its frequency.

The crystals characteristic or resonant frequency is inversely proportional to its physical thickness between the two metallised surfaces. A mechanically vibrating crystal can be represented by an equivalent electrical circuit consisting of low resistance, large inductance and small capacitance as shown below.

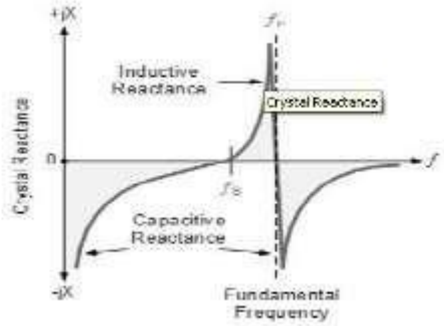
Quartz Crystal



The equivalent circuit for the quartz crystal shows an RLC series circuit, which represents the mechanical vibrations of the crystal, in parallel with a capacitance, Cp which represents the electrical connections to the crystal. Quartz crystal oscillators operate at "parallel resonance", and the equivalent impedance of the crystal has a series resonance where Cs resonates with inductance, L and a parallel resonance where L resonates with the series combination of Cs and Cp as shown.

Crystal Reactance

The slope of the reactance against frequency above, shows that the series reactance at frequency fs is inversely proportional to Cs because below fs and above fp the crystal appears capacitive, i.e. dX/df, where X is the reactance.



The slope of the reactance against frequency above, shows that the series reactance at frequency fs is inversely proportional to Cs because below fs and above fp the crystal appears capacitive, i.e. dX/d f, where X is the reactance. Between frequencies *ƒ*s and *ƒ*p, the crystal app ears inductive as the two parallel capacitances cancel out. The point where the reactance values of the capacitances and inductance cancel each other out Xc = XL is the fundamental frequency of the crystal.

A quartz crystal has a resonant frequency similar to that of an electrically tuned tank circuit but with a much higher Q factor due to its low resistance, with typical frequencies ranging from 4 kHz to 10MHz. The cut of the crystal also determines how it will behave as some crystals will vibrate at more than one frequency. Also, if the crystal is not of a parallel or uniform thickness it has two or more resonant frequencies having both a fundamental frequency and harmonics such as second or third harmonics. However, usually the fundamental frequency is stronger or pronounced than the others and this is the one used. The equivalent circuit above has three reactive components and there are two resonant frequencies, the lowest is a series type frequency and the highest a parallel type resonant frequency.

We have seen in the previous tutorials, that an amplifier circuit will oscillate if it has a loop gain greater or equal to one and the feedback is positive. In a Quartz Crystal Oscillator circuit the oscillator will oscillate at the crystals fundamental parallel resonant frequency as the crystal always wants to oscillate when a voltage source is applied to it.
However, it is also possible to "tune" a crystal oscillator to any even harmonic of the fundamental frequency,(2nd, 4th, 8^{th} etc.) And these are known generally as Harmonic Oscillators

While Overtone Oscillators vibrate at odd multiples of the fundamental frequency, 3rd, 5th, 11th etc). Generally, crystal oscillators that operate at overtone frequencies do so using their series resonant frequency output.

The output signal at the collector is then taken through an 180° phase shifting network which includes the crystal operating in a series resonant mode. The output is also fed back to the input which is "in-phase" with the input providing the necessary positive feedback. Resistors, R1 and R2 bias the resistor in a Class A type operation while resistor

Re is chosen so that the loop gain is slightly greater than unity.

Capacitors, C1 and C2 are made as large as possible in order that the frequency of oscillations can approximate to the series resonant mode of the crystal and is not dependent upon the values of these capacitors.

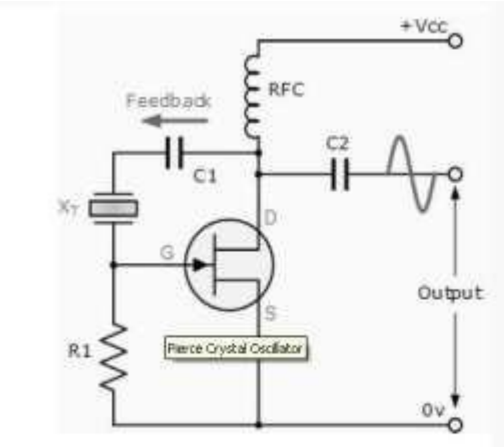
The circuit diagram above of the Colpitts Crystal Oscillator circuit shows that capacitors, C1 and C2 shunt the output of the transistor which reduces the feedback signal.

Therefore, the gain of the transistor limits the maximum values of C1 and C2. The output amplitude should be kept low in order to avoid excessive power dissipation in the crystal otherwise could destroy itself by excessive vibration.

Pierce Oscillator

The Pierce oscillator is a crystal oscillator that uses the crystal as part of its feedback path and therefore has no resonant tank circuit. The Pierce Oscillator uses a JFET as its amplifying device as it provides a very high input impedance with the crystal connected between the output Drain terminal and the input Gate terminal as shown below.

Pierce Crystal Oscillator



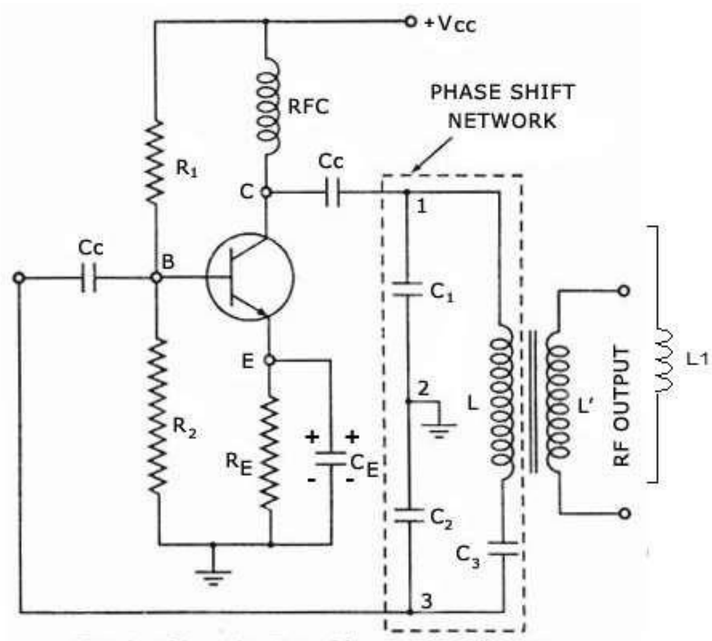
In this simple circuit, the crystal determines the frequency of oscillations and operates on its series resonant frequency giving a low impedance path between output and input.

There is a 180° phase shift at resonance, making the feedback positive. The amplitude of the output sine wave is limited to the maximum voltage range at the Drain terminal.

Resistor, R1 controls the amount of feedback and crystal drive while the voltages across the radio frequency choke, RFC reverses during each cycle. Most digital clocks, watches and timers use a Pierce Oscillator in some form or other as it can be implemented using the minimum of components.

2.14. Clapp Oscillator

The Clapp oscillator shown in figure. is a refinement of the Colpitt's oscillator. The single inductor found in the Colpitt's oscillator is replaced by a series L-C combination. Addition of capacitor Ca in series with L improves the frequency stability and eliminates the effect of transistor parameters on the operation of the circuit. The op•eration of the circuit is the same as that of the Colpitt's oscillator. As the circulating tank current flows through C1, C2 and C3 in series, the equivalent capacitance is



$$C = C1C2C3/C1C2 + C2C3 + C1C3$$

The frequency of oscillation is given as Capacitors C1 and C2 are kept fixed while capacitor C3 is employed for tuning purpose.

In a Clapp oscillator C3 is much smaller than C1 and C2 As a result, the equivalent capacitance C is approximately equal to C3, and the frequency of oscillation is given as

$$F = 1/2\prod\sqrt{}LC3$$

However, precaution is to be taken in selection of C3. If capacitor C3 is made too small, the L-C branch will not have a net inductive reactance and under such condition the circuit will refuse to oscillate.

In a Colpitt's oscillator, the resonant frequency is affected by the transistor and stray capacitances because the capacitors Cr and C2 are shunted by the transistor and stray capacitances and so their values are altered. But in a Clapp oscillator, the transistor and stray capacitances have no effect on capacitor C3, so the oscillation frequency is more stable and accurate. This is the reason that Clapp oscillator is preferred over a Colpitt's oscillator.

High frequency stability can further be obtained by enclosing the entire circuit in a constant temperature chamber and by maintaining the supply voltage constant with the help of a Zener diode.

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UNIT - III
ELECTRONIC CIRCUITS II – SECA1401

3. TUNED AMPLIFIERS

Introduction to tuned circuits

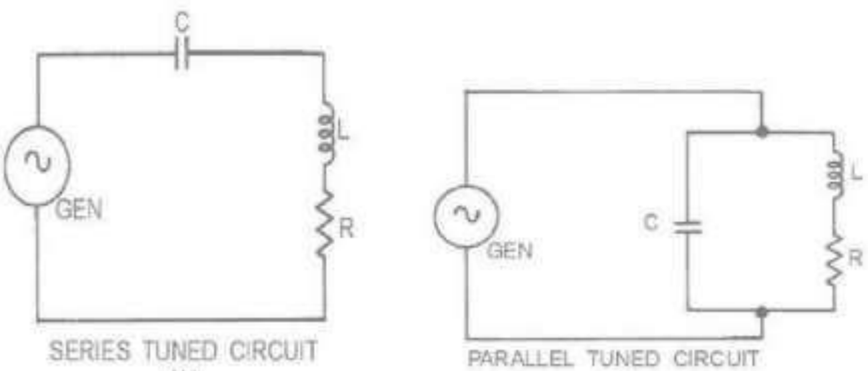
When a radio or television set is turned on, many events take place within the "receiver" before we hear the sound or see the picture being sent by the transmitting station. Many different signals reach the antenna of a radio receiver at the same time. To select a station, the listener adjusts the tuning dial on the radio receiver until the desired station is heard. Within the radio or TV receiver, the actual "selecting" of the desired signal and the rejecting of the unwanted signals are accomplished by means of a tuned circuit.

A tuned circuit consists of a coil and a capacitor connected in series or parallel. Whenever the characteristics of inductance and capacitance are found in a tuned circuit, the phenomenon as Resonance takes place.

Resonance circuits

The frequency applied to an LCR circuit causes XL and XC to be equal, and the circuit is RESONANT. If XL and XC are equal ONLY at one frequency (the resonant frequency). This fact is the principle that enables tuned circuits in the radio receiver to select one particular frequency and reject all others.

This is the reason why so much emphasis is placed on XL and XC. figure Shows that a basic tuned circuit consists of a coil and a capacitor, connected either in series, view (A), or in parallel, view (B).The resistance (R) in the circuit is usually limited to the inherent resistance of the components (particularly the resistance of the coil).



SERIES TUNED CIRCUIT
(A)

PARALLEL TUNED CIRCUIT
(B)

Tuned amplifier

- **Communication circuit widely uses tuned amplifier and they are used in MW & SW radio frequency 550 KHz – 16 MHz, 54 – 88 MHz, FM 88 – 108 MHz, cell phones 470 - 990 MHz Band width is 3 dB frequency interval of pass band and –30 dB frequency interval**

- **Tune amplifiers are also classified as A, B, C similar to power amplifiers based on conduction angle of devices.**

Series resonant circuit

Series resonant features minimum impedance (RS) at resonant.

- **f r = ½ √LC; q = L/Rs at resonance L=1/c, BW=fr/Q**

- **It behaves as purely resistance at resonance, capacitive below and inductive above resonance**

Parallel resonant circuit

- **Parallel resonance features maximum impedance at resonance = L/RsC**
- **At resonance Fr=1/2√1/(LC-Rs2/L2); if Rs=0, fr=1/2√(LC)**

- **At resonance it exhibits pure resistance and below fr parallel circuit exhibits inductive and above capacitive impedance**

Need for tuned circuits:

To understand tuned circuits, we first have to understand the phenomenon of self - induction. And to understand this, we need to know about induction. The first discovery about the interaction between electric current and magnetism was the realization that an electric current created a magnetic field around the conductor. It was then discovered that this effect could be enhanced greatly by winding the conductor into a coil. The effect proved to be two-way: If a conductor, maybe in the form of a coil was placed in a changing magnetic field, a current could be made to flow in it; this is called induction.

So imagine a coil, and imagine that we apply a voltage to it. As current starts to flow, a magnetic field is created. But this means that our coil is in a changing magnetic field, and this induces a current in the coil. The induced current runs contrary to the applied current, effectively diminishing it. We have discovered self-induction. What happens is that the self-induction delays the build-up of current in the coil, but eventually the current will reach its maximum and stabilize at a value only determined by the ohmic resistance in the coil and the voltage applied. We now have a steady current and a steady magnetic field. During the build-up of the field, energy was

supplied to the coil, where did that energy go? It went into the magnetic field, and as long as the magnetic field exists, it will be stored there.

Now imagine that we remove the current source. Without a steady current to uphold it, the magnetic field starts to disappear, but this means our coil is again in a variable field which induces a current into it. This time the current is in the direction of the applied current, delaying the decay of the current and the magnetic field till the stored energy is spent. This can give a funny effect: Since the coil must get rid of the stored energy, the voltage over it rises indefinitely until a current can run somewhere! This means you can get a surprising amount of sparks and arching when coils are involved. If the coil is large enough, you can actually get an electric shock from a low-voltage source like an ohmmeter.

Applications of tuned amplifier

A tuned amplifier is a type of electronic device designed to amplify specific ranges of electrical signals while ignoring or blocking others. It finds common use in devices that work with radio frequency signals such as radios, televisions, and other types of communication equipment; however, it also can be useful in many other applications. Tuned amplifiers can be found in aircraft autopilot systems, audio systems, scientific instruments, spacecraft, or anywhere else there is a need to select and amplify specific electronic signals while ignoring others.

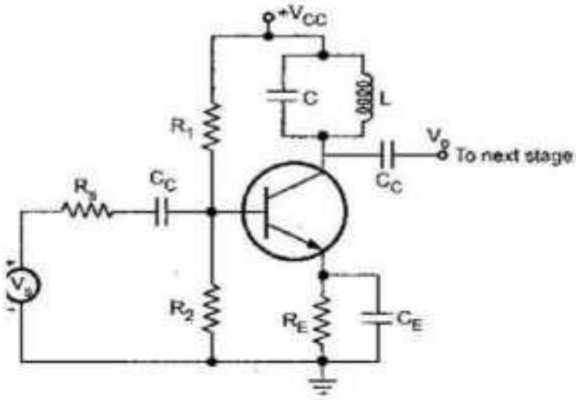
The most common tuned amplifiers an average person interacts with can be found in home or portable entertainment equipment, such as FM stereo receivers. An FM radio has a tuned amplifier that allows listening to only one radio station at a time. When the knob is turned to change the station, it adjusts a variable capacitor, inductor, or similar device inside the radio, which alters the inductive load of the tuned amplifier circuit. This retunes the amplifier to allow a different specific radio frequency to be amplified so a different radio station can be heard.

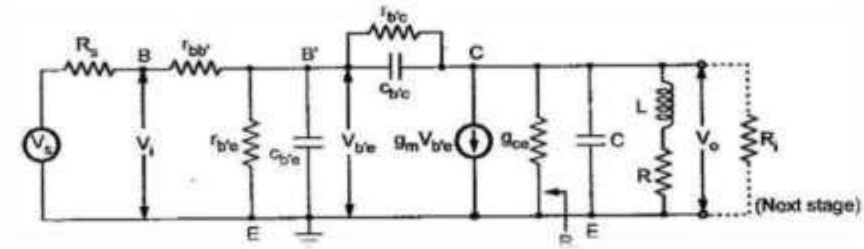
CLASSIFICATION:

- **Single tuned amplifier**
- **Double tuned amplifier**
- **Stagger tuned amplifier**

Single tuned amplifier

Single Tuned Amplifiers consist of only one Tank Circuit and the amplifying frequency range is determined by it. By giving signal to its input terminal of various Frequency Ranges. The Tank Circuit on its collector delivers High Impedance on resonant Frequency, Thus the amplified signal is completely available on the output Terminal. And for input signals other than Resonant Frequency, the tank circuit provides lower impedance; hence most of the signals get attenuated at collector Terminal.



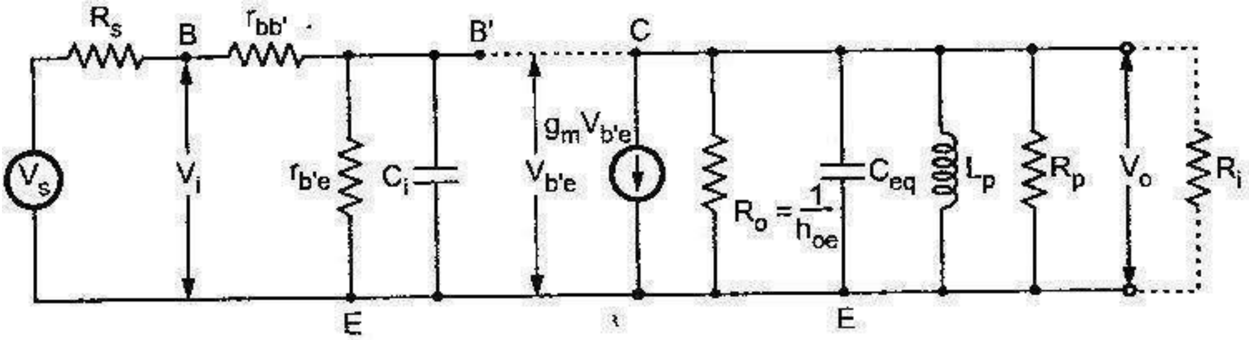


Ri- input resistance of the next stage

R0-output resistance of the generator gm

Vb`e Cc & CE are negligible small

The equivalent circuit is simplified by



Simplified equivalent circuit

$$C_i = C_{b'e} + C_{b'c}(1 - A)$$
$$C_{eq} = C_{b'c}\left(\frac{A-1}{A}\right) + C$$

Where,

A-Voltage gain of the amplifier

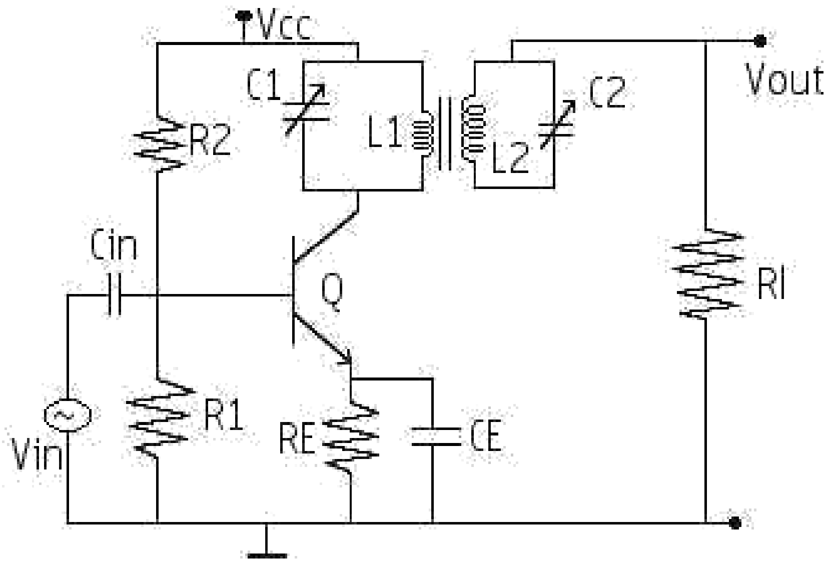
C-tuned circuit capacitance

$$g_{ce} = \frac{1}{r_{ce}} = h_{oe} - g_m h_{re} \approx h_{oe} = \frac{1}{R_o}$$

Double tuned amplifier

An amplifier that uses a pair of mutually inductively coupled coils where both primary and secondary are tuned, such a circuit is known as "double tuned amplifier". Its response will provide substantial rejection of frequencies near the pass band as well as relative flat pass band response. The disadvantage of potential instability in single tuned amplifiers can be overcome in Double tuned amplifiers.

