POWER SUPPLY

1.1Need for DC power supply

The aim of a DC power supply is to provide the required level of DC power to the load using an AC supply at the input. Different applications require different attributes, but more often than not these days DC power supplies provide an accurate output voltage - this is regulated using electronic circuitry so that it provides a constant output voltage over a wide range of output loads. The output of unregulated DC power supply is affected by the following factors

Poor regulation: - The output voltage is affected by the magnitude of current drawn from supply.

Variations in AC supply: - The DC output varies due to the fluctuation in the AC supply voltage.

Variations in temperature: - As performance of semiconductor devices is dependent on temperature, the DC output also varies

These variations in DC output voltage may cause in accurate or erratic operations of many electronic devices. To overcome these problems, the regulated DC power supply is needed

1.2 DC Power Supply block diagram

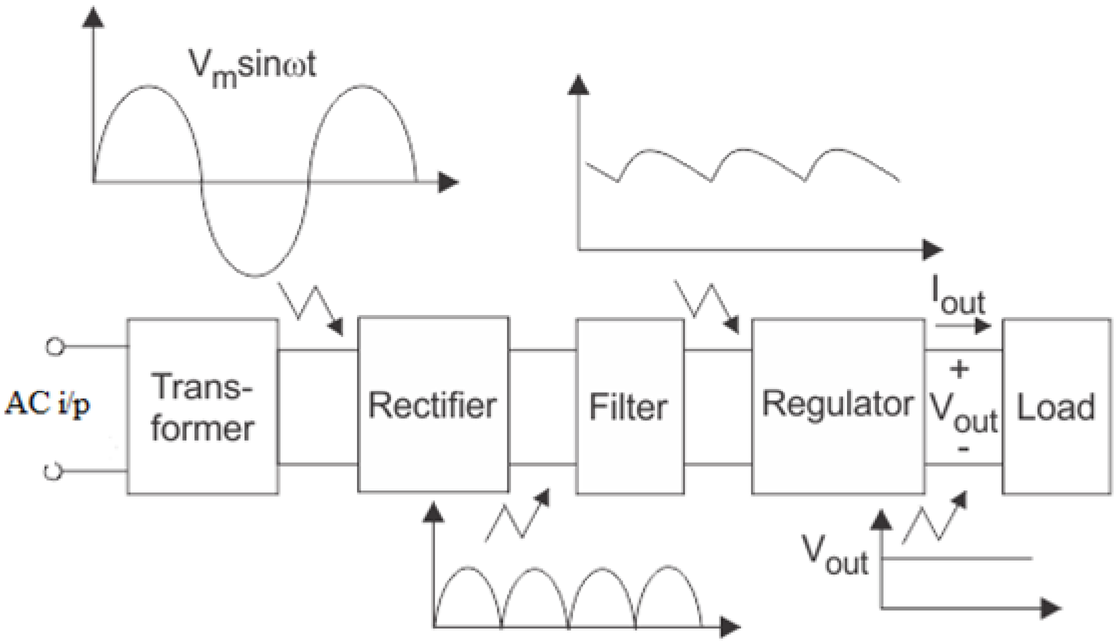


Fig.1.1 Block diagram of power supply

Transformer: The input transformer is used to transform the incoming line voltage down to the required level for the power supply. Typically the input transformer provides a step down function. It also isolates the output circuit from the line supply.

Rectifier: The power supply rectifier converts the incoming signal from an AC into pulsating DC. Either half wave or more commonly full wave rectifiers may be used as they make use of both halves of the incoming AC signal.

Filter: The output of rectifier consists of AC ripples which are also undesirable for electronic circuits. To remove such ripples filters are used.

Regulator: This stage of the power supply takes the smoothed voltage and uses a regulator circuit to provide a constant output virtually regardless of the output current and any minor fluctuations in the input level.

1.3 RECTIFIER

A rectifier is a circuit which converts AC to DC. The main component of rectifier is diode.

1.3.1 Important parameters of a rectifier

Ripple factor:

Ripple factor is defined as the ratio of r.m.s. value of AC component to DC component.

Efficiency:

It is defined as the ratio of DC output power to AC input power. It is denoted by η

$$\eta = \frac{\text{DC output power}}{\text{AC input power}}$$

Peak Inverse Voltage:
It is defined as the maximum reverse voltage that a diode can withstand.

Ripple Frequency (fo):
It is defined as the frequency of the rectifier output.

Types of Rectifiers

i) Half wave rectifier(HWR)
ii) Full wave Rectifier(FWR)

1.4 HALF WAVE RECTIFIER:

It is a circuit which consists only one diode and thus rectifies only one half cycle of AC input.

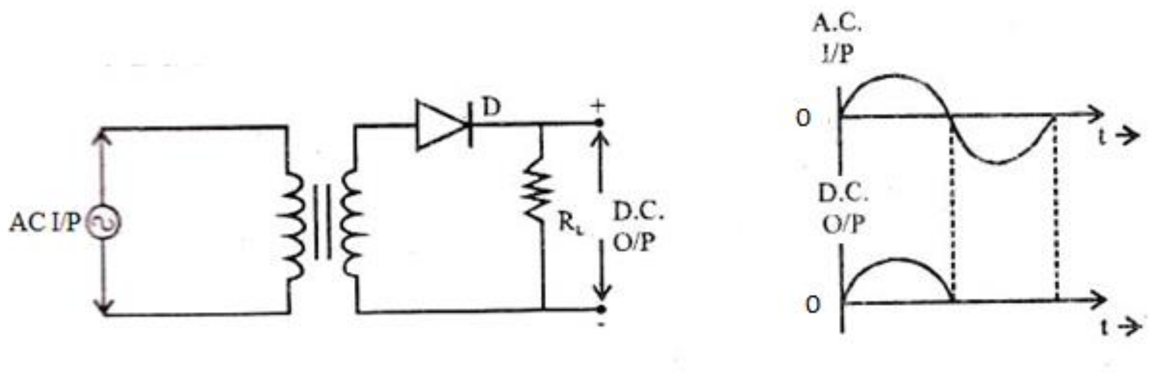


Fig.1.2 (a) Circuit Diagram of half wave rectifier (b) Waveform

Half wave rectifier consists of a diode and step down transformer which is used to decrease the input voltage to the required level as shown in fig1.2 (a). During positive cycle of AC input, the diode is forward biased and acts as a closed switch. Hence allows current to flow through R_L. During negative half cycle the diode is reverse biased and acts as open switch. Hence no current flows during the negative cycle of AC input as shown in Fig. 1.2(b). The disadvantage of half wave rectifier is it conducts only during one half cycle(either positive or negative) and hence the output is low.

Derivation of Ripple factor(HWR) :

$$\text{Ripple factor} = \frac{\text{RMS value of AC component}}{\text{DC component.}}$$

w.k.t.

$$I^2_{rms} = I^2_{dc} + I^2_{ac}$$

$$Iac = \sqrt{I^2 rms_{\cdot} - I^2 dc}$$

$$\text{Ripple factor} = \frac{Iac}{Idc}$$

$$= \frac{\sqrt{I^2 rms_{\cdot} - I^2 dc}}{Idc}$$

For half wave rectifier, $I_{rms}=I_m/2$ and $I_{dc}=I_m/\pi$

Therefore,

$$\boxed{\text{Ripple factor} = \sqrt{\left(\frac{\frac{Im}{2}}{\frac{Im}{\pi}}\right)^2 - 1} = 1.21}$$

Derivation of Efficiency:

$$\eta = \frac{\text{DC output power}}{\text{AC input power}} \quad X100\%$$

$= \underline{P}_{dc}$

P_{ac}

$$\eta = \frac{V_{dc}^{\ 2} / R_L}{V_{rms}^{\ 2} / R_L}$$

V_{dc} is calculated as below

$$V_{dc} = \frac{1}{T}\int_0^T v(t)dt$$

$$= \frac{1}{2\pi}[\int_0^\pi V_m \sin \omega t\, dt + \int_\pi^{2\pi} 0 dt]$$

$$= \frac{V_m}{2\pi}[-\cos \omega t]_0^\pi = \frac{V_m}{2\pi}[-\cos(\pi) - (-\cos 0)]$$

$$= \frac{V_m}{2\pi}[-(-1) - (-1)] = \frac{V_m}{\pi} = 0.318 V_m$$

$$= 0.318(\sqrt{2})V_{rms} = 0.45 V_{rms}$$

V_{rms} is calculated as below

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt}$$

$$= [\frac{1}{2\pi}[\int_0^{T/2} V_m^2 \sin^2 \omega t\, d(\omega t) + \int_{T/2}^{T} 0 d(\omega t)]^{1/2}$$

$$= [\frac{V_m^2}{2\pi}\int_0^{T/2} \sin^2 \omega t\, d(\omega t)]^{1/2}$$

$$\sin^2 \omega t = \frac{1}{2}(1 - \cos 2\omega t), \ \omega T = 2\pi, \ \theta = \omega t$$

$$V_{rms} = [\frac{V_m^2}{4\pi}\int_0^\pi (1 - \cos 2\theta)d\theta]^{1/2}$$

$$= [\frac{V_m^2}{4\pi}(t - \frac{1}{2}\sin 2\theta)\mid_0^\pi]^{1/2}$$

$$= [\frac{V_m^2}{4\pi}(\pi - \frac{1}{2}\sin(2\pi) - 0 + \frac{1}{2}\sin 2(0)]^{1/2}$$

$$= [\frac{V_m^2}{4\pi}(\pi - 0 - 0 + 0)]^{1/2}$$

$$= \frac{V_m}{2}$$

$$\eta = \frac{V_{dc}^2 / R_L}{V_{rms}^2 / R_L} = \frac{(V_m / \pi)^2}{(V_m / 2)^2} = \frac{4}{\pi^2} = 0.406$$

or

$$\eta = 40.6\%$$

PROBLEMS ON HALF WAVE RECTIFIER

1) If the secondary voltage of transformer v_m = 32.53V is applied to half wave rectifier circuit, calculate V_{dc},PIV.

solution:-

$$V_{dc} = \frac{v_m}{\pi}$$

$$= \frac{32.53}{\pi}$$

$$= 10.36V$$

PIV = V_m = 32.53V

2) If the applied i/p voltage to the half wave rectifier circuit is V=50sinωt and load resistance is 800 Ω find the following. Assume internal resistance of diode is 20 Ω

1)I_m,I_{dc},I_{rms} 2)Pac, Pdc 3)Vdc 4)η

solution:-

Given

V_m=50V, r_f=20 Ω , R_L=800 Ω

1)

$$I_m = \frac{vm}{rf+RL} = \frac{50}{20+800} = 0.061A = 61mA$$

$I_{dc} = \frac{Im}{\pi} = \frac{61}{\pi}$ =19mA

$I_{rms} = \frac{Im}{2} = \frac{61}{2}$ =30.5mA

2) $P_{ac} = I^2_{rms} X(r_{f+} R_L) = \left(\frac{30.5}{1000}\right)^2$ *(20+800)=0.763watt

$P_{dc} = I^2_{dc} X R_L = \left(\frac{19.4}{1000}\right)^2$ X 800=0.301 watt

3) $v_{dc} = I_{dc} X R_{L=}$ 19.4mA X 800=15.52 watt

4) $\eta = \frac{0.301}{0.763}$ = 39.5%

3) If the applied input voltage to the half wave rectifier circuit is V=50sin350t, calculate ripple frequency.

solution:-

Given

ω=350 rad/sec

ω=2πf = 350 rad/sec

therefore ,

$f = \frac{\omega}{2\pi} = \frac{350}{2\pi}$ = 55.73 Hz

Ripple frequency of HWR is 55.73 Hz

1.5 FULL WAVE RECTIFIER:

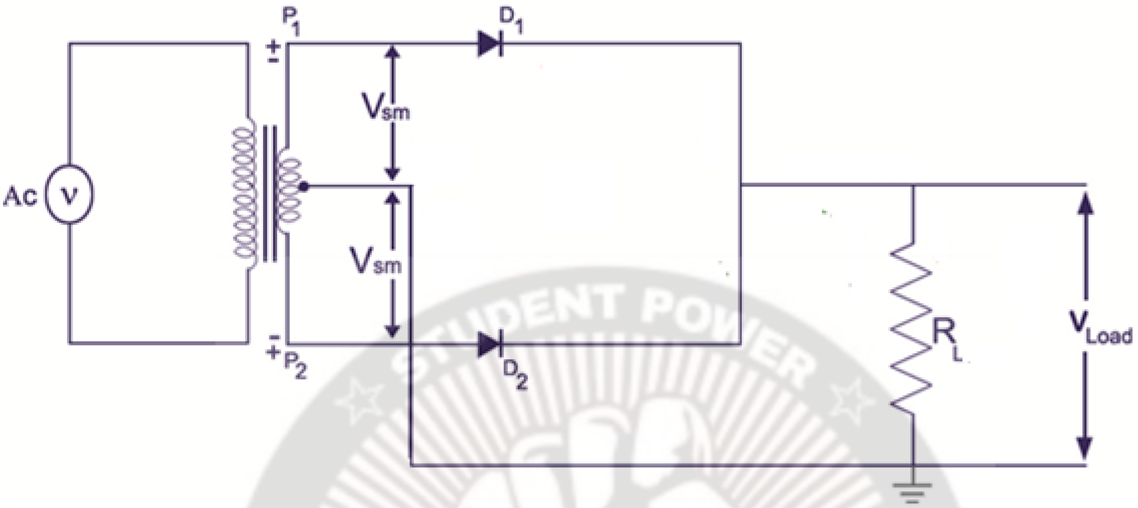


Fig 1.3(a) Circuit diagram of Full wave Rectifier (Centre- tap)

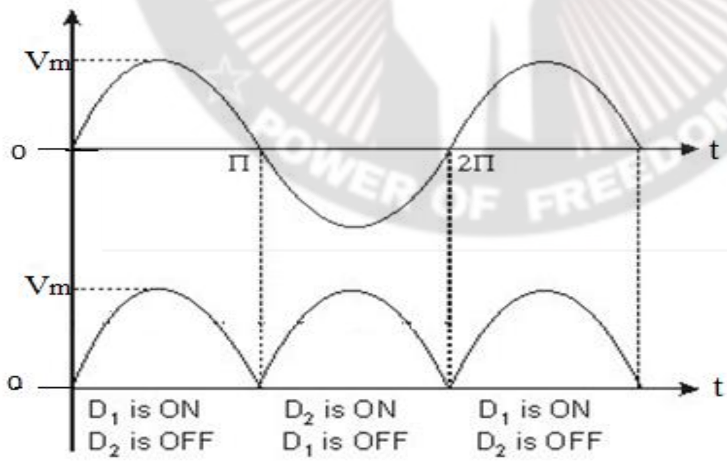


Fig 1.3(b) Waveform of Full wave Rectifier (Centre- tap)

Full wave rectifier consists of two diodes and step down transformer which is used to decrease the input voltage to the required level as shown in fig1.3 (a). During positive cycle of AC input, the P1 terminal of the transformer secondary becomes positive and the terminal P2 becomes negative. Therefore diode D1 is forward biased and acts as a closed switch whereas diode D2 is reverse biased and acts as open switch. Hence current flows via D1 through R_L .

During negative cycle of AC input, the P1 terminal of the transformer secondary becomes negative and the terminal P2 becomes positive. Therefore diode D2 is forward biased and acts as a closed switch whereas diode D1 is reverse biased and acts as open switch. Hence current flows via D2 through RL. The output waveform is as shown in Fig 1.3(b).

Derivation of Ripple factor :

$$\text{Ripple factor} = \frac{\text{RMS value of AC component}}{\text{DC component.}}$$

w.k.t.

$$I^2_{rms} = I^2_{dc} + I^2_{ac}$$

$$Iac = \sqrt{I^2rms - I^2dc}$$

Ripple factor $= \frac{Iac}{Idc}$

$$= \frac{\sqrt{I^2rms - I^2dc}}{Idc}$$

For full wave rectifier, $I_{rms}=I_m/\sqrt{2}$ and $I_{dc}=2I_m/\pi$

Therefore,

$$\text{Ripple factor} = \sqrt{\left(\frac{\frac{I_m}{\sqrt{2}}}{\frac{2I_m}{\pi}}\right)^2 - 1} = 0.48$$

Derivation of Efficiency:

$$\eta = \frac{\text{DC output power}}{\text{AC input power}} \quad \text{X100\%}$$

$$= \frac{P_{dc}}{P_{ac}}$$

$$\eta = \frac{V_{dc}^2 / R_L}{V_{rms}^2 / R_L}$$

V_{dc} is calculated as below

$$V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin \omega t \, d(\omega t)$$

$$= \frac{V_m}{\pi}\left[-\cos \omega t\right]_0^{\pi} = \frac{2V_m}{\pi}$$

V_{rms} is calculated as below

$$V_{rms} = \left[\frac{1}{\pi}\int_0^{\pi} V_m^2 \sin^2 \omega t \, d(\omega t)\right]^{1/2} = \frac{V_m}{\sqrt{2}}$$

$$\frac{V_{dc}^2 / R_L}{V_{rms}^2 / R_L} = \frac{\left[2V_m/\pi\right]^2}{\left[V_m/\sqrt{2}\right]^2} = 8/\pi^2 = 0.812 = \underline{\underline{81.2\%}}$$

Efficiency=

PROBLEMS ON FULL WAVE RECTIFIER

1) FWR uses two diodes with centre taped transformer. Transformer r.m.s secondary voltage from centre tap to each end is 50V . and Load resistance is 980 Ω. Find

1) mean load current 2) rms value of current

solution:-

given

V_{rms}=50v

R_L=980 Ω

$V_m = V_{rms} X \sqrt{2} = 50 X\sqrt{2} = 70.7V$

$I_m = \frac{vm}{rf+RL} = \frac{70.7}{0+980} = 0.0707A = 70.7mA$

1) mean load current = $I_{dc} = \frac{2Im}{\pi} = \frac{2*70.7}{\pi} = 45.mA$

2) $I_{rms} = \frac{Im}{\sqrt{2}} = \frac{70.7}{\sqrt{2}} = 50mA$

1.6 FULL WAVE BRIDGE RECTIFIERS

Centre tapped full wave rectifier is more expensive and requires more space than additional diodes. Hence to reduce the circuit space by omitting centre tap transformer four diodes are arranged in bridge fashion as shown in fig 1.4(a)

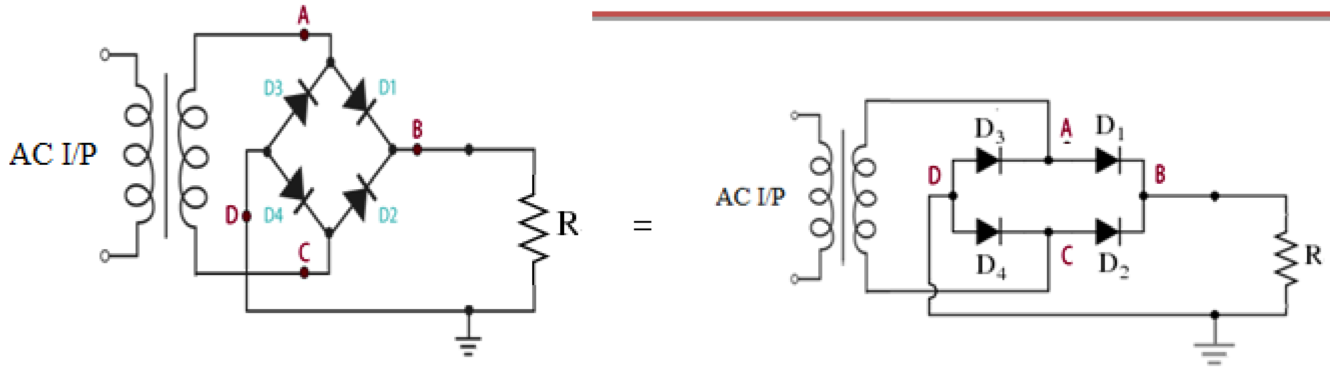


Fig. 1.4 (a)

During positive cycle of AC input, terminal A of becomes positive and the terminal C becomes negative. Therefore diodes D1 and D4 are forward biased and act as closed switches whereas diodes D2 and D3 are reverse biased and acts as open switch. Hence current flows via D1-R- D4 as shown in Fig 1.4(a).

During negative cycle of AC input, terminal A of becomes negative and the terminal C becomes positive. Therefore diodes D2 and D3 are forward biased and act as closed switches whereas diodes D1 and D4 are reverse biased and acts as open switch. Hence current flows via D2-R- D3 as shown in Fig 1.4(a).

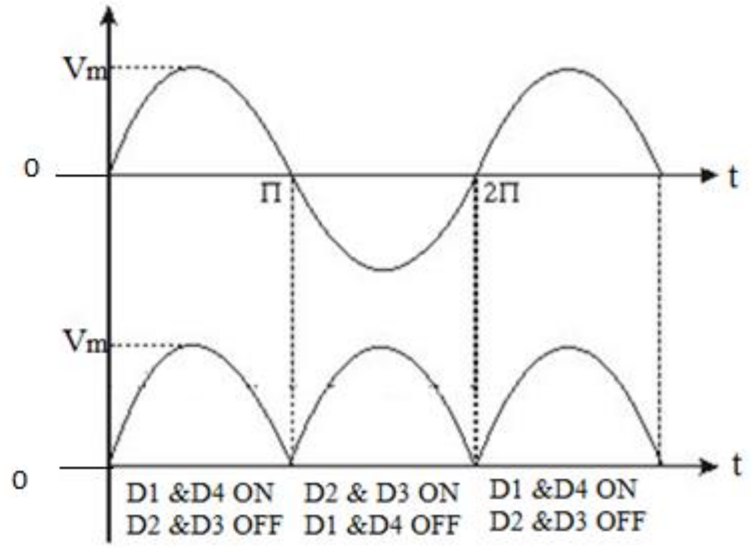


Fig 1.4 (b) Waveform

Parameters of Full wave Bridge Rectifier

Ripple factor = 0.48

Efficiency =81.2%

Peak Inverse Voltage, PIV=V_m

Ripple Frequency (fo) is equal to twice the input frequency.

Comparison of HWR, FWR, BRIDGE rectifiers

Parameters	**HWR**	**FWR**	**BRIDGE**
No of diodes	One	Two	Four
Ripple factor	1.21	0.48	0.48
Efficiency	40.6%	81.2%	81.2%
PIV	Vm	2Vm	Vm
Centre tap transformer	Not required	required	Not required
Ripple frequency	Same as i/p signal frequency	Double the i/p signal frequency	Double the i/p signal frequency

Formulas of HWR, FWR, BRIDGE rectifiers

Parameters	HWR	FWR	BRIDGE
DC load current(I_{dc})	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
RMS Load current (Irms)	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
DC load voltage (Average voltage)	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
RMS Load voltage	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{2}}$	$\frac{V_m}{\sqrt{2}}$
DC power	$\frac{I_m^2 R_L}{\pi^2}$	$\frac{4I_m^2 R_L}{\pi^2}$	$\frac{4I_m^2 R_L}{\pi^2}$

Peak load current (I_m)	$I_m = \frac{V_m}{R_s+R_f+R_L}$	$I_m = \frac{V_m}{R_s+R_f+R_L}$	$I_m = \frac{V_m}{R_s+2R_f+R_L}$
PIV	Vm	2Vm	Vm

1.7 Need for filters in power supplies:

The pulsating output of the rectifiers has an average DC value and an AC portion that is called ripple voltage. For most power supply purposes constant dc voltage is required than the pulsating output of the rectifier. In order to obtain the constant dc output, it is required to filter out the oscillations from the pulsating dc. Hence filters are needed in power supplies. The filter is a device that allows the dc component through the load and blocks the ac component of the rectifier output. Thus the output of the filter circuit will be a steady dc voltage.

1.7.1 Capacitor Filter

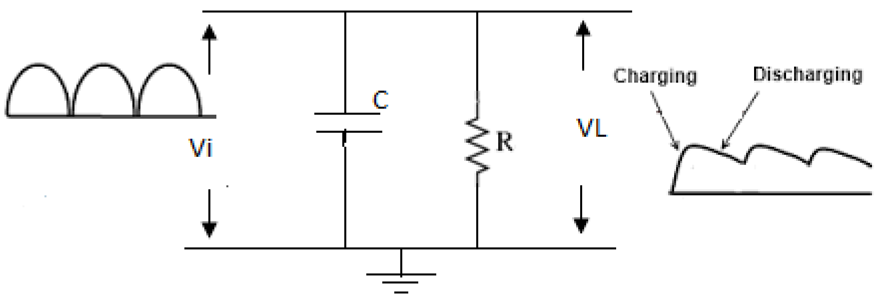


Fig. 1.5 Capacitor filter

As the name suggests, a capacitor is used as the filter and this high value capacitor is shunted or placed across the load impedance as shown in Fig1.5. This capacitor, when placed across a rectifier gets charged and stores the charged energy during the conduction period. When the rectifier is not conducting, this energy charged by the capacitor is delivered back to the load. Through this energy storage and delivery process, the time duration during which the current flows through the load resistor gets increased and the ripples are decreased by a great amount. Thus the dc components of the input signal along with the few residual ripple components, is only allowed to go through the load resistance R_L. The high amount of ripple components of current gets bypassed through the capacitor C.

The amount of ripples present in the output of capacitor filter is given by

Ripple factor = $\frac{1}{4\sqrt{3}fcR_L}$

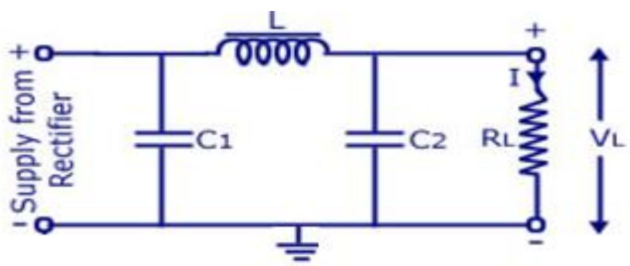
Where

f is frequency in Hz

C is capacitance in Farad

R_L is load resistance

1.7.2 PI(π) FILTER or CLC FILTER



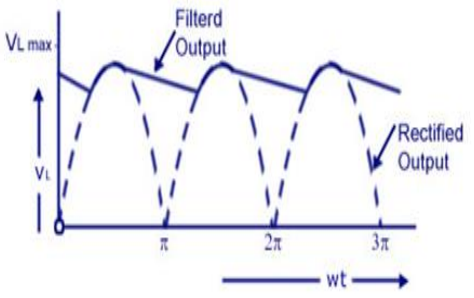


Fig. 1.6(a) PI Filter Circuit

Fig. 1.6(b) PI Filter waveform

The name PI – Filter implies to the resemblance of the circuit to a π shape with two shunt capacitances (C1 and C2) and an inductance filter 'L'. As the rectifier output is provided directly into the capacitor it also called a capacitor input filter. The output from the rectifier is first given to the shunt capacitor C. The rectifier used can be half or full wave and the capacitors are usually electrolytic even though they large in size. Circuit diagram and the waveform are shown in Fig 1.6. This filter is divided into two – a capacitor filter and a L-section filter. The capacitor C1 does most of the filtering in the circuit and the remaining ripple is removed by the L-section filter (L-C2). C1 is selected to provide very low reactance to the ripple frequency.

The amount of ripples present in the output of capacitor filter is given by

Ripple factor = $\frac{\sqrt{2}}{8\omega^3 L.C_1 C_2 R_L}$

Where

$\omega = 2\pi f$ is angular frequency

f is frequency in Hz

L is inductance in Henry

c1, c2 are capacitances in Farad

R_L is load resistance

1.8 Voltage Regulators

1.8.1 Need for voltage regulators in power supplies

The function of voltage regulator is to supply a stable voltage to a circuit or device that must be operated within certain power supply limits. A voltage regulator is designed to automatically maintain a constant voltage level even if the input dc voltage varies or the output load connected to the dc voltage changes.

1.8.2 Voltage Regulator Using Zener Diode

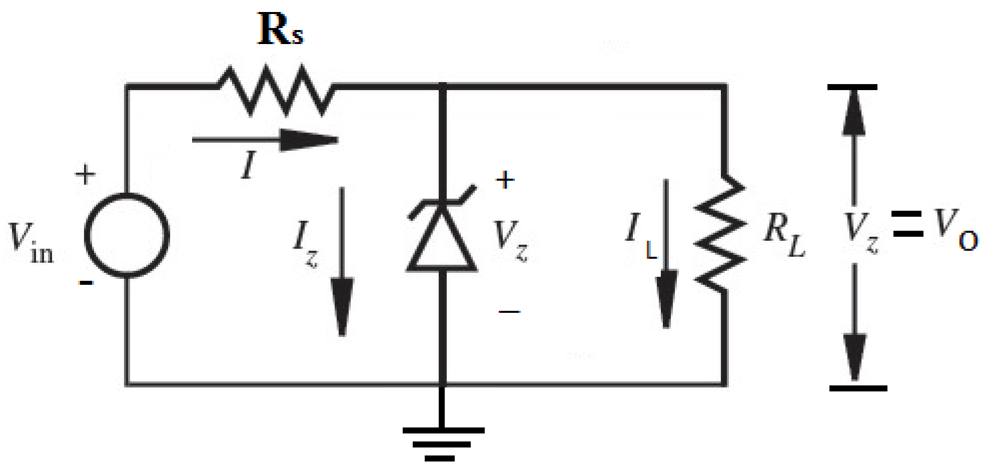


Fig.1.7 Zener Voltage Regulator Circuit

The source resistance R_s is connected in series with zener diode to limit the flow of current through the diode. The cathode terminal of zener diode is connected to the positive terminal of the voltage source so that the zener diode is biased in reverse condition and will be operating in breakdown region as shown in fig 1.7.

When the load is not connected across the zener diode, no load current will be conducted and all the current due to the circuit will pass through the zener diode dissipating maximum amount of power that causes overheating of the diode and damages permanently.

Selecting the appropriate values of series resistance R_s is also important because it also causes greater diode current, so that maximum power dissipation of the diode should not be exceeded under no load or at high impedance condition.

Whenever a load is connected in parallel with zener diode, voltage across the load is same as the zener diode voltage Vo=Vz. However the source voltage must be greater than the zener voltage and the upper limit of zener current depends on the power rating of the zener diode; otherwise the zener voltage will simply follow the applied input voltage.

If V_{in} increases, the total current I increases but I_L is constant as V_Z is constant. Hence the current I_Z increases to keep I_L constant i.e $I_Z = I - I_L$

1.8.3 Load regulation:

The load regulation is defined as the percentage change in the output voltage from no-load to full-load.

$$Load\ regulation = \left(\frac{V_{NL} - V_{FL}}{V_{FL}}\right) \times 100\%$$

where V_{NL}= load voltage with no load current (I_L=0) V_{FL}= load voltage with full load current I_L($I_L$max)

The smaller the load regulation, the better the power supply. A well-regulated power supply can have a load regulation of less than 1% (i.e., the load voltage varies less than 1% over the full range of load current).The ideal power supply has 0% regulation.

1.8.4 Line regulation:

The line regulation is defined as the percentage change in the output voltage for a given change in the input voltage.

$$Line\ regulation = \left(\frac{\Delta V_{OUT}}{\Delta V_{IN}}\right) \times 100\%$$

The smaller the line regulation, the better the power supply. A well-regulated power supply can have a line regulation of less than 0.1%.

1.9 IC voltage regulators

1.9.1Features of 78xx (Positive voltage regulator)

Three terminal fixed voltage regulator

The series 78xx regulators provide fixed regulated voltages from 5 V to 24 V.

output current up to 1A

No external components required

Internal short circuit current limiting

Internal thermal overload protection

Output transistor safe-area compensation

Output voltage offered in 4% tolerance

1.9.2 Circuit diagram of LM78xx

Typical connection of 78xx IC regulator is shown in fig. 1.8.The unregulated input voltage is filtered by capacitor CI and connected to the IC's Input (pin no.1) terminal. The IC's OUT terminal (pin no.3) provides a regulated voltage, which is filtered by capacitor CO (mostly for any high-frequency noise). The third IC terminal (pin no.2) is connected to ground (GND) as shown in fig 1.8. Whereas the input voltage may vary over some permissible limit.

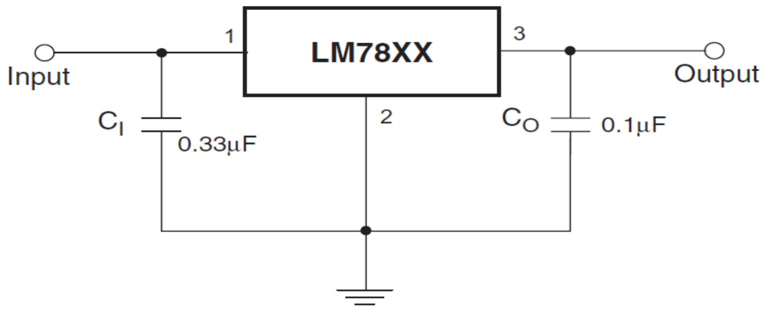


Fig 1.8 Typical connection of 78xx IC regulator

1.9.3 Features of 79xx (Negative voltage regulator)

Three terminal fixed voltage regulator

The series 79xx regulators provide fixed regulated voltages from -2 V to -24 V.

No external components required

Internal short circuit current limiting

Internal thermal overload protection

Output transistor safe-area compensation

1.9.4 Circuit diagram of LM 79xx

Fig. 1.9 shows the typical connection of 79xx IC regulator. the unregulated input voltage is filtered by capacitor CI and connected to the IC's Input (pin no.2) terminal. The IC's OUT terminal (pin no.3) provides a regulated voltage, which is filtered by capacitor CO (mostly for any high-frequency noise). The third IC terminal (pin no.1) is connected to ground (GND). Whereas the input voltage may vary over some permissible limit.

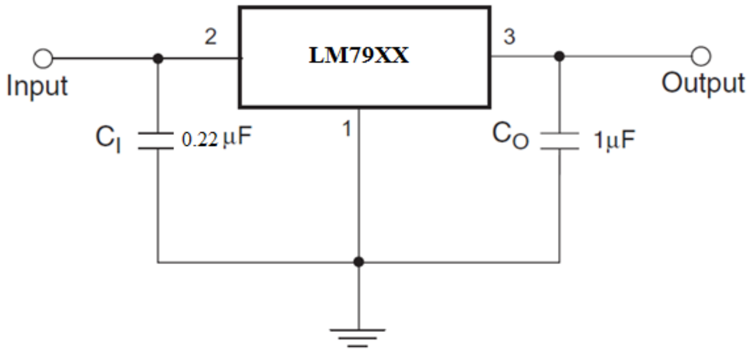


Fig 1.9 Typical connection of 79xx IC regulator

Negative Voltage Regulator IC's **Positive Voltage Regulator IC's**

IC No.	Output Voltage
7902	-2V
7905	-5V
7905.5	-5.2V
7906	-6V
7908	-8V
7912	-12V
7915	-15V
7918	-18V
7924	-24V

IC No.	Output Voltage
7805	5V
7806	6V
7808	8V
7812	12V
7815	15V
7818	18V
7824	24V

Different IC packages of Voltage Regulator

1.9.5 LM 317(Three terminal adjustable voltage regulator)

Features

Output voltage range: 1.2 to 37v

Output current in excess of 1.5A

0.1% line and load regulation

Floating operation for high voltages

Complete series of protections: current limiting, thermal shutdown.

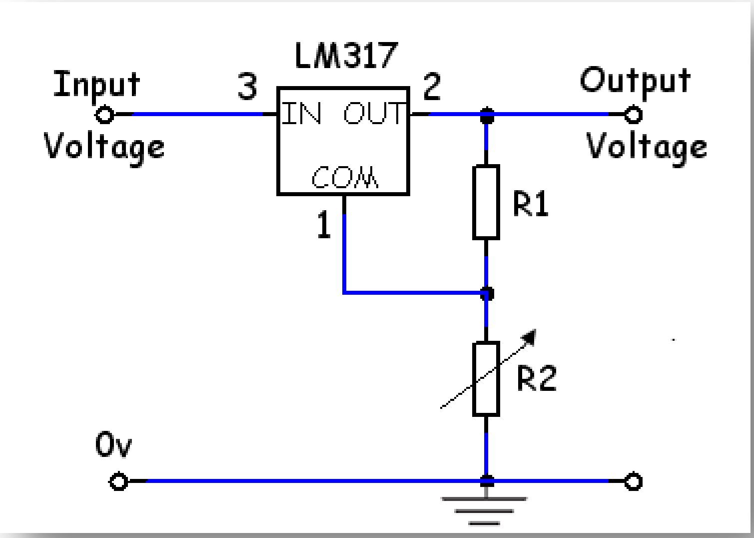


Fig 1.10 Typical connection of LM317.

1.10 Switching regulator

Switching regulator is a voltage regulator that uses a switching element to transform the supply into an alternating current, which is then converted to a different voltage using capacitors, inductors, and other elements, then converted back to DC. The circuit includes regulation and filtering components to insure a steady output. Advantages include the ability to generate voltages beyond the input supply range and efficiency; disadvantages include complexity. A switching regulator rapidly switches a series device ON and OFF. The switch's duty cycle sets the amount of charge transferred to the load. This is controlled by a feedback mechanism similar to that of a linear regulator. Switching regulators are efficient because the series element is either fully conducting or switched OFF because it dissipates almost no power. Switching regulators are able to generate output voltages that are higher than the input voltage or of opposite polarity, unlike linear regulators.

Types of Switching regulator

Step down switching regulator

Step up switching regulator

1.10.1 Step down switching regulator (Buck converter)

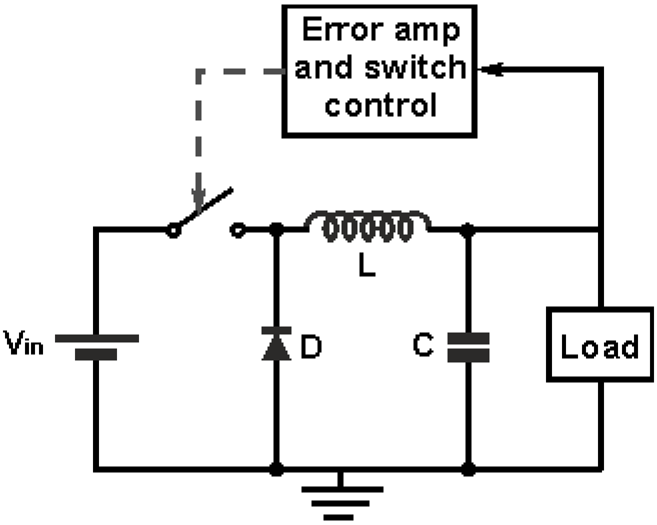


Fig 1.11 Circuit diagram buck converter

The fundamental circuit for a step down converter or buck converter consists of an inductor, diode, capacitor, switch and error amplifier with switch control circuitry as shown in fig 1.11.The circuit for the buck regulator operates by varying the amount of time in which inductor receives energy from the source.

In the basic circuit diagram the operation of the buck converter or buck regulator can be seen that the output voltage appearing across the load is sensed by the sense / error amplifier and an error voltage is generated that controls the switch. Typically the switch is controlled by a pulse width modulator, the switch remaining on of longer as more current is drawn by the load and the voltage tends to drop and often there is a fixed frequency oscillator to drive the switching.

When the switch in the buck regulator is on, the voltage that appears across the inductor is V_{in} - V_{out}. Using the inductor equations, the current in the inductor will rise at a rate of (V_{in}-V_{out})/L. At this time the diode D is reverse biased and does not conduct.

When the switch opens, current must still flow as the inductor works to keep the same current flowing. As a result current still flows through the inductor and into the load. The diode, D then forms the return path with a current I_{diode} equal to I_{out} flowing through it.

With the switch open, the polarity of the voltage across the inductor has reversed and therefore the current through the inductor decreases with a slope equal to -V_{out}/L.

1.10.2 Step up switching regulator (Boost regulator)

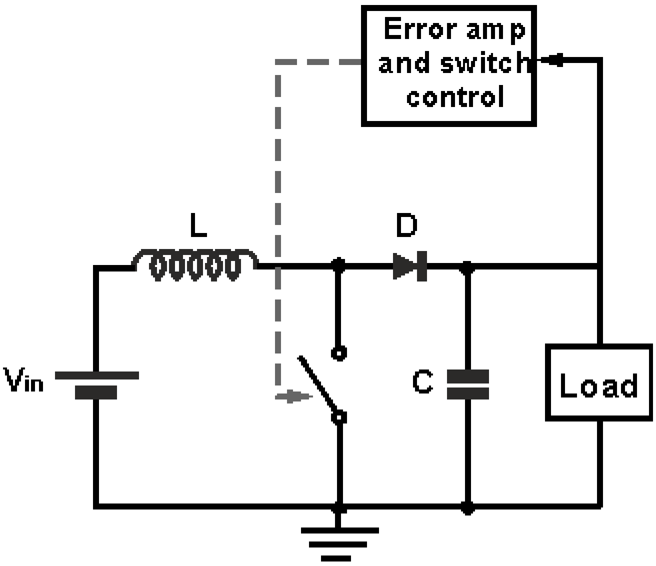


Fig 1.12 Circuit diagram boost regulator

The fundamental circuit for a boost converter or step up converter consists of an inductor, diode, capacitor, switch and error amplifier with switch control circuitry as shown in fig 1.12.

The circuit for the step-up boost converter operates by varying the amount of time in which inductor receives energy from the source. In the basic circuit diagram ,the operation of the boost converter can be seen that the output voltage appearing across the load is sensed by the sense / error amplifier and an error voltage is generated that controls the switch. Typically the boost converter switch is controlled by a pulse width modulator, the switch remaining on of longer as more current is drawn by the load and the voltage tends to drop and often there is a fixed frequency oscillator to drive the switching.

When the switch is in the ON position, the inductor output is connected to ground and the voltage V_{in} is placed across it. The inductor current increases at a rate equal to V_{in}/L.

When the switch is placed in the OFF position, the voltage across the inductor changes and is equal to ($V_{out}-V_{in}$) and the current that was flowing in the inductor decays at a rate equal to $(V_{out}-V_{in})/L$.

1.11 SWITCH MODE POWER SUPPLY(SMPS)

SMPS transfers power from a DC or AC source (often mains power), to DC loads, such as a personal computer, while converting voltage and current characteristics. Unlike a linear power supply, the pass transistor of a switching-mode supply continually switches between **low-dissipation**, **full-on** and **full-off** states, and spends very little time in the high dissipation transitions, which minimizes wasted energy. Ideally, a switched-mode power supply dissipates no power. Voltage regulation is achieved by varying the ratio of on-to-off time. In contrast, a linear power supply regulates the output voltage by continually dissipating power in the pass transistor. This higher power conversion efficiency is an important advantage of a switched-mode power supply. Switched-mode power supplies may also be substantially smaller and lighter than a linear supply due to the smaller transformer size and weight.

Switching regulators are used as replacements for linear regulators when higher efficiency, smaller size or lighter weight is required. They are, however, more complicated; their switching currents can cause electrical noise problems if not carefully suppressed, and simple designs may have a poor power factor.

BLOCK DIAGRAM OF SMPS

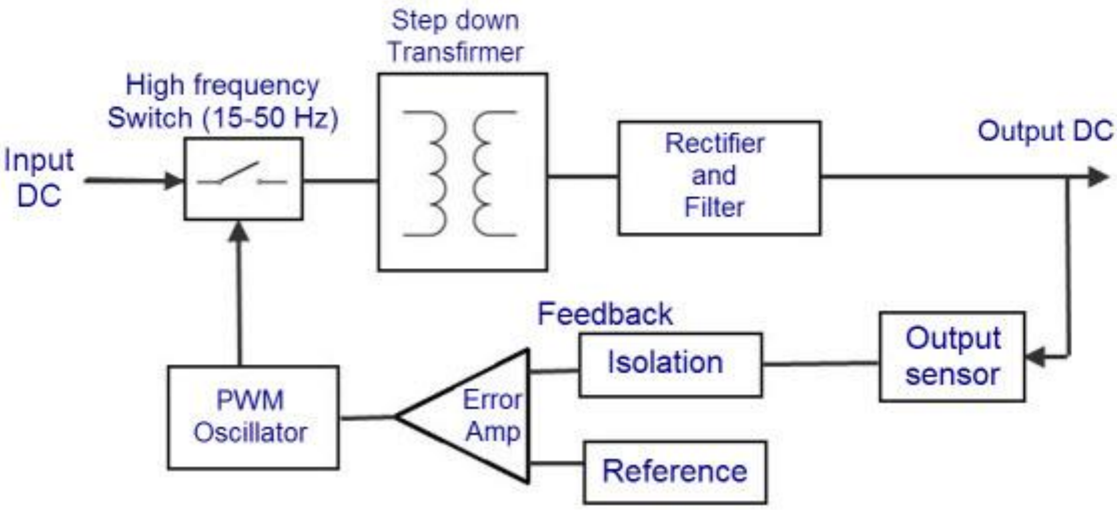


Fig 1.13 Block diagram of SMPS

The block diagram of SMPS is as shown in Fig.1.13. The input high-voltage DC power is switched at a very high switching speed usually in the range of 15 KHz to 50 KHz. And then it is fed to a step-down transformer (high frequency transformer size and weight are comparatively low) . The output of the step-down transformer is further fed into the rectifier. This filtered and rectified output DC power is used as a source for loads, and part of this output power is used as a feedback for controlling the output voltage. With this feedback voltage, the ON time of the oscillator is controlled, and a closed-loop regulator is formed.

The output of the switching-power supply is regulated by PWM (Pulse Width Modulation). As shown in the circuit above, the switch is driven by the PWM oscillator, such that the power fed to the step-down transformer is controlled indirectly. The width of PWM signal and the output voltage are inversely proportional to each other. If the duty cycle is 50%, then the maximum amount of power is transferred through the step-down transformer, and, if duty cycle decreases, then the amount of power transferred will decrease by decreasing the power dissipation.

1.12 Uninterrupted Power Supply (UPS)

An Uninterrupted power supply is essentially a back-up battery to power electronic gadgets like Computer in the event of a power failure. If it happens, the Gadget will draw power from the UPS and will run the load for a prescribed time depending on the capacity of the battery. The change over time from the mains to battery power is a fraction of a second, so that the computer will not shut down. This is essential to protect the data in the computer**.**

Types of UPS:

There are two types of UPS:

i) On-line UPS

ii) Off-line UPS

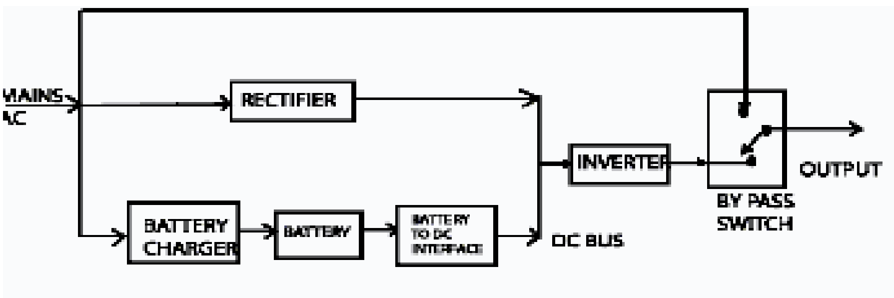
On-line UPS:

Online UPS is the one which gives output all the time from battery whether there is power failure or power on. It is possible to obtain power from battery all the time.

Off-line UPS

Offline UPS supplies mains to the output when power supply is regular and charges batteries at the same time. When power fails it switches those batteries to deliver power to load

On-line UPS :

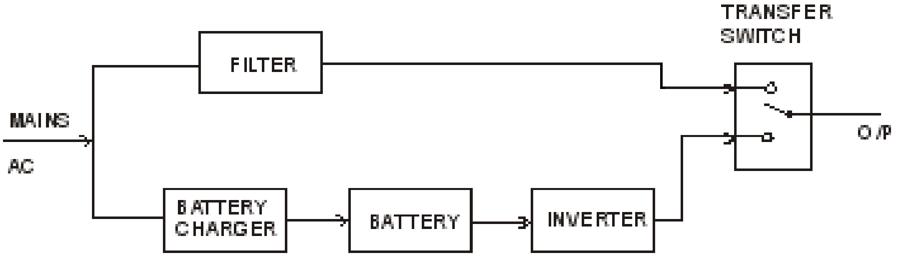


ONLINE UPS

There are two stages in its operation. In the first stage the mains AC is rectified to DC. Inverter can get power from both the DC battery and DC obtained by rectifying the mains AC. Inverter converts Dc to AC and this AC is connected to the output. In normal operation output comes from mains AC via rectifier and inverter. When mains AC fail, output comes from DC battery via inverter. The changeover is instantaneous. Hence no time delay. When a main AC is available normal operation continues and the rectifier recharges the battery. A bypass switch connects mains AC directly to the output in case there is some problem with the UPS.

A typical modern on line UPS is equipped with protections against short circuit, over-voltage and under-voltage etc.On line UPS models generally have capacity more than 5kVA. High capacity On Line UPS can be built for all possible requirements and battery backup time can be increased to suit particular need by adding batteries..

Off-line UPS



An off line UPS is also known as Stand by UPS or Backup UPS and supplies power when mains AC fails. The capacity of an off line UPS is generally below 1kVA. In the event of sudden load shedding the off line UPS supplies power to the load so that work can be continued till normal power is restored.

In normal mode, mains AC is directly connected to the output through a filter unit. The filter unit filters noise present in the mains AC. When mains AC fail the inverter converts DC power of battery to AC and transfer switch connects this AC to the output. This changeover happens very quickly but is not instantaneous and a time delay of few milliseconds is involved. This time delay normally does not affect ordinary load. Again when mains AC comes, the transfer switch connects mains AC to output.

Comparison of On-line and Off-line UPS

Sl No	parameter	Online UPS	Offline UPS
1	Inverter	Always ON	Turned On when mains fails
2	Rectifier cum charger	Supplies power to inverter as well as charges battery	Charges only battery
3	Output waveform	Sine wave	Quasi square wave
4	Harmonic distortion	Low	High
5	Efficiency	Low	High
6	Load	Isolated from supply	Not isolated from Supply
7	Cost	High	Low

https://www.youtube.com/watch?v=E5RKBWhEUAU

HWR

https://www.youtube.com/watch?v=CfoKSkzK6jg

BJT BIASING AND AMPLIFIERS

2.1 Transistor as a switch:

Consider the circuit diagram shown in Fig.2.1 in which the transistor is used as a switch. When the input voltage V_{in} is low(logic 0), i.e, 0V, the transistor is cutoff(Off) and the collector current I_C is 0, voltage drop across R_C is 0 and therefore voltage at the collector is V_{CC}.(logic 1). Thus acts as **open switch** as shown in fig.2.1 (a)

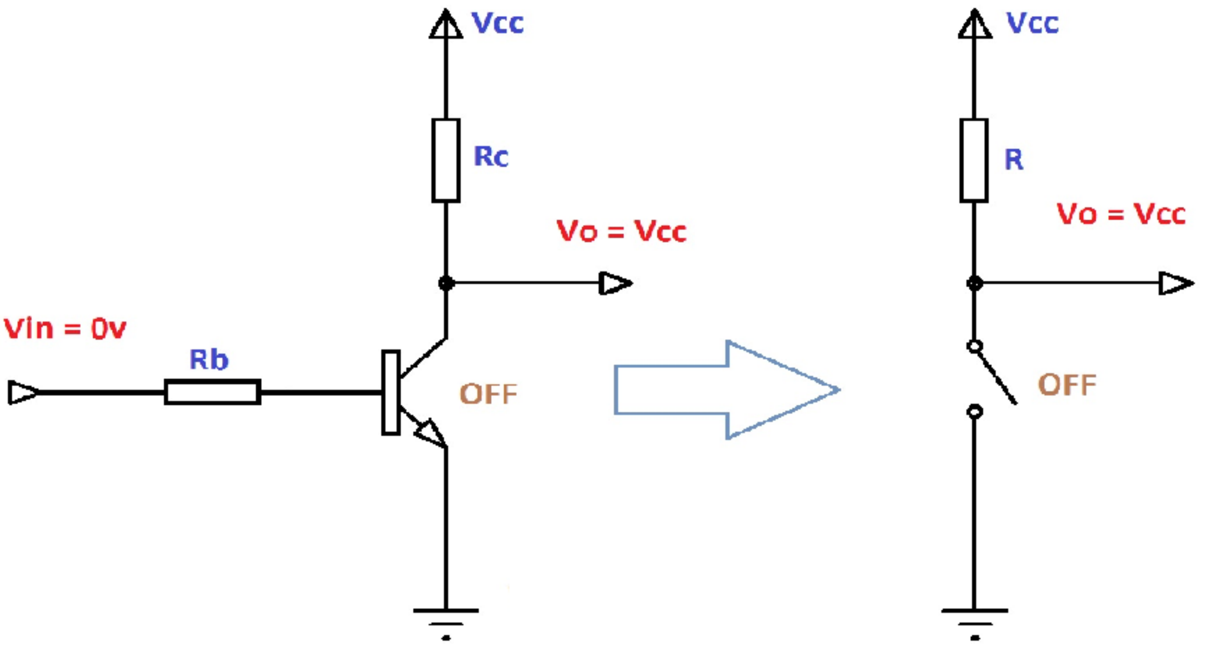


Fig.2.1 (a)

When input voltage V_i =5V (logic 1) is applied, transistor gets saturated and Ic becomes maximum and the voltage across collector is 0V(logic 0). Thus acts as **closed switch** as shown in fig.2.1(b)

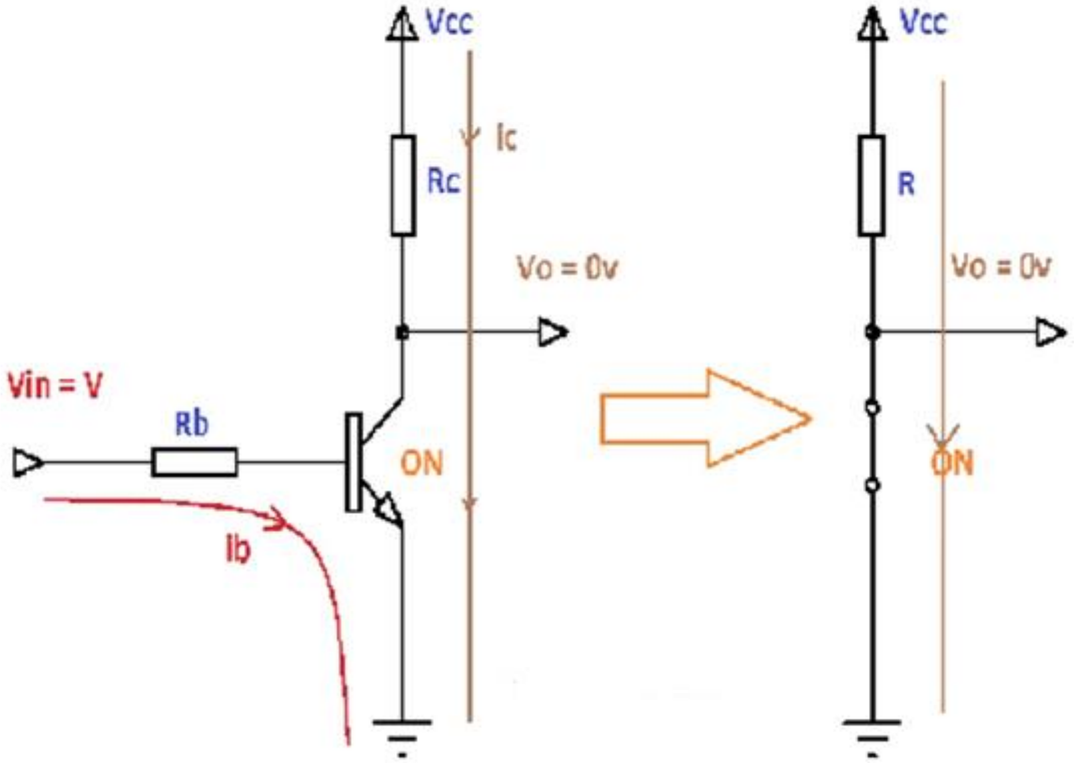


Fig.2.1(b)

2.2 Transistor as an amplifier:

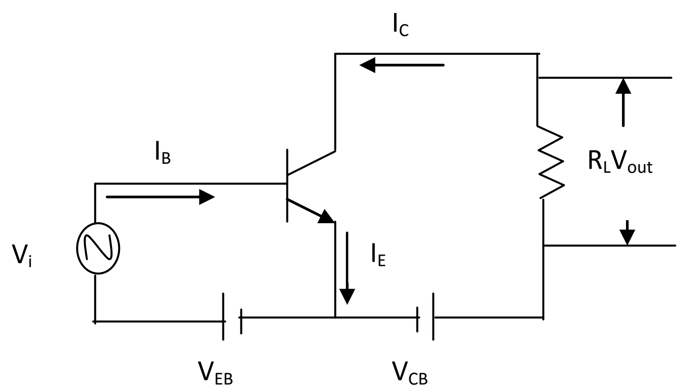


Fig.2.2 Circuit diagram of transistor amplifier

A transistor raises the strength of a weak input signal and thus acts as an amplifier. The weak signal to be amplified is applied between emitter and base and the output is taken across the load resistor R_L connected in the collector circuit. In order to use a transistor as an amplifier it should be operated in active region i.e. emitter junction should be always forward biased and collector junction should be reverse biased. Therefore in addition to the a.c. input source V_i two d.c. voltages V_{EB} and V_{CB} are applied as shown in fig2.2. This d.c. voltage is called bias voltage.

As the input circuit has low resistance, a small change in the signal voltage V_i causes a large change in the base current thereby causing the same change in collector current (because $I_C = \beta I_B$).The collector current flowing through a high load resistance R_L produces a large voltage across it. Thus a weak signal applied at the input circuit appears in the amplified form at the output. In this way transistor acts as an amplifier.

2.3 Need For Biasing:

- To turn the device "ON"
- To keep base emitter junction forward biased and collector base junction reverse biased.
- To ensure proper flow of zero signal collector current
- Maintenance of proper collector emitter voltage.
- Stabilization of operating point

2.4 DC Load Line:

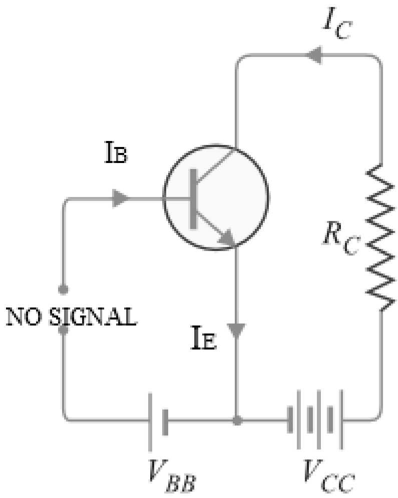
In the analysis of transistor circuits, it is essential to find collector current for different collector-emitter voltages. This can be achieved in two ways

i) Plot the output characteristics and determine the collector current for any desired collector-emitter voltage.

ii) Load line method: DC load line is a straight line drawn on output characteristics of transistor.

Lets us discuss the DC load line method of analysing the transistor circuits. Consider the circuit shown in fig.2.3 (a) in which no signal is applied the output characteristics is shown in fig.2.3(b). The collector-emitter voltage is given by

$$V_{CE} = V_{CC} - I_C R_C \longrightarrow (1)$$



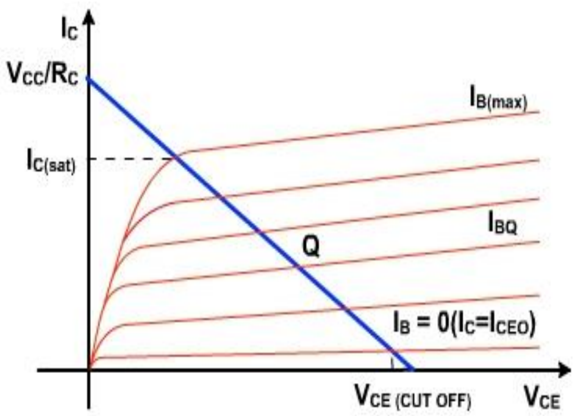


Fig. 2.3(a) Circuit diagram Fig.2.3 (b) Output characteristics

To add the load line on the output characteristics, we need two end points of the straight line. To find two end points for a straight line, first make Ic=0 in the equation (1).

Therefore $V_{CE} = V_{CC} – I_C R_C$

$V_{CE} = V_{CC}$ (since Ic=0)

This gives the coordinates (V_{CC}, 0)

Second point can be determined by making $V_{CE} = 0$ in the equation (1)

Therefore $V_{CE} = V_{CC} – I_C R_C$

$0 = V_{CC} – I_C R_C$

$I_C = V_{CC}/R_C$

This gives the coordinates of the point as (0, V_{CC} / R_C).The two end points so obtained are joined to form the load line. The load line intersects the output characteristics at various points corresponding to different IB.

2.4.1 Q-Point (Static Operation Point)

The zero signal values of I_C and V_{CE} are called as operating point. It is called operating point since the variations of I_C and V_{EC} take place about this point the signal is applied. The intersection of the dc bias value of I_B with the DC load line determines the Q-point as shown in fig.2.4

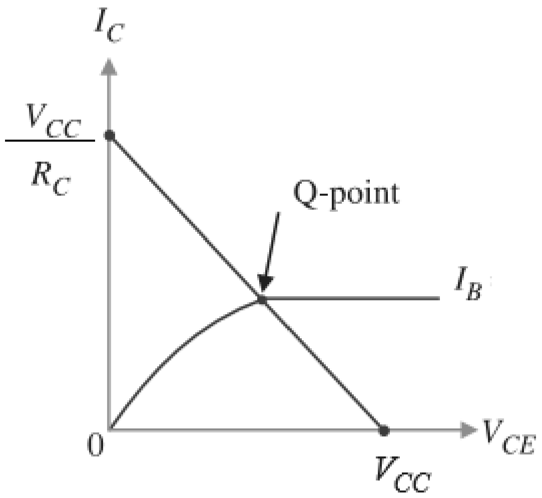


Fig.2.4 Q-point

2.5 Stability factor:

It is desirable and necessary to keep IC constant in the face of variations of ICBO (sometimes represented as ICO). The extent to which a biasing circuit is successful in achieving this goal is measured by stability factor S.

It is defined as the rate of change of collector current I_C w.r.t. the collector leakage current I_{CO} at constant β and I_B is called stability factor

i.e. Stability factor, $S = \frac{dI_C}{dI_{CO}}$ at constant I_B and β

The stability factor indicates the change in collector current I_C due to the change in collector leakage current I_{CO}. Thus a stability factor 50 of a circuit means that I_C changes 50 times as much as any change in I_{CO}. In order to achieve greater thermal stability, it is desirable to have as low stability factor as possible. The ideal value of S is 1 but it is never possible to achieve it in practice.