A double tuned amplifier consists of inductively coupled two tuned circuits. One L1, C1 and the other L2, C2 in the Collector terminals. A change in the coupling of the two tuned circuits results in change in the shape of the Frequency response curve.

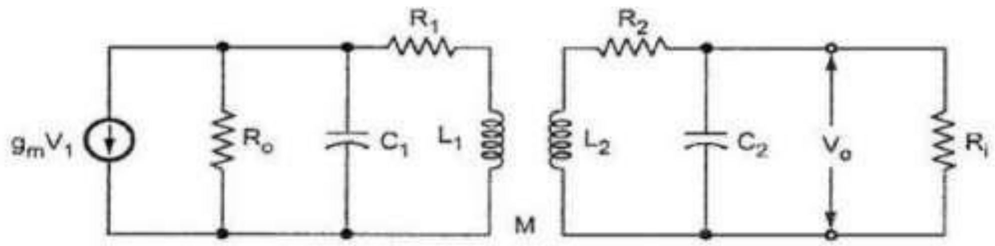


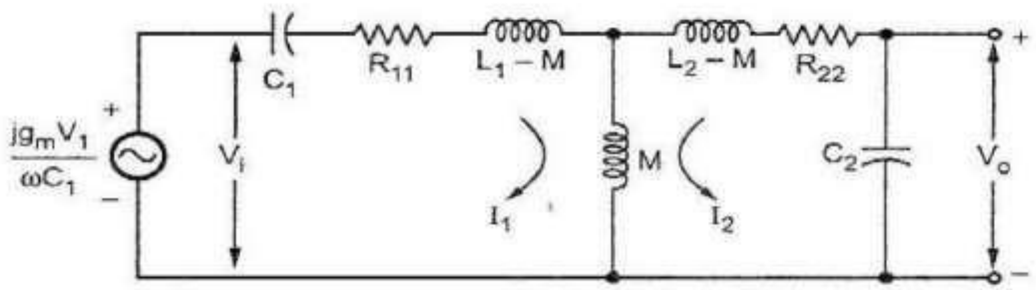
By proper adjustment of the coupling between the two coils of the two tuned circuits, the required results (High selectivity, high Voltage gain and required bandwidth) may be obtained.

Operation:

The high Frequency signal to be amplified is applied to the input terminal of the amplifier. The resonant Frequency of tuned circuit connected in the Collector circuit is made equal to signal Frequency by varying the value of C1. Now the tuned circuit L1, C1 offers very high Impedance to input signal Frequency and therefore, large output is developed across it. The output from the tuned circuit L1, C1 is transferred to the second tuned circuit L2, C2 through Mutual Induction. Hence the Frequency response in Double Tuned amplifier depends on the Magnetic Coupling of L1 and L2

Equivalent circuit of double tuned amplifier:





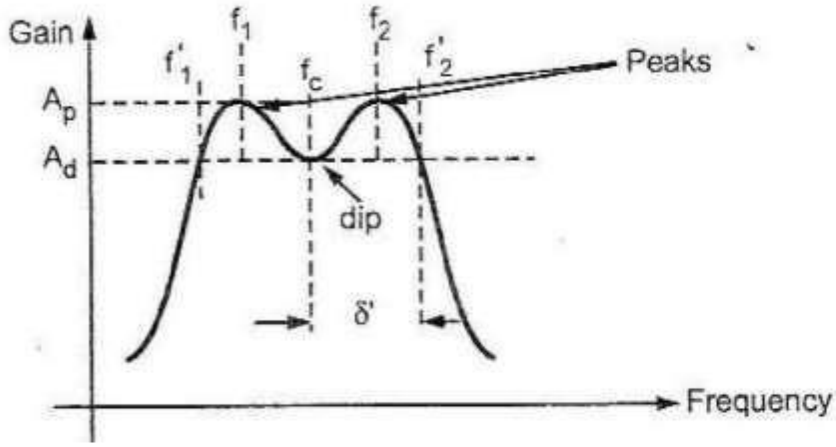
$$\dot{Y}_T = \frac{kQ^2}{\omega_r \sqrt{L_1 L_2}\left[4Q\delta - j(1 + k^2Q^2 - 4Q^2\delta^2)\right]}$$

$$|A_v| = g_m \omega_r \sqrt{L_1 L_2}\, Q \frac{kQ}{\sqrt{1 + k^2Q^2 - 4Q^2\delta^2 + 16Q^2\delta^2}}$$

Two gain peaks in frequencies f1 and f2

$$f_1 = f_r\left(1-\frac{1}{2Q}\sqrt{k^2Q^2-1}\right) \text{ and}$$

$$f_2 = f_r\left(1+\frac{1}{2Q}\sqrt{k^2Q^2-1}\right)$$



at

$$k^2Q^2 = 1, \text{ i.e. } k = \frac{1}{Q}, f_1 = f_2 = f_r$$

This condition is known as critical coupling.

For the values of k<1/Q the peak gain is less than the maximum gain and the coupling

^1_Q The gain magnitude at peak is given as,

$$|A_p| = \frac{g_m \omega_o \sqrt{L_1 L_2}\, kQ}{2}$$

And gain at the dip at $\delta = 0$ is given as,

$$|A_d| = |A_p| \frac{2kQ}{1+k^2Q^2}$$

is poor. For the values k>1/Q, the circuit is over coupled and the response shows double peak. This double ~~p~~eak is useful when more bandwidth is required

The ratio of peak and dip gain is denoted as γ and it represents the magnitude of the ripple in the gain curve.

$$\gamma = \left|\frac{A_p}{A_d}\right| = \frac{1 + k^2Q^2}{2\,kQ}$$

Using quadratic simplification and positive sign

$$kQ = \gamma + \sqrt{\gamma^2 - 1}$$

Bandwidth:

$$BW = 2\,\delta' = \sqrt{2}\,(f_2 - f_1)$$

At 3dB Bandwidth

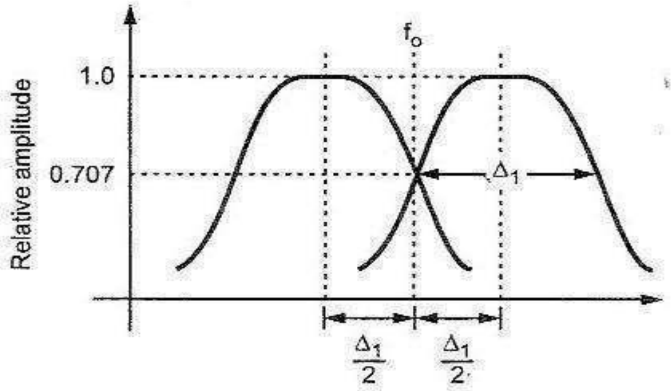
$$3\text{ dB BW} = \frac{3.1\,f_r}{Q}$$

Stagger tuned amplifier

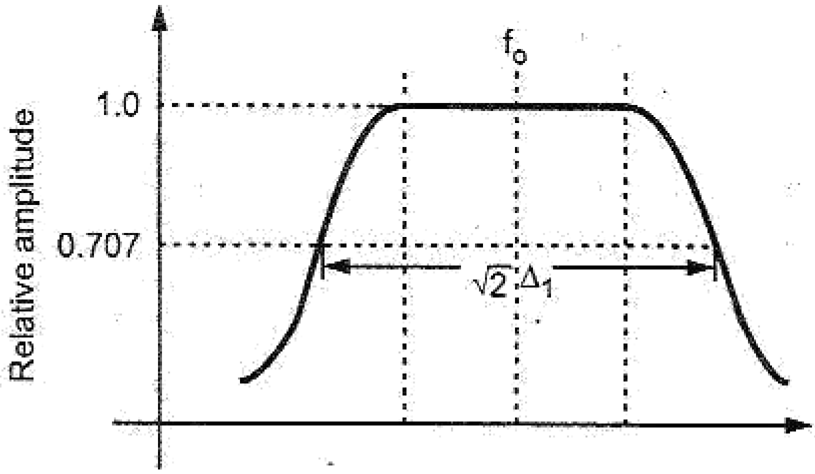
Double tuned amplifier gives greater 3 dB bandwidth having steeper sides and flat top. But alignment of double tuned amplifier is difficult.

To overcome this problem two single tuned cascaded amplifiers having certain bandwidth are taken and their resonant frequencies are so adjusted that they are separated by an amount equal to the bandwidth of each stage. Since the resonant frequencies are displaced or staggered, they are known as staggered tuned amplifiers. If it is desired to build a wide band high gain amplifier, one procedure is to use either single tuned or double tuned circuits which have been heavily loaded so as to increase the bandwidth.

The gain per stage is correspondingly reduced, by virtue of the constant gain - bandwidth product. The use of a cascaded chain of stages will provide for the desired gain. Generally, for a specified gain and bandwidth the double tuned cascaded amplifier is preferred, since fewer tubes are often possible, and also since the pass-band characteristics of the double tuned cascaded chain are more favourable, falling more sensitive to variations in tube capacitance and coil inductance than the single tuned circuits.



Response of individual stages



Over all response

Stagger Tuned Amplifiers are used to improve the overall frequency response of tuned Amplifiers. Stagger tuned Amplifiers are usually designed so that the overall response exhibits maximal flatness around the centre frequency. It needs a number of tuned circuits operating in union. The overall frequency response of a Stagger tuned amplifier is obtained by adding the individual response together.

Since the resonant Frequencies of different tuned circuits are displaced or staggered, they are referred as Stagger Tuned Amplifier.

The main advantage of stagger tuned amplifier is increased bandwidth. Its Drawback is Reduced Selectivity and critical tuning of many tank circuits. They are used in RF amplifier stage in Radio Receivers.

Analysis:

Gain of the single tuned amplifier:

$$\frac{A_v}{A_v\ (\text{at resonance})_1} = \frac{1}{1+j(X+1)}$$

$$\frac{A_v}{A_v\ (\text{at resonance})_2} = \frac{1}{1+j(X-1)}$$

where $X = 2\, Q_{eff}\, \delta$

Gain of the cascaded amplifier:

$$\frac{A_v}{A_v\ (\text{at resonance})_{cascaded}} = \frac{A_v}{A_v\ (\text{at resonance})_1} \times \frac{A_v}{A_v\ (\text{at resonance})_2}$$

$$\left|\frac{A_v}{A_v\ (\text{at resonance})}\right|_{cascaded} = \frac{1}{\sqrt{4+(2Q_{eff}\,\delta)^4}} = \frac{1}{\sqrt{4+16\,Q_{eff}^4\,\delta^4}}$$

$$= \frac{1}{2\sqrt{1+4Q_{eff}^4\,\delta^4}}$$

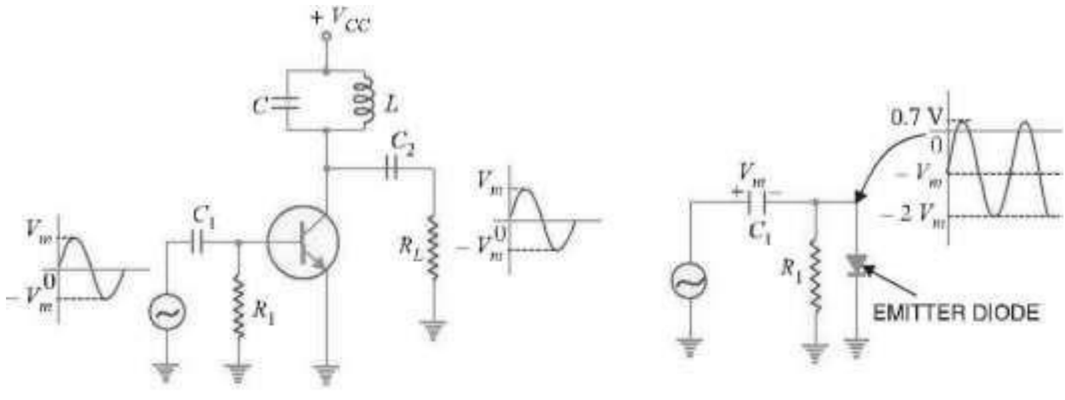
Class C Tuned Amplifier

Class C operation means that collector current flows for less than 180°. In a practical tuned class C amplifier, the collector current flows for much less than 180°; the current looks like narrow pulses as shown in Fig. As we shall see later, when narrow current pulses like these drive a high-Q resonant (i.e. LC) circuit, the voltage across the circuit is almost a perfect sine wave. One very important advantage of class C operation is its high efficiency. Thus 10 W supplied to a class A amplifier may produce only about 3.5 W of a.c. output (35 % efficiency). The same transistor biased to class C may be able to produce 7 W output (70 % efficiency). Class C power amplifiers normally use RF power transistors. The power ratings of such transistors range from 1 W to over 100 W.

Class C Operation

Fig. (i) shows the circuit of tuned class C amplifier. The circuit action is as under:

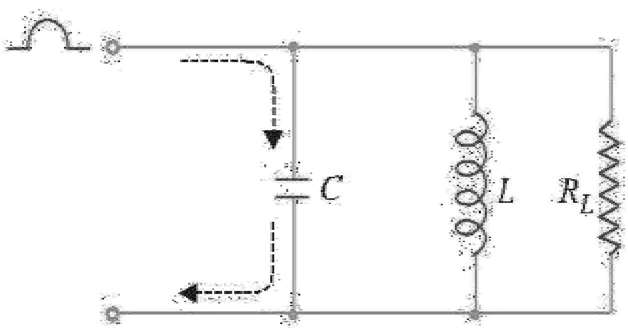
- **When no a.c. input signal is applied, no collector current flows because the emitter diode (i.e. base-emitter junction) is unbiased.**



(i) (ii)

- **When an a.c. signal is applied, clamping action takes place as shown in Fig. (ii). The voltage across the emitter diode varies between + 0.7 V (during positive peaks of input signal) to about −2Vm (during negative peaks of input signal). This means that conduction of the transistor occurs only for a short period during positive peaks of the signal. This results in the pulsed output i.e. collector current waveform is a train of narrow pulses.**

- **When this pulsed output is fed to the LC circuit, **sine-wave output is obtained. This can be easily explained. Since the pulse is narrow, inductor looks like high impedance and the capacitor like a low impedance. Consequently, most of the current charges the capacitor as shown in Fig.**



When the capacitor is fully charged, it will discharge through the coil and the load resistor, setting up oscillations just as an oscillatory circuit does. Consequently, sine-wave output is obtained.

(iv) If only a single current pulse drives the LC circuit, we will get damped sine-wave output. How-ever, if a train of narrow pulses drive the LC circuit, we shall get undamped sine-wave output.

Neutralization

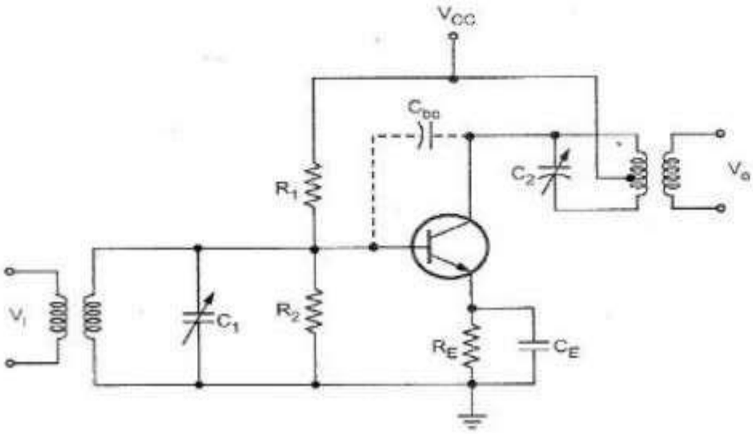
A completely neutralized amplifier must fulfil two conditions. The first is that the inter electrode capacitance between the input and output circuits be cancelled. The second requirement is that the inductance of the screen grid and cathode assemblies and leads be completely cancelled. Cancellation of these common impedances between the input and output will theoretically prevent oscillation. This also applies in practice, but often not without some difficulty.

There are a variety of methods of accomplishing these ends that will fulfil the two conditions. At frequencies up to about 500 KHz it is not normally necessary to neutralize a grid- driven triode. A grounded-grid cathode-driven ceramic-metal triode can usually be operated up into the VHF range without neutralization. Tetrode and pentode amplifiers generally will operate into the HF range without neutralization. As the gain of the amplifier increases, the need to cancel feedback voltage becomes that much more necessary. For this reason, it is usually necessary to neutralize tetrodes and pentodes at the higher frequencies.

3.7.1 Neutralization Methods

In tuned RF amplifiers, transistor are used at the frequencies nearer to their unity gain bandwidths (i.e. fT), to amplify a narrow band of high frequencies centred on a radio frequency. At this frequency, the inter junction capacitance between base and collector, Cbc of the transistor becomes dominant, i.e., its reactance between low enough to be considered, which is otherwise infinite to be neglected as open circuit. Being CE configuration capacitance Cbe, shown in the Fig.3.35 come across input and output circuits of an amplifier. As reactance of Cbc at RF is low enough it provide the feedback path from collector to base. With this circuit condition, if some feedback signal manages to reach the input from output in a positive manner with proper phase shift, then there is possibility of circuit converted to a positive manner with proper phase shift, then there is possibility of circuit converted to an unstable one, generating its own oscillations and can stop working as an amplifier.

This circuit will always oscillate if enough energy is fed back from the collector to the base in the correct phase to overcome circuit losses. Unfortunately, the conditions for best gain and selectivity are also those which promote oscillation. In order to prevent oscillations in tuned RF amplifiers it was necessary to reduce the stage gain to a level that ensured circuit stability. This could be accomplished in several ways such as lowering the Q of tune circuits; stager tuning, losses coupling between the stages or inserting a 'loser' element into the circuit. While all these methods reduced gain, detuning and Q reduction had detrimental effects on selectivity. Instead of losing the circuit performance to achieve stability, the professor L.A. Hazeltine introduced a circuit in which the troublesome effect o the collector to base capacitance of the transistor was neutralized by introducing a signal which cancels the signal coupled through the collector to base capacitance. He proved that the neutralization can be achieved by deliberately feeding back a portion of the output signal to the input in such a way that it has the same amplitude as the unwanted feedback but the opposite phase. Later on many neutralizing circuits were introduced. Let us study some of these circuits.



Hazeltine Neutralization

The Fig. shows one variation of the Hazeline circuit. In this circuit a small value of variable capacitance CN is connected from the bottom of coil, point B, to the base. Therefore, the internal capacitance Cbc, shown dotted, feeds a signal from the top end of the coil, point A, to the transistor base and the CN feeds a signal o equal magnitude but opposite polarity room the bottom o coil, point B, to the base. The neutralizing capacitor, CN can be adjusted correctly to completely nullify the signal ed through the Cbc.

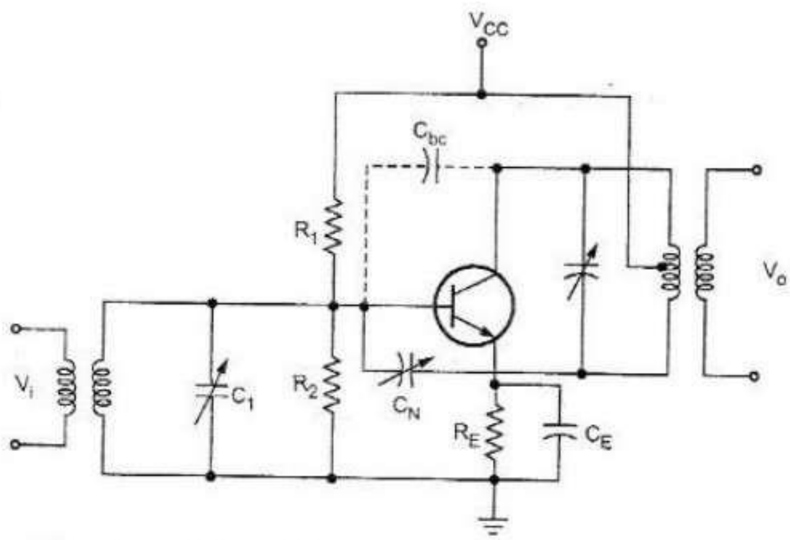


Fig. Tuned RF amplifier with Hazeltine neutralization

Neutralization using coil

The Fig. shows the neutralization o RF amplifier using coil. In this circuit, L part of the tuned circuit at the base o next stage is oriented or minimum coupling to the other winding. It is wound on a separate from and is mounted at right angle to the coupled windings. If the windings are properly polarized, the voltage across L due to the circulating current in the base circuit will have the proper phase to cancel the signal coupled through the base to collector, Cbc capacitance.

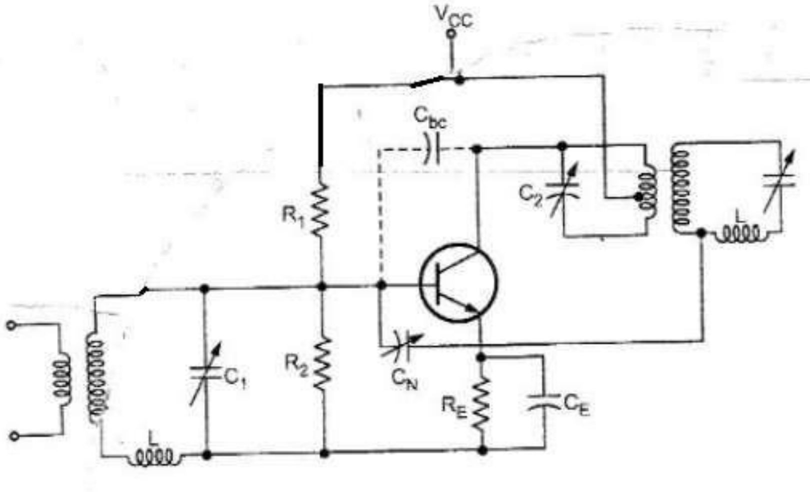


Fig. Tuned RF amplifier using coil

Unilateralisation

It is the phenomenon by which a signal can be transmitted from the input to the output alone and not vice versa. In a unilateralised amplifier both resistive and reactive effects are cancelled. Otherwise Use of an external feedback circuit in a high-frequency transistor amplifier to prevent undesired oscillation by cancelling both the resistive and reactive changes produced in the input circuit by internal voltage feedback with neutralization, only the reactive changes are cancelled.

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ELECTRONIC CIRCUITS II – SECA1401

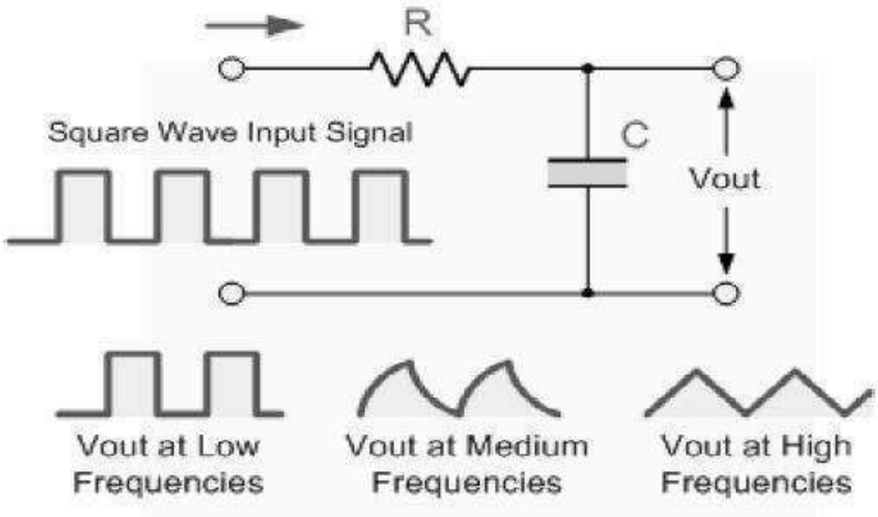
4. WAVE SHAPING CIRCUITS AND MULTIVIBRATORS

Linear wave shaping: Process by which the shape of a non-sinusoidal signal is changed by passing the signal through the network consisting of linear elements

RC Integrator

The Integrator is basically a low pass filter circuit operating in the time domain that converts a square wave "step" response input signal into a triangular shaped waveform output as the capacitor charges and discharges.

A Triangular waveform consists of alternate but equal, positive and negative ramps. As seen below, if the RC time constant is long compared to the time period of the input waveform the resultant output waveform will be triangular in shape and the higher the input frequency the lower will be the output amplitude compared to that of the input.



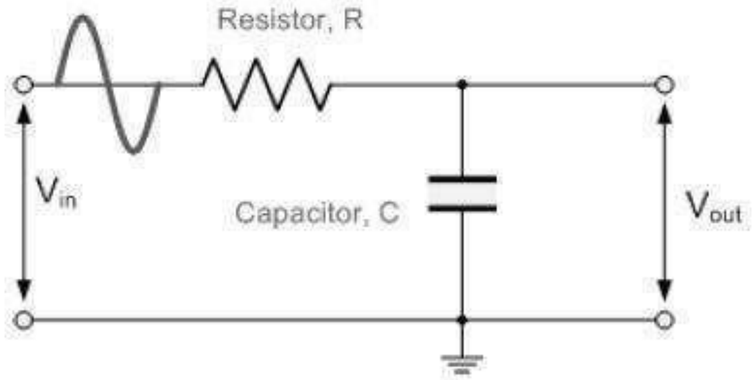
This then makes this type of circuit ideal for converting one type of electronic signal to another for use in wave-generating or wave-shaping circuits.

The Low Pass Filter

A simple passive Low Pass Filter or LPF, can be easily made by connecting together in series a single Resistor with a single Capacitor as shown below. In this type of filter arrangement the input signal (Vin) is applied to the series combination (both the Resistor and Capacitor together) but the output signal (Vout) is taken across the capacitor only.

This type of filter is known generally as a "first-order filter" or "one-pole filter", why first- order or single-pole, because it has only "one" reactive component in the circuit, the capacitor.

Low Pass Filter Circuit



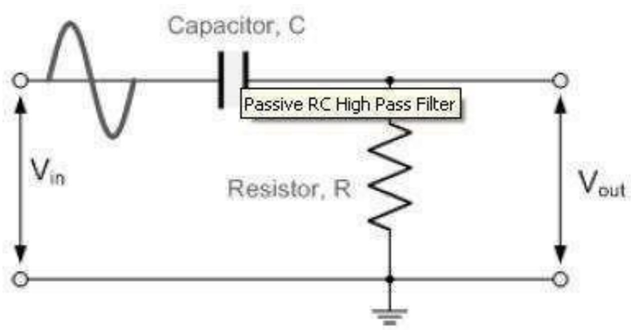
The reactance of a capacitor varies inversely with frequency, while the value of the resistor remains constant as the frequency changes. At low frequencies the capacitive reactance, (Xc) of the capacitor will be very large compared to the resistive value of the resistor, R and as a result the voltage across the capacitor, Vc will also be large while the voltage drop across the resistor, Vr will be much lower. At high frequencies the reverse is true with Vc being small and Vr being large.

High Pass Filters

A High Pass Filter or HPF, is the exact opposite to that of the Low Pass filter circuit, as now the two components have been interchanged with the output signal (Vout) being taken from across the resistor as shown.

Where the low pass filter only allowed signals to pass below its cut -off frequency point, fc. The passive high pass filter circuit as its name implies, only passes signals above the selected cut-off point fc eliminating any low frequency signals from the waveform. Consider the circuit below

The High Pass Filter Circuit

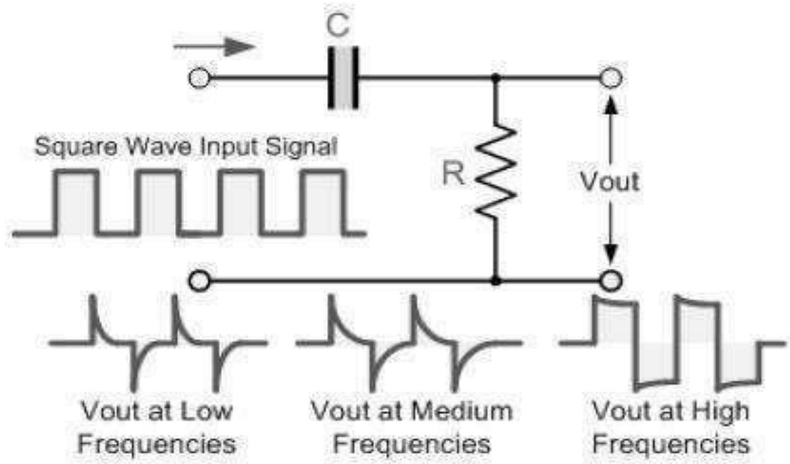


In this circuit arrangement, the reactance of the capacitor is very high at low frequencies so the capacitor acts like an open circuit and blocks any input signals at Vin until the cut-off frequency point (fc) is reached. Above this cut -off frequency point the reactance of the capacitor has reduced sufficiently as to now act more like a short circuit allowing all of the input signal to pass directly to the output as shown below in the High Pass Frequency Response Curve.

RC Differentiator

Up until now the input waveform to the filter has been assumed to be sinusoidal or that of a sine wave consisting of a fundamental signal and some harmonics operating in the frequency domain giving us a frequency domain response for the filter.

However, if we feed the High Pass Filter with a Square Wave signal operating in the time domain giving an impulse or step response input, the output waveform will consist of short duration pulse or spikes as shown.



Each cycle of the square wave input waveform produces two spikes at the output, one positive and one negative and whose amplitude is equal to that of the input. The rate of dec ay of the spikes depends upon the time constant, (RC) value of both components, (t = R x C) and the value of the input frequency. The output pulses resemble more and more the shape of the input signal as the frequency increases

Multivibrators

Introduction

The type of circuit most often used to generate square or rectangular waves is the multivibrator. A multivibrator, is basically two amplifier circuits arranged with regenerative feedback. One of the amplifiers is conducting while the other is cut off When an input signal

to one amplifier is large enough, the transistor can be driven into cutoff, and its collector voltage will be almost V CC. However, when the transistor is driven into saturation, its collector voltage will be about 0 volts.

A circuit that is designed to go quickly from cutoff to saturation will produce a square or rectangular wave at its output. This principle is used in multivibrators. Multivibrators are classified according to the number of steady (stable) states of the circuit. A steady state exists when circuit operation is essentially constant; that is, one transistor remains in conduction and the other remains cut off until an external signal is applied.

The three types of multivibrators :

- **ASTABLE**
- **MONOSTABLE**
- **BISTABLE.**

The astable circuit has no stable state. With no external signal applied, the transistors alternately switch from cutoff to saturation at a frequency determined by the RC time constants of the coupling circuits.

The monostable circuit has one stable state; one transistor conducts while the other is cut off. A signal must be applied to change this condition. After a period of time, determined by the internal RC components, the circuit will return to its original condition where it remains until the next signal arrives.

The bistable multivibrator has two stable states. It remains in one of the stable states until a trigger is applied. It then FLIPS to the other stable condition and remains there until another trigger is applied. The multivibrator then changes back (FLOPS) to its first stable state.

Astable Multivibrator

A multivibrator which generates square waves of its own (i.e. without any external trigger pulse) is known as astable multivibrator. It is also called free ramming multivibrator. It has no stable state but only two quasi-stables (half-stable) makes oscillating continuously between these states. Thus it is just an oscillator since it requires no external pulse for its operation of course it does require D.C power.

In such circuit neither of the two transistors reaches a stable state. It switches back and forth from one state to the other, remaining in each state for a time determined by circuit constants. In other words, at first one transistor conducts (i.e. ON state) and the other stays in the OFF state for some time. After this period of time, the second transistor is automatically turned ON and the first transistor turned OFF. Thus the multivibrator will generate a square wave of its own. The width of the square wave and it frequency will depend upon the circuit constants.

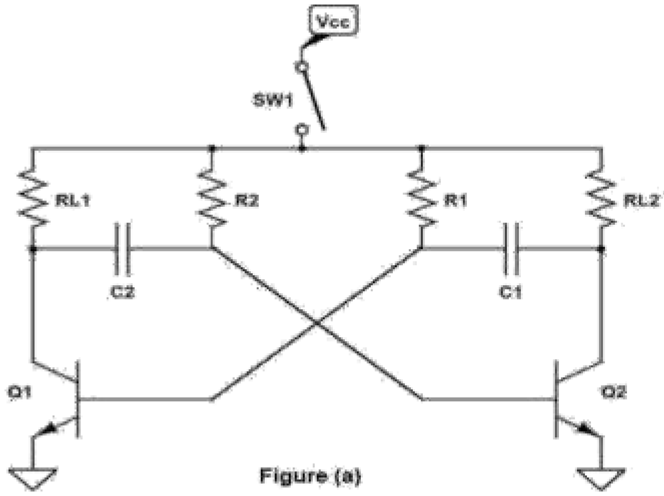


Figure (a)

Here we like to describe.

- **Collector - coupled Astabe multivibrator**
- **Emitter - coupled Astable multivibrator**

Figure (a) shows the circuit of a collector coupled astable multivibrator using two identical NPN transistors Q1 and Q 2. It is possible to have R L1 = RL2 = RL = R1 = R2 = R and C 1
= C2 = C. In that case , the circuit is known as symmetrical astable multivibrator. The transistor Q 1 is forward biased by the Vcc supply through resistor R2. Similarly the transistor Q2 is forward biased by the Vcc supply through resistor R1. The output of transistor Q1 is coupled to the input of transistor Q2 through the capacitor C2. Similarly the output of transistor Q2 is coupled to the input of transistor Q1 through the capacitor C1.

It consists of two common emitter amplifying stages. Each stage provides a feedback through a capacitor at the input of the other. Since the amplifying stage introduces a 180^{o} phase
shift and another 180^{o} phase shift is introduced by a capacitor, therefore the feedback signal and the circuit works as an oscillator. In other words because of capacitive coupling none of the transistor can remain permanently out-off or saturated, instead of circuit has two quasi- stable states (ON and OFF) and it makes periodic transition between these two states.

The output of an Astable multivibrator is available at the collector terminal of the either
transistors as shown in figure (a). However, the two outputs are 180 ^{o} out of phase with each other. Therefore one of the outputs is said to be the complement of the other.

Let us suppose that

When Q1is ON, Q2 is OFF and

When Q2 is ON, Q1 is OFF.

When the D.C power supply is switched ON by closing S, one of the transistors will start conducting before the other (or slightly faster than the other). It is so because characteristics of no two similar transistors can be exactly alike suppose that Q1 starts

conducting before Q2 does. The feedback system is such that Q1 will be very rapidly driven ton saturation and Q 2 to cut-off. The circuit operation may be explained as follows.

Since Q 1 is in saturation whole of VCC drops across R L1. Hence V C1 = 0 and point A is at zero or ground potential. Since Q2 is in cut -off i.e. it conducts no current, there is no drop across R
L2. Hence point B is at VCC. Since A is at 0V C2 starts to charge through R2 towards VCC.

When voltage across C2 rises sufficiently (i.e. more than 0.7V), it biases Q2 in the forward direction so that it starts conducting and is soon driven to saturation.