2.6 Voltage divider bias for BJT

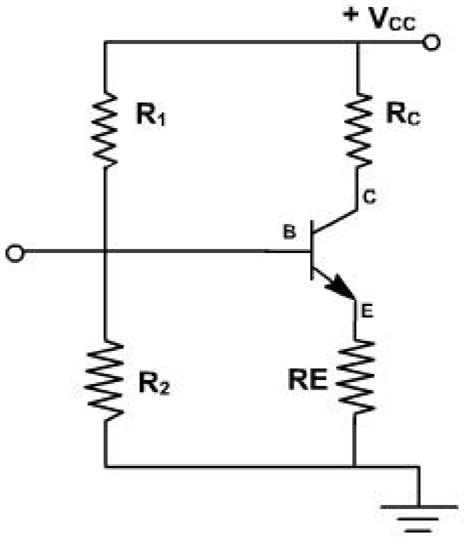


Fig.2.5 Voltage divider bias Circuit

In voltage divider bias method, two resistances R_1 and R_2 are connected across the supply voltage V_{CC} as shown in fig.2.5. The emitter resistance R_E provides stabilisation. The name ‘‘voltage divider’’ comes from the voltage divider formed by R_1 and R_2. The voltage drop across R_2 forward biases the base- emitter junction. This causes the base current and hence collector current flows in the zero signal conditions. From the circuit it can be seen that the voltage applied to base, V_{BB} is Voltage across R_2. The voltage V_{CC} is divided by the resistors R_1 & R_2 (neglecting base current).

$$V_{BB} = V_{R2} = \frac{V_{CC}}{R_1 + R_2} \times R_2.$$

The operating point is calculated as follows:

$$V_E = V_{BB} - V_{BE}$$

$$I_E = \frac{V_E}{R_E}$$

$$I_C \approx I_E$$

$$V_C = V_{CC} - I_C R_C.$$

$$V_{CE} = V_C - V_E.$$

Now suppose I_C tends to increase, because of say increased I_{CO} due to temperature rise.

This increases I_E, as a consequence voltage drop across R_E, which decreases the base current. Hence, I_C increases less than it would have if there were no self biasing resistor R_E. A more detailed analysis is obtained from the equivalent circuit of fig 2.5(a) as given in 2.5(b).

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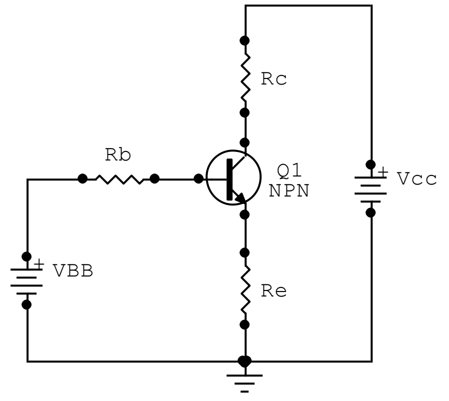

Fig 2.5(b) Voltage divider bias equivalent circuit

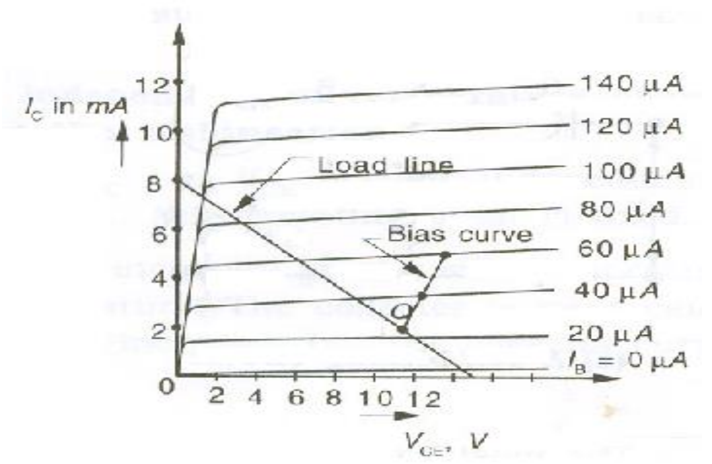

Fig.2.5(c) Bias Curve

R_b is the equivalent resistance at base given by $R_1 \parallel R_2$.

The ***KVL for collector circuit*** gives the equation

$$V_{CC} = I_C R_C + V_{CE} + R_E\,(I_C + I_B)$$

Neglecting drop due to I_B, we get

$$V_{CE} = V_{CC} - I_C(R_C + R_E).$$

Hence the ***load line has a slope $R_C + R_E$.***

KVL for the base circuit yields

$$V_{BB} = I_B R_B + V_{BE} + R_e(I_C + I_B).$$

Substituting for I_C, we get relationship between V_{CE} & I_B. This is called the ***bias curve Fig.2.5(c).*** The intersection of load line with bias curve is the operating point.

2.6 Features of amplifiers

Features Direct coupled Amplifiers:

In direct coupled amplifiers the individual stages are coupled directly without any coupling devices.

i) Circuit is simple to design
ii) Low cost
iii) Used to amplify low frequency signals
iv) Q-point is not stable for temperature variations

Features of RC coupled Amplifiers:

i) It is best suited for audio signals
ii) Low voltage and power gain
iii) Impedance matching is poor
iv) They have the tendency to become noisy on aging
v) Excellent audio fidelity over wide range of frequency

Features of Transformer coupled Amplifiers:

i) Excellent impedance matching
ii) It provides high gain
iii) Poor frequency response
iv) Frequency distortion is higher
v) Transformers are bulky, expensive at audio frequency

.

Comparison of different types of coupling

Sl. No.	Characteristics	RC Coupling	Transformer Coupling	Direct Coupling
1.	Size	Small	Large and Bulky	Very Small
2.	Cost	Small	Costlier	Very Small
3.	Frequency Response	Excellent in Audio Frequency	Poor	Best
4.	Impedance Matching	Not Good	Excellent	Good
5.	Application	Voltage Amplification	Power Amplification	Low Frequency Signal Amplification

2.7 Features of AF Amplifiers:

- Audio frequency amplifiers are used to amplify signals in the range of human hearing, approximately 20Hz to 20kHz, although some Hi-Fi audio amplifiers extend this range up to around 100kHz, whilst other audio amplifiers may restrict the high frequency limit to 15kHz or less.
- Audio voltage amplifiers are used to amplify the low level signals from microphones, tape and disk pickups etc.
- With extra circuitry they also perform functions such as tone correction equalisation of signal levels and mixing from different inputs, they generally have high voltage gain and medium to high output resistance.
- Audio power amplifiers are used to receive the amplified input from a series of voltage amplifiers, and then provide sufficient power to drive loudspeakers.

2.8 Features of RF Amplifiers:

Radio Frequency amplifiers are tuned amplifiers in which the frequency of operation is governed by a tuned circuit. This circuit may or may not, be adjustable depending on the purpose of the amplifier.

Bandwidth depends on use and may be relatively wide, or narrow.

Input resistance is generally low, as is gain. (Some RF amplifiers have little or no gain at all but are primarily a buffer between a receiving antenna and later circuitry to prevent any high level unwanted signals from the receiver circuits reaching the antenna, where it could be re-transmitted as interference).

A special feature of RF amplifiers where they are used in the earliest stages of a receiver is low noise performance. It is important that background noise generally produced by any electronic device, is kept to a minimum because the amplifier will be handling very low amplitude signals from the antenna (µV or smaller). For this reason it is common to see low noise FET transistors used in these stages.

2.9 Voltage amplifiers:

Voltage amplifiers are devices that amplify the input voltage, if possible with minimal current at the output.
Technically, an amplifier with high voltage gain is a voltage amplifier, but it may or may not have a low current gain. The power gain of an amplifier is also low due to these properties.

Transistors, and op amps, given proper biasing and other conditions, act as basic voltage amplifiers.
The main application of voltage amplifiers is to strengthen the signal to make it less affected by noise and attenuation.

When transmitted signals lose its strength and get deformed, an amplification of the voltage at the transmitter will minimize the effect and receiver will be able to capture and interpret the signal with reasonable accuracy.

Ideal voltage amplifiers have infinite input impedance and zero output impedance.

In practice, an amplifier with high input impedance relative to the output impedance is considered as a good voltage amplifier.

2.10 Power Amplifiers:

Power amplifiers are devices used to amplify the input power, if possible with minimal change in the output voltage with respect to the input voltage. That is, power amplifiers have a high power gain, but the output voltage may or may not change.

The amplifier efficiency of power amplifiers is always lower than 100%. Therefore, high heat dissipation is observed at power amplification stages.

Power amplifiers are used in devices which require a large power across the loads. In multi stage amplifiers, power amplification is made in the final stages of amplification.

Audio amplifiers and RF amplifiers use power amplifiers at the final stage to deliver sufficient power the load. Servo motor controllers also use power amplifiers to drive the motors.

Power amplifiers are classified into several classes depending on the fraction of the input signal used in amplification. Classes A, B, AB and C are used in analog circuits, while classes D and E are used in switching circuits.

In modern electronics, most power amplifiers are constructed with semiconductor based components while, vacuum tube (valve) based amplifiers are still used in environments, where precision, frequency response, and endurance are a primary requirement. For example, guitar amplifiers use valves for quality and military equipment use valves for its endurance against strong electromagnetic pulses.

Comparison of voltage and power amplifiers:

Sl.no.	Characteristics	Voltage Amplifier	Power Amplifier
1	Current Gain	High, exceeding 100	Low 20-50
2	Collector Load	High about 10KΩ	Low 5-20Ω
3	Input Voltage	Low, a few mV	High, 2-4V
4	Collector Current	Low about 1mA	High exceeding 100mA
5	Power output	Low	High
6	Power dissipation capacity	Less than 0.5W	More than 0.5W
7	Output Impedance	High about 10KΩ	Low about 200Ω
8	Coupling	Usually RC coupling	Transformer or tuned circuit

2.11 Feedback in amplifiers:

The process of injecting a fraction of output energy of some device back to the input is known as feedback.

Types of feedback:

Feedback amplifiers can be classified as positive or negative feedback depending on how the feedback signal gets added to the incoming signal.

Positive feedback:

If the feedback signal is of the same phase as the incoming signal, they get added & this is called as **positive feedbac**k. It is illustrated in fig 2.6

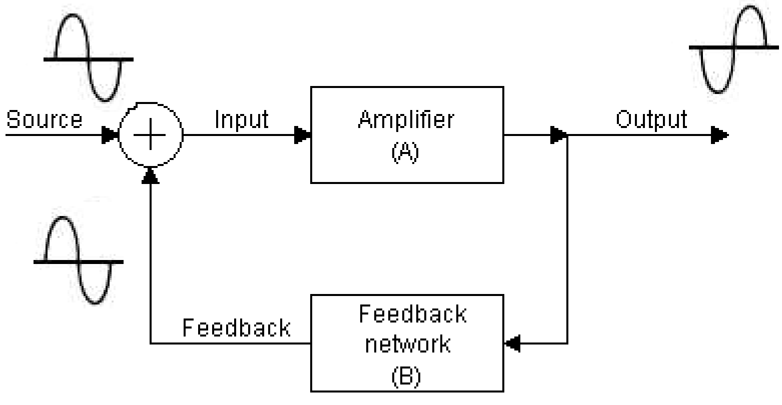

Fig 2.6 Positive feedback

Feature of positive feedback

1. Feedback network introduces 180º phase shift
2. Overall gain is increased
3. Distortion is increased
4. Stability is decreased

Negative feedback:

If the feedback signal is in phase inverse with the incoming signal, they get subtracted from each other it will is called as **negative feedback**. It is illustrated in fig 2.7

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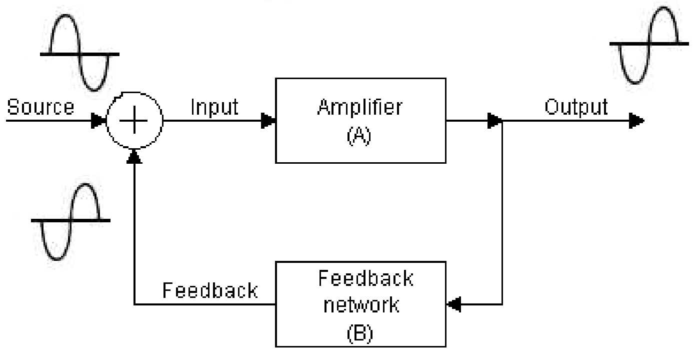


Fig 2.7 Negative feedback

Feature of negative feedback amplifiers:

1. Feedback network introduces 0º phase shift
2. Overall gain is reduced
3. Bandwidth is improved
4. Distortion is reduced
5. Stability is improved
6. Noise is reduced

Positive feedback is employed in oscillators whereas negative feedback is used in amplifiers

2.12 Small-signal Amplifier:

The amplifiers which handle small input a.c signals are called small-signal amplifiers. Voltage amplifiers generally fall in this class. They are designed to operate over the linear portion of the output characteristics.

2.12.1 Single stage RC coupled amplifier:

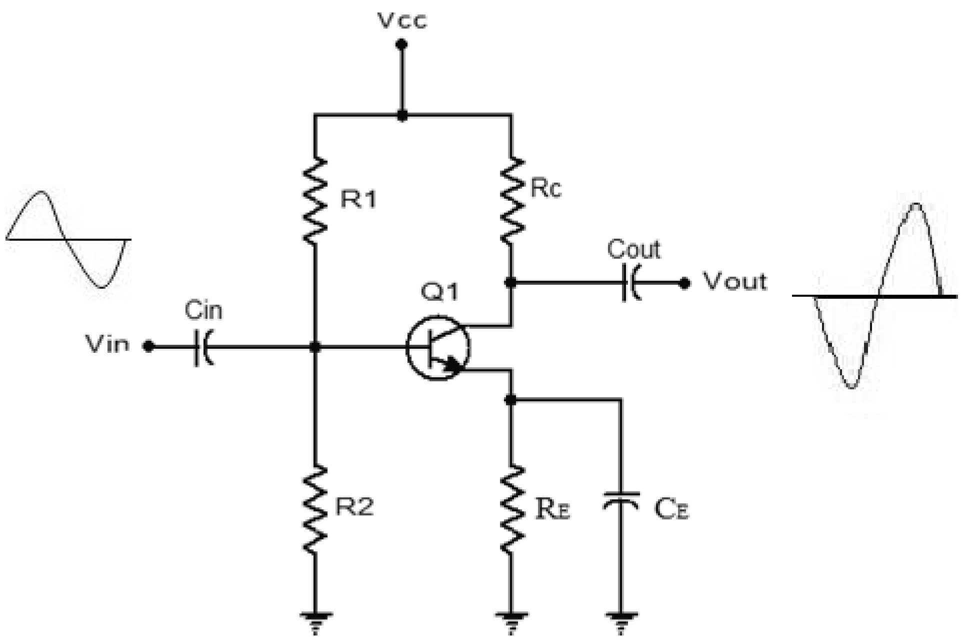


Fig. 2.8 (a) Single stage RC coupled amplifier

Figure 2.8(a). Shows a circuit of a single stage RC coupled amplifier. The different circuit components and their functions are as described. Input capacitor (C_{in}) is used to couple the input signal to the base of the transistor. If it is not used, the signal source resistance R_S gets in parallel with R_2 thus changes the bias voltage. The capacitor C_{in} blocks any d.c. component present in the signal and passes only a.c. signal for amplification. The resistances R_1, R_2 and R_E forms the biasing and stabilization circuit for the CE amplifier. It sets the proper operating point for the amplifier. Emitter bypass capacitor (C_E) is connected in parallel with the emitter resistance R_E to provide low reactance path to the amplified a.c. signal. If it is not used, the amplified a.c. signal passing through R_E will cause voltage drop across it thereby reducing the output voltage of the amplifier.

Coupling capacitor(Cc) couples the output of the amplifier to the load or to the next stage of the amplifier. If it is not used, the biasing conditions of the next stage will change due to the parallel effect of collector resistor R_C.

2.12.2 Frequency response in amplifier

Frequency response is the curve between the gain of the amplifier ($A = V_o / V_i$) verses the frequency of the input signal. The frequency response of a typical RC-coupled amplifier is shown in fig 2.8(b).

Frequency response has 3 regions.

1. Low frequency range
2. Mid frequency range
3. High frequency range

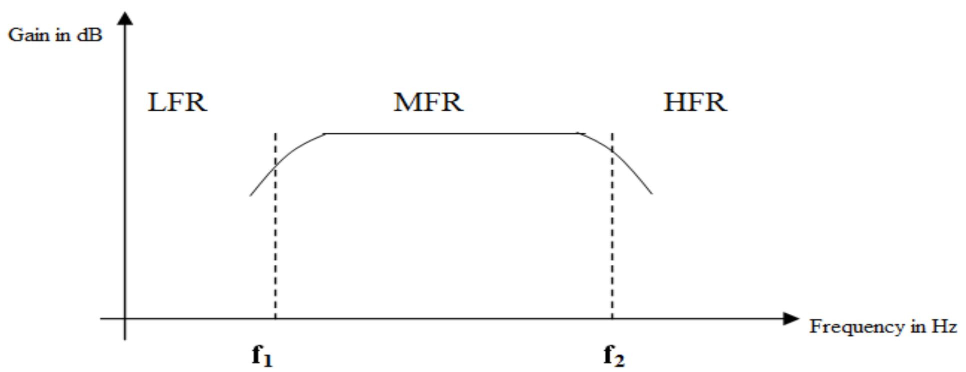


Fig 2.8(b) frequency response

Low frequency range (< 50 Hz)

Capacitive reactance is given by

$X_c = \dfrac{1}{2\pi RC}$ where X_C ----- reactance of capacitor.;

f-----frequency

Since frequency is inversely proportional to the reactance, the reactance of the coupling capacitor C_C will be quite high at low frequencies. Hence very small amount of signal will pass through one stage to the next stage. Moreover C_E cannot shunt the emitter resistance R_E effectively because of its large reactance at low frequency. These two factors causes the fall of voltage gain at low frequencies.

Mid frequency range (50Hz –20KHz)

In this range of frequencies, voltage gain of the amplifier is constant. The effect of coupling capacitor in this range is as such to maintain a uniform voltage gain.

High frequency range (> 20 KHz)

In this range of frequency, the reactance of the coupling capacitor C_C is very small and it behaves as a short circuit. This increases the loading effect of next stage (R_C will comes in parallel with R_1) and reduces the voltage gain. This reduces the current amplification there by the voltage drops at high frequencies.

2.12.3 Two stage RC coupled amplifier

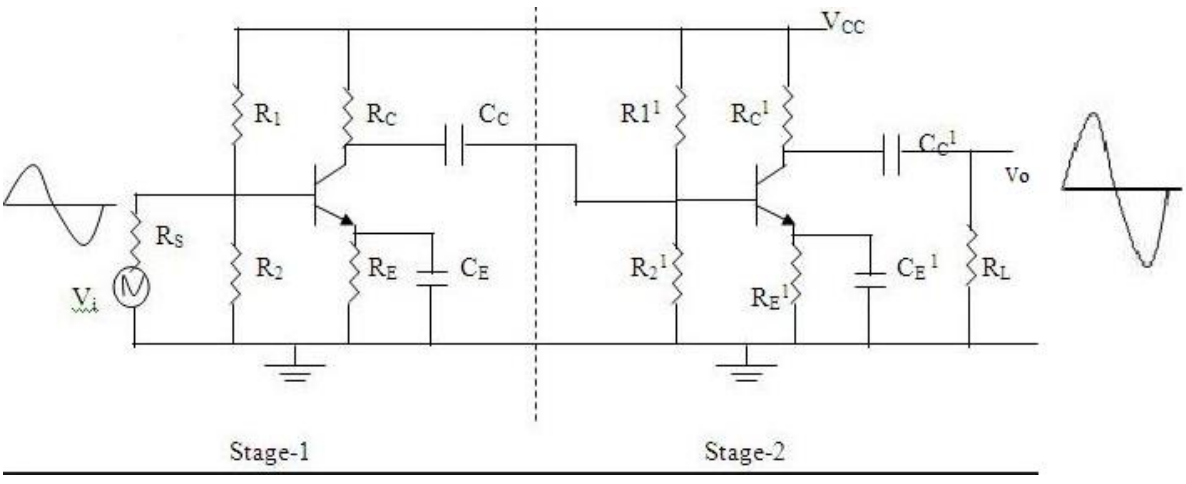


Fig. 2.9 (a)Two stage RC coupled amplifier

Fig.2.9(a) above shows the circuit diagram of a two stage RC coupled amplifier. The coupling capacitor C_C connects the output of the first stage to the input of the second stage. Since the coupling from one stage to the next stage is achieved by coupling capacitor along with a shunt resistor the amplifier is called RC coupled amplifier. The input signal is first applied to the transistor T_1 and output is taken at the collector of T_1. The signal at the output will be 180^0 out of phase when compared to the input. The output is taken across R_C with the help of a coupling capacitor. This signal is fed as input to the next stage i.e transistor T_2. The signal is amplified further and the amplified output is taken across R_c^1 of T_2. The phase of the signal is reversed again. The output is amplified twice and its is a amplified replica of the input signal. The frequency response of two stage RC coupled amplifier is similar to single stageRC coupled amplifier but its gain is more comparatively.

2.12.4 Advantages of RC coupled amplifier

1. **Low cost-**Because only resistors and capacitors are used for biasing and coupling which are cheap.
2. **Compact-**Because modern resistor and capacitors are small and light
3. **Good frequency response-** The gain is constant over the audio frequency range and hence suitable for audio frequency amplification.

2.13 Large-signal Amplifier:

The amplifiers which handle large input a.c. signals are called large-signal amplifiers. Power amplifiers generally fall in this class. They are designed to provide a large amount of a.c. power output so that they can operate the output device.

AC load line:

It is the line on the output characteristics of a transistor circuit which gives the values of i_C and v_{CE} when signal is applied.

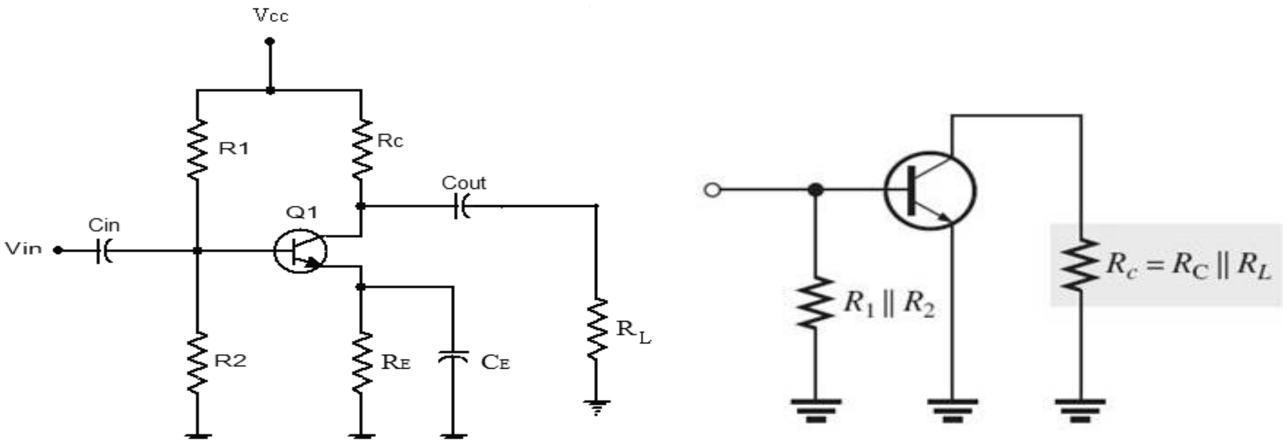


Fig.2. 10(a) Transistor Amplifier Fig.2. 10(b) a.c. equivalent circuit

Consider the transistor amplifier shown in Fig 2.10 (a), its a.c. equivalent circuit is shown in Fig.2.10 (b). To add a.c. load line to the output characteristics, we require two end points- one maximum collector-emitter voltage point and the other maximum collector current point.

Maximum collector-emitter voltage=$V_{CE}+I_C R_{AC}$. This locates the point A of the a.c. load line on the collector-emitter voltage axis.

Maximum collector current= $I_C + \dfrac{V_{CE}}{R_{AC}}$

Where $R_{AC} = R_C \| R_L = \dfrac{R_C R_L}{R_C + R_L}$

This locates the point B of a.c. load line on the collector-current axis. By joining points A and B , the a.c. load line is constructed as shown in Fig 2.10 (c)

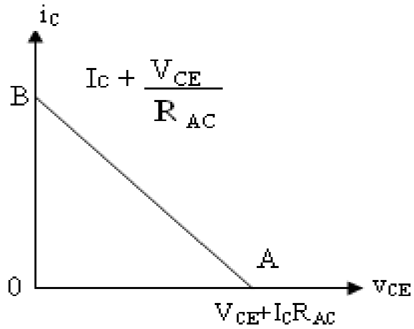


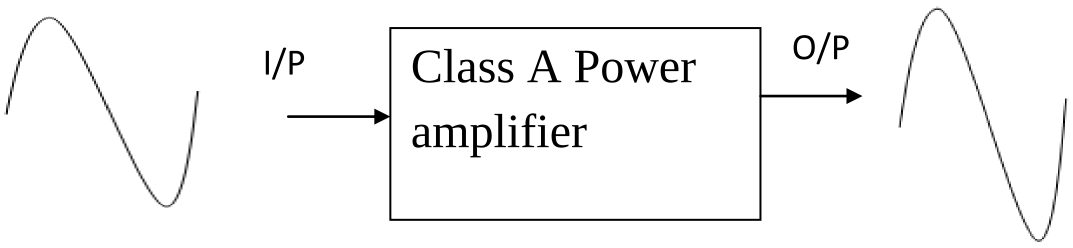
Fig.2.10(c)

2.14 POWER AMPLIFIERS

A voltage amplifier provides voltage amplification primarily to increase the voltage of the input signal. Large-signal or power amplifiers, on the other hand, primarily provide sufficient power to an output load to drive a speaker or other power device, typically a few watts to tens of watts. The main features of a large-signal amplifier are the circuit's power efficiency, the maximum amount of power that the circuit is capable of handling, and the impedance matching to the output device.

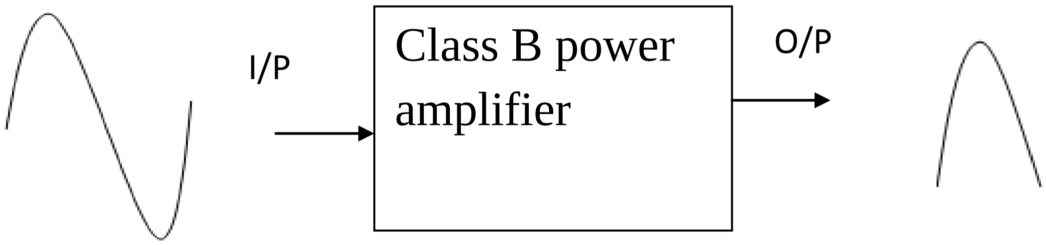
Based on the portion of signal amplifies over one cycle of operation, power amplifiers are classified as class A, class B, class C, class AB

Class A: In class A amplifier **t**he output signal varies for full 360° of the input cycle.



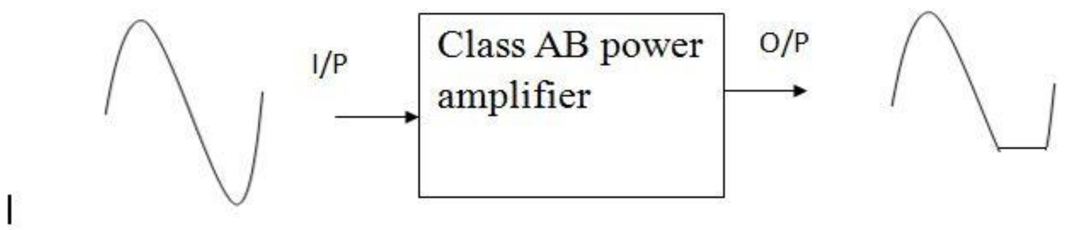
Q-point to be biased at a level so that the whole cycle gets amplified without any distortion,i.e Q-point must be fixed at the middle of DC load line.

Class B: In class B amplifier, **t**he output signal varies for half of input signal cycle (180° of signal).

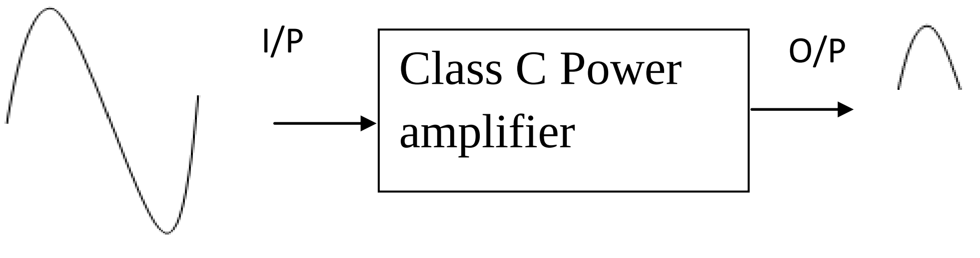


Dc bias point for class B is therefore at 0 V, with the output then varying from this bias point for a half-cycle. Obviously, the output is not a faithful reproduction of the input if only one half-cycle is present.

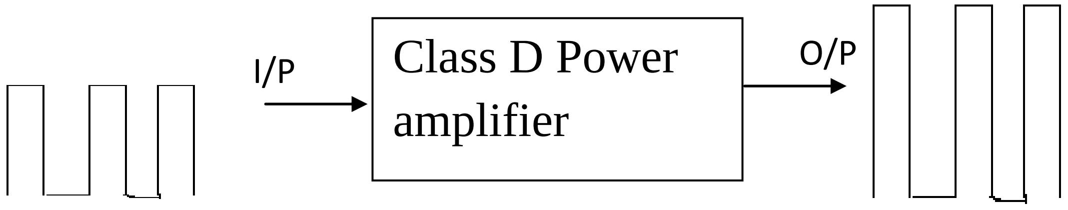
Class AB: In class AB amplifier, the output signal swing occurs between 180° and 360° and is neither class A nor class B operation. An amplifier may be biased at a dc level above the zero base current level of class B and below the bias level of class A



Class C: In class C amplifier, the output signal swing occurs for less than 180°. This operating class is therefore used in special areas of tuned circuits, such as radio or communication.



Class D: In class-D amplifier or switching amplifier is an electronic amplifier in which the amplifying devices (transistors, usually MOSFETs) operate as electronic switches and not as linear gain devices as in other amplifiers. The signal to be amplified is a train of constant amplitude pulses, so the active devices switch rapidly back and forth between a fully conductive and nonconductive state. The analog signal to be amplified is converted to a series of pulses by pulse width modulation, pulse density modulation or other method before being applied to the amplifier.



Amplifier Efficiency

The power efficiency of an amplifier, defined as the ratio of power output to power input, improves (gets higher) going from class A to class D. In general terms, we see that a class A amplifier, with dc bias at one-half the supply voltage level, uses a *good* amount of power to maintain bias, even with no input signal applied. This results in very poor efficiency, especially with small input signals, when very little ac power is delivered to the load.

Power amplifier	Efficiency
Class A (direct coupled–series fed)	25%
Class A (transformer coupled)	50%

Class B	78.5%
Class AB	25% - 78.5%
Class C	90%
Class D	90%

2.15 SERIES-FED CLASS A AMPLIFIER

This simple fixed-bias class A series-fed amplifier circuit is as shown in fig 2.11. Here the transistor used is a power transistor that is capable of operating in the range of a few to tens of watts, and the input voltage will be in terms of few volts. power transistors that are capable of handling large power or current while not providing much voltage gain.