VCC decreases and becomes almost zero when Q 2 gets saturated. The potential of point B decreases from VCC to almost 0V. This potential decrease (negative swing) is applied to the base of
Q1 through C1. Consequently, Q1 is pulled out of saturation and is soon driven to cut-off.

Since, now point B is at 0V, C1 starts charging through R1 towards the target voltage VCC.

When voltage of C1 increases sufficiently. Q1 becomes forward-biased and starts conducting. In this way the whole cycle is repeated.

It is observed that the circuit alternates between a state in which Q1 is ON and Q2 is OFFand the state in which Q1 is OFF and Q2 is ON. This time in each state depends on RC values. Since each transistor is driven alternately into saturation and cut-off. The voltage waveform at either collector (points A and B in figure (b)) is essentially a square waveform with peak amplitude equal to VCC.

Calculation of switching times and frequency of oscillations:

The frequency of oscillations can be calculated by charging and discharging capacitances and its base resistance RB.

The voltage across the capacitor can be written as

$$V_o = V_f - \left(V_f - V_i\right) e^{\frac{-t}{RC}} = V_B$$

Vi= intial voltage = VB =-VCC thus the transistors enters from ON to OFF state Vf = final voltage = VB = -VCC then the resistor enters from OFF to ON state T1 is ON & T2 is OFF the above equation can be written as

VB1=VCC $\left[1\ 2e^{\frac{-t}{RB_2C_2}}\right]$

Substitute at t=T1, VB1=0 hence this equation

becomes T1=.69RB2C2

The total time period

T=.694(RB1C1+RB2C2) When

RB!=RB2=R & C1=C2=C

T=1.39RC

Frequency of free running multivibrator is given by

$$F = \frac{1}{total\ time\ period(T)} = \frac{1}{1.39RC} = \frac{0.7}{RC}$$

the frequency stability of the circuit is not good as only the function of the product of RC but also depends on load resistances, supply voltages and circuit parameters. In order to stabilize the frequency, synchronizing signals are injected which terminate the unstable periods earlier than would occur naturally.

Bistable multivibrator

The bistable multivibrator has two absolutely stable states. It will remain in whichever state it happens to be until a trigger pulse causes it to switch to the other state. For instance, suppose at any particular instant, transistor Q 1 is conducting and transistor Q 2 is at cut-off. If left to itself, the bistable multivibrator will stay in this position for ever. However, if an external pulse is applied to the circuit in such a way that Q 1 is cut-off and Q2 is turned on, the circuit will stay in the new position. Another trigger pulse is then required to switch the circuit back to its original state.

In other words a multivibrator which has both the state stable is called a bistable multivibrator. It is also called flip-flop, trigger circuit or binary. The output pulse is obtained

When, and why a driving (triggering) pulse is applied to the input. A full cycle of output is produced for every two triggering pulses of correct polarity and amplitude.

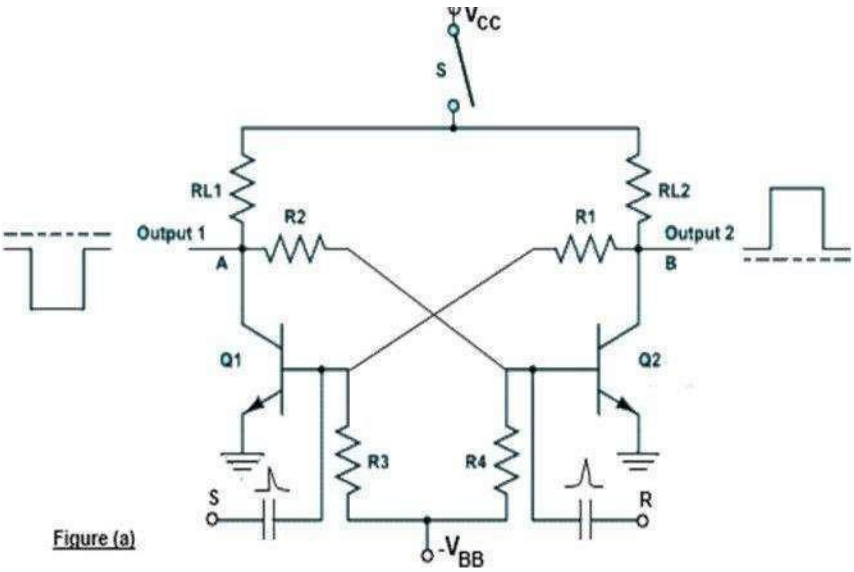


Figure (a)

Figure (a) shows the circuit of a bistable multivibrator using two NPN transistors. Here the output of a transistor Q2 is coupled put of a transistor Q1 through a resistor R2. Similarly, the output of a transistor Q1 is coupled to the base of transistor Q2 through a resistor R1. The capacitors C 2 and C1 are known as speed up capacitors. Their function is to increase the speed of the circuit in making abrupt transition from one stable state to another stable state. The base resistors (R3 and R4) of both the transistors are connected to a common source (-V BB). The output of a bistable multivibrator is available at the collector terminal of the both the transistor Q1 and Q. However, the two outputs are the complements of each other.

Let us suppose, if Q1 is conducting, then the fact that point A is at nearly ON makes the base of Q2 negative (by the potential divider R2 - R4) and holds Q2 off. Similarly with Q2 OFF, the potential divider from VCC to -VBB (RL2, R1, R3) is designed to keep base of Q1 at about 0.7V ensuring that Q1 conducts. It is seen that Q1 holds Q2 OFF and Q2 hold Q1 ON. Suppose, now a positive pulse is applied momentarily to R. It will cause Q2 to conduct. As collector of Q2 falls to zero, it cuts Q1 OFF and consequently, the BMV switches over to its other state.

Similarly, a positive trigger pulse applied to S will switch the BMV back to its original state. Uses:

- In timing circuits as frequency divider
- In counting circuits
- In computer memory circuits

4.5.2.1 Bistable Multivibrator Triggering

To change the stable state of the binary it is necessary to apply an appropriate pulse in the circuit, which will try to bring both the transistors to active region and the resulting regenerative feedback will result on the change of state.

Triggering may be of two following types:

(I) Asymmetrical triggering
(II) Symmetrical triggering

(I) Asymmetrical triggering

In asymmetrical triggering, there are two trigger inputs for the transistors Q1 and Q2. Each trigger input is derived from a separate triggering source. To induce transition among the stable states, let us say that initially the trigger is applied to the bistable. For the next transition,
now the identical trigger must appear at the transistor Q2. Thus it can be said that the asymmetrical triggering the trigger pulses derived from two separate source and connected to the two transistors Q1 and Q2 individually, sequentially change the state of the bistable.

Figure (b) shows the circuit diagram of an asymmetrically triggered bistable multivibrator.

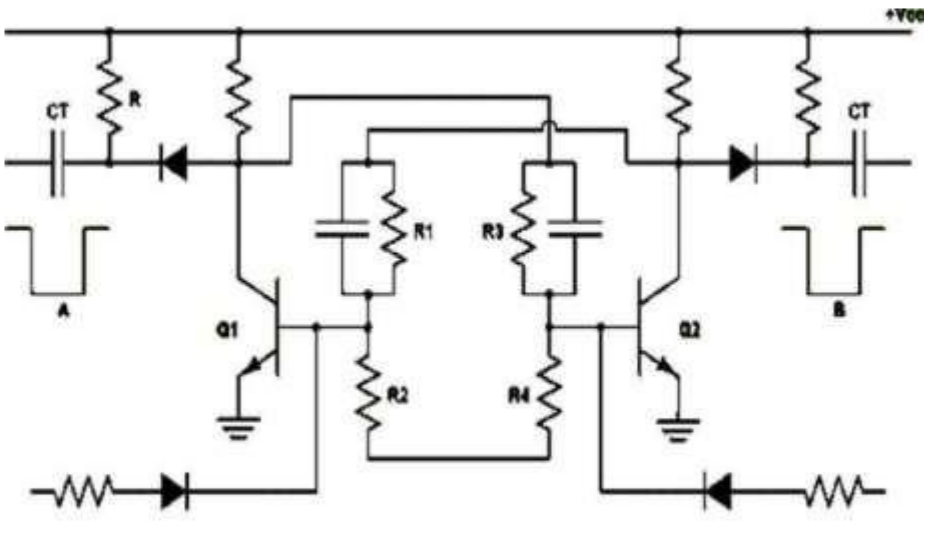


Figure: (b) Asymmetrical triggered bistable multivibrator

Initially Q1 is OFF and transistor Q2 is ON. The first pulse derived from the trigger source A, applied to the terminal turn it OFF by bringing it from saturation region to active transistor Q 1 is ON and transistor Q2 is OFF. Any further pulse next time then the trigger pulse is applied at the terminal B, the change of stable state will result with transistor Q2 On and transistor Q1 OFF.

Asymmetrical triggering finds its application in the generation of a gate waveform, the duration of which is controlled by any two independent events occurring at different time instants. Thus measurement of time interval is facilitated.

(II) symmetrical triggeringhere are various symmetrical triggering methods called symmetrical collector triggering, symmetrical base triggering and symmetrical hybrid triggering. Here we would liked to explain only symmetrical base triggering (positive pulse) only as given under symmetrical Base Triggering.

Figure (c) shows the circuit diagram of a binary with symmetrical base triggering applying a positive trigger pulses.

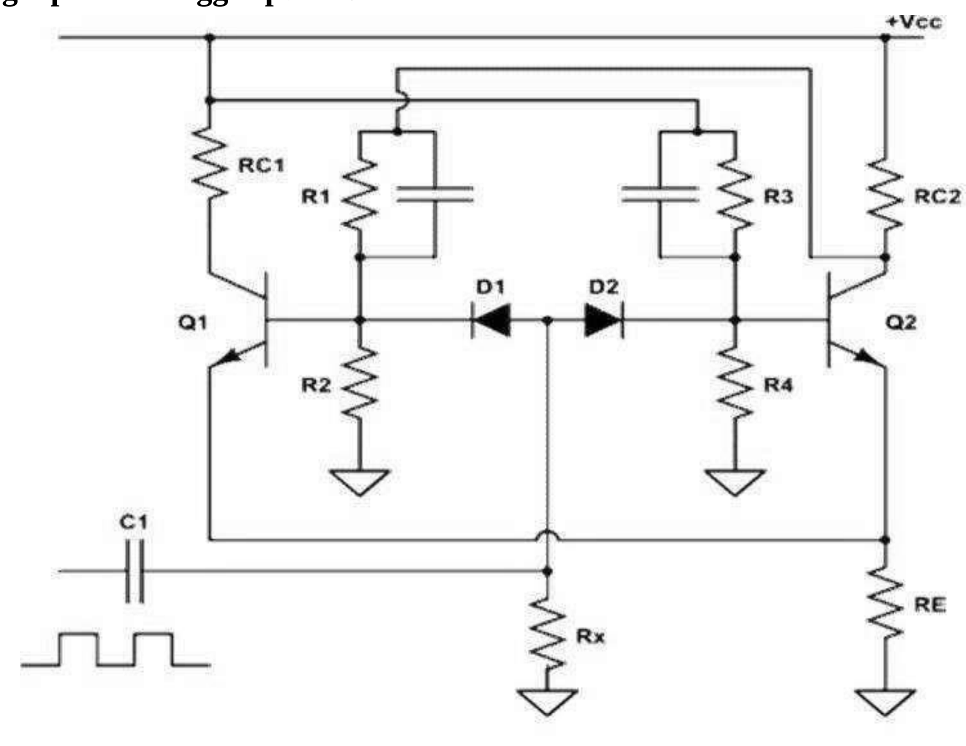


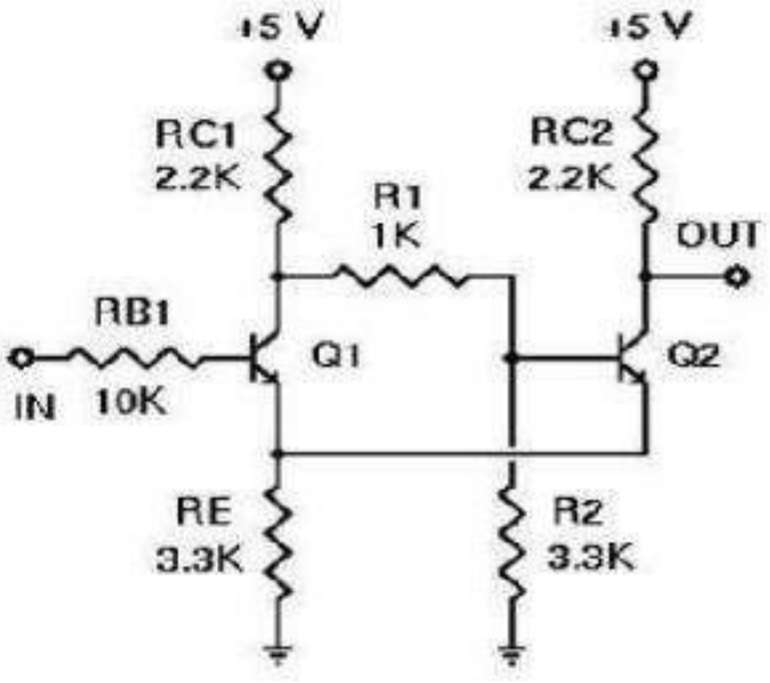
Figure (c): Symmetrical base triggering employing positive triggering pulses

Diodes D1 and D2 are steering diodes. Here the positive pulses, try to turn ON and OFF transistor. Thus when transistor Q1 is OFF and transistor Q2 is ON, the respective base voltages and VB1N, OFF and V B2N, ON. It will be seen that VB1N, OFF > VB1N, ON. Thus diode D2 is more reverse-biased compared to diode D1.

When the positive differentiated pulse of amplitude greater than (VB1N, OFF + Vɣ) appears, the diode D1 gets forward biased, and transistor Q1 enters the active region and with subsequent regenerative feedback Q1 gets ON, and transistor Q2 becomes OFF. On the arrival of the next trigger pulse now the diode D 2 will be forward biased and ultimately with regenerative feedback it will be in the ON state.

Schmitt Trigger

Sometimes an input signal to a digital circuit does not directly fit the description of a digital signal. Reason slow rise and/or fall times, or may have for various it may have acquired. Some noise that could be sensed by further circuitry. It may even be an analog signal whose frequency we want to measure. All of these conditions, and many others, require a specialized circuit that will "clean up" a signal and force it to true digital shape.



The required circuit is called a Schmitt Trigger. It has two possible states just like other multivibrators. However, the trigger for this circuit to change states is the input voltage level, rather than a digital pulse. That is, the output state depends on the input level, and will change only as the input crosses a pre- defined threshold.

Unlike the other multivibrators you have built and demonstrated, the Schmitt Trigger makes its feedback connection through the emitters of the transistors as shown in the schematic diagram to the right. This makes for some useful possibilities, as we will see during our discussion of the operating theory of this circuit.

While Q1 is off, Q2 is on. Its emitter and collector current are essentially the same, and are set by the value of RE and the emitter voltage, which will be less than the Q2 base voltage by VBE. If Q2 is in saturation under these circumstances, the output voltage will be within a fraction of the threshold voltage set by RC1, R1, and R2.

It is important to note that the output voltage of this circuit cannot drop to zero volts, and generally not to a valid logic 0. We can deal with that, but we must recognize this fact.

Now, suppose that the input voltage rises, and continues to rise until it approaches the threshold voltage on Q2's base. At this point, Q1 begins to conduct. Since it now carries some collector current, the current through RC1 increases and the voltage at the collector of Q1 decreases. But this also affects our voltage divider, reducing the base voltage on Q2. But since Q1 is now conducting it carries some of the current flowing through RE, and the voltage across RE doesn't change as rapidly. Therefore, Q2 turns off and the output voltage rises to +5 volts. The circuit has just changed states.

If the input voltage rises further, it will simply keep Q1 turned on and Q2 turned off.
However, if the input voltage starts to fall back towards zero, there must clearly be a point at which this circuit will reset itself. The question is, What is the falling threshold voltage? It will be the voltage at which Q1's base becomes more negative than Q2's base, so that Q2 will begin conducting again. However, it isn't the same as the rising threshold voltage, since Q1 is currently affecting the behavior of the voltage divider.

Second, since the common emitter connection is part of the feedback system in this circuit, RE must be large enough to provide the requisite amount of feedback, without becoming so large as to starve the circuit of needed current. If RE is out of range, the circuit will not operate properly, and may not operate as anything more than a high-gain amplifier over a narrow input voltage range, instead of switching states.

The third factor is the fact that the output voltage cannot switch over logic levels, because the transistor emitters are not grounded. If a logic-level output is required, which is usually the case, we can use a circuit such as the one shown here to correct this problem. This circuit is basically two RTL inverters, except that one uses a PNP transistor. This works because when Q2 above is turned off, it will hold a PNP inverter off, but when it is on, its output will turn the PNP transistor on. The NPN transistor here is a second inverter to re- invert the signal and to restore it to active pull-down in common with all of our other logic circuits.

The circuit you will construct for this experiment includes both of the circuits shown here, so that you can monitor the response of the Schmitt trigger with L0.

Schmitt Waveform Generators

Simple Waveform Generators can be constructed using basic Schmitt trigger action Inverters such as the TTL 74LS14. This method is by far the easiest way to make a basic astable waveform generator. When used to produce clock or timing signals, the astable multivibrator must produce a stable waveform that switches quickly between its "HIGH" and "LOW" states without any distortion or noise, and Schmitt inverters do just that.

We know that the output state of a Schmitt inverter is the opposite or inverse to that of its input state, (NOT Gate principles) and that it can change state at different voltage levels giving it "hysteresis". Schmitt inverters use a Schmitt Trigger action that changes state between an upper and a lower threshold level as the input voltage signal increases and decreases about the input terminal.

This upper threshold level "sets" the output and the lower threshold level"resets" the output which equates to a logic "0" and a logic "1" respectively for an inverter. Consider the circuit below.

TTL Schmitt Waveform Generator

The circuit consists simply of a TTL 74LS14 Schmitt inverter logic gate with a capacitor, C connected between its input terminal and ground, (0v) with the positive feedback required for the circuit to oscillate is provided by the feedback resistor, R. So how does it work?. Assume that the charge across the capacitors plates is below the Schmitt's lower threshold level of 0.8 volt (Datasheet value). This therefore makes the input to the inverter at a logic "0" level resulting in a logic "1" output level (inverter principals). One side of the resistor R is now connected to the logic "1" level (+5V) output while the other side of the resistor is connected to the capacitor, C which is at a logic "0" level (0.8v or below). The capacitor now starts to charge up in a positive direction through the resistor at a rate determined by the RC time constant of the combination. When the charge across the capacitor reaches the 1.6 volt upper threshold level of the Schmitt trigger (Datasheet value) the output from the Schmitt inverter changes rapidly from a logic level "1" to a logic level "0" state and the current flowing through the resistor changes direction.

This change now causes the capacitor that was originally charging up through the resistor, R to begin to discharge itself back through the same resistor until the charge across the capacitors plates reaches the lower threshold level of 0.8 volts and the inverters output switches state again with the cycle repeating itself over and over again as long as the supply voltage is present.

So the capacitor, C is constantly charging and discharging itself during each cycle between the upper and lower threshold levels of the Schmitt inverter producing a logic level "1" or a logic level "0" at the inverters output. However, the output square wave signal is not symmetrical producing a duty cycle of about 33% or 1/3 as the mark-to -space ratio between "HIGH" and "LOW" is 1:2 respectively due to the input gate characteristics of the TTL inverter.

The value of the feedback resistor, R must also be kept low to below 1kΩ for the circuit to oscillate correctly, 220R to 470R is good, and by varying the value of the capacitor, C to vary the frequency. Also at high frequency levels the output waveform changes shape from a square shaped waveform to a trapezoidal shaped waveform as the input characteristics of the TTL gate are affected by the rapid charging and discharging of the capacitor.

With a resistor value between: 100R to 1kΩ, and a capacitor value of between: 1nF to

1000uF.This would give a frequency range of between 1Hzto 1MHz, (high frequencies produce waveform distortion).

Low-Pass RC Circuit

Figure shows a low-pass RC circuit. A low-pass circuit is a circuit, which transmits only low-frequency signals and attenuates or stops high-frequency signals.

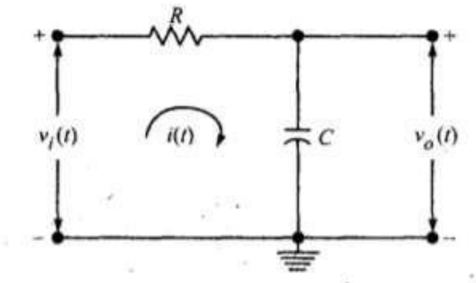


Figure The low-pass *RC* circuit.

At zero frequency, the reactance of the capacitor is infinity (i.e. the capacitor acts as an open circuit) so the entire input appears at the output, i.e. the input is transmitted to the output with zero attenuation. So the output is the same as the input, i.e. the gain is unity. As the frequency increases the capacitive reactance (Xc = H2nfC) decreases and so the output decreases.

At very high frequencies the capacitor virtually acts as a short-circuit and the output falls to zero.

Step Input

A step signal is one which maintains the value zero for all times $t < 0$, and maintains the value V for all times $t > 0$. The transition between the two voltage levels takes place at $t = 0$ and is accomplished in an arbitrarily small time interval. Thus, in Figure (a), vi = 0 immediately before t = 0 (to be referred to as time t = 0-) and vi = V, immediately after t= 0 (to be referred to as time t = 0 +). In the low-pass RC circuit shown in Figure 1.1, if the capacitor is initially uncharged, when a step input is applied, since the voltage across the capacitor cannot change instantaneously, the output will be zero at t = 0, and then, as the capacitor charges, the output voltage rises exponentially towards the steady-state value V with a time constant RC as shown in Figure (b).

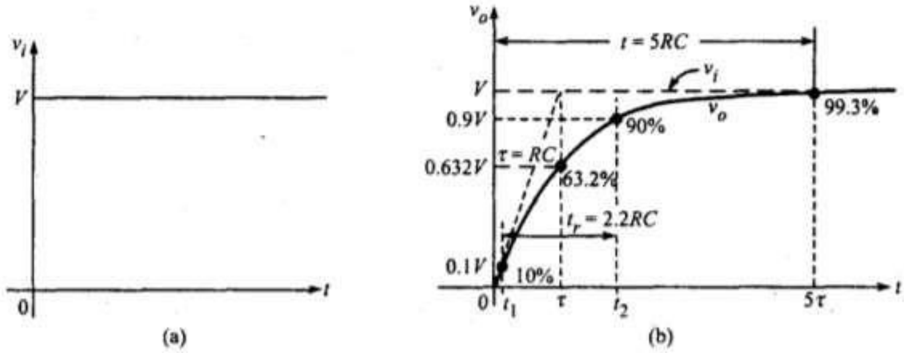


Figure (a) Step input and (b) step response of the low-pass *RC* circuit.

Let V' be the initial voltage across the capacitor. Write KVL around the Loop in Figure.

$$v_i(t) = Ri(t) + \frac{1}{C}\int i(t)\,dt$$

Differentiating this equation,

$$\frac{dv_i(t)}{dt} = R\frac{di(t)}{dt} + \frac{1}{C}i(t)$$

Since $\quad v_i(t) = V, \quad \frac{dv_i(t)}{dt} = 0$

$\therefore \quad 0 = R\frac{di(t)}{dt} + \frac{1}{C}i(t)$

Taking the Laplace transform on both sides,

$$0 = R[sI(s) - I(0^+)] + \frac{1}{C}I(s)$$

$\therefore \quad I(0^+) = I(s)\left(s + \frac{1}{RC}\right)$

The initial current $I(0^+)$ is given by

$$I(0^+) = \frac{V - V'}{R}$$

$\therefore \quad I(s) = \frac{I(0^+)}{s + \frac{1}{RC}} = \frac{V - V'}{R\left(s + \frac{1}{RC}\right)}$

and $\quad V_o(s) = V_i(s) - I(s)R = \frac{V}{s} - \frac{(V - V')R}{R\left(s + \frac{1}{RC}\right)} = \frac{V}{s} - \frac{V - V'}{s + \frac{1}{RC}}$

Taking the inverse Laplace transform on both sides,

$$v_o(t) = V - (V - V')e^{-t/RC}$$

Taking the inverse Laplace transform on both sides,

$$v_o(t) = V - (V - V')e^{-t/RC}$$

where V' is the initial voltage across the capacitor (V_{initial}) and V is the final voltage (V_{final}) to which the capacitor can charge.

So, the expression for the voltage across the capacitor of an RC circuit excited by a step input is given by

$$v_o(t) = V_{\text{final}} - (V_{\text{final}} - V_{\text{initial}})e^{-t/RC}$$

If the capacitor is initially uncharged, then $v_o(t) = V(1 - e^{-t/RC})$

Expression for rise time

When a step signal is applied, the rise time tr is defined as the time taken by the output voltage waveform to rise from 10% to 90% of its final value: It gives an indication of how fast the circuit can respond to a discontinuity in voltage. Assuming that the capacitor in Figure is initially uncharged, the output voltage shown in Figure 1.3(b) at any instant of time is given by

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

At $t = t_1$, $v_o(t) = 10\%$ of $V = 0.1\,\text{V}$

$$\therefore \quad 0.1V = V(1 - e^{-t_1/RC})$$

$$\therefore \quad e^{-t_1/RC} = 0.9 \quad \text{or} \quad e^{t_1/RC} = \frac{1}{0.9} = 1.11$$

$$\therefore \quad t_1 = RC \ln (1.11) = 0.1RC$$

At $t = t_2$, $v_o(t) = 90\%$ of $V = 0.9\,\text{V}$

$$\therefore \quad 0.9V = V(1 - e^{-t_2/RC})$$

$$\therefore \quad e^{-t_2/RC} = 0.1 \quad \text{or} \quad e^{t_2/RC} = \frac{1}{0.1} = 10$$

$$\therefore \quad t_2 = RC \ln 10 = 2.3RC$$

$$\therefore \quad \text{Rise time, } t_r = t_2 - t_1 = 2.2RC$$

This indicates that the rise time tr is proportional to the time constant RC of the circuit. The larger the time constant, the slower the capacitor charges, and the smaller the time constant, the faster the capacitor charges.

Relation between rise time and upper 3-dB frequency

We know that the upper 3-dB frequency (same as bandwidth) of a low-pass circuit is

$$f_2 = \frac{1}{2\pi RC} \quad \text{or} \quad RC = \frac{1}{2\pi f_2}$$

$$\text{Rise time, } t_r = 2.2RC = \frac{2.2}{2\pi f_2} = \frac{0.35}{f_2} = \frac{0.35}{\text{BW}}$$

Thus, the rise time is inversely proportional to the upper 3-dB frequency. The time constant (T= RC) of a circuit is defined as the time taken by the output to rise to 63.2% of the amplitude of the input step. It is same as the time taken by the output to rise to 100% of the amplitude of the input step, if the initial slope of rise is maintained. See Figure (b).

Ramp Input

When a low-pass RC circuit shown in Figure is excited by a ramp input, i.e.

$$v_i(t) = \alpha t, \text{ where } \alpha \text{ is the slope of the ramp}$$

we have,

$$V_i(s) = \frac{\alpha}{s^2}$$

From the frequency domain circuit of Figure 1.2(a), the output is given by

$$V_o(s) = V_i(s) \frac{\frac{1}{Cs}}{R + \frac{1}{Cs}} = \frac{\alpha}{s^2} \cdot \frac{1}{1 + RCs} = \frac{\alpha}{RC} \frac{1}{s^2\left(s + \frac{1}{RC}\right)}$$

$$= \frac{\alpha}{RC}\left[\frac{-(RC)^2}{s} + \frac{RC}{s^2} + \frac{(RC)^2}{s + \frac{1}{RC}}\right]$$

i.e. $$V_o(s) = \frac{-\alpha RC}{s} + \frac{\alpha}{s^2} + \frac{\alpha RC}{s + \frac{1}{RC}}$$

When the time constant is very small relative to the total ramp time T, the ramp will be transmitted with minimum distortion. The output follows the input but is delayed by one time.

Taking the inverse Laplace transform on both sides,

$$v_o(t) = -\alpha RC + \alpha t + \alpha RCe^{-t/RC}$$
$$= \alpha(t - RC) + \alpha RCe^{-t/RC}$$

If the time constant RC is very small, $e^{-t/RC} \approx 0$

$$\therefore \quad v_o(t) = \alpha(t - RC)$$

Constant RC from the input (except near the origin where there is distortion) as shown in Figure (a). If the time constant is large compared with the sweep duration, i.e. if RCIT » 1, the output will be highly distorted as shown in Figure (b).

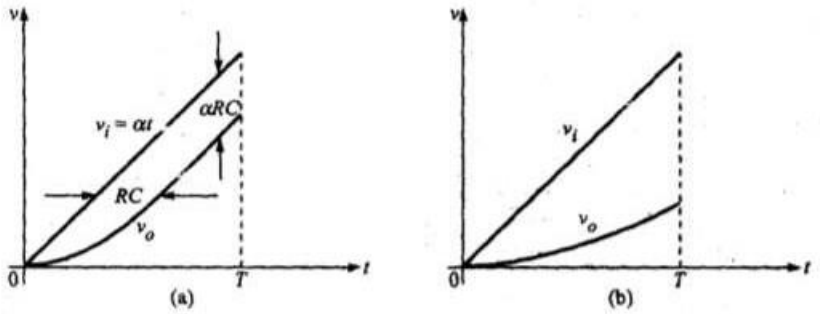


Figure Response of a low-pass RC circuit for a ramp input for (a) $RC/T << 1$ and (b) $RC/T >> 1$.

Expanding $e^{-t/RC}$ in to an infinite series in t/RC in the above equation for $v_o(t)$,

$$v_o(t) = \alpha(t - RC) + \alpha RC\left(1 - \frac{t}{RC} + \left(\frac{t}{RC}\right)^2 \frac{1}{2!} - \left(\frac{t}{RC}\right)^3 \frac{1}{3!} + \ldots\right)$$
$$= \alpha t - \alpha RC + \alpha RC - \alpha t + \frac{\alpha t^2}{2RC} - \ldots$$
$$\approx \frac{\alpha t^2}{2RC} = \frac{\alpha}{RC}\left(\frac{t^2}{2}\right)$$

This shows that a quadratic response is obtained for a linear input and hence the circuit acts as an integrator for RC/T » 1. The transmission error e_t for a ramp input is defined as the difference between the input and the output divided by the input at the end of the ramp, i.e. at t = T. For RC/T « 1,

$$e_t = \left.\frac{\alpha t - (\alpha t - \alpha RC)}{\alpha t}\right|_{t=T}$$
$$= \frac{\alpha RC}{\alpha T} = \frac{RC}{T} = \frac{1}{2\pi f_2 T}$$

where f2 is the upper 3-dB frequency. For example, if we desire to pass a 2 ms pulse with less than 0.1% error, the above equation yields f2 > 80 kHz and RC < 2 µ.s.

Exponential Input

For the low-pass RC circuit shown in Figure 1.1, let the input applied as shown in Figure be vi(t) = V(l – $e^{tl\tau}$), where T is the time constant of the input waveform.

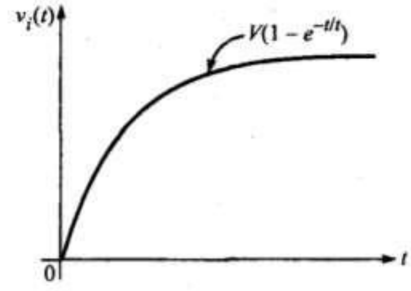


Figure Exponential input.

Writing the KVL around the loop,

$$v_i(t) = Ri(t) + v_o(t) = RC\frac{dv_o(t)}{dt} + v_o(t)$$

$\therefore$

$$V(1 - e^{-t/\tau}) = RC\frac{dv_o(t)}{dt} + v_o(t)$$

Taking the Laplace transform on both sides and neglecting the initial conditions,

$$\frac{V}{s} - \frac{V}{s+\frac{1}{\tau}} = RCsV_o(s) + V_o(s)$$

i.e.

$$V\left[\frac{\frac{1}{\tau}}{s\left(s+\frac{1}{\tau}\right)}\right] = V_o(s)(RCs+1) = RCV_o(s)\left(s+\frac{1}{RC}\right)$$

$$\therefore \qquad V_o(s) = \frac{V}{RC\tau}\left[\frac{1}{s\left(s+\frac{1}{\tau}\right)\left(s+\frac{1}{RC}\right)}\right]$$

$$= V\left[\frac{1}{s} - \frac{1}{\left(1-\frac{RC}{\tau}\right)\left(s+\frac{1}{\tau}\right)} + \frac{1}{\left(\frac{\tau}{RC}-1\right)\left(s+\frac{1}{RC}\right)}\right]$$

Taking the inverse Laplace transform on both sides and letting $RC/\tau = n$,

$$v_o(t) = V\left[1 - \frac{e^{-t/\tau}}{1-n} + \frac{e^{-t/RC}}{\frac{1}{n}-1}\right]$$

If $t/\tau = x$, then $v_o(t) = V\left[1 - \frac{e^{-x}}{1-n} + \frac{n}{1-n}e^{-x/n}\right]$, if $n \neq 1$

and $\qquad v_o(t) = 1 - (1+x)e^{-x}, \qquad$ if $n = 1$

These are the expressions for the voltage across the capacitor of a low-pass RC circuit excited by an exponential input of rise time t_{r1} - 2.2r. If an exponential of rise time tr1 is passed through a low-pass circuit with rise time t_{r2}, the rise time of the output waveform t_r will be given by an empirical relation, $tr = 1.05\sqrt{t_{r1}^2 + t^2}$

This is same as the rise time obtained when a step is applied to a cascade of two circuits of rise times t_{r1} and t_{r2} assuming that the second circuit does not load the first.

High-Pass RC Circuit

Figure shows a high-pass RC circuit. At zero frequency the reactance of the capacitor is infinity and so it blocks the input and hence the output is zero. Hence, this capacitor is called the blocking capacitor and this circuit, also called the capacitive coupling circuit, is used to provide dc isolation between the input and the output. As the frequency increases, 'the Reactance of the capacitor decreases and hence the output and gain increase. At very high frequencies, the capacitive reactance is very small so a very small voltage appears, across C and, so the output is almost equal to the input and the gain is equal to 1. Since this circuit attenuates low-frequency signals and allows transmission of high-frequency signals with little or no attenuation, it is called a high-pass circuit.

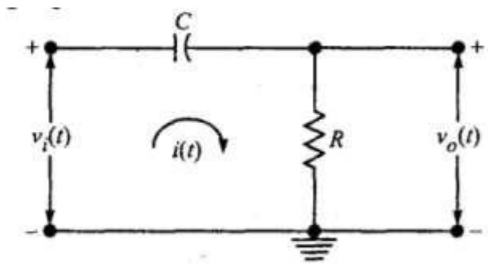
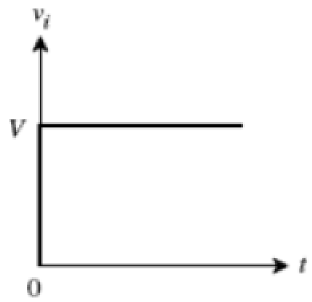


Figure The high-pass *RC* circuit.