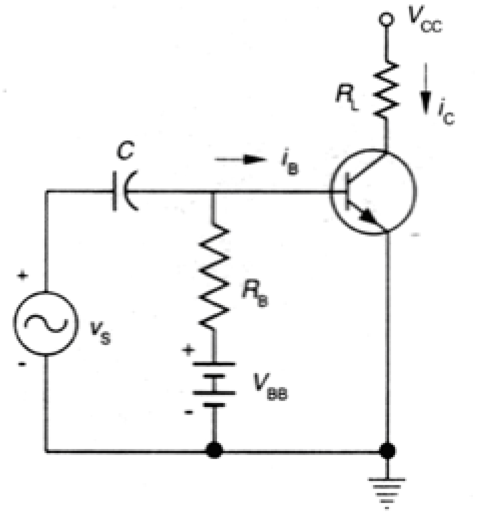


Fig .2.11 Series-fed class A large-signal amplifier DC Bias Operation

The dc bias set by V_{CC} and R_B fixes the dc base-bias current at

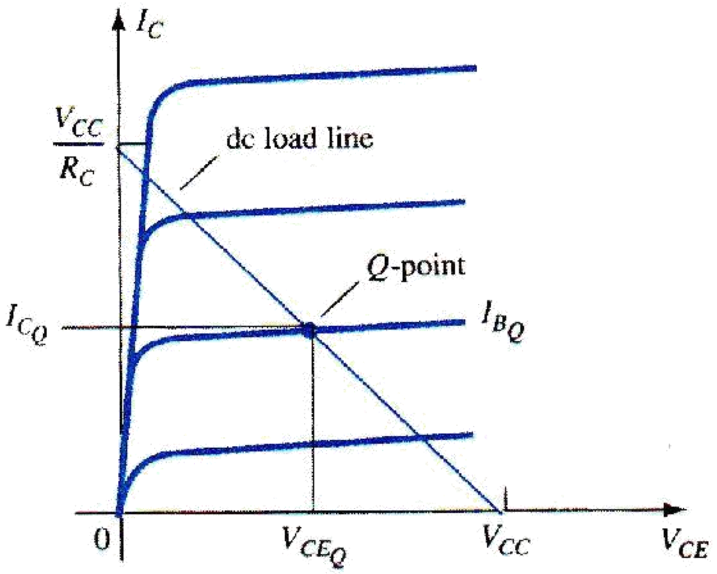
$$I_B = \frac{V_{CC} - 0.7V}{R_B}$$

Then collector current is,

$$I_C = \beta I_B$$

Collector-emitter voltage is

$$V_{CE} = V_{CC} - I_C R_C$$



To appreciate the importance of the dc bias on the operation of the power amplifier, consider the collector characteristic shown in Fig 2.12. An ac load line is drawn using the values of V_{CC} and R_C.. The intersection of the dc bias value of I_B with the dc load line then determines the operating point (Q-point) for the circuit. If the dc bias collector current is set at one-half the possible signal swing (between 0 and V_{CC}/R_C), the largest collector current swing will be possible. Additionally, if the quiescent collector-emitter voltage is set at one-half the supply voltage, the largest voltage swing will be possible.

Fig .2.12 Transistor characteristic showing load line and Q-point

AC Operation

When an input ac signal is applied to the amplifier of Fig 2.13, the output will vary from its dc bias operating voltage and current. A small input signal, as shown in Fig will cause the base current to vary above and below the dc bias point, which will then cause the collector current (output) to vary from the dc bias point set as well as the collector-emitter voltage to vary around its dc bias value.

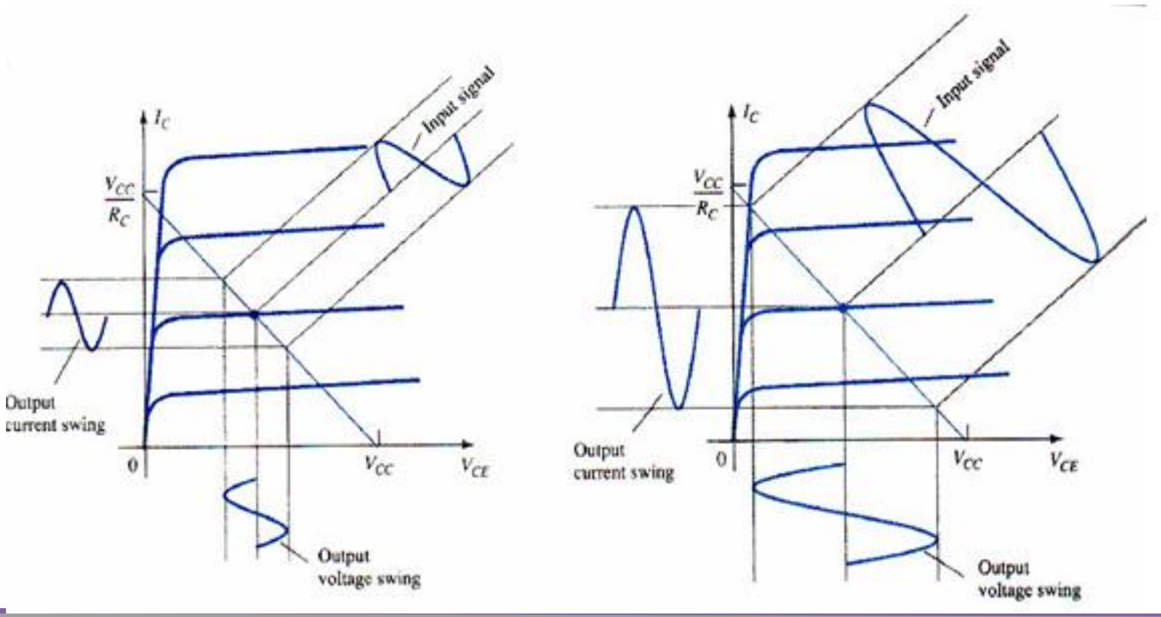


Fig. 2.13. Amplifier input and output signal variation

As the input signal is made larger, the output will vary further around the established dc bias point until either the current or the voltage reaches a limiting condition. For the current this limiting condition is either zero current at the low end or V_{CC}/R_C at the high end of its swing. For the collector-emitter voltage, the limit is either 0 V or the supply voltage, V_{CC}

Calculation of Efficiency

The efficiency of an amplifier represents the amount of ac power delivered (transferred) from the dc source. The efficiency of the amplifier is calculated using

$$\%\eta = \frac{P_O\ (ac)}{P_i\ (dc)} x100\%$$

The input DC power to the power amplifier is given by,

$$P_i(dc)=V_{CC}I_{CQ}$$

Even with an ac signal applied, the average current drawn from the supply remains the same, so that Eq. represents the input power supplied to the class A series-fed amplifier.

The output voltage and current varying around the bias point provide ac power to the load. This ac power is delivered to the load, *Rc*, in the circuit can be calculated as follows.

$$P_O(ac)= \frac{VCE(p)Ic(P-P)}{8}$$

$$P_O(ac)= \frac{VCE(p-p)Ic(P-P)}{8}$$

But $V_{CE}(p\text{-}p)=V_{CC}$

$$I_C(p\text{-}p) = \frac{V_{CC}}{R_C}$$

Maximum $P_O(ac) = \dfrac{V_{CC}(\frac{V_{CC}}{R_C})}{8}$

$$= \frac{V_{CC}^2\,(P)}{8R_C}$$

The maximum power input can be calculated using the dc bias current set to one-half the maximum value:

Maximum $P_i(dc) == V_{CE}$ (maximum)X Ic$= \frac{V_{CC}(\frac{V_{CC}}{R_C})}{2}$

$$= \frac{V_{CC}^2}{2R_C}$$

Then the maximum efficiency is

$$\text{Maximum } \eta = \frac{\text{Maximum PO(ac)}}{\text{Maximum Pi(dc)}} \text{x}100\%$$

$$= \frac{\frac{V_{CC}^2}{8R_C}}{\frac{V_{CC}^2}{2R_C}} \text{X}100\%$$

$$= 25\%$$

The maximum efficiency of a class A series-fed amplifier is thus seen to be 25%. Since this maximum efficiency will occur only for ideal conditions of both voltage swing and current swing, most series-fed circuits will provide efficiencies of much less than 25%.

2.16 TRANFORMER-COUPLED CLASS A AMPLIFIER

A form of class A amplifier having maximum efficiency of 50% uses a transformer to couple the output signal to the load as shown in Fig2.14.

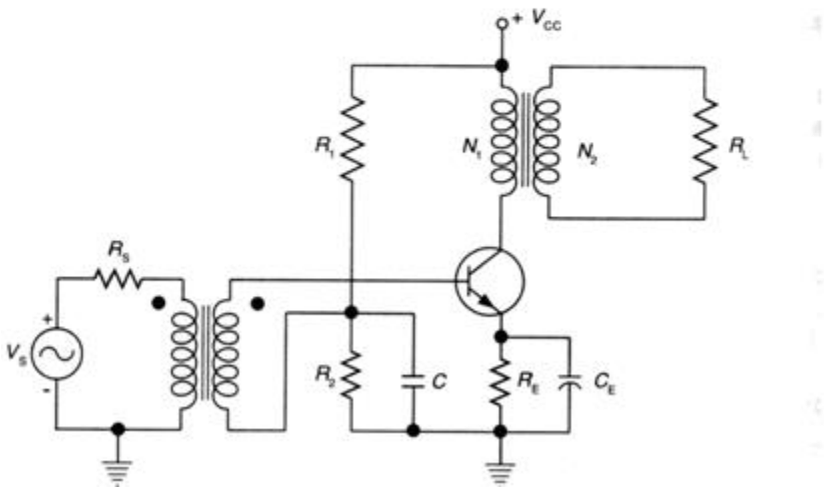


Fig.2.14 Transformer-coupled audio power amplifier

Transformer Action

A transformer can increase or decrease voltage or current levels according to their turns ratio, In addition, the impedance connected to one side of a transformer can be made to appear either larger or smaller (step up or step down) at the other side of the transformer, depending on the square of the transformer winding turns ratio.

SIGNAL SWING AND OUTPUT AC POWER

Figure 2.15 shows the voltage and current signal swings from the circuit of Fig2.14. From the signal variations the values of the peak-to-peak signal swings are

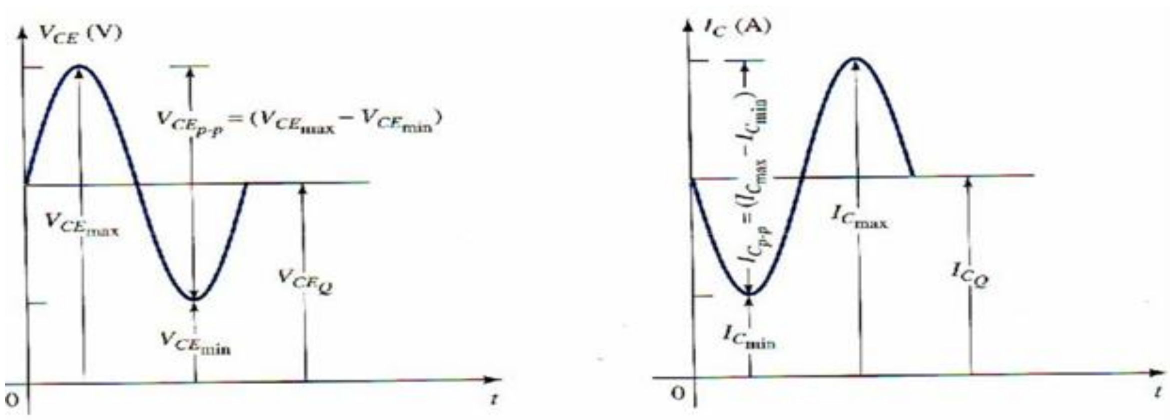


Fig.2.15 Voltage and current waveforms

$$V_{CE}(p\text{-}p)=V_{CEmax}-V_{CE\ min}$$

$$I_C(p\text{-}p) = I_{Cmax}-I_{Cmin}$$

The ac power developed across the transformer primary can then be calculated using

$$P_O(ac)= \frac{(V_{CE_{max}}-V_{CE_{min}})(I_{C_{max}}-I_{C_{min}})}{2\sqrt{2}X2\sqrt{2}} \quad (v_{rms} = \frac{Vm}{2\sqrt{2}})$$

The ac power calculated is that developed across the primary of the transformer. The output ac power can be determined using the voltage delivered to the load

For the ideal transformer, the voltage delivered to the load can be calculated as,

$$V_L=V_2=\frac{N_2V_1}{N_1}$$

The power across the load can then be expressed as

$$P_L= \frac{v_L^2\ (rms)}{RL}$$

And the load current yields,

$$I_L=I_2=\frac{N_1I_C}{N_2}$$

Then output ac power is

$$P_L=I^2_{L(rms)}\, R_L$$

Maximum theoretical efficiency

For a class A transformer-coupled amplifier, the maximum theoretical efficiency goes up to 50%. Based on the signals obtained using the amplifier, the efficiency can be expressed as

$$\%\ \eta =50\left(\frac{V_{CE_{max}}-V_{CE_{min}}}{V_{CE_{max}}+V_{CE_{min}}}\right)^2$$

If $V_{CEmax}, = V_{CEmin}$,

$\% \eta = 50$

2.17 Push Pull Amplifier

A push pull amplifier is an amplifier which has an output stage that can drive a current in either direction through the load. The output stage of a typical push pull amplifier consists of of two identical BJTs one sourcing current through the load while the other one sinking the current from the load. Push pull amplifiers are superior over single ended amplifiers (using a single transistor at the output for driving the load) in terms of distortion and performance.

2.17.1 Class B-push-pull amplifier

The Class B push pull amplifier there is no biasing resistors. This means that the two transistors are biased at the cut off point. The Class B configuration can provide better power output and has higher efficiency(up to 78.5%). Since the transistor is biased at the cut-off point, they consumes no power during idle condition and this adds to the efficiency. The advantages of Class B push pull amplifiers are, ability to work in limited power supply conditions (due to the higher efficiency), absence of even harmonics in the output, simple circuitry when compared to the Class A configuration etc. The disadvantages are higher percentage of harmonic distortion when compared to the Class A, cancellation of power supply ripples is not as efficient as in Class A push pull amplifier and which results in the need of a well regulated power supply. The circuit diagram of a classic Class B push pull amplifier is shown in the fig

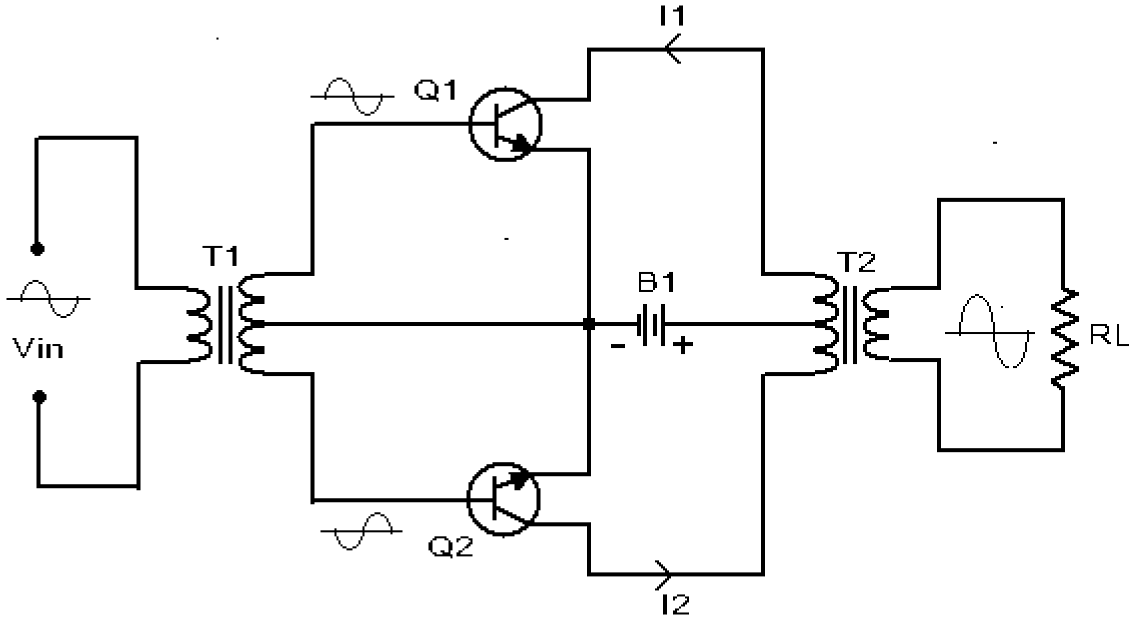


Fig 2.16. Class B-push-pull amplifier

. T1 is the input coupling capacitor and the input signal is applied to its primary. Q1 and Q2 are two identical transistors and their emitter terminals are connected together. Center tap of the input coupling transformer and the negative end of the voltage source is connected to the junction point of the emitter terminals. Positive end of the voltage source is connected to the center tap of the output coupling transformer. Collector terminals of each transistor are connected to the respective ends of the primary of the output coupling transformer T2. Load RL is connected across the secondary of T2.

The input signal is converted into two similar but phase opposite signals by the input transformer T1. One out of these two signals is applied to the base of the upper transistor while the other one is applied to the base of the other transistor. When transistor Q1 is driven to the positive side using the positive half of its input signal, the reverse happens in the transistor Q2. That means when the collector current of Q1 is going in the increasing direction, the collector current of Q2 goes in the decreasing direction. Anyway the current flow through the respective halves of the primary of the T2 will be in same direction. This current flow through the T2 primary results in a wave form induced across its secondary. The wave form induced across the secondary is similar to the original input signal but amplified in terms of magnitude.

2.17.2 Calculation of efficiency

Input Power (P_{dc})

The power supplied to the load by an amplifier is drawn from the power supply that provides the input or dc power. The amount of this input power can be calculated using

$$P_i(dc)=V_{CC}I_{dc}$$

Where I_{dc} is the average or dc current drawn from the power supplies. In class B operation, the current drawn from a single power supply has the form of a full-wave rectified signal, while that drawn from two power supplies has the form of a half-wave rectified signal from each supply. In either case, the value of the average current drawn can be expressed as

$$I_{dc}=\frac{2}{\pi}I(p)$$

here $I(p)$ is the peak value of the output current waveform. Using Eq. (15.18) in the power input equation results in

$$P_i(dc)=V_{CC}(\frac{2}{\pi}I(p))$$

Output (AC) Power

The power delivered to the load (usually referred to as a resistance, R_L) can be calculated using anyone of a number of equations. If one is using an rms meter to measure the voltage across the load, the output power can be calculated as

$$P_o(ac)=\frac{v_L^2\ (rms)}{RL}$$

If one is using an oscilloscope, the peak, or peak-to-peak, output voltage measured can be used:

$$P_o(ac)=\frac{v_L^2\ (p-p)}{8R_L}=\frac{v_L^2\ (p)}{2R_L}$$

The larger the rms or peak output voltage, the larger the power delivered to the load

Efficiency

The efficiency of the class B amplifier can be calculated using the basic equation:

$\%\eta = \frac{P_O\ (ac)}{P_O\ (dc)} x100\%$

$\%\eta = \frac{P_O\ (ac)}{P_O\ (dc)} x100\% = \frac{\frac{V_L^2\ (p)}{2R_L}}{[VCC(\frac{2}{\pi}I(p))]}\ X100 \quad = \frac{\pi\, V_L}{4V_{CC}} X100\%$

when $V_L(p) = V_{CC}$, this maximum efficiency then being

Maximum efficiency= $\frac{\pi}{4} X100\%$ =78.5%

2.18 Complementary symmetry push pull amplifier

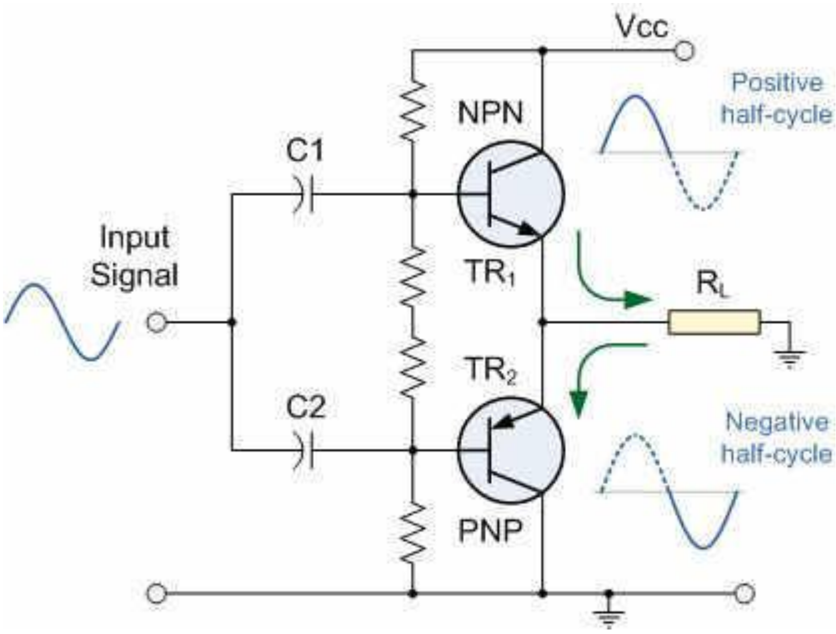


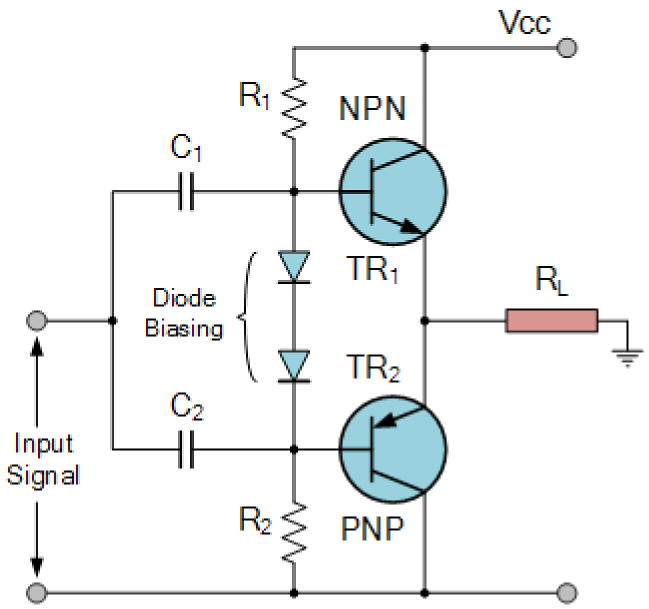
Fig 2.17 Complementary symmetry push pull amplifier

The Class B amplifier circuit above uses complimentary transistors for each half of the waveform and while Class B amplifiers have a much high gain than the Class A types, one of the main disadvantages of class B type push-pull amplifiers is that they suffer from an effect known commonly as Crossover Distortion.In a pure class B amplifier, the output transistors are not “pre-biased” to an “ON” state of operation.This means that the part of the output waveform which falls below this 0.7 volt window will not be reproduced accurately as the transition between the two transistors (when they are switching over from one transistor to the other), the transistors do not stop or start conducting exactly at the zero crossover point even if they are specially matched pairs.The output transistors for each half of the waveform (positive and negative) will each have a 0.7 volt area in which they are not conducting. The result is that both transistors are turned “OFF” at exactly the same time.

A simple way to eliminate crossover distortion in a Class B amplifier is to add two small voltage sources to the circuit to bias both the transistors at a point slightly above their cut-off point. This then would give us what is commonly called an Class AB Amplifier circuit. However, it is impractical to add additional voltage sources to the amplifier circuit so PN-junctions are used to provide the additional bias in the form of silicon diodes.

2.19 Class AB Amplifier

The base-emitter voltage to be greater than 0.7v is needed for a silicon bipolar transistor to start conducting, so if we were to replace the two voltage divider biasing resistors connected to the base terminals of the transistors with two silicon Diodes, the biasing voltage applied to the transistors would now be equal to the forward voltage drop of the diode. These two diodes are generally called Biasing Diodes or Compensating Diodes and are chosen to match the characteristics of the matching transistors. The circuit below shows diode biasing.

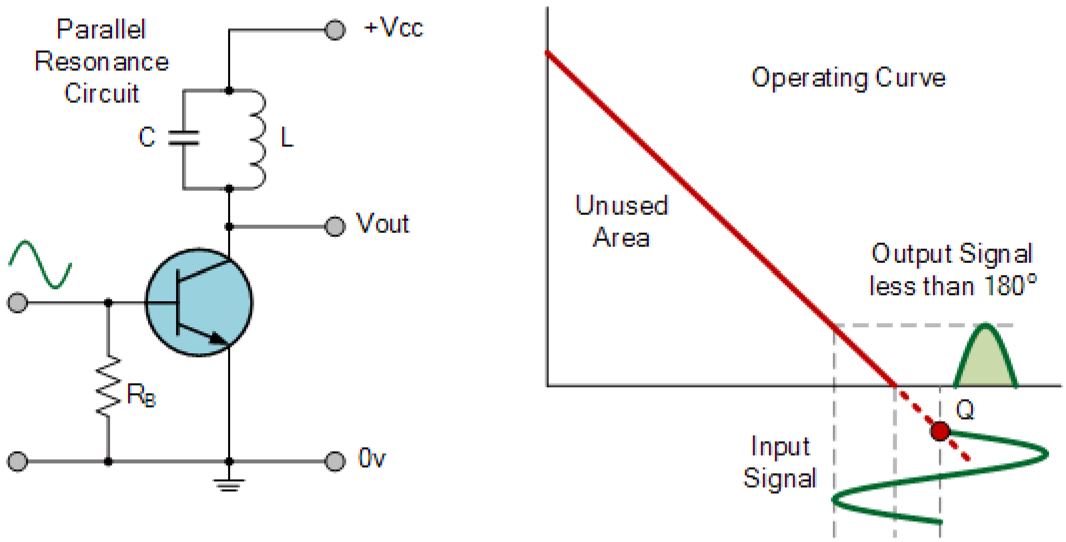


The Class AB Amplifier circuit is a compromise between the Class A and the Class B configurations. This very small diode biasing voltage causes both transistors to slightly conduct even when no input signal is present. An input signal waveform will cause the transistors to operate as normal in their active region thereby eliminating any crossover distortion present in pure Class B amplifier designs.

A small collector current will flow when there is no input signal but it is much less than that for the Class A amplifier configuration. This means then that the transistor will be "ON" for more than half a cycle of the waveform but much less than a full cycle giving a conduction angle of between 180 to 360^{o} or 50 to 100% of the input signal depending upon the amount of additional biasing used. The amount of diode biasing voltage present at the base terminal of the transistor can be increased in multiples by adding additional diodes in series.

2.20 Class C amplifier

The **Class C Amplifier** design has the greatest efficiency but the poorest linearity of the classes of amplifiers mentioned However, the class C amplifier as shown in fig is heavily biased so that the output current is zero for more than one half of an input sinusoidal signal cycle with the transistor idling at its cut-off point. In other words, the conduction angle for the transistor is significantly less than 180 degrees, and is generally around the 90 degrees area.While this form of transistor biasing gives a much improved efficiency of around 80% to the amplifier, it introduces a very heavy distortion of the output signal. Therefore, class C amplifiers are not suitable for use as audio amplifiers.



Due to its heavy audio distortion, class C amplifiers are commonly used in high frequency sine wave oscillators and certain types of radio frequency amplifiers, where the pulses of current produced at the amplifiers output can be converted to complete sine waves of a particular frequency by the use of LC resonant circuits in its collector circuit.

2.21 Multistage amplifier

The voltage gain of single-stage amplifier is insufficient for many applications; hence several stages may be combined forming a multistage amplifier. These stages are connected in cascade as shown in Fig 2.17.

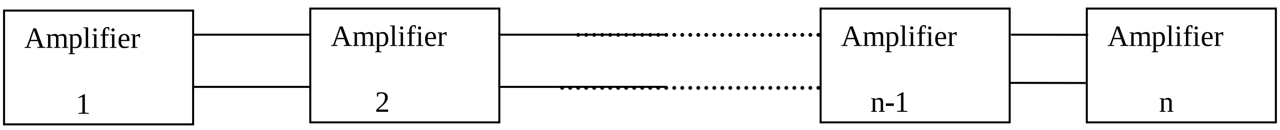


Fig 2.17. Multistage amplifier

The output of the first stage is connected to input of second stage, whose output becomes input of third stage, and so on. The overall gain of a multistage amplifier(A) is the product of the gains of the individual stages(A_1,A_2...An).

Gain (A) = $A_1 \times A_2 \times A_3 \times A_4 \times \ldots \times A_n$.

If the gain of each amplifier stage is expressed in decibels (dB), the total gain is the *sum* of the gains of the individual stages:

Gain in dB (A) = $A_1 + A_2 + A_3 + A_4 + \ldots A_n$

Unit 3: OP-amp and applications **10 Hours**

Basic differential amplifier: Working principle. **Op-amp:** Block diagram, ideal and practical characteristics. **Op-amp parameters:** Input offset voltage, input offset current, power supply rejection ratio, CMRR, input and output impedance, gain, gain-bandwidth product, slew-rate. **Open-loop configuration:** comparator, disadvantages of open-loop mode. **Closed-loop configuration:** virtual ground, applications - inverting, non-inverting, voltage follower, summing & difference amplifiers, differentiator, integrator, Schmitt trigger, and concept of precision rectifier. Simple problems.

Differential Amplifier

A differential amplifier is a type of electronic amplifier that amplifies the difference of two input voltages. It is an analog circuit with two inputs and one output. The output is directly proportional to the difference between two voltages. It is the building block of analog integrated circuits and operational amplifiers (opamp).

3.1 Working principle of a Differential Amplifier

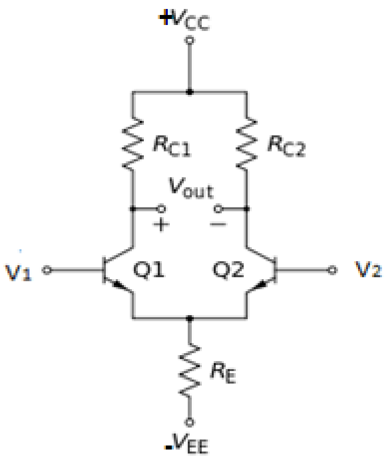


Fig 3.1 Basic Differential Amplifier

The simplest form of differential amplifier can be constructed using Bipolar Junction Transistors as shown in the circuit diagram. It is constructed using two matching transistors in common emitter configuration whose emitters are tied together. The Fig.3.1 shows the generalized form of a differential amplifier with two inputs V1 and V2. The two identical transistors Q1 and Q2 are biased at the same operating point with their emitters connected together. The circuit operates from a dual supply +Vcc and $-V_{EE}$ which ensures a constant supply.

The output of the amplifier Vout is the difference between the two input signals. As the two inputs are in anti-phase, the forward bias of transistor Q1 is increased and the forward bias of transistor Q2 is decreased and vice versa. If the two transistors are perfectly matched, the current flowing through the common emitter resistor R_E, will remain constant.

Since the collector voltage either swings in opposite direction or in the same direction. Like the input signal, the output signal is also perfectly balanced to obtain the zero difference between the two collector voltages. This is known as the common mode of operation with the common mode gain of the amplifier being the output gain when the input is zero.

3.2 Op-Amp

An operational amplifier is popularly known as op-amp is basically a high gain differential amplifier which amplifies both AC and DC signals. Mathematical operations like addition, subtraction, multiplication, integration and differentiation can be done with the help of op-amp, hence the name operational amplifier.

Fig 3.2. Block Diagram of Opamp

Fig 3.2 shows the block diagram of an op-amp with a differential input and single ended output. It has four stages.