Response of the High-pass RC Circuit to Step Input

A step voltage, shown in Fig. (a), is represented mathematically as:



$$v_i = \frac{1}{C}\int i\,dt + v_o$$

But $v_o = iR$

$$i = \frac{v_o}{R}$$

$$\therefore v_i = \frac{1}{RC}\int v_o\,dt + v_o$$

For a step input, put $v_i = V$ and $RC = \tau$. Taking Laplace transforms:

$$\frac{V}{s} = \frac{v_o(s)}{s\tau} + v_o(s) \qquad v_o(s)\left(1 + \frac{1}{s\tau}\right) = \frac{V}{s} \qquad v_o(s)\left(s + \frac{1}{\tau}\right) = V$$

$$v_o(s) = \frac{V}{\left(s + \frac{1}{\tau}\right)}$$

Taking Laplace inverse:

$$v_o(t) = Ve^{-t/\tau}$$

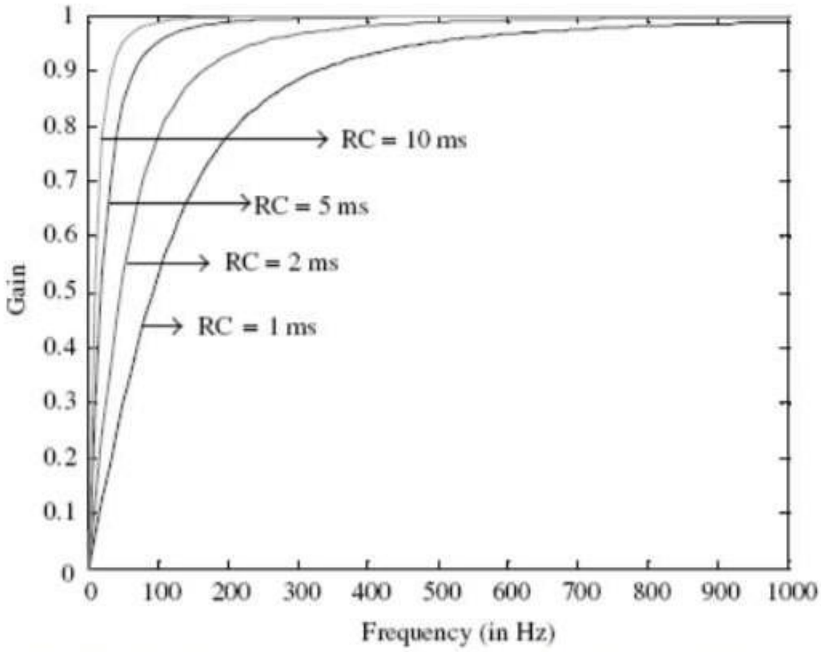


FIGURE The frequency–response curve for different values of τ

Response of the High-pass RC Circuit to Exponential Input

If the input to the high-pass circuit in Fig. (a) is an exponential of the form:

$$V_i = V(1 - e^{-t/\tau 1})$$

where, τ_1 is the time constant of the circuit that has generated the exponential signal as shown in Fig (a).

we know:

$$\frac{dv_i}{dt} = \frac{v_o}{\tau} + \frac{dv_o}{dt}$$

As $v_i = V(1 - e^{-t/\tau 1})$,

$$\frac{dv_i}{dt} = \frac{V}{\tau_1} e^{-t/\tau_1}$$

Substituting Eq. (2.48) in Eq. (2.30):

$$\frac{V}{\tau_1} e^{-t/\tau_1} = \frac{v_o}{\tau} + \frac{dv_o}{dt}$$

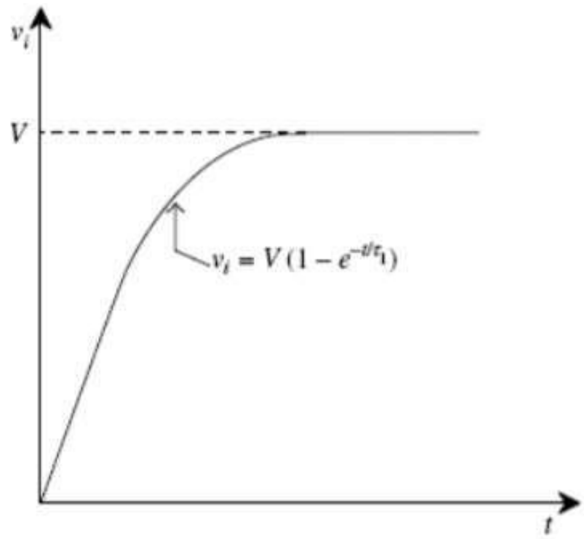


FIGURE (a) Exponential input

Taking Laplace transforms:

$$\frac{\frac{V}{\tau_1}}{\left(s+\frac{1}{\tau_1}\right)} = \frac{v_o(s)}{\tau} + s v_o(s)$$

where, τ is the time constant of the high-pass circuit.

$$\frac{\frac{V}{\tau_1}}{\left(s+\frac{1}{\tau_1}\right)} = v_o(s)\left(s+\frac{1}{\tau}\right)$$

Therefore,

$$v_o(s) = \frac{\frac{V}{\tau_1}}{\left(s+\frac{1}{\tau_1}\right)\left(s+\frac{1}{\tau}\right)}$$

Case 1: $\tau = \tau_1$

Applying partial fractions, Eq. can be written as:

$$v_o(s) = \frac{A}{\left(s+\frac{1}{\tau_1}\right)} + \frac{B}{\left(s+\frac{1}{\tau}\right)} = \frac{\frac{V}{\tau_1}}{\left(s+\frac{1}{\tau_1}\right)\left(s+\frac{1}{\tau}\right)}$$

Therefore,

$$\frac{V}{\tau_1} = A\left(s + \frac{1}{\tau}\right) + B\left(s + \frac{1}{\tau_1}\right)$$

Put $s = -1/\tau_1$ in Eq.

$$\frac{V}{\tau_1} = A\left(\frac{-1}{\tau_1} + \frac{1}{\tau}\right) \quad \text{or} \quad A = \frac{\frac{V}{\tau_1}}{\left(\frac{1}{\tau} - \frac{1}{\tau_1}\right)} = \frac{V}{\left(\frac{\tau_1}{\tau} - 1\right)}$$

Now put $s = -1/\tau$ in Eq. . Then:

$$\frac{V}{\tau_1} = B\left(\frac{1}{\tau_1} - \frac{1}{\tau}\right)$$

Therefore,

$$B = \frac{-V}{\left(\frac{\tau_1}{\tau} - 1\right)}$$

Substituting the values of A and B in Eq.

$$v_o(s) = \frac{V}{\left(\frac{\tau_1}{\tau} - 1\right)\left(s + \frac{1}{\tau_1}\right)} - \frac{V}{\left(\frac{\tau_1}{\tau} - 1\right)\left(s + \frac{1}{\tau}\right)} = \frac{V}{\left(\frac{\tau_1}{\tau} - 1\right)}\left[\frac{1}{\left(s + \frac{1}{\tau_1}\right)} - \frac{1}{\left(s + \frac{1}{\tau}\right)}\right]$$

Taking inverse Laplace transform:

$$v_o(t) = \frac{V}{\left(\frac{\tau_1}{\tau} - 1\right)}\left(e^{-t/\tau_1} - e^{-t/\tau}\right)$$

This is the expression for the output voltage where $\tau \neq \tau_1$.

Let $t/\tau_1 = x$ and $\tau/\tau_1 = n$. For $n \neq 1$, i.e., $\tau \neq \tau_1$, we have from Eq.

$$v_o(t) = \frac{V}{\left(\frac{1}{n} - 1\right)}\left(e^{-x} - e^{-x/n}\right) \quad \text{since} \quad \frac{t}{\tau_1} \times \frac{\tau_1}{\tau} = \frac{x}{n} = \frac{t}{\tau}$$

Therefore,

$$v_o(t) = \frac{Vn}{(1-n)}\left(e^{-x} - e^{-x/n}\right) = \frac{Vn}{(n-1)}\left(e^{-x/n} - e^{-x}\right)$$

If $\tau >> \tau_1$, the second term in the Eq. is small when compared to the first. Thus,

$$v_o(t) \cong \frac{Vn}{(n-1)}e^{-x/n} = \frac{Vn}{(n-1)}e^{-t/\tau}$$

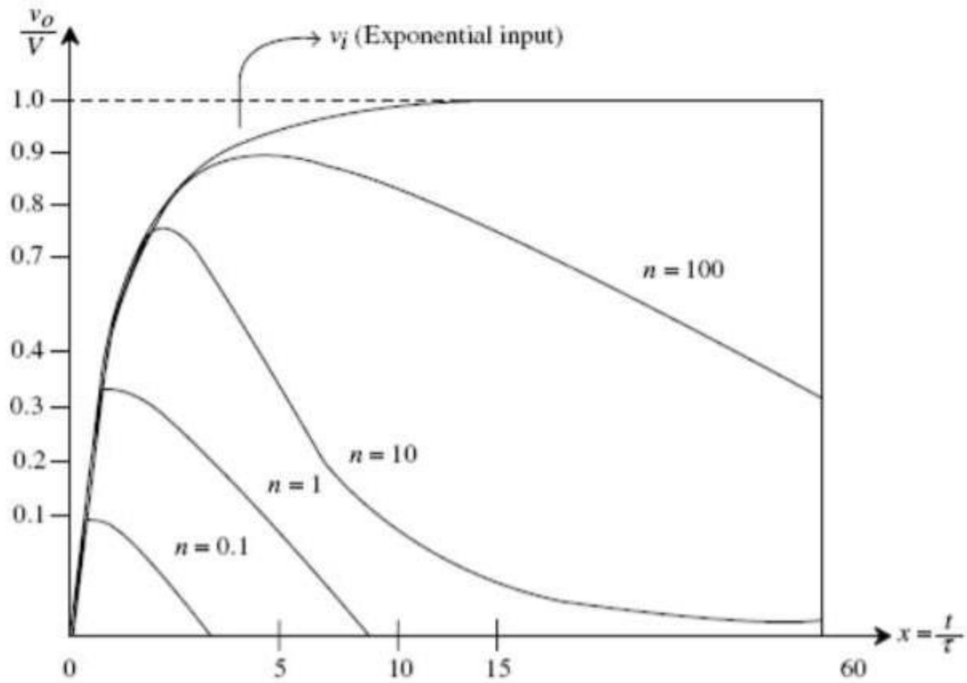


FIGURE The response of a high-pass circuit to an exponential input

Response of the High-pass RC Circuit to Ramp Input

Let the input to the high-pass circuit be vi = αt where, α is the slope, as shown in Fig. (a).
For the high-pass circuit, we have:
For the high-pass circuit, we have:

$$v_i = \frac{1}{\tau}\int v_o dt + v_o$$

$$\alpha t = \frac{1}{\tau}\int v_o dt + v_o$$

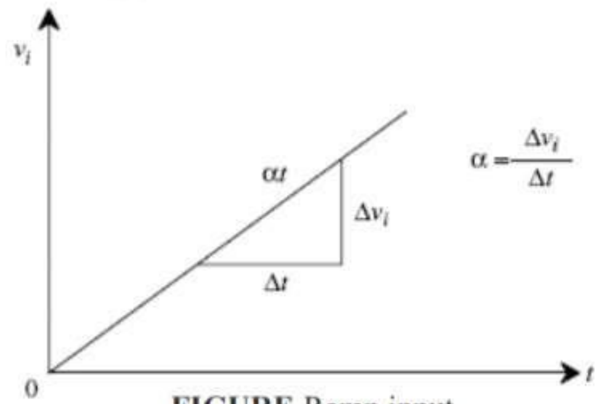


FIGURE Ramp input

Taking Laplace transforms:

$$\frac{\alpha}{s^2} = \frac{1}{s\tau} v_o(s) + v_o(s) = v_o(s)\left(1 + \frac{1}{s\tau}\right)$$

Multiplying throughout by s:

$$\frac{\alpha}{s} = v_o(s)\left(s + \frac{1}{\tau}\right)$$

Therefore,

$$v_o(s) = \frac{\alpha}{s\left(s + \frac{1}{\tau}\right)} = \frac{A}{s} + \frac{B}{\left(s + \frac{1}{\tau}\right)}$$

From which, $A = \alpha\tau$ and $B = -\alpha\tau$

$$v_o(s) = \frac{\alpha\tau}{s} - \frac{\alpha\tau}{\left(s + \frac{1}{\tau}\right)} = \alpha\tau\left[\frac{1}{s} - \frac{1}{\left(s + \frac{1}{\tau}\right)}\right]$$

Taking Laplace inverse:

$$v_o(t) = \alpha\tau\left(1 - e^{-t/\tau}\right)$$

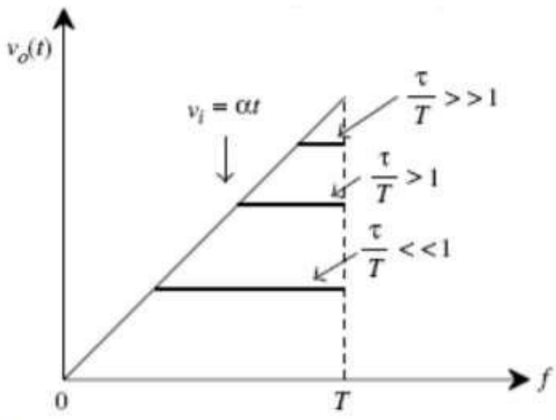


FIGURE The response of a high-pass circuit to ramp input

The Response of a High-Pass RL Circuit to Step Input

A high-pass RL circuit is represented in Fig. If a step of magnitude V is applied, let us find the response. Writing the KVL equation:

$$v_i = iR + L\frac{di}{dt}$$

$$v_o = L\frac{di}{dt}$$

Therefore, from Eq. (80)

$$\frac{di}{dt} = \frac{v_o}{L} \quad di = \frac{1}{L}v_o dt \quad i = \frac{1}{L}\int v_o dt$$

As $v_i = V$, Eq. (2.79) can also be written as:

$$V = \frac{R}{L}\int v_o dt + v_o$$

Applying Laplace transforms:

$$\frac{V}{s} = \left(\frac{1}{s\tau} + 1\right) v_o(s) \quad \text{where } \tau = \frac{L}{R}$$

$$V = \left(s + \frac{1}{\tau}\right) v_o(s) \qquad v_o(s) = \frac{V}{\left(s + \frac{1}{\tau}\right)}$$

Taking Laplace inverse:

$$v_o(t) = Ve^{-t/\tau}$$

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5.TIME BASE GENERATORS AND BLOCKING OSCILLATORS

Time Base Generator

An Electronic generator that generates the high frequency saw tooth waves can be termed as a Time Base Generator. It can also be understood as an electronic circuit which generates an output voltage or current waveform, a portion of which varies linearly with time. The horizontal velocity of a time base generator must be constant.

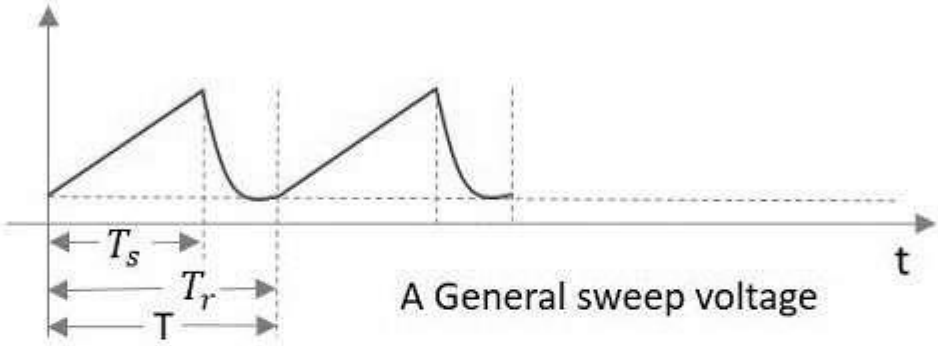
To display the variations of a signal with respect to time on an oscilloscope, a voltage that varies linearly with time, has to be applied to the deflection plates. This makes the signal to sweep the beam horizontally across the screen. Hence the voltage is called as Sweep Voltage. The Time Base Generators are called as Sweep Circuits.

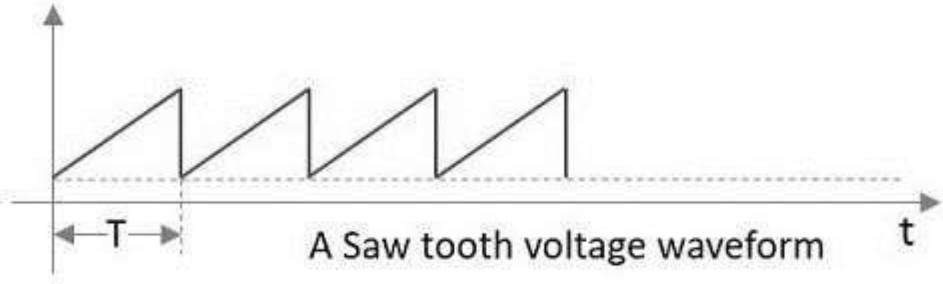
Features of a Time Base Signal

To generate a time base waveform in a CRO or a picture tube, the deflecting voltage increases linearly with time. Generally, a time base generator is used where the beam deflects over the screen linearly and returns to its starting point. This occurs during the process of Scanning. A cathode ray tube and also a picture tube works on the same principle. The beam deflects over the screen from one side to the other (generally from left to right) and gets back to the same point.

This phenomenon is termed as Trace and Retrace. The deflection of beam over the screen from left to right is called as Trace, while the return of the beam from right to left is called as Retrace or Fly back. Usually this retrace is not visible. This process is done with the help of a saw tooth wave generator which sets the time period of the deflection with the help of RC components used.

Let us try to understand the parts of a saw-tooth wave.





In the above signal, the time during which the output increases linearly is called as Sweep Time (T_S) and the time taken for the signal to get back to its initial value is called as Restoration Time or Fly back Time or Retrace Time (T_r). Both of these time periods together form the Time period of one cycle of the Time base signal.

Actually, this Sweep voltage waveform we get is the practical output of a sweep circuit whereas the ideal output has to be the saw tooth waveform shown in the above figure.

Types of Time base Generators

There are two types of Time base Generators. They are −

- **Voltage Time Base Generators − A time base generator that provides an output voltage waveform that varies linearly with time is called as a Voltage Time base Generator.**

- **Current Time Base Generator − A time base generator that provides an output current waveform that varies linearly with time is called as a Current Time base Generator.**

Applications

Time Base Generators are used in CROs, televisions, RADAR displays, precise time measurement systems, and time modulation.

Errors of Sweep Signals

After generating the sweep signals, it is time to transmit them. The transmitted signal may be subjected to deviation from linearity. To understand and correct the errors occurred, we must have some knowledge on the common errors that occur.

The deviation from linearity is expressed in three different ways. They are −

- **The Slope or Sweep Speed Error**
- **The Displacement Error**
- **The Transmission**

Error Let us discuss these in

detail.

Slope or Sweep Speed Error (e_s)

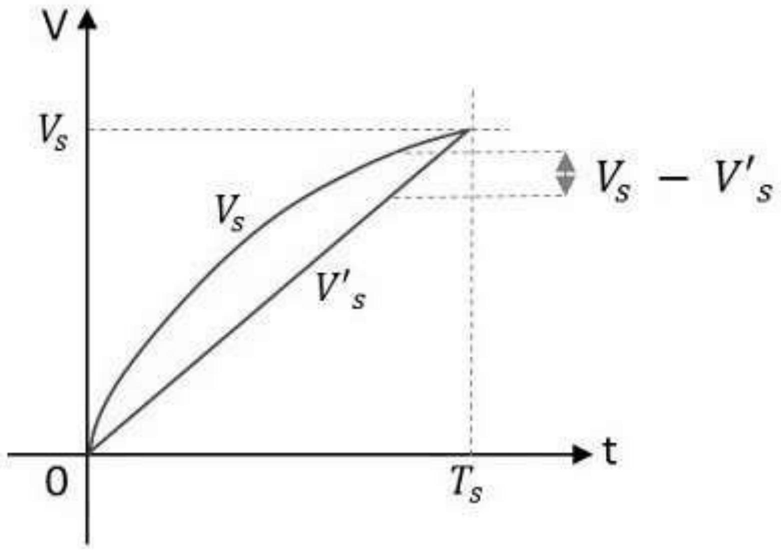
A Sweep voltage must increase linearly with time. The rate of change of sweep voltage with time must be constant. This deviation from linearity is defined as Slope Speed Error or Sweep Speed Error.

$$\text{Slope or Sweep speed eror } e_s = \frac{\text{difference in slope at the beginning and end of sweep}}{\text{initial value of slope}}$$

$$= \frac{\left(\frac{dV_0}{dt}\right)_{t=0} - \left(\frac{dV_0}{dt}\right)_{t=T_s}}{\left(\frac{dV_0}{dt}\right)_{t=0}}$$

An important criterion of linearity is the maximum difference between the actual sweep voltage and the linear sweep which passes through the beginning and end points of the actual sweep.

This can be understood from the following figure.



The displacement error e_d is defined as

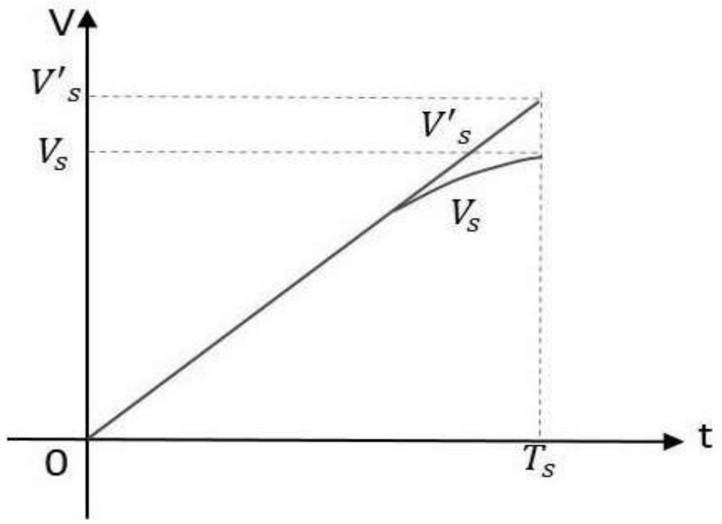
$$e_d = \frac{(actual\ speed) \sim (linear\ sweep\ that\ passes\ beginning\ and\ ending\ of\ actual\ sweep)}{amplitude\ of\ sweep\ at\ the\ end\ of\ sweep\ time}$$

$$= \frac{(V_s - V'_s)_{max}}{V_s}$$

Where Vs is the actual sweep and V's is the linear sweep.

The Transmission Error (e_t)

When a sweep signal passes through a high pass circuit, the output gets deviated from the input as shown below.



This deviation is expressed as transmission error.

$$\text{Transmission Error} = \frac{(input) \sim (output)}{input\ at\ the\ end\ of\ the\ sweep}$$

$$e_t = \frac{V'_s - V}{V'_s}$$

Where V'_s is the input and V_s is the output at the end of the sweep i.e. at $t = T_s$.

If the deviation from linearity is very small and the sweep voltage may be approximated by the sum of linear and quadratic terms in t, then the above three errors are related as

The sweep speed error is more dominant than the displacement error.

$$e_d = \frac{e_s}{8} = \frac{e_t}{4}$$

$$e_s = 2e_t = 8e_d$$

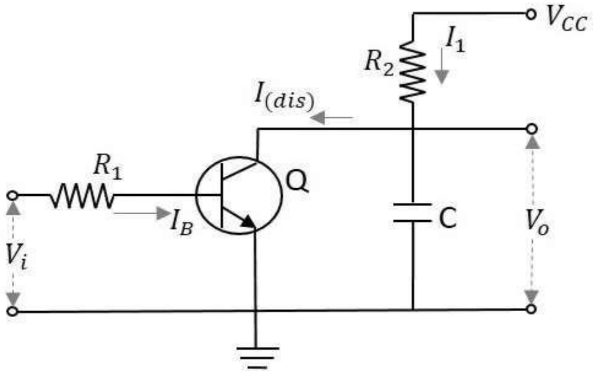
Voltage Time base Generator

A time base generator that provides an output voltage waveform that varies linearly with time is called as a Voltage Time base Generator.

Let us try to understand the basic voltage time base generator.

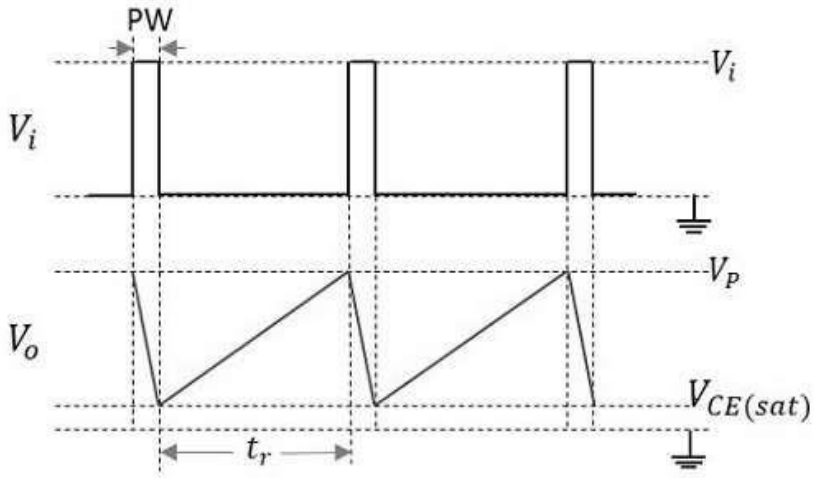
A Simple Voltage Time base Generator

A basic simple RC time base generator or a Ramp generator or a sweep circuit consists of a capacitor C which charges through V_{CC} via a series connected resistor R_2. It contains a BJT whose base is connected through the resistor R_1. The capacitor charges through the resistor and discharges through the transistor.



The above figure shows a simple RC sweep circuit

By the application of a positive going voltage pulse, the transistor Q turns ON to saturation and the capacitor rapidly discharges through Q and R_1 to $V_{CE\ (sat)}$. When the input pulse ends, Q switches OFF and the capacitor C starts charging and continues to charge until the next input pulse. This process repeats as shown in the waveform below.



When the transistor turns ON it provides a low resistance path for the capacitor to discharge quickly. When the transistor is in OFF condition, the capacitor will charge exponentially to the supply voltage V_{CC}, according to the equation

$$V_0 = V_{CC}[1 - exp(-t/RC)]$$

Where

- **V_O = instantaneous voltage across the capacitor at time t**
- **V_{CC} = supply voltage**
- **t = time taken**
- **R = value of series resistor**
- **C = value of the capacitor**

Let us now try to know about different types of time base generators.

The circuit just we had discussed, is a voltage time base generator circuit as it offers the output in the form of voltage.

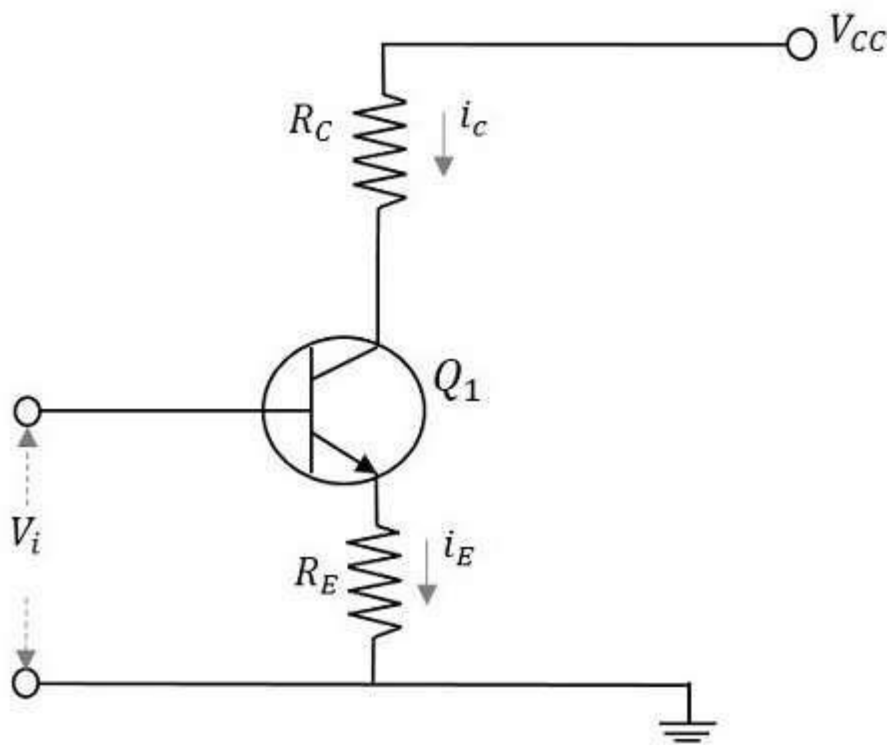
Current Time base Generator

A time base generator that provides an output current waveform that varies linearly with time is called as a Current Time base Generator.

Let us try to understand the basic current time base

generator. A Simple Current Time base Generator

A basic simple RC time base generator or a Ramp generator or a sweep circuit consists of a common-base configuration transistor and two resistors, having one in emitter and another in collector. The V_{CC} is given to the collector of the transistor. The circuit diagram of a basic ramp current generator is as shown here under.



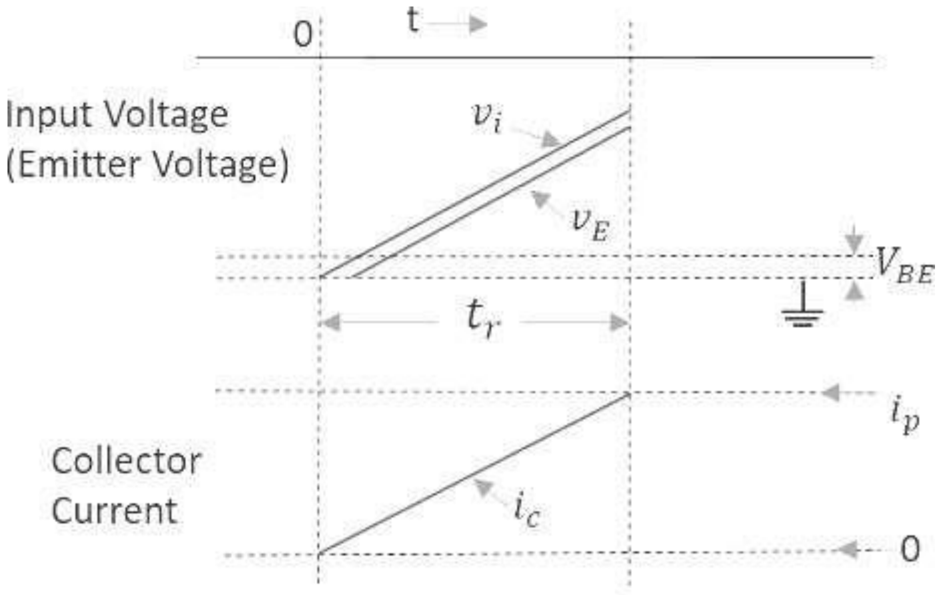
A transistor connected in common-base configuration has its collector current vary linearly with its emitter current. When the emitter current is held constant, the collector current also will be near constant value, except for very smaller values of collector base voltages.

As the input voltage V_i is applied at the base of the transistor, it appears at the emitter which produces the emitter current i_E and this increases linearly as V_i increase from zero to its peak value. The collector current increases as the emitter current increases, because i_C is closely equal to i_E.

The instantaneous value of load current is

$$i_L i_C \approx (v_i - V_{BE})/R_E$$

The input and output waveforms are as shown below.



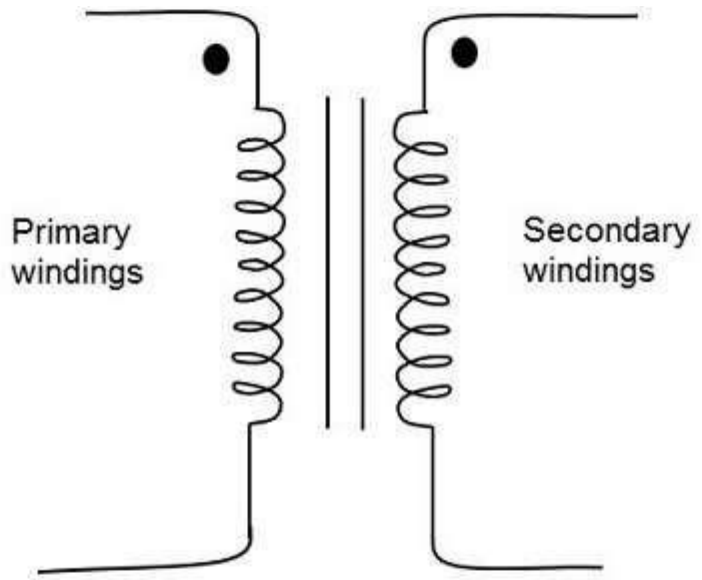
An oscillator is a circuit that provides an alternating voltage or current by its own, without any input applied. An Oscillator needs an amplifier and also a feedback from the output. The feedback provided should be regenerative feedback which along with the portion of the output signal, contains a component in the output signal, which is in phase with the input signal. An oscillator that uses a regenerative feedback to generate a non-sinusoidal output is called as Relaxation Oscillator.

We have already seen UJT relaxation oscillator. Another type of relaxation oscillator is the Blocking oscillator.

Blocking Oscillator

A blocking oscillator is a waveform generator that is used to produce narrow pulses or trigger pulses. While having the feedback from the output signal, it blocks the feedback, after a cycle, for certain predetermined time. This feature of blocking the output while being an oscillator, gets the name blocking oscillator to it.

In the construction of a blocking oscillator, the transistor is used as an amplifier and the transformer is used for feedback. The transformer used here is a Pulse transformer. The symbol of a pulse transformer is as shown below.



A Pulse transformer indicating the winding polarities

Pulse Transformer

A Pulse transformer is one which couples a source of rectangular pulses of electrical energy to the load. Keeping the shape and other properties of pulses unchanged. They are wide band transformers with minimum attenuation and zero or minimum phase change.

The output of the transformer depends upon the charge and discharge of the capacitor connected.

The regenerative feedback is made easy by using pulse transformer. The output can be fed back to the input in the same phase by properly choosing the winding polarities of the pulse transformer. Blocking oscillator is such a free-running oscillator made using a capacitor and a pulse transformer along with a single transistor which is cut off for most of the duty cycle producing periodic pulses.

Using the blocking oscillator, Astable and Monostable operations are possible. But Bistable operation is not possible. Let us go through them.

Monostable Blocking Oscillator

If the blocking oscillator needs a single pulse, to change its state, it is called as a Monostable blocking oscillator circuit. These Monostable blocking oscillators can be of two types. They are

- **Monostable blocking oscillator with base timing**
- **Monostable blocking oscillator with emitter timing**

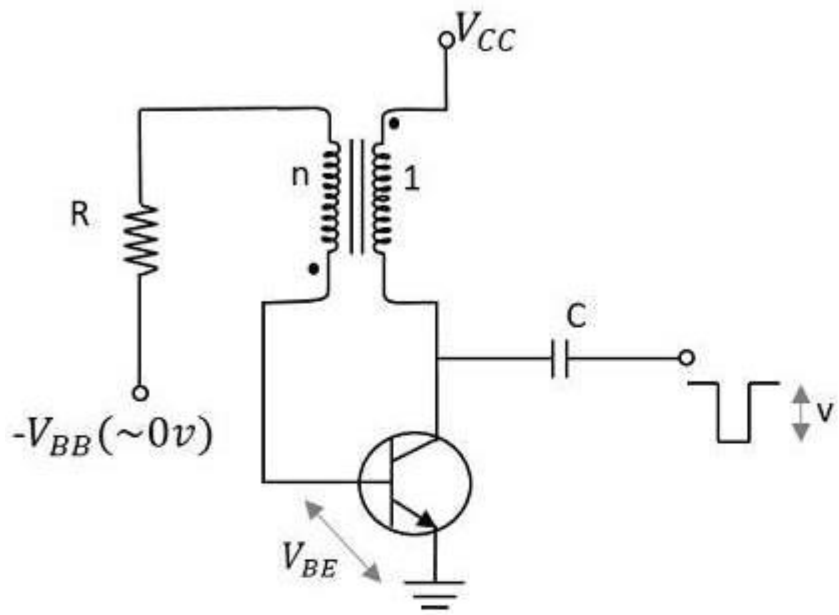
In both of these, a timing resistor R controls the gate width, which when placed in the base of transistor becomes base timing circuit and when placed in the emitter of transistor becomes emitter timing circuit.

To have a clear understanding, let us discuss the working of base timing Monostable Multivibrator.

Transistor Triggered Monostable blocking oscillator with Base timing

A transistor, a pulse transformer for feedback and a resistor in the base of the transistor constitute the circuit of a transistor triggered Monostable blocking oscillator with base timing. The pulse transformer used here has a turns ratio of n: 1 where the base circuit has n turns for every turn on the collector circuit. A resistance R is connected in series to the base of the transistor which controls the pulse duration.

Initially the transistor is in OFF condition. As shown in the following figure, VBB is considered zero or too low, which is negligible.



The voltage at the collector is V_{CC}, since the device is OFF. But when a negative trigger is applied at the collector, the voltage gets reduced. Because of the winding polarities of the transformer, the collector voltage goes down, while the base voltage rises.

When the base to emitter voltage becomes greater than the cut-in voltage, i.e.

$$V_{BE} > V_{\gamma}$$

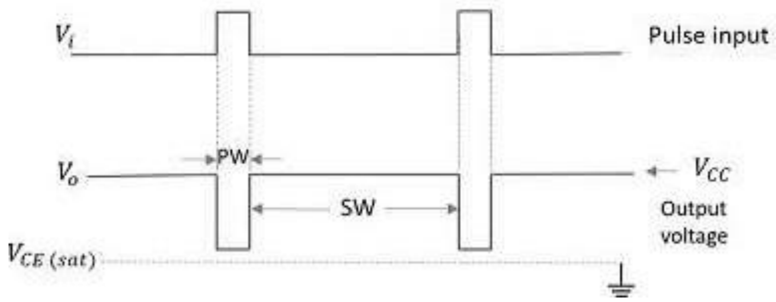
Then, a small base current is observed. This raises the collector current which decreases the collector voltage. This action cumulates further, which increases the collector current and decreases the collector voltage further. With the regenerative feedback action, if the loop gain increases, the transistor gets into saturation quickly. But this is not a stable state.