Input stage :-

The input stage is a dual-input, balanced output differential amplifier. The two inputs are inverting and non-inverting input terminals. This stage provides maximum voltage gain of the opamp and decides the input resistance value.

Intermediate stage :-

This stage consists of another differential amplifier. It is driven by the output of the input stage. This stage is a dual-input unbalanced output (single ended output) differential amplifier.

Level shifting stage:-

Due to the direct coupling between the first two stages, the input of level shifting stage is an amplified signal with some non-zero dc level. Level shifting stage is used to bring this dc level to zero volts with respect to ground.

Output Stage :-

This stage is normally a complementary output stage. It increases the magnitude of the voltage and raises the current supplying capability of opamp. It also provides a low output resistance.

3.2.1 Opamp parameters

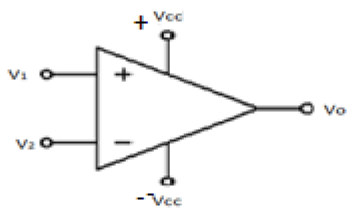


Fig: 3.3 Symbol of an opamp

The opamp parameters include

1. Input Offset Voltage

Input offset voltage is the voltage that is applied between the two input terminals of the op-amp to make output voltage zero.

2. Input Offset Current

Input Offset Current is the algebraic difference between the currents into the inverting and non-inverting terminals.

3. Input impedance

Input impedance of the operational amplifier is defined as the impedance between its two inputs. The input impedance is very high around 2MΩ.

4. Output impedance

Output impedance is the equivalent resistance that is measured between the output terminal and ground. The opamp has low output impedance of 75Ω.

5. Common Mode Rejection Ratio (CMRR)

CMRR is the ratio of the differential voltage gain to the common mode voltage gain. If the value of CMRR is high, there is better matching between the 2 input terminals.

6. Power Supply Rejection Ratio (PSRR)

The change in the op-amp's offset voltage caused by variations in supply voltage is called PSRR The lower the value of PSRR, the better will be the op-amp performance.

7. Slew Rate

Slew Rate is one of the most important parameters for selecting op-amps for high frequencies. Slew Rate is the maximum rate of change of output voltage per unit of time and is expressed in volts per microseconds.

8. Open Loop Gain

Open loop gain is the ratio of single ended output to the differential input. The open-loop gain of an amplifier is the gain obtained when no feedback is used in the circuit amplifiers .An *ideal* operational amplifier has infinite open-loop gain. Typically an op-amp may have a maximum open-loop gain of around 10^5 .

9. Closed loop Gain

Closed loop gain is the gain that results when feedback is applied to control the open loop gain.

10. Bandwidth

Bandwidth of an opamp is the range of frequencies over which gain of the amplifier is constant. The bandwidth is as high as 1MHz.

11. Gain Bandwidth

The gain–bandwidth for an amplifier is the product of the amplifier's bandwidth and the gain at which the bandwidth is measured.

3.3 Ideal Opamp Characteristics:

. In real, an ideal op amp does not exist. However, it is possible to construct an efficient opamp with better output in real-world conditions. An ideal op-amp has the following characteristics.

Infinite open-loop gain

Infinite input impedance

Zero input offset voltage

Infinite output voltage range

Infinite bandwidth with zero phase shifts

Infinite slew rate

Zero output impedance

Zero noise

Infinite common-mode rejection ratio (CMRR)

Infinite power supply rejection ratio.(PSSR)

3.3.1 Practical Opamp Characteristics:

The various characteristics of a practical op-amp can be described as below

Open loop gain : It is the voltage gain of the op-amp when no feedback is connected, it is several thousand ohms.

Input impedance: It is finite and typically greater than 1 MΩ.

Output impedance: It is typically few hundred ohms. With the help of negative feedback, it can be reduced to a very small value like 1 or 2 ohms.

Bandwidth: The bandwidth of practical op-amp in open loop configuration is very small. By application of negative feedback, it can be increased to a desired value.

Input offset voltage: It is the voltage that must be applied between the two input terminals of an opamp to null the output. It is about 6mV DC

Input bias current: It is the average of the currents that flow into the inverting and non inverting input terminals of the amplifier.

3.4 Open Loop configurations

Operational amplifiers can have either a closed-loop operation or an open-loop operation. An op-amp functions as a high gain amplifier when connected in open loop configuration. This open-loop operation is practical only when the operational amplifier is used as a comparator.

3.4.1 Comparator

A comparator is a device that compares two voltages or currents and outputs a digital signal indicating which is larger. It has two analog input terminals V_{in} and V_{ref} and one output V_o.

$$Vo = \begin{cases} 1, & if \quad V_{in} > V_{ref} \\ 0, & if \quad V_{in} < V_{ref} \end{cases}$$

A comparator consists of a specialized high-gain differential amplifier and comparator is basically a 1-bit analog-to-digital converter.

Application: They are commonly used in devices that measure and digitize analog signals, such as analog-to-digital converters (ADCs), as well as relaxation oscillators.

Non-inverting comparator

The basic non inverting comparator circuit is an op-amp arranged in the open-loop configuration as shown on the circuit of Figure 3.4.

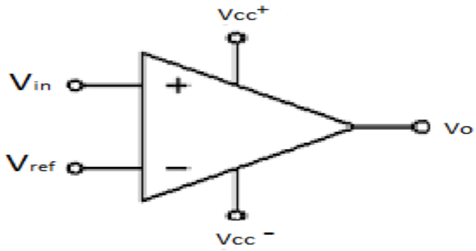
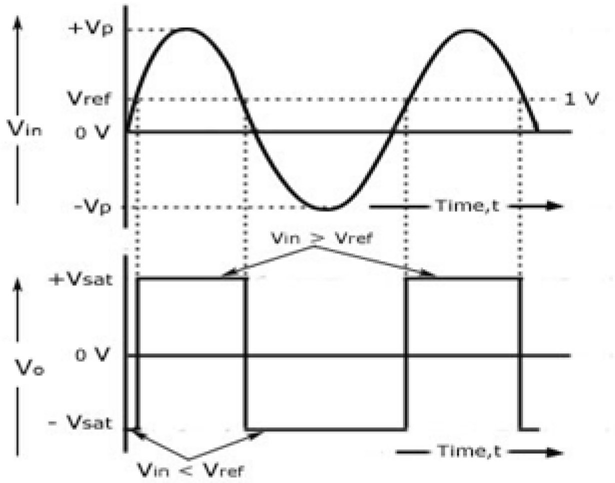


Fig 3.4:Basic non inverting comparator

In non inverting comparator, the reference voltage is applied to the inverting input and the voltage to be compared is applied to the non inverting input. Whenever the voltage Vin to be compared goes above the reference voltage, the output of the opamp swings to positive saturation and vice versa. The difference between V_{in} and V_{ref}, (V_{in} –V_{ref}) will be a positive value and is amplified to infinity by the opamp. Since there is no feedback resistor the opamp is in open loop configuration and so the voltage gain will be close to infinity. When the V_{in} goes below V_{ref}, the reverse occurs. Fig 3.5 shows the input and output waveforms of a non inverting comparator



Fig,3.5 The input and output waveforms of non inverting comparator

Inverting comparator

In the case of an inverting comparator, the reference voltage is applied to the non inverting input and voltage to be compared is applied to the inverting input as shown in Fig 3.6.Whenever the input voltage $V_{in,}$ goes above the V_{ref}, the output of the opamp swings to negative saturation. Here the difference between two voltages (V_{in}-V_{ref}) is inverted and amplified to infinity by the opamp. Since there is no feedback resistor, the gain will be close to infinity and the output voltage will be as negative as possible. Fig,3.7 shows the input and output waveforms of an inverting comparator

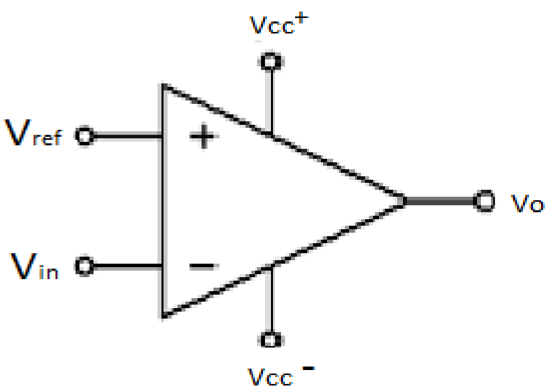


Fig 3.6: Inverting Comparator

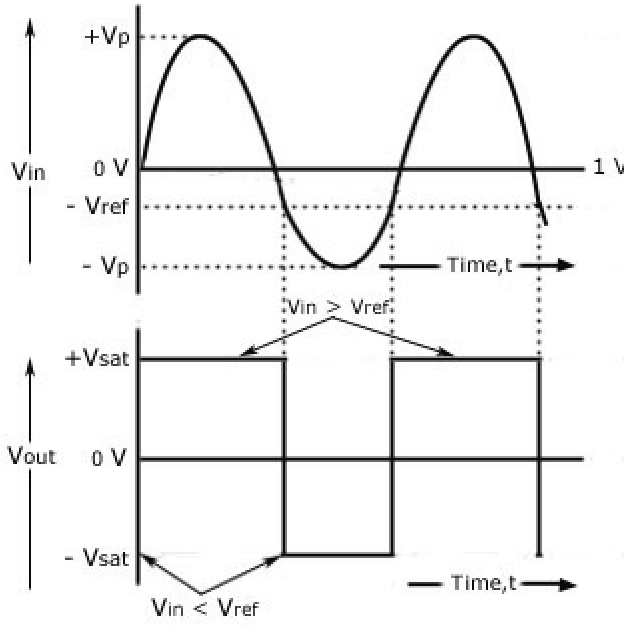


Fig 3.7 Input and output waveforms of an inverting comparator

Disadvantage of open loop mode/configuration

As opamp is a high gain device, the noise voltage can also be amplified to large extent. Since the feedback is not used (normally negative), the output of open loop configuration is always saturated. Such types of configuration cannot be used in real time application

3.5 Closed Loop Configuration

In closed loop configuration, the output is determined by the feedback that is used. Closed-loop configuration has many advantages over open-loop configurations. The primary advantage of a closed-loop mode is its ability to reduce a system's sensitivity to external disturbances. This mode is preferred due to the following advantages.

To reduce errors by adjusting the systems input.

To improve stability of an unstable system.

To enhance robustness.

To produce a reliable performance.

3.5.1 Virtual Ground

The non-inverting input of the operational amplifier is grounded; therefore, its inverting input, although not connected to ground, will assume a similar potential, becoming a virtual ground. It's the summing junction and of the opamp is in a linear mode of operation then the sum of the currents into and out of this node is zero.

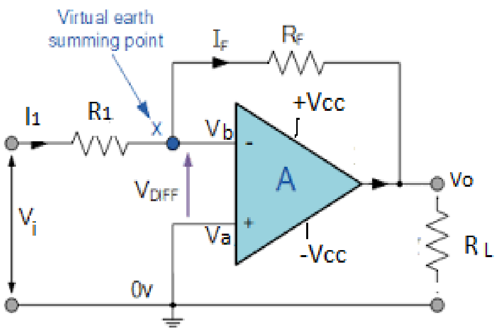


Fig 3.8 Inverting amplifier with a virtual ground concept

In Fig 3.8, the non inverting terminal is grounded and the input signal is applied to the inverting terminal through resistor $R_{1.}$ Here, the differential input voltage is ideally zero. The inverting terminal voltage V_b is approximately at ground potential .Hence the inverting terminal is said to be at virtual ground. By using the virtual ground concept, $I_1 = I_f$ and $V_a = V_b = 0$

3.6 Applications of closed loop configuration:

Operational amplifiers can be used in a wide variety of circuit configurations. One of the most widely used is the inverting amplifier configuration.

3.6.1 Inverting Amplifier

The circuit is called an inverting amplifier because its voltage gain is negative The basic circuit for the inverting op amp circuit is shown in Fig 3.9. It consists of a resistor R_1 and feedback resistor R_F .The non-inverting input is connected to ground.

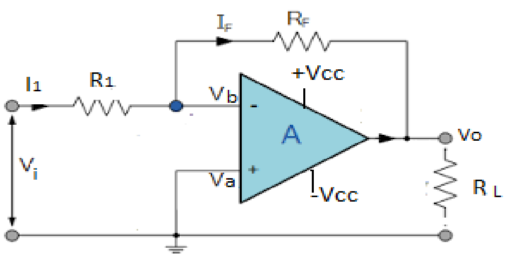


Fig 3.9 Inverting amplifier

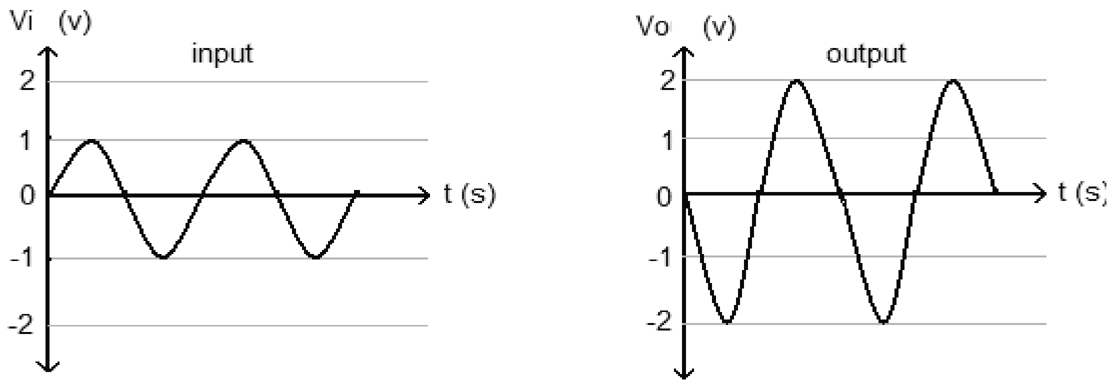


Fig 3.10 The input and output wave forms of an inverting amplifier with gain assumed to be 2.

As the input to the op-amp itself draws no current virtually, this means that the current flowing in the resistors R_1 and R_F is the same.

By using the virtual ground concept, $I_1 \approx I_f$

i.e , $\frac{Vi-Vb}{R_1} = \frac{Vb-Vo}{R_F}$

However, $V_a = V_b = 0$ volts

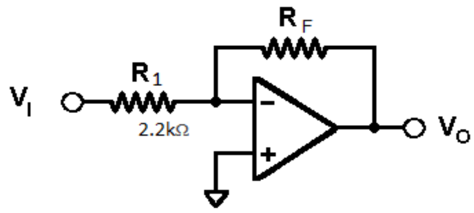
Therefore, $\frac{Vi}{R_1} = \frac{-Vo}{R_F}$

Then the closed loop voltage gain , $A_F = \frac{V_0}{V_i} = \frac{-R_F}{R_1}$; output is 180^0 out of phase

Application: It is used in integrator, summer, differentiator , phase shift and analog computation.

Solved Problems

1) Given the opamp configuration in the circuit, determine the value of R_F required to produce a closed loop voltage gain of -100

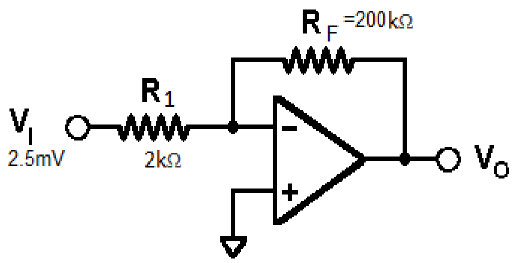


w.k.t $A_F = \frac{-R_F}{R_1}$

$-100 = -\frac{R_F}{2200}$

$R_F = 100 \times 2200 = \mathbf{220k\Omega}$

2) Determine the output voltage for the circuit shown below



$A_F = -\frac{R_F}{R_1}$

$A_F = -\frac{200k\Omega}{2k\Omega} = -100$

$V_o = A_F \times V_i = (-100) \times (2.5mV) = -250mV = -0.25V$

Therefore, $\mathbf{V_o = 0.25V}$

3.6.2 Non Inverting Amplifier

A non-inverting amplifier is an op-amp circuit configuration which produces an amplified output signal and is in-phase with the input signal applied. The non inverting amplifier produces an output which is in phase with the input.

Fig 3.12 shows the input and output wave forms of a non inverting amplifier with gain=2

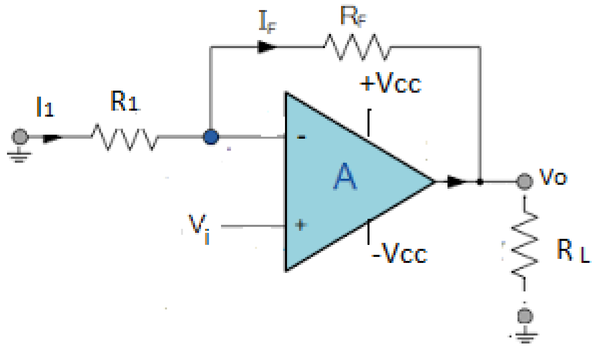


Fig3.11: Non-inverting amplifier

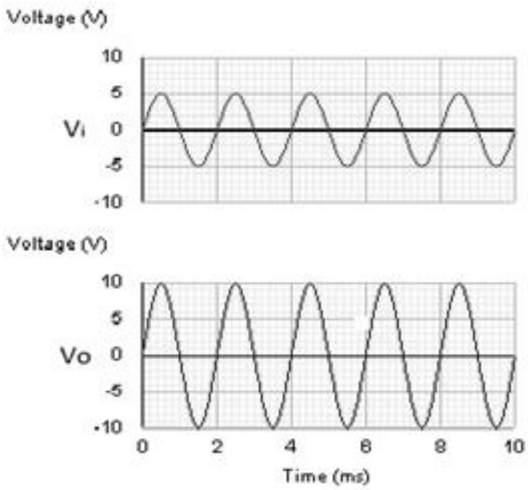


Fig 3.12 Input and output wave forms of a non inverting amplifier

It is seen that in the Fig 3.11 , I_1-I_f =0

Therefore,

$$\frac{V_o - V_i}{R_F} - \frac{V_i}{R_1} = 0$$

$$\frac{V_o - V_i}{R_F} = \frac{V_i}{R_1}$$

$$\frac{V_o}{R_F} = \frac{V_i}{R_F} + \frac{V_i}{R_1}$$

$$\frac{V_o}{R_F} = V_i\left(\frac{1}{R_F} + \frac{1}{R_1}\right)$$

$$\frac{V_o}{V_i} = R_F\left(\frac{1}{R_F} + \frac{1}{R_1}\right)$$

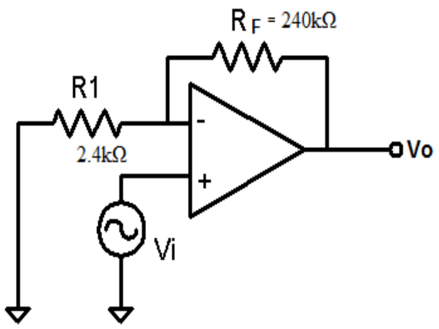
$$\frac{V_o}{V_i} = \left(1 + \frac{R_F}{R_1}\right)$$

Therefore the gain of the non inverting amplifier is $A_F = \left(1 + \frac{R_F}{R_1}\right)$

Application: The high input impedance and low output impedance of the non-inverting amplifier makes the circuit ideal for impedance buffering applications.

Solved Problems

1) Calculate the output voltage from the non inverting amplifier circuit shown in below figure for an input of 120µV.



Voltage gain is given by,

$A_F = \left(1 + \frac{R_F}{R_1}\right) = 1 + \frac{240k\Omega}{2.4k\Omega}$

A_F =101

Output voltage is given by

$V_o = A_F \times V_i = 101 \times 120\,\mu V$

V_o = 12.12mV

3.6.3 Voltage Follower

A voltage follower (also called a unity-gain amplifier, a buffer amplifier, and an isolation amplifier) is a op-amp circuit which has a voltage gain of 1. Figure 3.13 shows the circuit diagram of a voltage follower, in which the output voltage is fed back to the inverting terminal of opamp. When the non-inverting amplifier is configured for unity gain, it is called a voltage follower because the output voltage is equal to and in phase with the input. In other words, in the voltage follower the output follows the input.

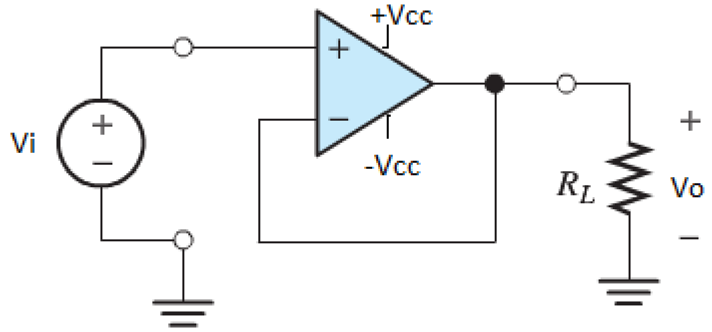


Fig 3.13 voltage follower

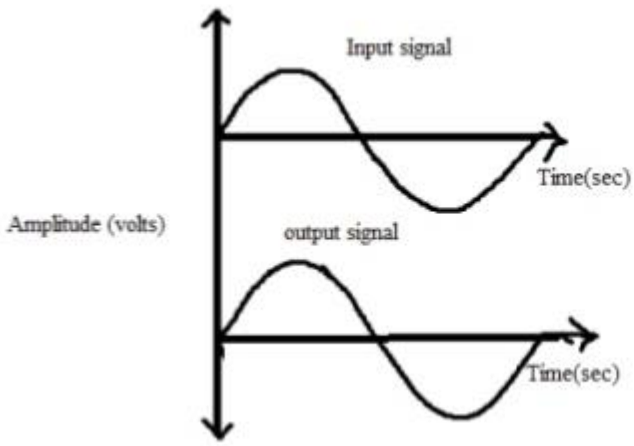


Fig 3.14: Input and output wave forms of a voltage follower

Voltage follower is a special case of a non-inverting amplifier. The gain A_F is given by

$$A_F = \frac{V_o}{V_i} = \left(1 + \frac{R_F}{R_1}\right)$$

When R_F=0,the closed loop voltage gain of the voltage follower is 1. Fig 3.14 shows the input and output wave forms of a voltage follower with unity gain The most important feature of voltage follower is its very high input impedance and very low output impedance.

Application: A voltage follower acts as a buffer, providing no amplification or attenuation to the signal.

3.6.4 Adder/Summing Amplifier

A summing amplifier is an amplifier that can accept two or more inputs. A direct voltage addition can be obtained when all the resistances are of equal value .

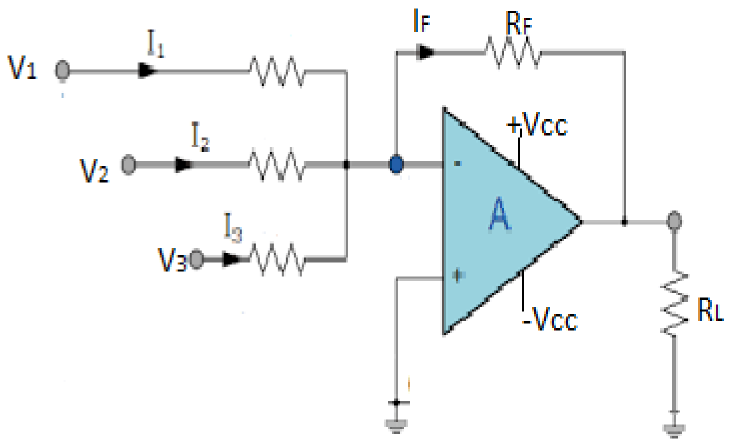


Fig 3.15 Summing Amplifier

Fig.3.15 shows the summer with three inputs V_1,V_2 and V_3 .Here $I_1+I_2+I_3=I_F$

Therefore,

$$\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}=-\frac{V_0}{R_F}$$

$$V_o=-\left(\frac{R_F}{R_1}V_1+\frac{R_F}{R_2}V_2+\frac{R_F}{R_3}V_3\right)$$

If $R_1=R_2=R_3=R_F=R$ then the above equation can be written as

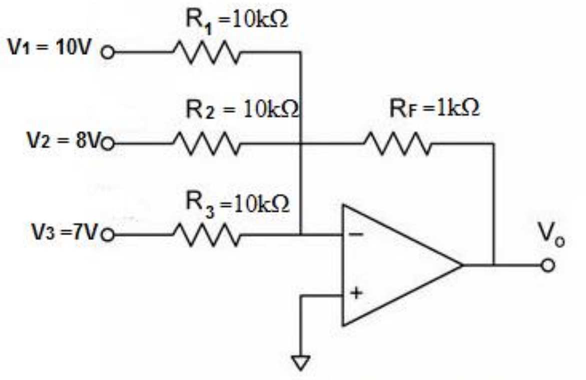
$$V_o=-(V_1+V_2+V_3)$$

Thus, the output voltage is equal to the negative sum of all input voltages.

Application: It is used in audio mixer to add the waveforms together from various channels before sending the mixed signal to a recorder. It is also used to construct a subtractor, average amplifier etc.

Solved problems

1) Determine the output voltage for the summing amplifier as shown below



$$w.k.t \quad V_o = -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right)$$

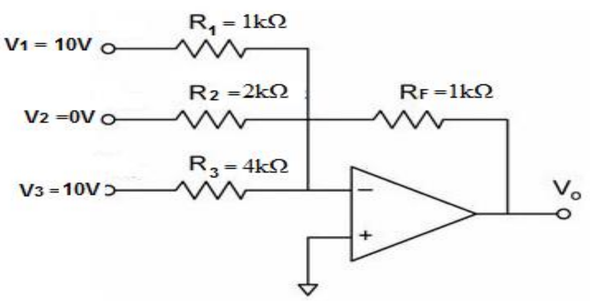
As R_1=R_2=R_3=10kΩ=R and R_F = 1kΩ the above equation gets modified as

$$V_o = -\frac{R_F}{R}(V_1 + V_2 + V_3)$$

$$V_o = -\frac{1k\Omega}{10k\Omega}(10 \ + 8 + 7)$$

$$\boldsymbol{V_o = -2.5\,V}$$

2) Determine the output voltage from the circuit shown below.



$$w.k.t \quad V_o = -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right)$$

Substituting the values the above equation is written as

$$V_o = -\left(\frac{1k\Omega}{1k\Omega} \times 10 + \frac{1k\Omega}{2k\Omega} \times 0 + \frac{1k\Omega}{4k\Omega} \times 10\right)$$

$$V_o = -(10 + 0 + 2.5)$$

$$\boldsymbol{V_o = -12.5\ V}$$

3.6. 5 Subtractor /Difference Amplifier

The Subtractor also called a differential amplifier uses both the inverting and non-inverting inputs to produce an output signal which is the difference between the input voltages. Fig 3.16 shows the circuit of a subtractor. It is also possible to construct a subtractor using adders.

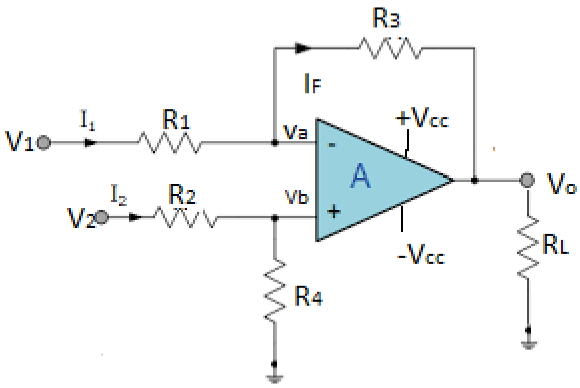


Fig 3.16 Subtractor

Here,

$$I_1 = \frac{V_1 - V_a}{R_1}, \qquad I_2 = \frac{V_2 - V_b}{R_2}$$

$$I_F = \frac{V_a - V_o}{R_3}$$

At Summing point $V_a = V_b$ and $V_b = V_2\left(\frac{R_4}{R_2+R_4}\right)$

If V_2=0, then $\quad V_{o(a)} = -V_1\left(\frac{R_3}{R_1}\right)$

If V_1=0 then $\quad V_{o(b)} = V_2\left(\frac{R_4}{R_2+R_4}\right)\left(\frac{R_1+R_3}{R_3}\right)$

Therefore $V_0 = -V_{o(a)} + V_{o(b)}$

$$V_0 = -V_1\left(\frac{R_3}{R_1}\right) + V_2\left(\frac{R_4}{R_2 + R_4}\right)\left(\frac{R_1 + R_3}{R_3}\right)$$

When resistors, R1 = R2 = R3 = R4=R, the output voltage can be obtained as, $V_0 = V_2 - V_1$

Application: It is possible to detect temperature using subtractor

3.6.6 Differentiator

The differentiator produces an output voltage which is proportional to the differentiation of the input voltage

Fig 3.17 shows the circuit of a differentiator. The input signal to the differentiator is applied to the capacitor. The capacitor blocks any DC content so there is no current flow to the amplifier summing point, X resulting in zero output voltage. At low frequencies the reactance of the capacitor is “High” resulting in a low gain) and low output voltage from the op-amp. At higher frequencies the reactance of the capacitor is much lower resulting in a higher gain and higher output voltage from the differentiator amplifier. Fig 3.18 shows the input and output waveforms of a differentiator

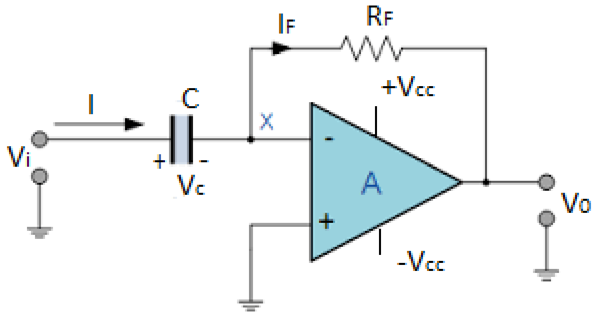


Fig 3.17 Differentiator

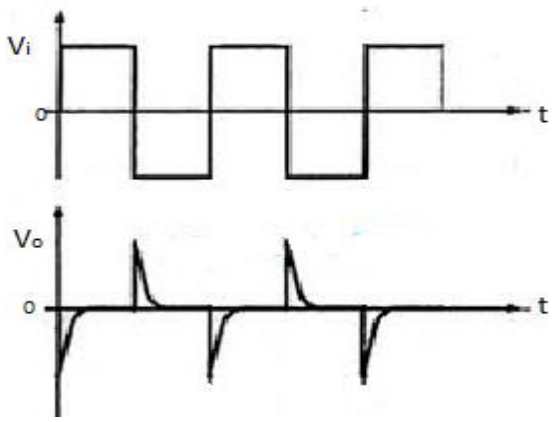


Fig 3.18 Input and output waveforms

The current flowing through the capacitor will be given as:

$$I = I_F \text{ and } I_F = -\frac{V_o}{R_F}$$

The charge on the capacitor is, Q=C x V_i

The rate of change of this charge is:

$$\frac{dQ}{dt} = C\frac{dV_i}{dt}$$

but dQ/dt is the capacitor current

$$I = C\frac{dV_i}{dt} = I_F$$

Replacing I_F by $-\frac{V_o}{R_F}$, we get

$$-\frac{V_o}{R_F} = C\frac{dV_i}{dt}$$

From which an ideal voltage output for the op-amp differentiator is obtained as:

$$V_o = -R_F\, C\, \frac{dV_i}{dt}$$

Application: It is used in wave shaping circuits The differentiator circuit is essentially a high pass filter. It can generate a square wave from a triangle wave input, and will produce alternating-direction voltage spikes when a square wave is applied. Differentiators are an important part of electronic analogue computers and analogue PID controllers.

3.6.7 Integrator

Op-amp integrator produces an output voltage which is proportional to the integral of the input voltage. Fig 3.19 shows the circuit diagram of an integrator and Fig 3.20 shows the input and output waveforms of an integrator

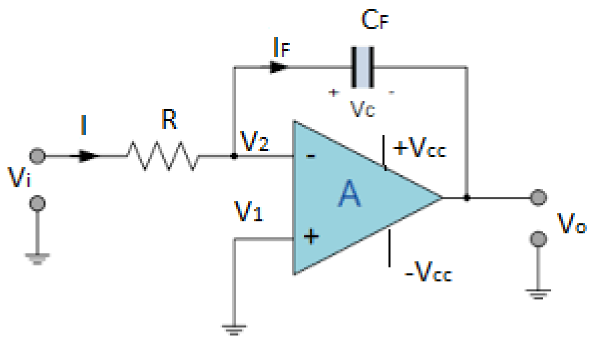


Fig 3.19: Integrator

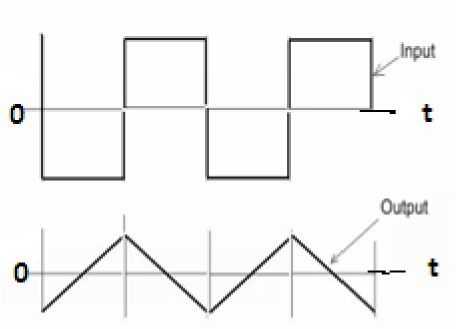


Fig 3.20:Input and output waveforms

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Considering the circuit and assuming the input impedance of the op-amp is infinite (ideal op-amp), no current flows into the opamp terminal. Therefore, the equation at the inverting input terminal is given as: $I = I_F$

Furthermore, the capacitor has a voltage-current relationship governed by the equation:

$$I_c = C\frac{dV_c}{dt}$$

Therefore,

$$\frac{V_i - V_2}{R} = C_F\left(\frac{d}{dt}\right)(V_2 - V_0)$$

In an ideal opamp V_2=V_1 =0 resulting in

$$\frac{V_i}{R} = -C_F\frac{dV_o}{dt}$$

Integrating both the sides with respect to time

$$\int_0^t \frac{V_i}{R}dt = -\int_0^t C_F\frac{dV_o}{dt}\,dt$$

Therefore,

$$V_0 = -\frac{1}{RC_F}\int_0^t V_i\,dt + C$$

Where C is the integration constant.

Application: The integrator circuit is mostly used in analog computers, analog-to-digital converters and wave-shaping circuits.

3.6.8 Schmitt Trigger:

A Schmitt trigger circuit is also called a regenerative comparator circuit. The circuit is designed with a positive feedback and hence will have a regenerative action which will make the output switch levels. Fig 3.20 shows an inverting comparator with a positive feedback which forms the Schmitt trigger.

In a Schmitt trigger, the voltages at which the output switches from $+v_{sat}$ to $-v_{sat}$ or vice versa are called upper trigger point (UTP) and lower trigger point (LTP).

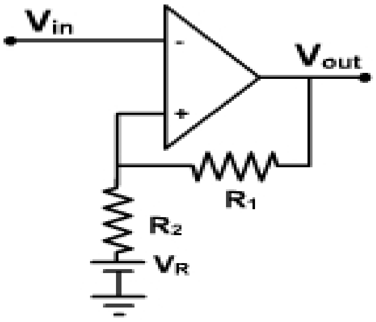


Fig 3.21:Schmitt Trigger

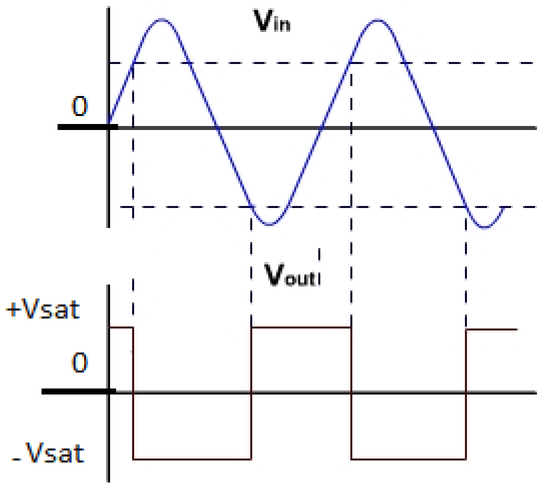


Fig 3.22: Input/output Waveforms

Fig 3.21 shows the Schmitt trigger using op-amp and Fig 3.22 shows the input and output waveforms of Schmitt trigger. Schmitt trigger produces square wave output for any given input wave. Schmitt trigger is also an application of comparator. Input is applied to inverting terminal. Output is feedback to non inverting terminal using R_1 and R_2.

R_1 and R_2 acts like voltage divider

$$V_{R2} = \left(\frac{R2}{R1+R2}\right) Vout$$

When output is in +ve saturation level,

$$V_{R2} = \left(\frac{R2}{R1+R2}\right)(+Vsat) = UTP$$

When o/p is in –ve saturation level

$$V_{R2} = \left(\frac{R2}{R1+R2}\right)(-Vsat) = LTP$$

These voltages are called threshold voltages or trip points. By selecting different values of R_1 and R_2 the threshold points can be changed. The circuit uses closed loop operation. When signal at inverting input terminal is zero, small noise voltage or disturbance will saturate the op-amp and output will be at + Vsat, the feedback voltage is V_{R2} and it is +ve.

When input signal exceeds V_{R2}, net input difference becomes –ve. Output switches to –Vsat, V_{R2} becomes –ve. When input voltage goes to –ve cycle and when it exceed VR2, net input difference becomes +ve. The o/p switches to + Vsat and VR2 become +ve. If input is continuous sine wave, the output will be square wave. Fig 3.23 shows the hysteresis curve of the Schmitt trigger.

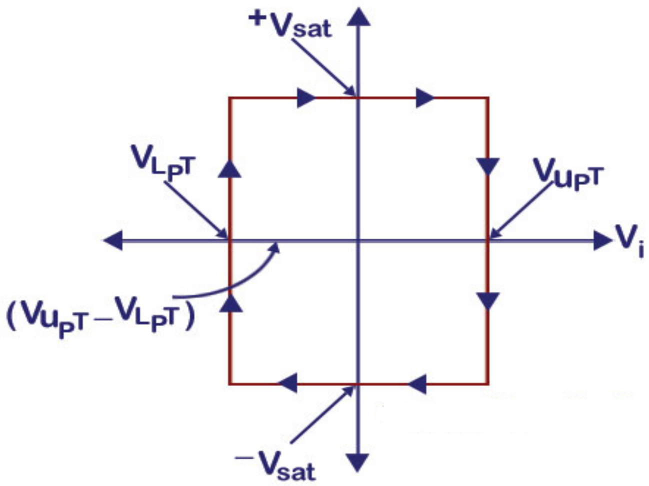


Fig 3.23: Hysteresis Curve

+ve peak of output = + Vsat

–ve peak of output = -Vsat

+ve V_{R2} is called Upper threshold point(UTP)

-ve V_{R2} is called Lower threshold point(LTP)

Applications: A Schmitt trigger is used in most applications where a level needs to be sensed. It is used in digital to analog conversion, level detection and line reception. Schmitt triggers are typically used in open loop configurations for noise immunity and closed loop configurations to implement function generators.

3.6.9 Precision Rectifier

The precision rectifier, also known as a super diode (a half wave precision rectifier) is a configuration obtained with an operational amplifier in order to have a circuit behave like an ideal diode and rectifier.

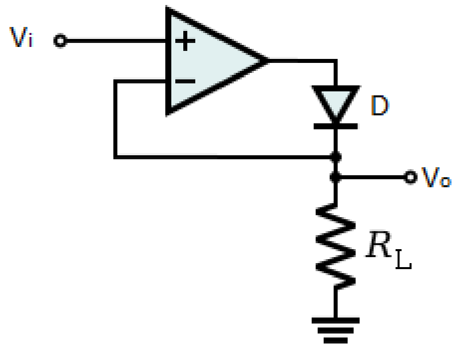


Fig 3.24 Precision Rectifier

The basic circuit implementing such a feature is shown in Fig:3.24. When the input voltage is negative, there is a negative voltage on the diode, so it works like an open circuit, no current flows through the load, and the output voltage is zero. When the input is positive, it is amplified by the operational amplifier which switches the diode on. Current flows through the load and, because of the feedback, the output voltage is equal to the input voltage.

Application :

It is useful for high-precision signal processing.

It is used in audio circuits

For further details refer,

www.circuitstoday.com

https://en.wikipedia.org/wiki

https://electrosome.com

Unit 4: Active filters and instrumentation amplifier 07 Hours

Active filter: Classification, circuits, working, expressions for cut-off frequencies and frequency response of 1st order Butterworth LPF, HPF, BPF and BEF (No Derivation). Problems to design and analyse 1st order Butterworth filters. Realization of BPF and BEF using LPF and HPF. Mention of applications of active filters. Instrumentation amplifier: Need for instrumentation amplifier, working of instrumentation amplifier circuit. Phase Locked Loop (PLL): voltage to frequency converter, PLL operation with mention of its applications.

4.1 **Active filters**

A filter is a frequency selective circuit that passes specific band of frequencies and blocks or attenuates signals of frequencies outside this band. An active filter is a type of analog electronic filter that uses active components such as an amplifier. Amplifiers included in a filter design can be used to improve the performance and predictability of a filter, while avoiding the need for inductors. An active filter makes use of active elements such as transistors, op-amps in addition to resistor and capacitors.

Classification of active filters

- High-pass filter
- Low-Pass filter
- Band-Pass filter
- Band-stop (band-rejection; notch;elimination) filter
- All pass filter

4.1.1 First order low pass Butterworth filter

LPF has constant gain from 0Hz to high cut off frequency f_H . The first order low pass butterworth filter is realised by R-C circuit used along with an op-amp, used in the noninverting configuration. The circuit diagram is shown in Fig. 4.1.

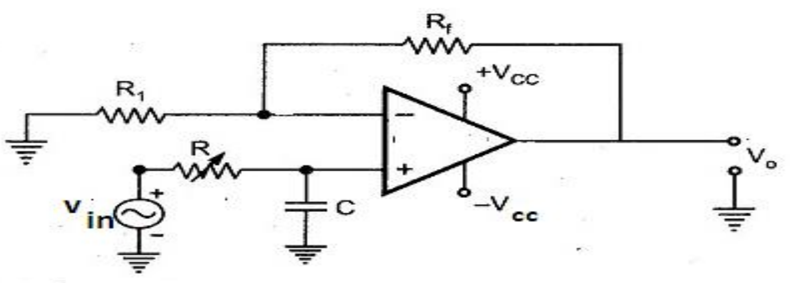


Fig 4.1 First order low pass butterworth filter

The equation below describes the behaviour of the low pass filter.

Magnitude of gain of LPF is $\left|\frac{V_0}{V_i}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}}$

Where $\frac{V_0}{V_{in}}$ the gain of the filter and A_F is is the pass band filter gain $=\left(1+\frac{R_f}{R_1}\right)$

Here f is the frequency of input signal

and f_H is the higher cut off frequency of LPF = $\frac{1}{2\pi RC}$

At very low frequencies $f<f_H$, $\left|\frac{V_0}{V_i}\right| = A_F$

At cut off frequencies $f= f_H$, , $\left|\frac{V_0}{V_i}\right| = \frac{A_F}{\sqrt{2}}$ =0.707A_F

At higher frequenciesf > f_H , $\left|\frac{V_0}{V_i}\right| < A_F$

Thus, for the range of frequencies, $0 < f < f_H$, the gain is almost constant equal to f_H which is higher cut off frequency. At $f = f_H$, gain reduces to 0.707 A_F i.e. 3 dB down from A_F. And as the frequency increases than f_H, the gain decreases at a rate of 20dB/decade. The rate 20 dB/decade means decrease of 20 dB in gain per 10 times change in frequency.The frequency response is shown in the Fig. 4.2. The frequency range 0 to f_H Hz is called pass band and frequency beyond f_H is called stop band.

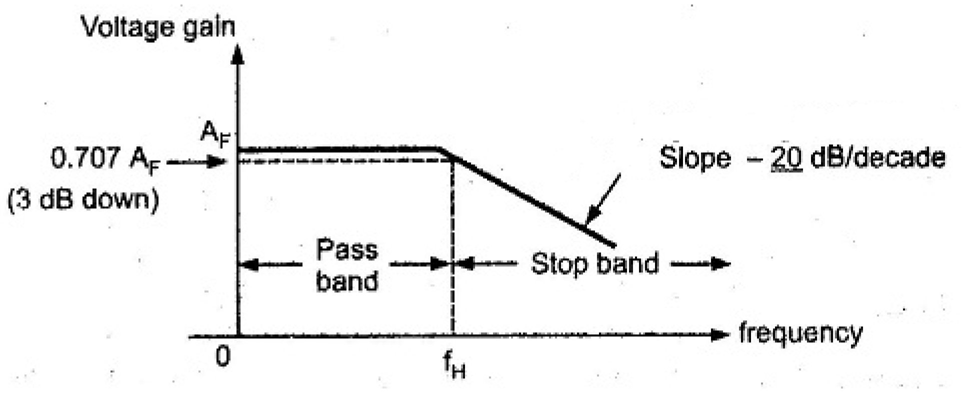


Fig 4.2:Frequency response

Solved Problems

1) Design a low pass filter at a cut-off frequency of 1 kHz with a pass band gain of 2.

Solution:

Given f_H = 1 kHz. Let C = 0.01 μF.

w.k.t cut off frequency $f_H = \frac{1}{2\pi RC}$

Therefore, R can be obtained as

$$R= \frac{1}{2\pi\, f_H C}$$

$$\text{Therefore, } R = \frac{1}{2\pi\times 1\times 10^{3}\ \times 0.01\times 10^{-6}}$$

R= 15.9 kΩ

Hence, 20 kΩ potentiometer can be used to set the resistance R.

Pass band gain= $A_F = \left(1+\frac{R_f}{R_1}\right)$

Substituting A_F = 2, we get

$$2=\left(1+\frac{R_f}{R_1}\right)$$

Hence , R_1 and R_f must be equal.

Filter can be designed with $R_1 = R_f$ = 10 kΩ

2) Design a non-inverting active low pass filter circuit that has a gain of ten at low frequencies, a high frequency cut-off or corner frequency of 159Hz and an input impedance of 10KΩ.

The voltage gain of a non-inverting operational amplifier is given as:

$$A_F = \left(1+\frac{R_f}{R_1}\right)$$

Assuming R1 = 1kΩ,

value of R_f is

$$R_f = (A_f - 1)R_L$$

$R_f = (10 - 1) \times R_1 = 9 \times 1 \times 10^3 = 9k\Omega$

For a voltage gain of 10, R1 = 1kΩ and R_f = 9kΩ.

The cut-off (fc) is given as 159Hz with an input impedance of 10kΩ

$$f_H = \frac{1}{2\pi RC}$$

Therefore, $C = \frac{1}{2\pi f_H R}$

$$C = \frac{1}{2\pi \times 159 \times 10 \times 10^3} = 100nF$$

4.1.2 First order High-pass butterworth filter

The high pass filter has constant gain from a very high frequency to a low cut off frequency f_L.The first order high pass butterworth filter is realised by R-C circuit used along with an op-amp, used in the non-inverting configuration. The circuit diagram is shown in Fig. 4.3

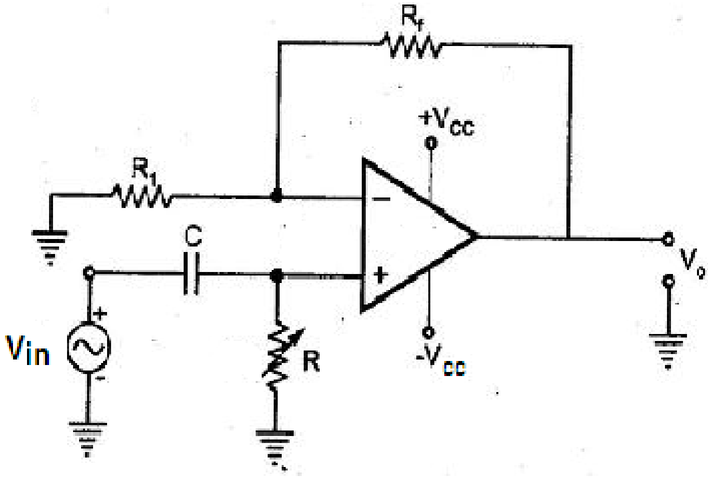


Fig 4.3:First order high pass butterworth filter

Magnitude of gain of HPF is $\left|\frac{V_0}{V_i}\right| = A_F \frac{\left(\frac{f}{f_L}\right)}{\sqrt{1+\left(\frac{f}{f_L}\right)^2}}$

Where $\frac{V_0}{V_{in}}$the gain of the filter and A_F is the pass band filter gain $=\left(1 + \frac{R_f}{R_1}\right)$

Here f is the frequency of input signal

and f_L is the lower cut off frequency of HPF = $\frac{1}{2\pi RC}$

At very low frequencies $f < f_L$, $\left|\frac{V_0}{V_i}\right| < A_F$

At cut off frequencies $f= f_L$, , $\left|\frac{V_0}{V_i}\right| = \frac{A_F}{\sqrt{2}}$ $=0.707A_F$

At higher frequencies $f > f_L$, $\left|\frac{V_0}{V_i}\right| = A_F$

Thus, for the range of frequencies, $0 < f < f_L$, the gain increases at a rate of 20dB/decade. At $f = f_L$, gain is equal to 0.707 A_F i.e. 3 dB down from A_F. As the frequency increases beyond f_L, the gain remains constant as A_F.

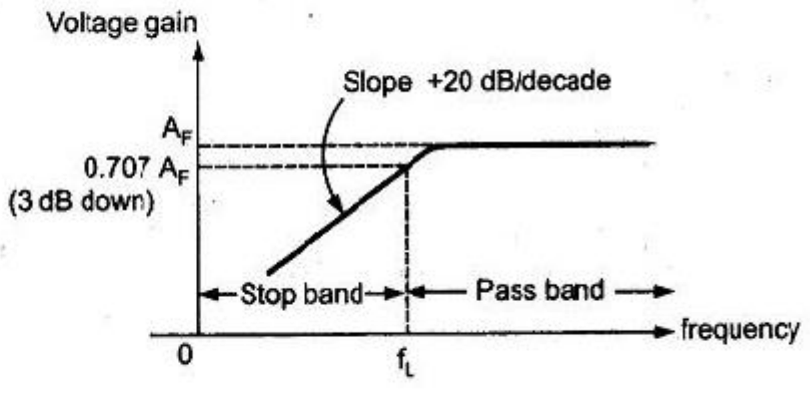


Fig: 4.4: Frequency Response

The frequency response is shown in the Fig. 4.4. The frequency range f_L Hz to ∞ is called pass band and below f_L is called stop band.

Solved Problems

1) A first order active high pass filter has a pass band gain of 2 and a cut-off frequency of 5kHz. If the input capacitor has a value of 10nF. Calculate the value of the resistor and the resistors in the feedback network.

Given, $A_F = 2$, $f_c = 5\text{kHz}$, C=10nF

The cut off frequency for HPF is given by $f_H = \frac{1}{2\pi RC}$

Therefore R= $\frac{1}{2\pi f_H C}$

R= $\frac{1}{2\times\pi\times5\times10^3\times10^{-9}}$

R =3.18k Ω.

$$A_F = \left(1 + \frac{R_f}{R_1}\right)$$

$$2 = \left(1 + \frac{R_f}{R_1}\right)$$

$$\text{Therefore } \frac{R_f}{R_1} = 1$$

Assuming $R_1 = R_f = 10\ k\Omega$.

4.1.3 Band-Pass filter

A band pass filter is a frequency selector circuit. It allows one particular band of frequencies to pass. BPF has a passband between two cut off frequencies f_H and f_L where $f_H > f_L$ and two stopbands at $0 < f < f_L$ and $f > f_H$. The passband which is between f_H and f_L is called Bandwidth.

There are two types of band pass filters classified based on Quality factor (Q)

Wide band pass filter

Narrow band pass filter

Wide Band Pass Filter:

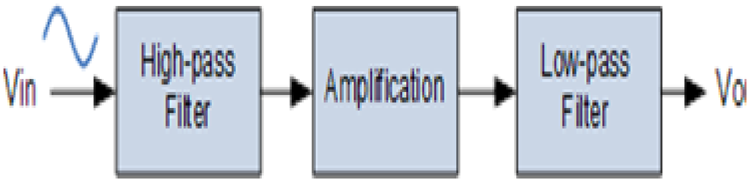


Fig 4.5 Block diagram of Wide Band Pass Filter:

For Q < 10, the band pass band filter is called wide band pass filter .The block diagram of Wide Band Pass Filter is as shown in fig 4.5.Wide Band pass filter is formed by cascading high pass followed by a low pass filter as shown in Fig 4.6.

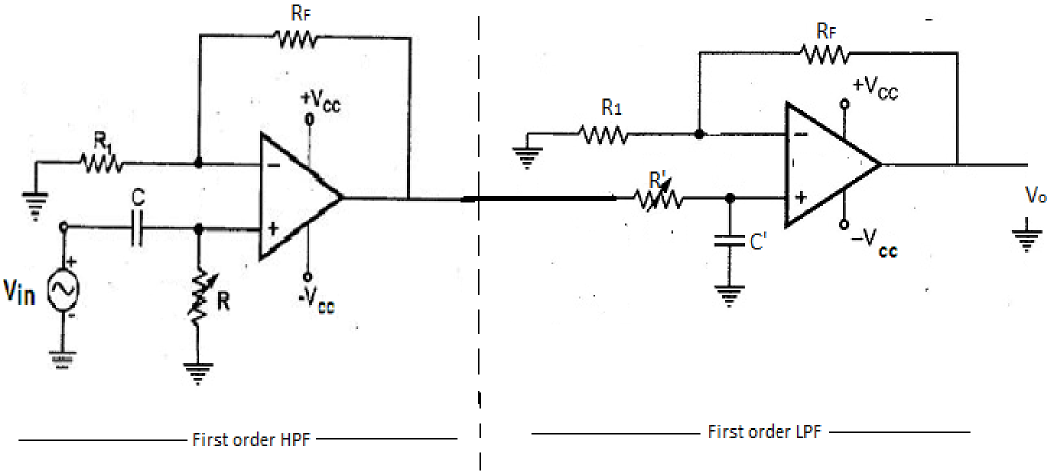


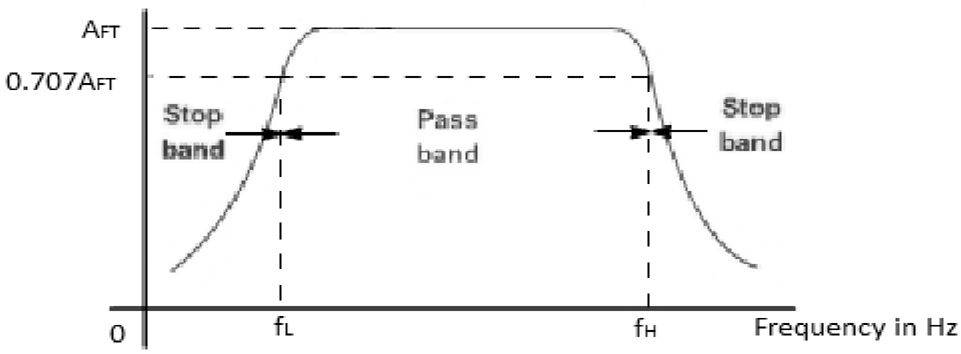
Fig 4.6 Wide Band Pass Filter:

The overall gain of the BPF is the product of the two gains expressed as

$$\left|\frac{V_0}{V_i}\right| = A_{FT}\frac{\left(\frac{f}{f_L}\right)}{\sqrt{\left[1+\left(\frac{f}{f_L}\right)^2\right]\left[1+\left(\frac{f}{f_H}\right)^2\right]}}$$

Where A_{FT} =total pass band gain= A_1A_2 (A_1 is the gain of HPF, A_2 is the gain of LPF) and f_L is lower cut off frequency in Hz $=\frac{1}{2\pi RC}$ and f_H is higher cut off frequency in Hz $=\frac{1}{2\pi R'C'}$

The frequency response of band pass filter is shown in Fig 4.7



Note: This is only Basic Information for students. Please refer "Reference Books" prescribed as per syllabus

Fig 4.7 Frequency response of a Wide Band Pass Filter

Narrow band Pass Filter

For Q > 10 ,the band pass filter is called narrow band pass filter i.e bandwidth of band pass filter is very small. The Fig 4.8 shows the circuit diagram of narrow band pass filter.

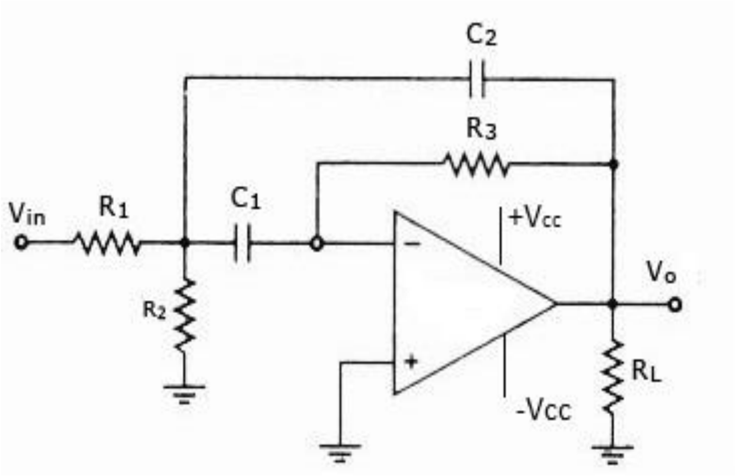


Fig 4.8 Narrow band pass filter

The frequency response of narrow band pass filter is shown Fig 4.9. In this filter the gain peaks at center frequency f_C which is approximately at the centre of bandwidth.

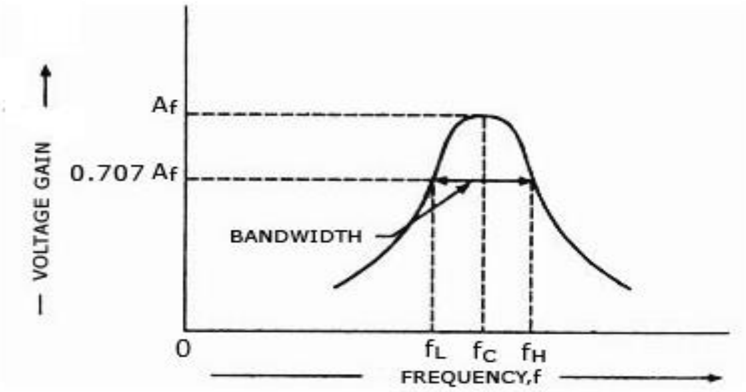


Fig 4.9 Frequency response of narrow band pass filter

4.1.4 Band Elimination Filter

Band elimination filter has a stop band two cut frequencies f_H and f_L and two pass bands at $0 < f < f_L$ and $f > f_H$. The band elimination filter is also called as band stop/band rejection filter.

Band elimination filter is classified as

Wide band reject filter

Narrow band reject filter.

Wide Band Reject Filter

The wide band stop filter can be made using first order low and high pass filters along with a summing op-amp circuit to reject a wide band of frequencies .The Fig 4.10 shows the block diagram of band stop filter and fig 4.11 shows the circuit of wide band stop filter

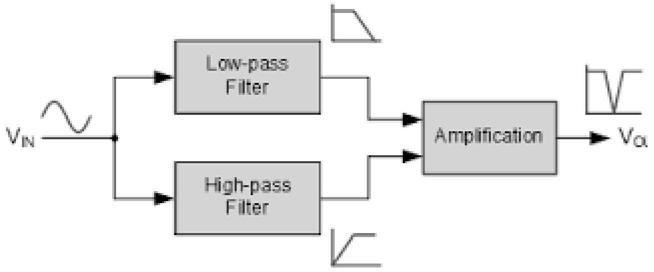


Fig 4.10 Block diagram of band stop filter

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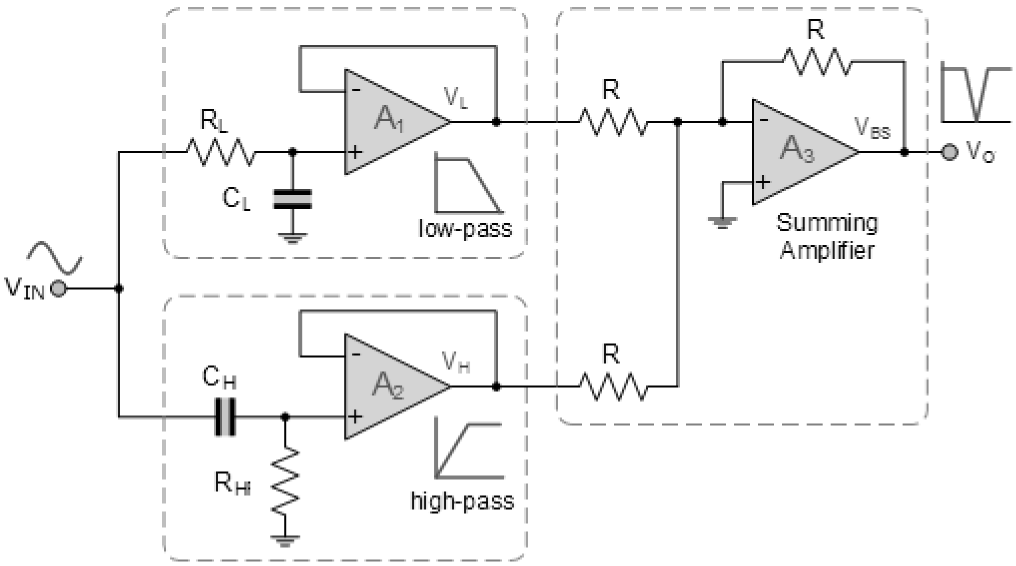


Fig 4.11 Wide band stop filter

For a proper band reject response, the low cut-off frequency f_L of high-pass filter must be larger than the high cut-off frequency f_H of the low-pass filter. In addition, the passband gain of both the high-pass and low-pass sections must be equal

Notch filter

A notch filter is a band-stop filter with a narrow stopband (high Q factor).Because of higher Q the bandwidth of BRF is very small than that of wide BRF. The most widely used notch filter is twin T network as shown in Fig.4.12 and the frequency response of notch filter is shown in the Fig 4.13

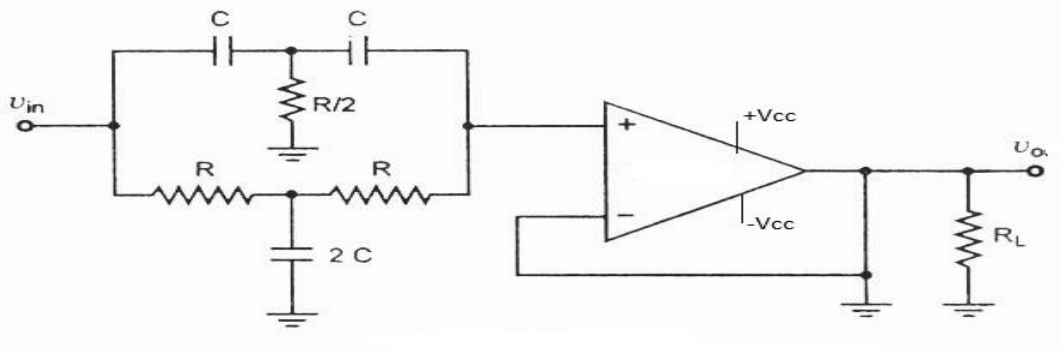


Fig 4.12 Notch filter

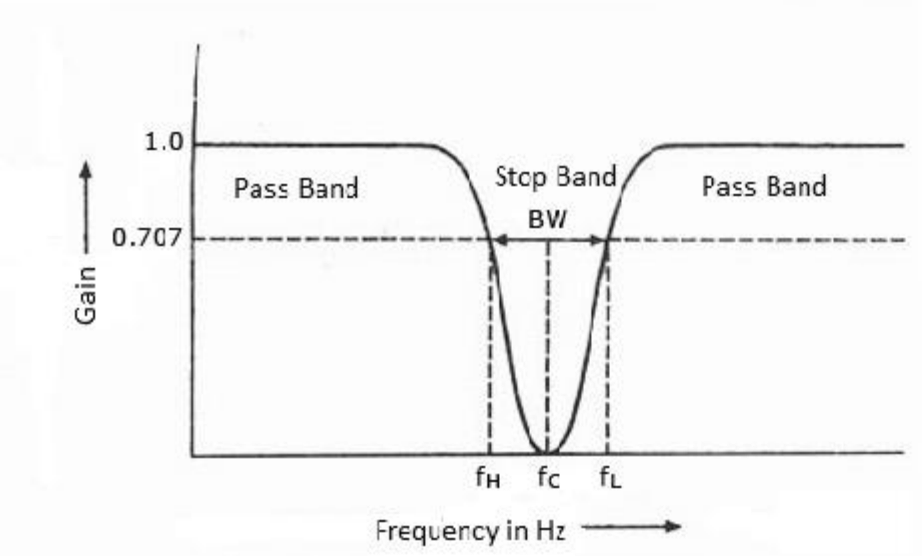


Fig 4.13 Frequency response of notch filter

This filter is commonly used to attenuate single frequency. Narrow band or notch filters are commonly used in biomedical instruments and communications to remove the unwanted frequencies.