Then, a small base current is observed. This raises the collector current which decreases the collector voltage. This action cumulates further, which increases the collector current and decreases the collector voltage further. With the regenerative feedback action, if the loop gain increases, the transistor gets into saturation quickly. But this is not a stable state.

When the transistor gets into saturation, the collector current increases and the base current is constant. Now, the collector current slowly starts charging the capacitor and the voltage at the transformer reduces. Due to the transformer winding polarities, the base voltage

gets increased. This in turn decreases the base current. This cumulative action, throws the transistor into cut off condition, which is the stable state of the circuit.

The output waveforms are as follows −



The main disadvantage of this circuit is that the output Pulse width cannot be maintained stable. We know that the collector current is

$$i_c = h_{FE} i_B$$

As the h_{FE} is temperature dependent and the pulse width varies linearly with this, the output pulse width cannot be stable. Also h_{FE} varies with the transistor used.

Anyways, this disadvantage can be eliminated if the resistor is placed in emitter, which means the solution is the emitter timing circuit. When the above condition occurs, the transistor turns OFF in the emitter timing circuit and so a stable output is obtained.

Astable Blocking Oscillator

If the blocking oscillator can change its state automatically, it is called as an Astable blocking oscillator circuit. These Astable blocking oscillators can be of two types. They are

- **Diode controlled Astable blocking oscillator**
- **RC controlled Astable blocking oscillator**

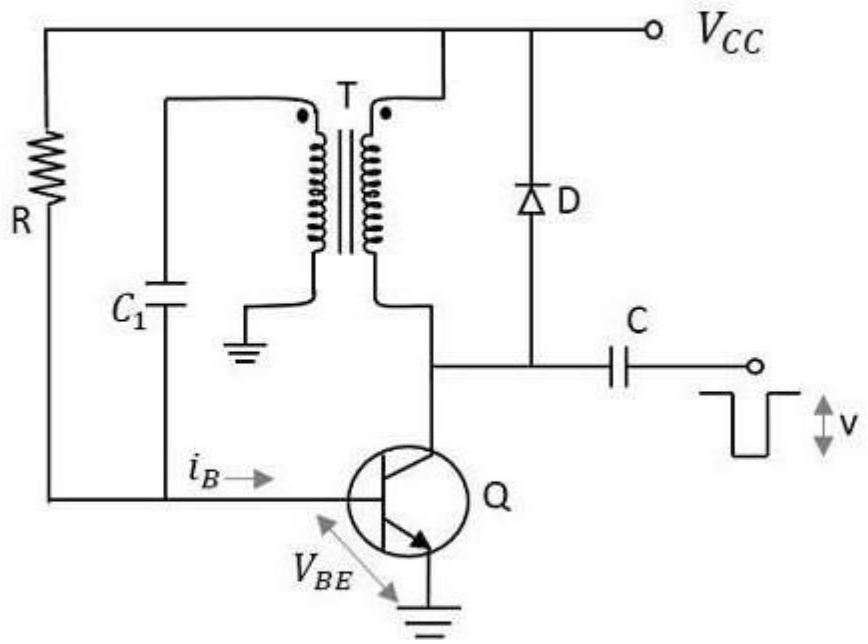
In diode controlled Astable blocking oscillator, a diode placed in the collector changes the state of the blocking oscillator. While in the RC controlled Astable blocking oscillator, a timing resistor R and capacitor C form a network in the emitter section to control the pulse timings.

To have a clear understanding, let us discuss the working of Diode controlled Astable blocking oscillator.

Astable blocking oscillator (Diode controlled)

The diode controlled Astable blocking oscillator contains a pulse transformer in the collector circuit. A capacitor is connected in between transformer secondary and the base of the transistor. The transformer primary and the diode are connected in the collector.

An initial pulse is given at the collector of the transistor to initiate the process and from there no pulses are required and the circuit behaves as an Astable Multivibrator. The figure below shows the circuit of a diode controlled Astable blocking oscillator.



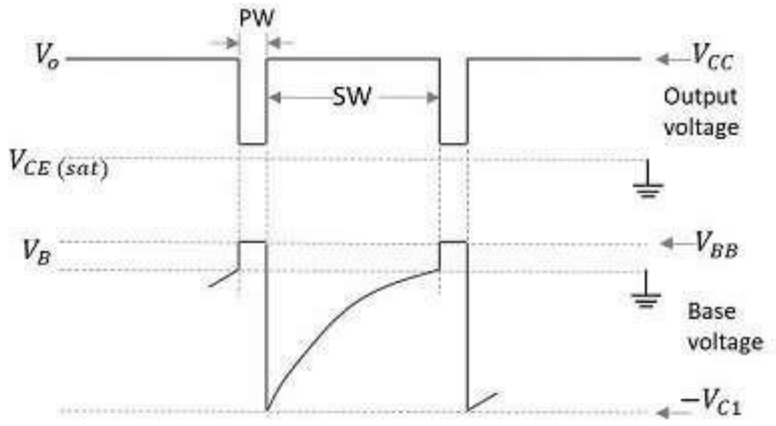
Initially the transistor is in OFF state. To initiate the circuit, a negative trigger pulse is applied at the collector. The diode whose anode is connected to the collector, will be in reverse biased condition and will be OFF by the application of this negative trigger pulse.

This pulse is applied to the pulse transformer and due to the winding polarities (as indicated in the figure), same amount of voltage gets induced without any phase inversion. This voltage flows through the capacitor towards the base, contributing some base current. This base current, develops some base to emitter voltage, which when crosses the cut-in voltage, pushes the transistor Q_1 to ON. Now, the collector current of the transistor Q_1 raises and it gets applied to both the diode and the transformer. The diode which is initially OFF gets

ON now. The voltage that gets induced into the transformer primary windings induces some voltage into the transformer secondary winding, using which the capacitor starts charging.

As the capacitor will not deliver any current while it is getting charged, the base current i_B stops flowing. This turns the transistor Q_1 OFF. Hence the state is changed.

Now, the diode which was ON, has some voltage across it, which gets applied to the transformer primary, which is induced into the secondary. Now, the current flows through the capacitor which lets the capacitor discharge. Hence the base current i_B flows turning the transistor ON again. The output waveforms are as shown below.



As the diode helps the transistor to change its state, this circuit is diode controlled. Also, as the trigger pulse is applied only at the time of initiation, whereas the circuit keeps on changing its state all by its own, this circuit is an Astable oscillator. Hence the name diode controlled Astable blocking oscillator is given.

Another type of circuit uses R and C combination in the emitter portion of the transistor and it is called as RC controlled Astable blocking oscillator circuit.

Astable Blocking Oscillator (RC-Controlled)

When power is applied to the circuit, R1 provides forward bias and transistor Q1 conducts. Current flow through Q1 and the primary of Te induces a voltage in L2. The phasing dots on the transformer indicate 180-degree, phase shift. As the bottom side of L1 is going negative, the bottom side of L2 is going positive. The positive voltage of L2 is coupled to the base of the transistor through Cl, and Q1 conducts more.

This provides more collectors current and more current through L1. This action is regenerative feedback. Very rapidly, sufficient voltage is applied to saturate the base of Q1. Once the base becomes saturated, it loses control over collector current. The circuit now can be compared to a small in series with a relatively C large inductor (L1), or a series RL circuit. The operation of the circuit to this point has generated a very steep leading edge for the output pulse. Figure shows the idealized collector and base waveforms. Once the base of Q1 becomes saturated, the current increase in L1 is determined by the time constant of L1 and the total series resistance. From T0 to T1 in figure the current increase (not shown) is approximately linear. The voltage across L1 will be a constant value as long as the current increase through L1 is linear.**

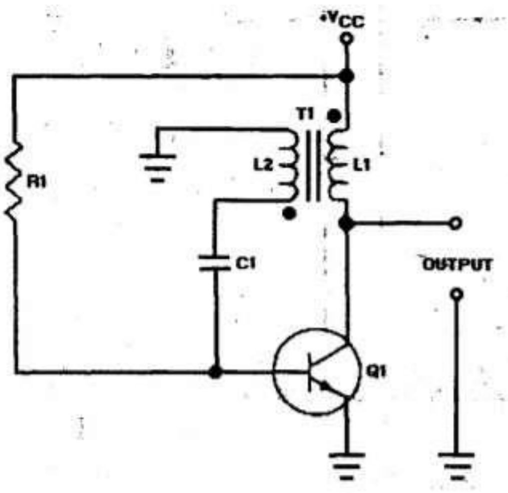


Fig: Blocking oscillator.

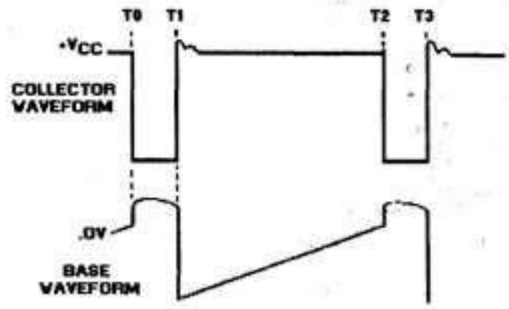
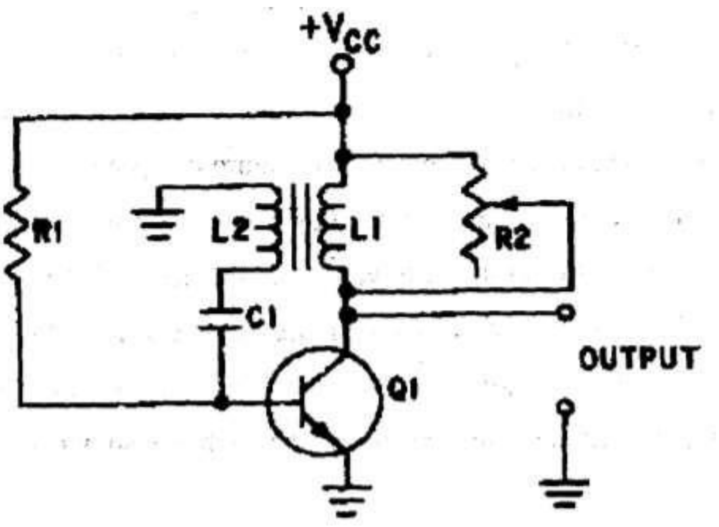


Fig: Blocking oscillator idealized waveforms.

At time T1, L1 saturates. At this time, there is no further change in magnetic flux and no coupling from L1 to L2. Cl, which has charged during time to T0 to T1, will now discharge through R1 and cut off Q1. This causes collector current to stop, and the voltage across LI returns to 0. The length of time between T0 and T1 (and T2 to T3 in the next cycle) is the pulse width, which depends mainly on the characteristics of the transformer and the point at which the transformer saturates. A transformer is chosen that will saturate at about 10 percent of the total circuit current. This ensures that the current increase is nearly linear. The transformer controls the pulse width because it controls the Slope of collector current increase between points T0 and T1. Since TC= L / R, the greater the L, the longer the TC. The longer the time constant, the slower the rate of current increase. When the rate of current increase is slow, the voltage across L1 is constant for a longer time. This primarily determines the pulse width.

From TI to T2, transistor Q1 is held at cutoff by C1 discharging through R1. The transistor is now said to be "blocked." As Cl gradually loses its charge, the voltage on the base of Q1 returns to a forward-bias condition. At T2, the voltage on the base has become sufficiently positive to forward bias Q1, and the cycle is repeated.

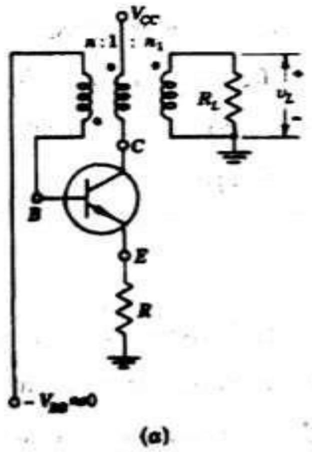


The collector waveform may have a 1nductive Overshoot (Parasitic Oscillations) at the end of the pulse. When Q1- cuts often, currents through L1 ceases, and the magnetic field collapses, inducing a positive voltage at- the collector of Q1. These oscillations ate not desirable, so same means must be employed to reduce them. The transformer primary may be designed to have a high dc resistance resulting in a low Q, this resistance will decrease the amplitude of the oscillations.

However, more damping- may be necessary than such a low-Q transformer primary alone can achieve, If so, a DAMPING resistor can be placed in parallel with L1, as shown in figure. When an external resistance is placed across a tank, the formula for the Q of the tank circuit is Q = R/XL, where R is the equivalent total circuit resistance in parallel with L. You should be able to see from the equation that the Q is directly proportional to the damping resistance (R). In figure damping resistor R2 is used to adjust the Q which reduce the amplitude of overshoot parasitic oscillations. As R2 is varied from infinity toward zero, the decreasing resistance will load the transformer to the joint that pulse amplitude, width, and prf are affected. If reduced enough, the oscillator will cease to function. By varying R2, varying degrees of damping can be achieved, three of which are shown in figure.

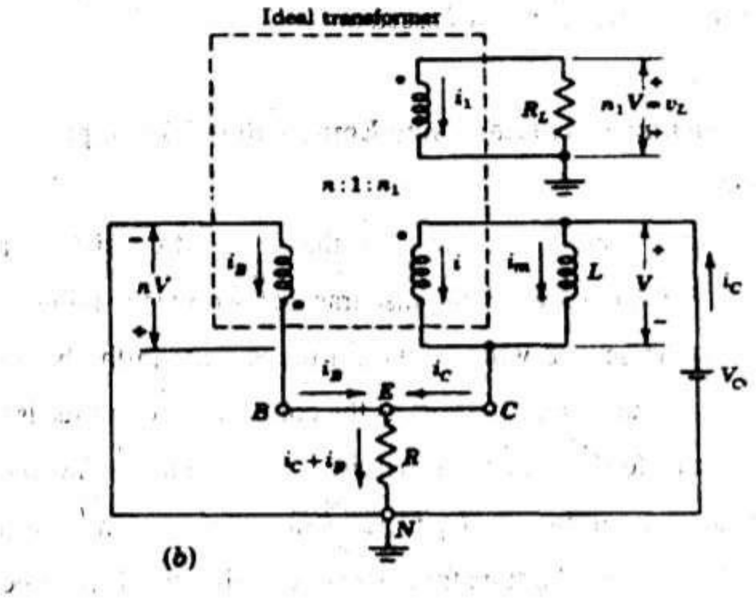
Monostable Blocking Oscillator Using Emitter Timing

A monostable blocking oscillator is shown in the figure. It consists of a transistor with an emitter resistor and a 3 winding pulse transformer.



Fig(a): A monostable blocking oscillator with emitter timing

One winding is present in the collector circuit, the second winding with n times turns in the base circuit, the third winding with n1 times as many turns as the collector winding feeds the resistor RI which may be the load or may be required for damping. The base and the collector turns must be connected for regenerative but the relative winding direction for the third leg of the transformer may be arbitrary. It may be chosen to obtain either a positive or negative output pulse across the load. The equivalent circuit from which the current and vo1tage waveforms are calculated is shown.



Fig(b): The equivalent circuit during pulse formation

$$ic = \frac{Vcc}{(n+1)^2}\left(\frac{n^2}{R} + \frac{n_1^2}{R_L} + \frac{t}{L}\right)$$

$$ib = \frac{Vcc}{(n+1)^2}\left(\frac{n}{R} - \frac{n_1^2}{R_L} + \frac{t}{L}\right)$$

As the time passes ic increases and the operating point moves up the saturation line. ¬ While ic grows with time the base current is decreasing and reaches a point where i=Ib and ic=hfe.Ib.

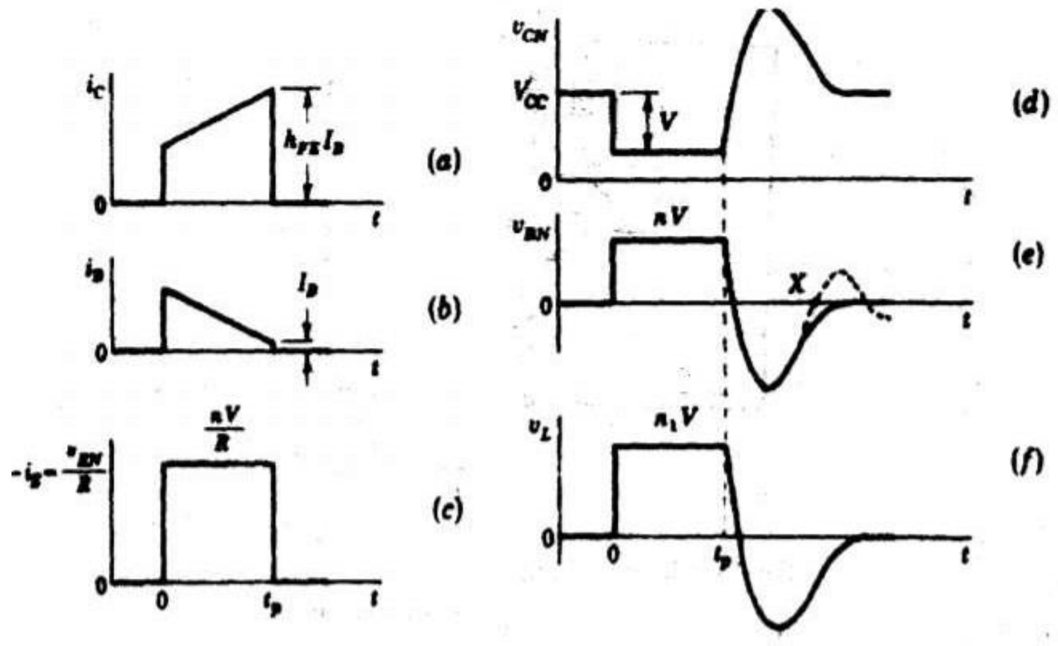


Fig: The current and voltage waveforms in a transistor-blocking oscillator.

$$tp = \frac{nL}{R}\frac{hfe - n}{hfe + 1} - \frac{n_1^2 L}{R_L}$$

TEXT / REFERENCE BOOKS

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