Application of Active filters:

1) Used in the field of communication and signal processing.

2) Used in various sophisticated electronic systems such as radio, TV, telephone, radar , space satellites etc.

3) Used to suppress high frequency transients in power supplies

4) Used in medical electronics equipments

5) Used for AC coupling at the input of audio amplifiers.

4.2 Instrumentation Amplifier

An instrumentation amplifier is a differential amplifier optimized for high input impedance and high CMRR.

Need for Instrumentation Amplifier

The industrial and consumer applications require the measurement and control of physical conditions. For example, measurements of temperature and humidity inside a plant to accurately maintain product quality and precise control of the physical quantities .These changes in physical conditions must be converted to electrical quantities using transducers, and then amplified. In such cases, instrumentation amplifiers are required. Most of the transducer outputs are of very low-level signals .therefore before it is connected to the next stage, it is necessary to amplify the level of the signal, rejecting noise and the interference , where general single ended amplifiers are not suitable for such operations. For the rejection of noise, amplifiers must have high common-mode rejection ratio.The instrumentation amplifier has high CMRR, high input impedance which makes it suitable for providing necessary amplification.

4.2.1 Working of Instrumentation Amplifier

The most commonly used instrumentation amplifier uses opamp hence called three opamp instrumentation amplifier.

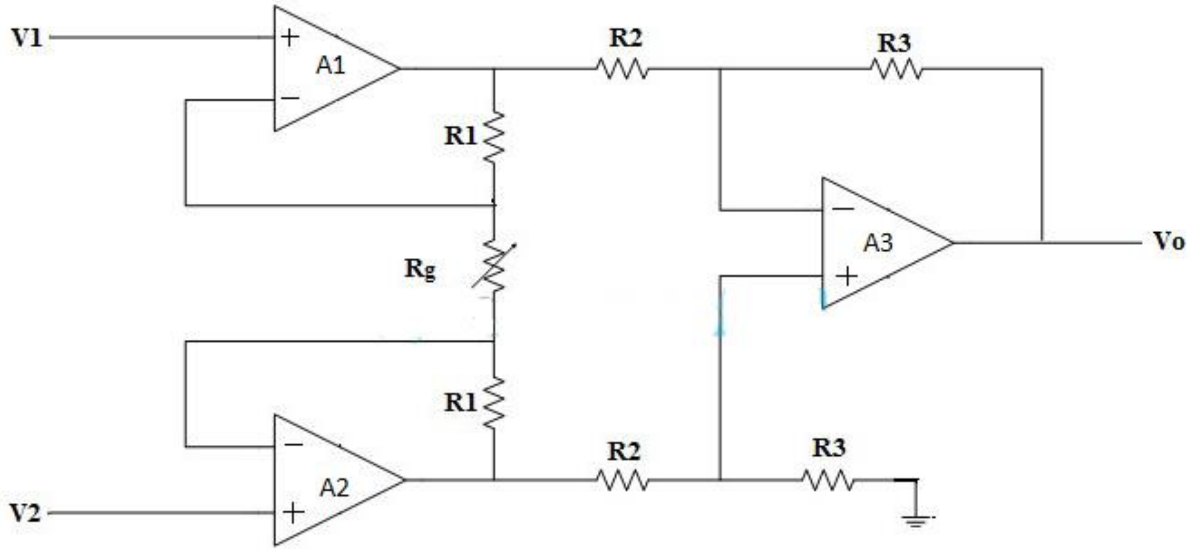


Fig 4.14.Three opamp instrumentation amplifier.

A circuit providing an output based on the difference between two inputs V1 and V2 is given in the Fig 4.13 . In the circuit diagram, opamps A1 and A2 are the input buffers. The gain of these buffer stages are not unity because of the presence of R1 and Rg. Op amp labelled A3 is wired as a standard differential amplifier. R3 connected from the output of A3 to its non inverting input is the feedback resistor. R2 is the input resistor. The voltage gain A_v of the instrumentation amplifier can be expressed by using the equation below.

$$A_V = \frac{V_o}{V_2 - V_1} = \left(1 + \frac{2R_1}{R_g}\right)\frac{R_3}{R_2}$$

If need a setup for varying the gain, replace Rg with a suitable potentiometer. Instrumentation amplifiers are generally used in situations where high sensitivity, accuracy and stability are required. A high gain accuracy can be achieved by using precision metal film resistors for all the resistances.

4.3 Phase Locked Loop (PLL)

A phase-locked loop or phase lock loop (PLL) is a control system that generates an output signal whose phase is related to the phase of an input signal.

4.3.1 Voltage to frequency convertor

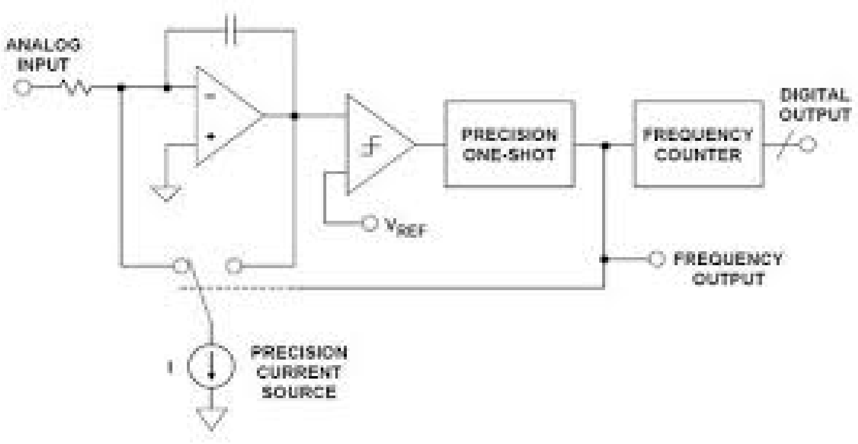


Fig 4.15 Voltage-to-frequency converter (VFC)

A voltage-to-frequency converter (VFC) is an oscillator whose frequency is linearly proportional to a control voltage. The circuit diagram of VFC is shown in Fig: 4.15..The integrator capacitor is charged by the signal. When it passes the comparator threshold, a fixed charge is removed from the capacitor, but the input current continues to flow during the discharge, so no input charge is lost. The fixed charge is defined by the precision current source and the pulse width of the precision monostable. The output pulse rate is thus accurately proportional to the rate at which the integrator charges from the input. At low frequencies, the limits on the performance of this VFC are set by the stability of the current source and the monostable timing (which depends on the monostable capacitor). The absolute value and temperature stability of the integration capacitor do not affect the accuracy, although its leakage and dielectric absorption (DA) do. At high frequencies, second-order effects, such as switching transients in the integrator and the precision of the monostable when it is retriggered very soon after the end of a pulse, take their toll on accuracy and linearity

4.3.2 Operation of basic Phase Locked Loop (PLL)

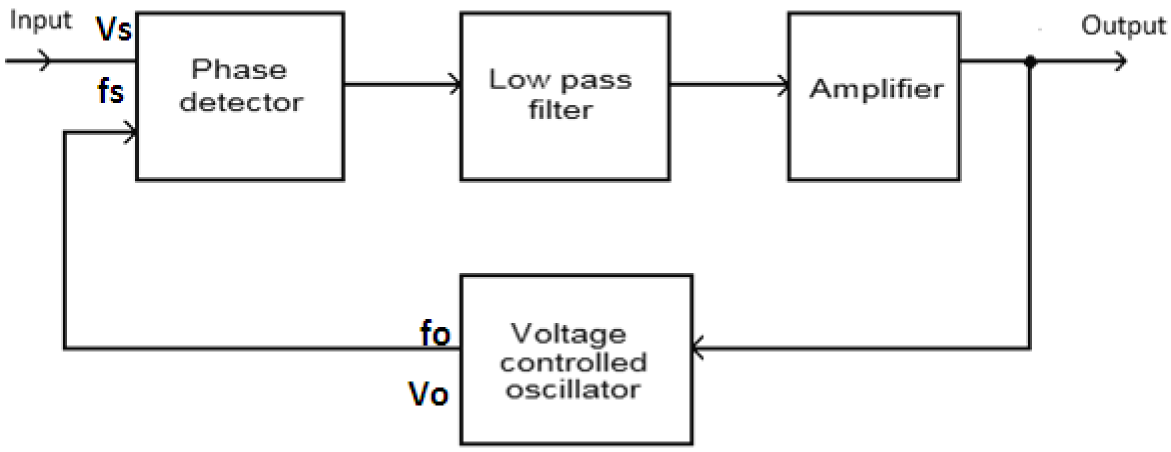


Fig 4.16 Block diagram of Phase Locked Loop (PLL)

The block diagram showing the operating principle of PLL is given in Fig 4.16 . The PLL consists of phase detector, low pass filter and VCO.

The phase detector is basically a comparator that compares the input frequency f_s with the feedback frequency f_o . This receives two digital signal one from input and other from the feedback. The loop is locked when these two signals are of the same frequencies and have a fixed phase difference. The output of the phase detector is DC voltage (error voltage). The output of the phase detector is applied to low pass filter to remove high frequency noise from the DC voltage. By using an amplifier between the filter and the VCO, the actual error between the signals can be reduced to very small levels. The sense of any change in the error voltage tries to reduce the phase difference and hence the frequency difference between the two signals.

When, the error voltage cannot be further reduced, the PLL is in locked state and steady state error voltage is produced. The presence of steady error voltage means that the phase difference between the reference signal and the VCO is not changing. As the phase between these two signals is not changing means that the two signals are on exactly the same frequency. However some voltage must always be present at the control terminal of the VCO as this will help in correcting the frequency.

4.3.3Application of Phase-locked loops

Used in frequency multiplier,

Used to synthesize new frequencies which are a multiple of a reference frequency

Used in demodulation of both FM and AM signals.

Used in recovery of small signals that otherwise would be lost in noise .

Used in recovery of clock timing information from a data stream.

Used in signal processing of video signals .

www.electronics-tutorials

https://focus.ti.com/lit/ml/sloa088/sloa088.pdf

www.schematica.com

www.circuitstoday.com

Unit 5: Wave-shaping circuits **06 Hours**

RC Circuits: Differentiator and Integrator circuits and their response to sine and square-wave signals. **Clippers:** positive and negative series clippers, positive and negative shunt clippers, combinational clippers and simple problems. **Clampers:** positive and negative clampers. Mention on the applications of clippers and clampers.

Wave shaping circuit

A wave shaping circuit is the one which can be used to change the shape of a waveform from alternating current or direct current. These circuits used to create specified time-varying electrical voltage or current waveforms using combinations of active electronic devices, such as transistors or analog or digital integrated circuits, and resistors, capacitors, and inductors. The different types of wave shaping circuits are :

Differentiator

Integrator

Clipper

Clamper

5.1 RC -Differentiator

The high-pass RC circuit is known as a differentiator. The circuit in which output voltage is directly proportional to the derivative of the input is known as a differentiator. The name high pass is so called because the circuit blocks the low frequencies and allows high frequencies to pass through it. It is due to reason that reactance of the capacitor decreases with the increasing frequency. The differentiating circuit is a simple series RC circuit where the output is taken across the resistor R.

The Fig 5.1 shows the RC differentiator circuit. The circuit acts as a differentiator when time constant (RC) is very small. Under this case, voltage drop across R is negligible compared to drop across C. Thus Vc =Vin.

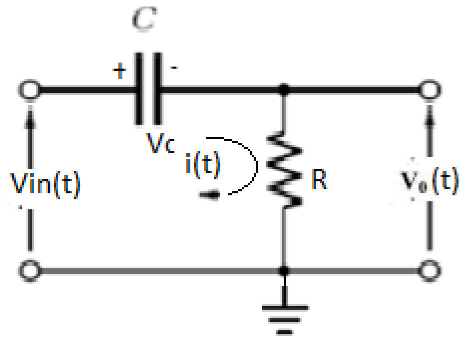


Fig 5.1 RC- Differentiator

Then the current **i** is given by $i(t) = C\,\frac{dV_C}{dt} = C\frac{V_{in}(t)}{dt}$

Hence the output $V_o = i(t)R = RC\,\frac{dV_{in}(t)}{dt}$

Response to square signal

Consider a square wave input as shown in the Fig 5.2. At t=0 the input is changing 0 to A in a small interval of time dt→0. Hence the output of the differentiator is

$V_o = RC\,\frac{dV_{in}(t)}{dt}$

Where dV_{in}=A-0 and dt →0.

Therefore $V_0 = RC\,\frac{A}{0} = \infty$

Thus at the output, an impulse of infinite magnitude with zero width exists at t=0. Practically the magnitude of impulses is 'A' because the voltage across R is neglected during the analysis. Thus, the input to the differentiator is a square wave, the output consists of sharp narrow pulse.

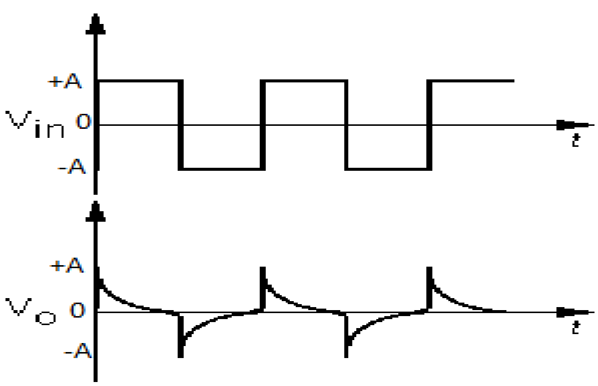


Fig. 5.2 Input and output wave form of a differentiator for a square wave

Response to sine wave signal

Consider a sinusoidal input applied to the differentiator is $V_{in}(t) = V \sin\omega t$

Therefore $V_o(t) = RC\frac{d(\mathrm{V}\sin\omega t)}{dt}$

$= \mathrm{RC\ V}\ \omega\cos\omega t$

$= +\mathrm{V'}\cos\omega t.$

Thus the ouput is a cosine wave for the sinusoidal input as shown in Fig:5.3

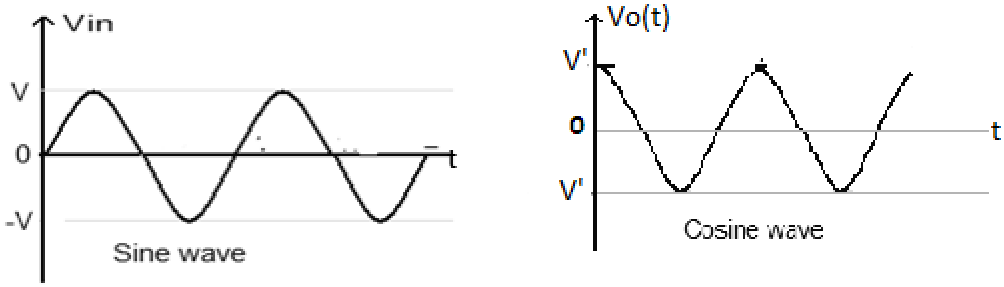


Fig. 5.3 Input and output wave form of a differentiator for a sinewave

Application: **of differentiator**

Used in wave shaping circuits,

Used to detect high frequency components in the input signal.

5.1.2 RC Integrator:

The low-pass RC circuit is known as integrator. The integrator performs the mathematical operation of integration with respect to time; that is, its output voltage is proportional to the input voltage integrated over time. A basic RC integrator circuit is simply a capacitor in series with a resistor and the source as shown in Fig 5.4. Here the output is taken across the capacitor.

Waveforms for the RC integrator depend on the time constant (RC) of the circuit. If the time constant is large it acts as an integrator.

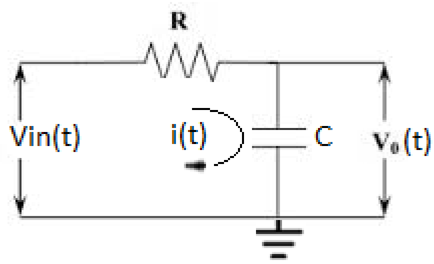


Fig 5.4: RC Integrator

Under this case the drop across C is negligible compared to drop across R. Thus the entire input can be assumed to be appearing across R. The current i(t) is given by

$V_R = V_{in}(t) = i(t)R.$

Hence the output which is the voltage across capacitor is given by

$V_o(t) = V_c = \frac{1}{C}\int i(t)dt$

Therefore $V_o(t) = \frac{1}{RC}\int V_{in}(t)dt$

Response of the integrator for square input

Consider a square wave as shown in Fig 5.5

Vin(t)= +A for $0 < t < T1$

= -A for $T1 < t < T2$

Hence the output is $Vo(t) = \frac{1}{RC}\int A\,dt = \frac{A}{RC}t$ for $0 < t < T1$

$Vo(t) = \frac{1}{RC}\int -A\,dt = \frac{-A}{RC}t$ for $T1 < t < T2$

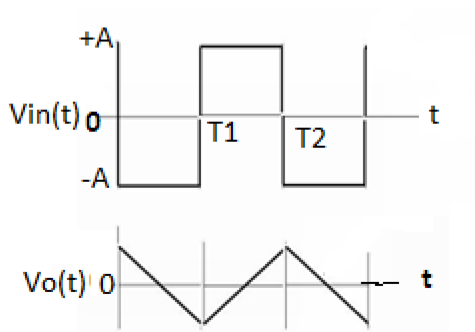


Fig 5.5: Integrator output for square wave input

Response of integrator for sin wave input

Consider a sinusoidal input applied to the integrator is $V_{in}(t)$ = V sinωt

Therefore $V_o(t) = \frac{1}{RC}\int V_{in}\,(t)dt$

$= \frac{1}{RC}\int \mathrm{V}\ \mathrm{sin}\omega t\ dt$

$= \frac{V}{RC\omega}(-cos\omega t)$

= -V'cosωt

Thus the ouput is a cosine wave for the sinusoidal input as shown in Fig: 5.6

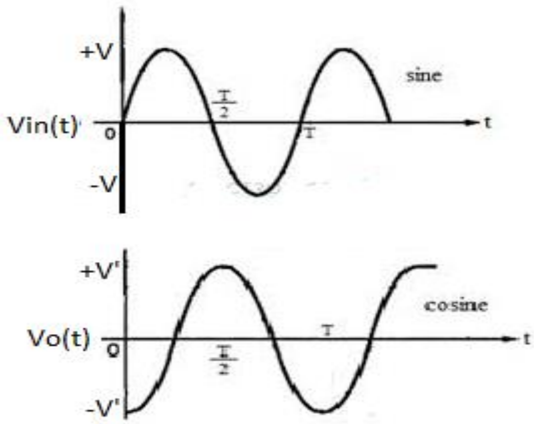


Fig 5.6: Integrator output for sin wave input

Application of integrators

1. Used in analog computers, analog-to-digital converters
2. Used in wave-shaping circuits.

5.2 Clippers

A clipper is a device which limits, remove or prevents some portion of the wave form (input signal voltage) above or below a certain level.

A clipping circuit consists of linear elements like resistors and non-linear elements like junction diodes or transistors, but it does not contain energy-storage elements like capacitors. Clipping circuits are also called slicers, amplitude selectors or limiters.

Clippers may be classified into two types based on the positioning of the diode.

Series Clippers, where the diode is in series with the load resistance.

Shunt Clippers, where the diode is shunted across the load resistance.

5.2.1 Series Positive Clipper

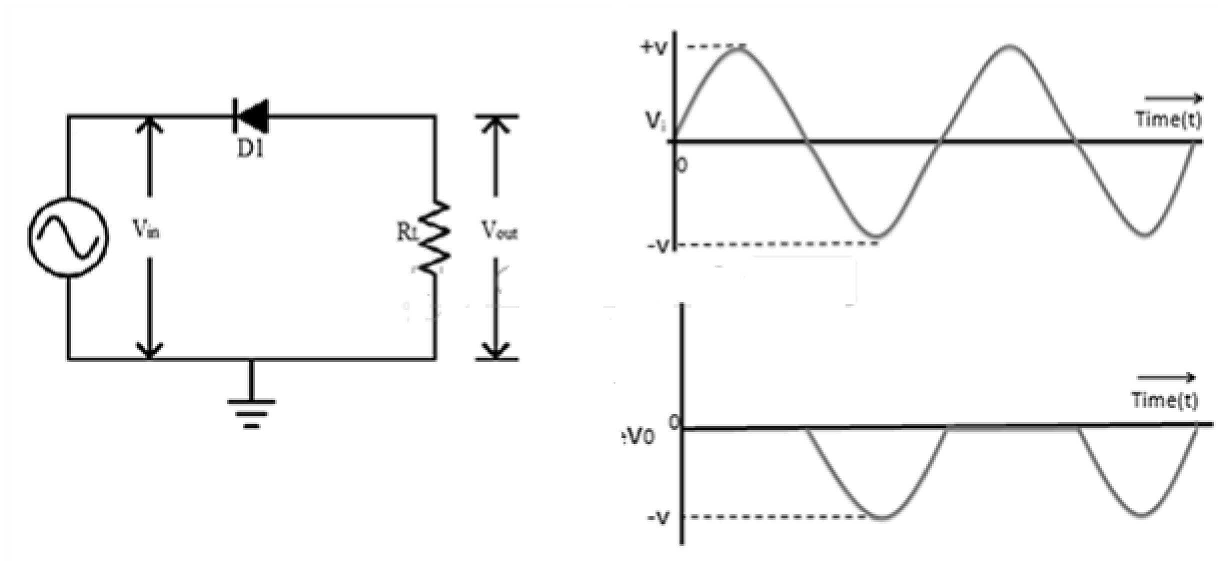


Fig 5.7: Series Positive clipper and input and output wave form

In series positive clipper, the positive half cycles of the input voltage will be removed. The circuit is illustrated in Fig 5.7. Here, diode is kept in series with the load. Cathode is connected to the power supply and anode is maintained at ground potential. During positive half cycle, the diode D1 is reverse biased which maintains output voltage VOut = 0 Volts. This causes positive half cycle to be clipped off .During negative half cycle, the diode is forward biased and output voltage VOut = V_{in} Volts and negative half cycle appears across the output as shown in Fig 5.7.

5.2.2 Series Negative Clipper

In series negative clipper, the negative half cycles of the input voltage will be removed. The circuit is illustrated in Fig 5.8. Here, the diode is connected in series with the load. The anode is connected to the power supply and cathode is maintained at ground potential. During positive half cycle , the diode D1 is forward biased which maintains output voltage V_{Out} = Vin Volts and positive half cycle appears across the output .During negative half cycle, the diode is reverse biased and output voltage V_{Out} = 0 Volts and negative half cycle is clipped off as shown .

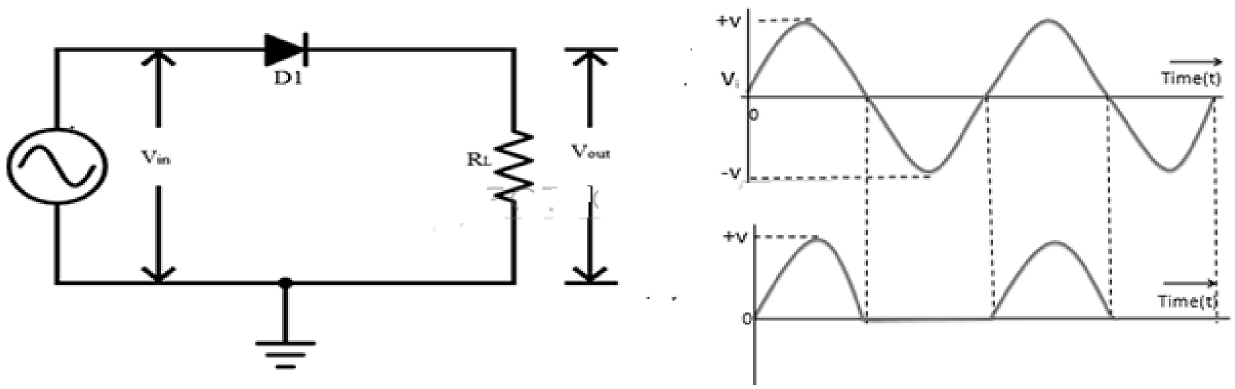


Fig 5.8: Series negative clipper and input /output wave form

5.2.3 Shunt Positive Clipper

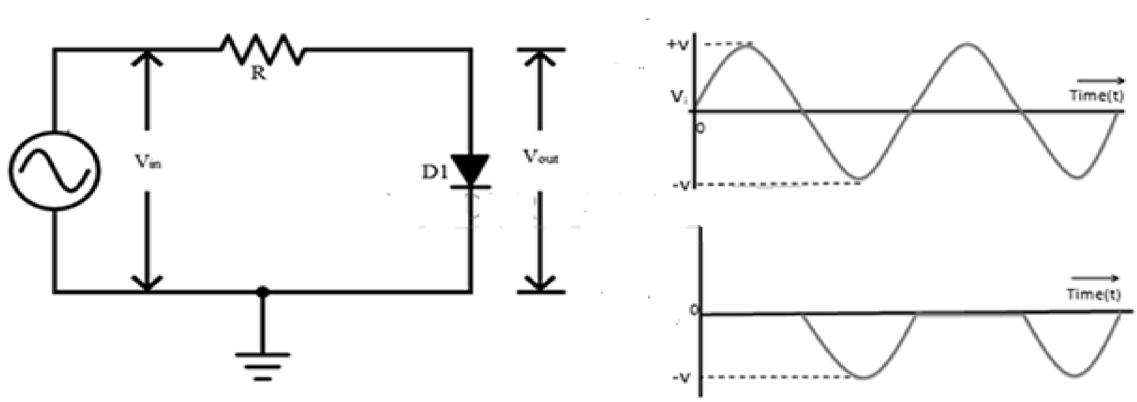


Fig 5.9: Shunt positive clipper and input/output waveform

In shunt positive clipper, the positive half cycles of the input voltage will be removed. The circuit is illustrated in Fig 5.9. Here, diode is connected in parallel with the load. The anode is connected to the power supply through a resistor R and cathode is maintained at ground potential. During Positive Half Cycle , the diode D1 is forward biased which maintains output voltage V_{Out} = 0 Volts which causes positive half cycle to be clipped off . During negative half cycle, the diode is reverse biased and output voltage V_{Out} = V_{in} Volts and negative half cycle appears across the output.

5.2.4. Shunt Negative Clipper

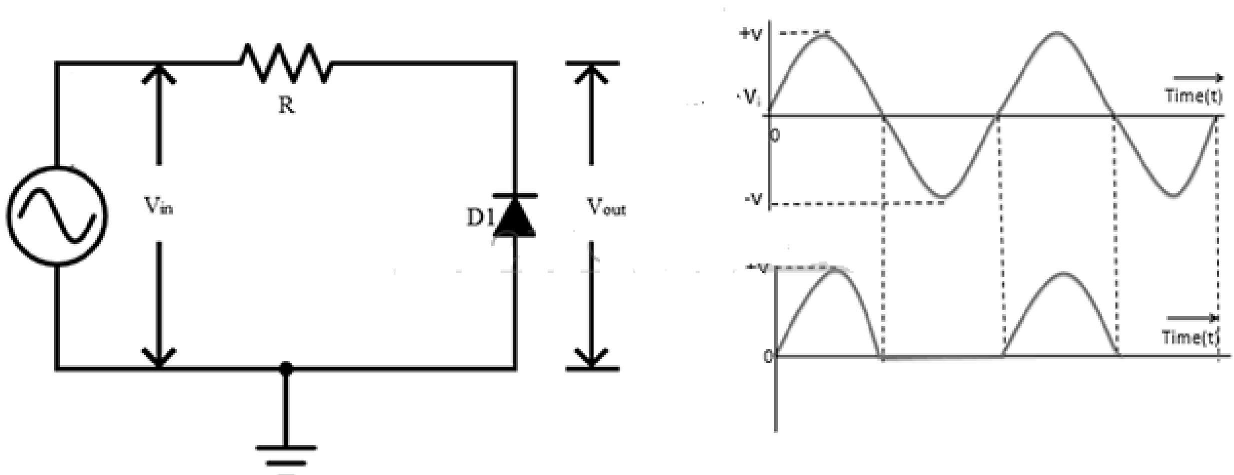


Fig: 5.10: Shunt negative clipper and input/ output waveform

In shunt negative clipper, the negative half cycles of the input voltage will be removed. The circuit is illustrated in Fig 5.10. Here, diode is connected in parallel with the load. The cathode is connected to the power supply through a resistor R and anode is maintained at ground potential .During positive half cycle , the diode D1 is reversed biased which maintains output voltage VOut = V_{in} Volts which causes positive half cycle to appear across the output .During negative half cycle, the diode is forward biased and output voltage V_{Out} = 0V.

5.3 Biased clippers

A biased clipper is used to remove a small portion of positive or negative half cycles of the signal voltage .When a small portion of the negative half cycle is to be removed, it is called a biased negative clipper and when a small portion of the negative half cycle is to be removed, it is called a biased negative clipper.

5.3.1 Series Positive Clipper with Positive Bias Voltage

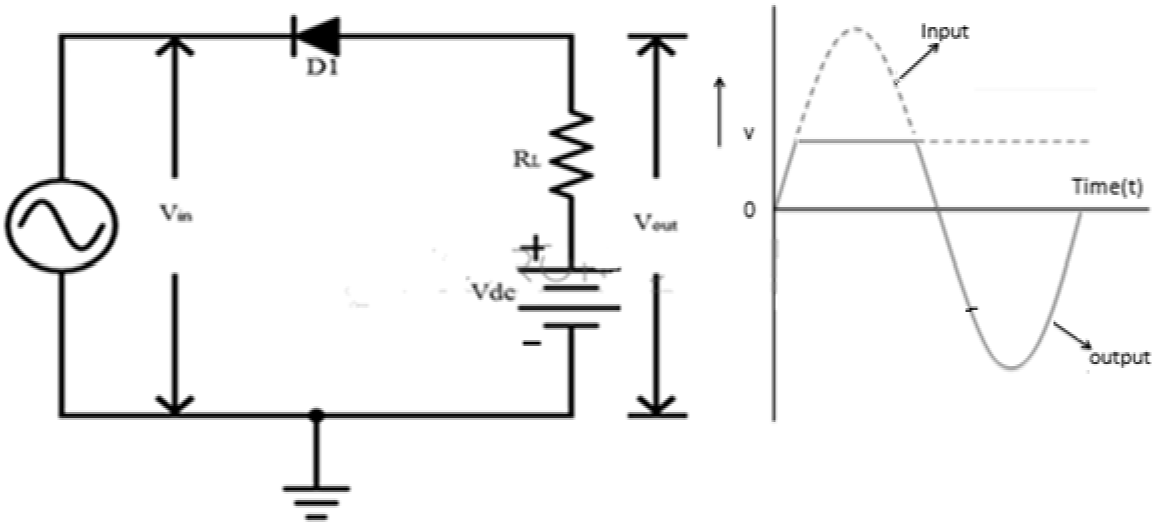


Fig 5:11: Series positive clipper with positive bias voltage and waveform

In Fig 5.11 cathode is connected to the negative supply and the anode is maintained at positive bias potential as shown in Fig 5.11. When $V_{in} < V_{dc}$, the diode gets forward biased, hence output voltage VOut = V_{in} Volts and when $V_{in} > V_{dc}$, diode becomes reverse biased, circuit becomes opened and output Voltage VOut = V_{dc} Volts.

5.3.2 Series Positive Clipper with Negative Bias Voltage

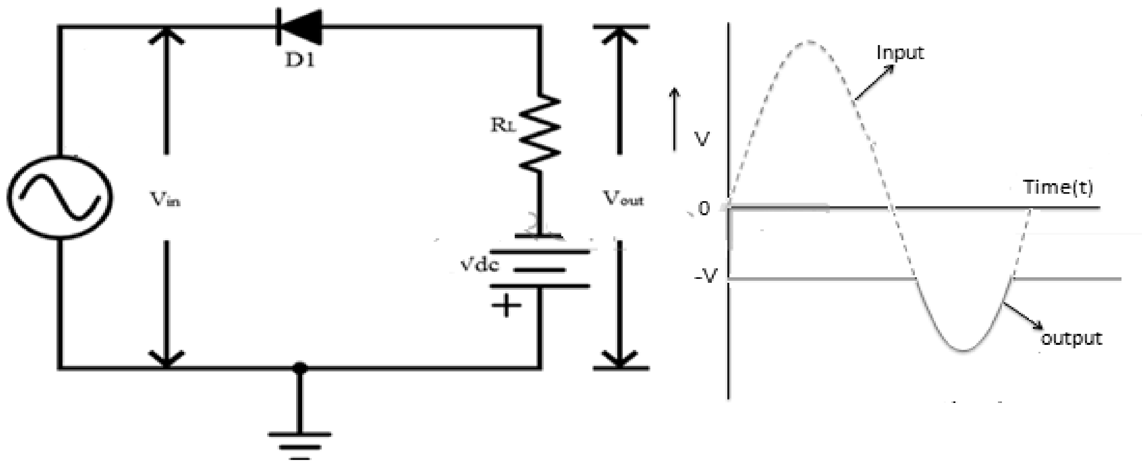


Fig 5.12: Series positive clipper with negative bias voltage and waveform

In Fig 5.12, cathode is connected to the negative supply and anode is maintained at negative bias potential as shown in Fig: 5.12. When $V_{in} > V_{dc}$, diode is reverse biased, circuit becomes opened and output Voltage VOut = – V_{dc} Volts and when $V_{in} < V_{dc}$, diode is forward biased and hence the Output Voltage VOut = V_{in} Volts.

5.3.3. Series Negative Clipper with Positive Bias Voltage

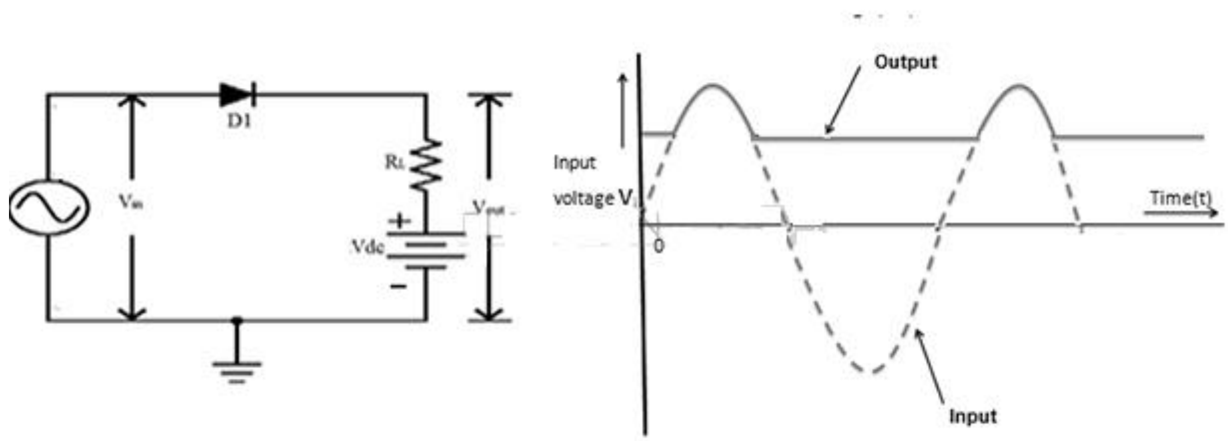


Fig 5.13: Series negative clipper with positive bias voltage and waveform

In Fig 5.13the anode is connected to the negative supply and the cathode is maintained at positive bias potential as shown in Fig 5.13. When $V_{in} < V_{dc}$, output voltage VOut $=V_{dc}$ Volts and when $V_{in} > V_{dc}$, Output Voltage VOut = V_{in} Volts.

5.3.4. Series Negative Clipper with Negative Bias Voltage

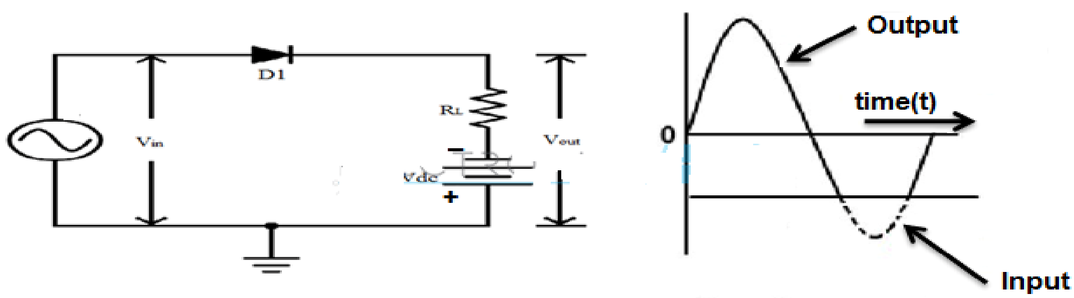


Fig 5.14: Series negative clipper with negative bias voltage and waveform

In Fig 5.14, the anode is connected to the positive supply and the cathode is maintained at negative bias potential. When $V_{in} < V_{dc}$, output Voltage VOut $=-V_{dc}$ Volts .When $V_{in} > V_{dc}$, output Voltage VOut = Vin Volts

5.3.5. Shunt Positive Clipper with Positive Shunt Bias Voltage

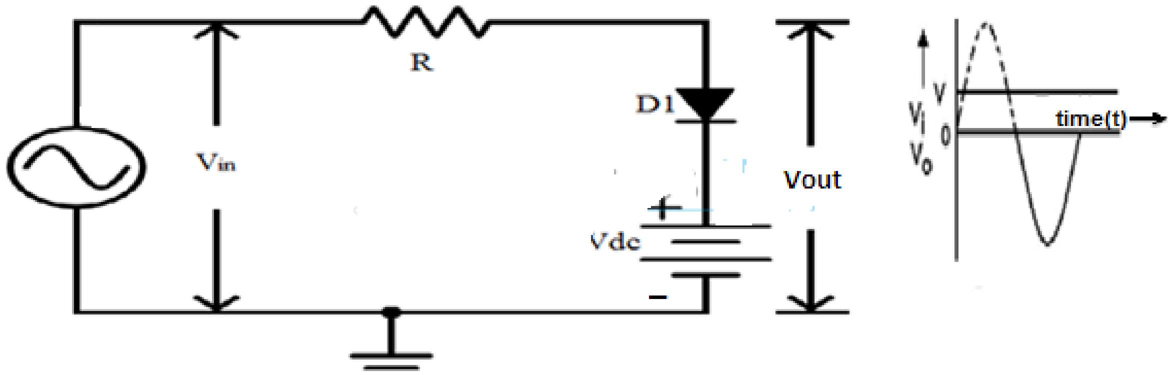


Fig 5.15: Shunt positive clipper with positive bias voltage and waveform

In Fig 5.15, anode is connected to the negative supply and the cathode is maintained at positive bias potential. When $V_{in} < V_{dc}$, output voltage VOut = V_{in} Volts and when $V_{in} > V_{dc}$, output Voltage VOut = V_{dc} Volts

5.3.6. Shunt Positive Clipper with Negative Shunt Bias Voltage

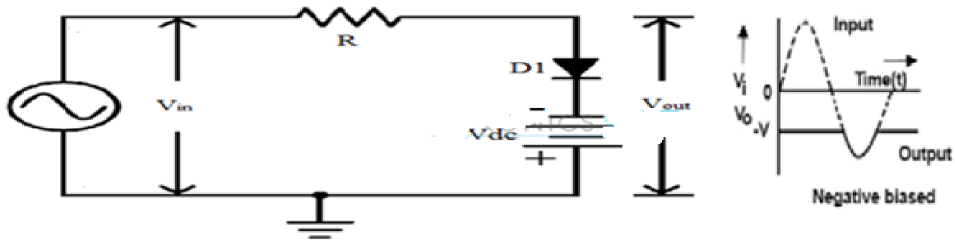


Fig 5.16: Shunt positive clipper with negative bias voltage and waveform

In Fig 5.16, anode is connected to the positive supply and the cathode is maintained at negative bias potential. The output voltage VOut = -V_{dc} Volts. When $V_{in} > V_{dc}$, output voltage VOut = V_{in} Volts.

5.3.7. Shunt Negative Clipper with Positive Bias Voltage

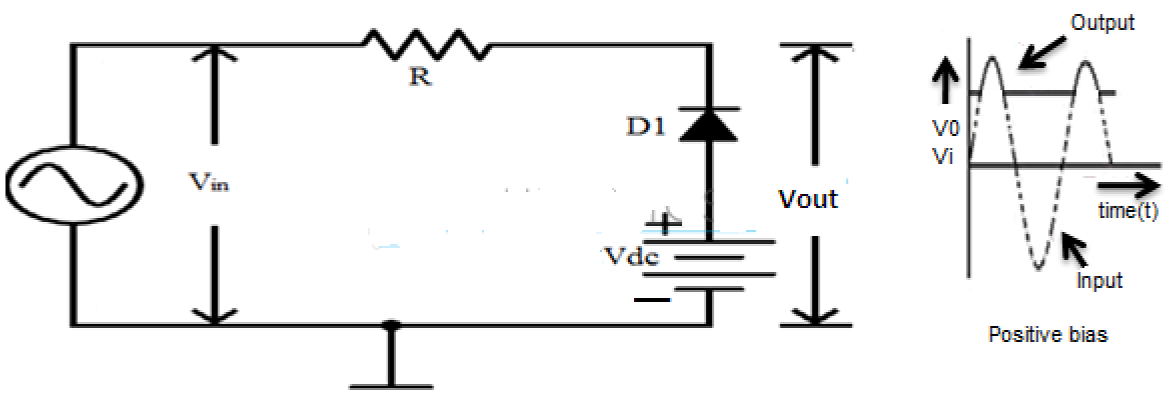


Fig 5.17: Shunt negative clipper with positive bias voltage and waveform

In Fig 5.17, cathode is connected to the negative supply and the anode is maintained at positive bias potential. When $V_{in} < V_{dc}$, The output voltage VOut = V_{dc} Volts and when $V_{in} > V_{dc}$, output voltage VOut = V_{in} Volts.

5.4. Combinational clipper

The combination clipper is one in which a portion of both positive and negative of each half cycle of the input voltage is clipped (or removed). The circuit for such a clipper is given in the Fig 5.18.

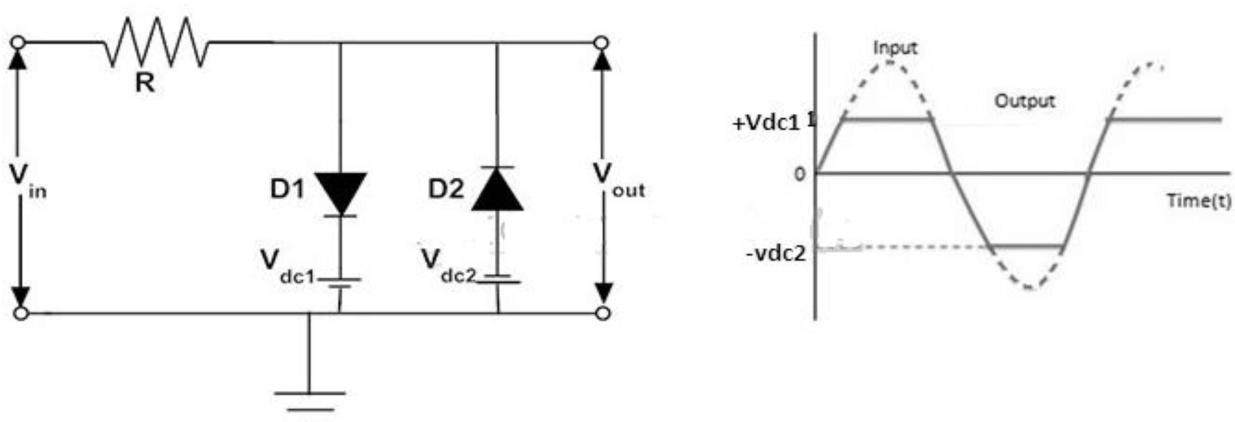


Fig 5.18: Combinational clipper and output waveform

Positive Half Cycle: In this cycle, cathode of first diode D1 is maintained at $+V_{dc1}$ and its anode observes a variable positive voltage. Similarly anode of diode D2 is maintained at $-V_{dc2}$ and its cathode observes a variable positive voltage. The diode D2 will be completely reverse biased during the whole positive half cycle.

When $V_{in} < V_{dc1}$, diodes D1 &D2 are reverse biased, output voltage VOut = V_{in} Volts.

When $V_{in} > V_{dc1}$, diode D1 will be forward biased and D2 will be reverse biased, output voltage VOut = V_{dc1} Volts

Negative Half Cycle: In this cycle, cathode of diode D1 is maintained at $+V_{dc1}$ and its anode observes a variable negative voltage. Similarly anode of diode D2 is maintained at $-V_{dc2}$ and its cathode observes a variable negative voltage. The diode D1 will be completely reverse biased during the whole negative half cycle.

When $V_{in} < V_{dc2}$, diodes D1 &D2 are reverse biased, output voltage VOut = Vin Volts.

When $V_{in} > V_{dc2}$, diode D2 will be forward biased and D1 will be reverse biased, output voltage VOut = $-V_{dc2}$ Volts

In this two side clipping circuit, both the positive and negative clipping levels can be varied independently. This type of circuit is called as Parallel based Clipper. It uses two diodes and two voltage sources connected in opposite directions.

5.5 Diode Clampers

A clamper is an electronic circuit that fixes either the positive or the negative peak of a signal to a defined value by shifting its DC value. Clampers can also be referred as DC restorers. Clamping circuits are designed to shift the input waveform either above or below the DC reference level without altering the waveform shape. This shifting of the waveform results in a change in the DC average voltage of the input waveform. The levels of peaks in the signal can be shifted using the clamper circuit; hence clampers can also be referred as level shifters.

Clampers can be broadly classified into two types. They are positive clampers and negative clampers.

Positive Clamper: This type of clamping circuit shifts the input waveform in a positive direction; as a result the waveform lies above a DC reference voltage.

Negative Clamper: This type of clamping circuit shifts the input waveform in a negative direction; as a result the waveform lies below a DC reference voltage.

The direction of the diode in the clamping circuit determines the clamper circuit type. The operation of a clamping circuit is mainly based on the switching time constants of the capacitor. However, capacitor in the circuit charges through the diode and discharges through the load.

5.5.1. Negative Clamper

The Negative Clamping circuit consists of a diode connected in parallel with the load. The capacitor used in the clamping circuit can be chosen such that it must charge very quickly and it should not discharge very drastically. The anode of the diode is connected to the capacitor and cathode to the ground. During the positive half cycle of the input, the diode is in forward bias and as the diode conducts the capacitor charges very quickly.

During the negative half cycle of the input, the diode will be in reverse bias and the diode will not conduct, the output voltage will be equal to the sum of the applied input voltage and the charge stored in the capacitor during reverse bias. The output waveform is same as input waveform, but shifted below 0 volts.

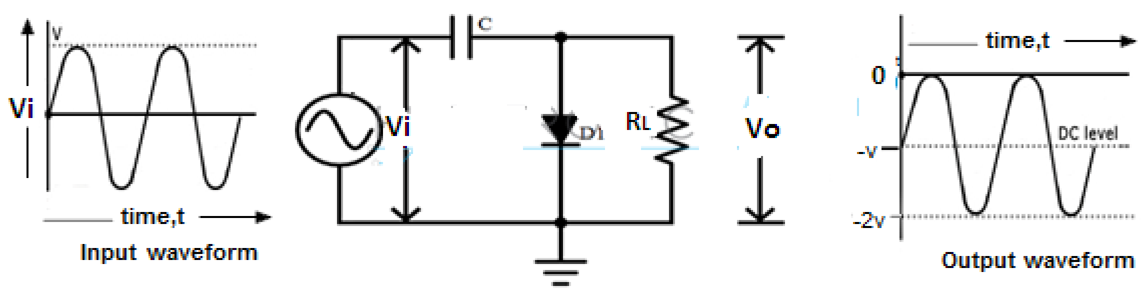


Fig 5.19: Negative clamper and output waveform

5.5.2. Positive Clamper

The circuit of the positive clamper is similar to the negative clamper but the direction of the diode is inverted in such a way that the cathode of the diode is connected to the capacitor. During the positive half wave cycle, output voltage of the circuit will be the sum of applied input voltage and the charge stored at capacitor. During the negative half wave cycle, the diode starts to conduct and charges the capacitor very quickly to its maximum value. The output waveform of the positive clamper shifts towards the positive direction above the 0 volts.

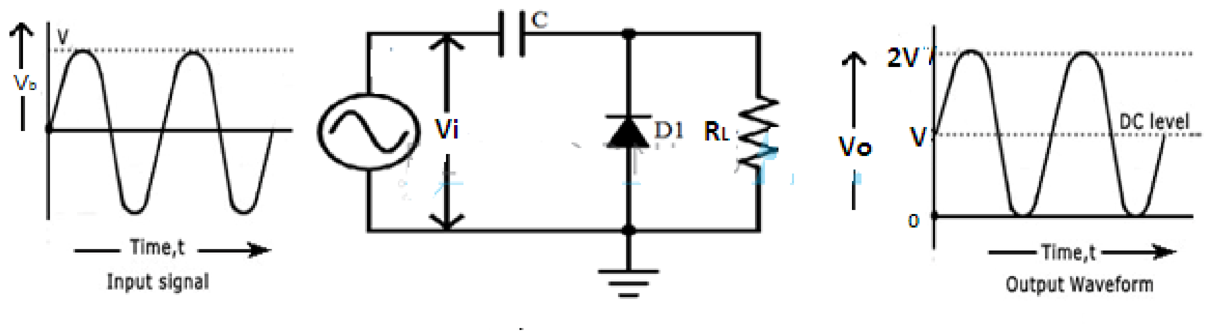
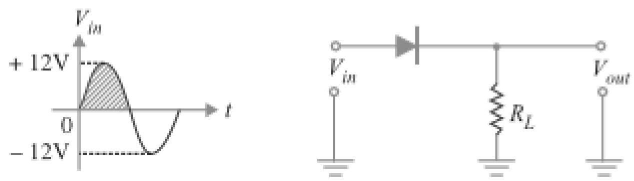


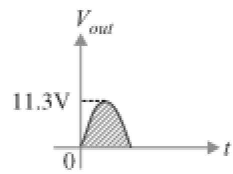
Fig 5.20: Positive clamper and output waveform

Solved Problems:

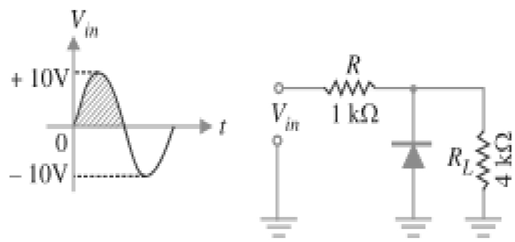
1. For the negative series clipper shown in Figure, what is the peak output voltage from the circuit ?



When the diode is connected in series with the load, it is called a series clipper. Since it is a negative clipper, it will remove negative portion of input a.c. signal.
During the positive half-cycle of input signal, the diode is forward biased. As a result, the diode will conduct.
The output voltage is V_{out} (peak) = Vin (peak) − 0.7 = 12 − 0.7 = 11.3 V
During the negative half-cycle of input signal, the diode is reverse biased and consequently it will not conduct. Therefore, $V_{out} = 0$. Note that under this condition, the entire input voltage will appear across the diode.
The output waveform is shown below.



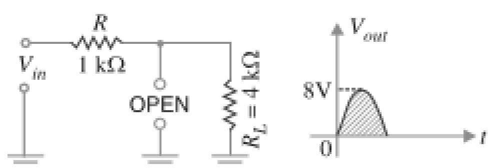
2. The negative shunt clipper shown in Figure has a peak input voltage of + 10 V. What is the peak output voltage from this circuit ?



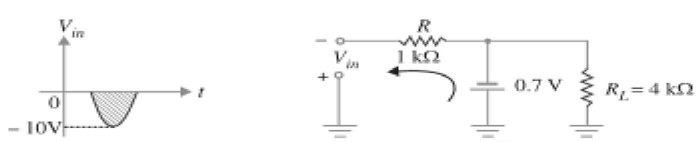
When the diode is connected in parallel with the load, it is called a shunt clipper. During the positive half-cycle of input ac signal, the diode is reverse biased and it will behave as an open.
With diode as an open,
Vout (peak) = Peak voltage across R_L =

$$V_{out\,(peak)} = \text{Peak voltage across } R_L$$
$$= \frac{R_L}{R + R_L} V_{in\,(peak)} = \frac{4}{1+4} \times 10 = 8\text{V}$$

The output waveform is shown below



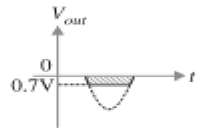
3. In what will be the output voltage and voltage across R when the input voltage is − 10 V ?



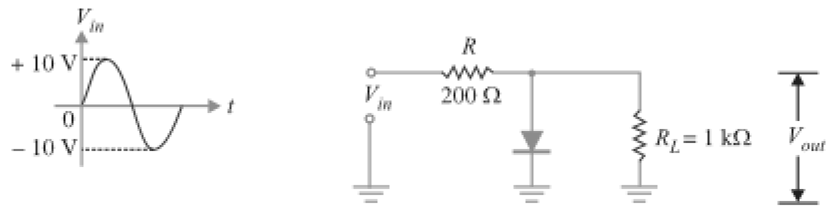
During the negative half-cycle of input signal, the diode is forward biased. Therefore, diode can be replaced by its simplified equivalent circuit as shown. Since load is connected in parallel with the diode,

$$\therefore \quad V_{out} = -0.7\ \mathbf{V}$$

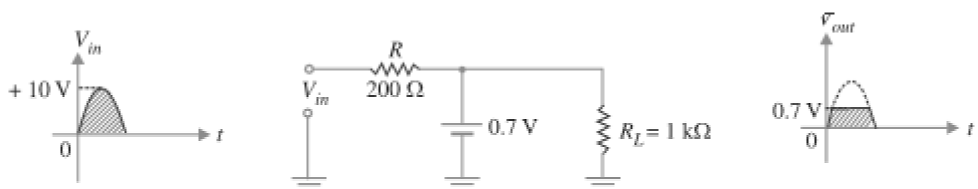
$$\text{Voltage across } R,\ V_R = (-10) - (-0.7) = -10 + 0.7 = -9.3\ \mathbf{V}$$



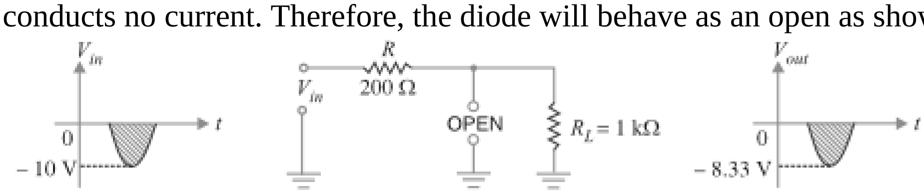
4. The positive shunt clipper shown in Figure has the input waveform as indicated. Determine the value of V_{out} for each of the input alternations.



Positive half-cycle. During the positive half-cycle of the input ac signal, the diode is forward biased. Therefore, diode can be replaced by its simplified equivalent circuit as shown below.
Since the load is connected in parallel with the diode, ∴ Vout = 0.7 V



Negative half-cycle: During the negative half-cycle of the input a.c. signal, the diode is revers biased and it conducts no current. Therefore, the diode will behave as an open as shown



$$\therefore \quad V_{out\,(peak)} = \frac{R_L}{R + R_L} V_{in\,(peak)}$$

$$= \left(\frac{1000}{200 + 1000}\right)(-10\ \mathrm{V}) = -8.33\ \mathbf{V}$$

5.6 Applications of Clippers

Used In the case of generating new waveforms and/or shaping the existing older waveforms.

Used as freewheeling diodes in protecting the transistors from transient effects by connecting the diodes in parallel with the inductive load.

Used in power supplies.

Used In the separation of synchronizing signals existing from the composite color picture signals.

Used in FM transmitters for removing the excess ripples in the signals above a certain noise level.

5.7 Applications of Clampers

Used in removing the distortions and identification of polarity of the circuits.

Used For improving the reverse recovery time, clampers are used.

Used as voltage doublers and for modeling the existing waveforms to a required shape and range.

Used in test equipments and other sonar systems.

For more details refer the following.

www.**circuits**today.com

www.conceptselectronics.com

www.electronicshub.org

Unit 6: Sinusoidal oscillators 05 Hours

Concept of feedback and types, open and closed-loop gains, Barkhausen criteria, LC Tank circuit and stability. Working of Hartley, Collpits and crystal oscillator using BJT. Working of RC phase-shift and Wein-bridge oscillators using Op-amp. Mention on applications and features of these oscillators.

CONCEPT OF FEEDBACK

A feedback system is one in which the output signal is sampled and then fed back to the input to form an error signal that drives the system. and depending on the type of feedback used, the feedback signal which is mixed with the systems input signal, can be either a voltage or a current. Feedback will always change the performance of a system and feedback arrangements can be either positive (regenerative) or negative (degenerative) type feedback systems.

6.1.TYPES OF FEEDBACK

Feedback means fraction of output (V_f) is fed back to input (V_i) through feedback network.

6.1.1 Positive feedback:- If the feedback loop around the system produces a loop-gain which is negative, the feedback is said to be negative or degenerative . The main effect of the negative feedback is in reducing the systems gain i.e fraction of output(V_f) and input(V_i) are in same phase then such feedbacks are called positive feedback.

6.1.2 Negative feedback:- If however the gain around the loop is positive, the system is said to have positive feedback or regenerative feedback. The effect of positive feedback is to increase the gain which can cause a system to become unstable and oscillate i.e fraction of output(V_f) and input(V_i) are in different phase then such feedbacks are called negative feedback

6.2 Concepts of positive feedback:

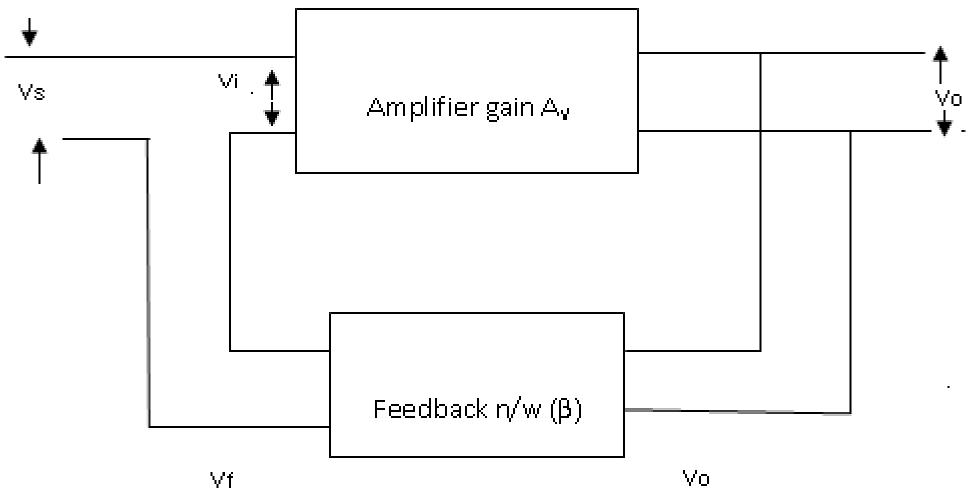


Fig 6.1: Feedback system

Fig 6.1 shows the concept of general feedback concept. Feedback means fraction of output is fed back to input through feedback network.

A_V → voltage gain of op-amp

B→feedback factor.

V_i → i/p signal to amplifier,

V_f → feed back signal.

V_s → external i/p to amplifier.

Voltage gain of amplifier Av = $\frac{V_o}{V_i}$

For positive feedback vi and vf are in phase.

$V_i = V_s + V_f$

o/p $V_o = A_v V_i$

$= A_v(V_s + V_f)$

$= A_v(V_s+\beta V_o)$

$= A_vV_s+A_v\beta V_o$

$V_o - A_v\beta V_o = A_vV_s$

$V_o(1-A_v\beta) = A_vV_s$

$$\boxed{\frac{V_o}{V_i} = \frac{AV_i}{1-A_V\beta}}$$

This equation is gain equation and contains feedback factor β, and it is called gain with feedback.

Therefore, $A_{V_f} = \frac{AV_i}{1-A_V\beta}$

6.3 BARKHAUSEN's CRITERIA:

Voltage gain with positive feedback is given by

$$\boldsymbol{A_{V_f} = \frac{AV_i}{1-A_V\beta}}$$

Assuming, $A_V\beta = 1$

$$\boldsymbol{A_{V_f} = \frac{AV_i}{1-1} = \frac{AV_i}{0} = \infty}$$

i.e the gain with feedback tends to ∞ . Practically, circuit can't have ∞ gain.

For sustained oscillations in any circuit,

1) The closed loop gain $A_V\beta = 1$

2) The total phase shift around closed loop must be zero or integral multiples of 2π. This ensures positive feedback.

These two conditions are called Barkhausen criteria or conditions for sustained oscillations.

6.4 Oscillatory circuit (TANK CIRCUIT)

A circuit, which produces electrical oscillations of any desired frequency, is known as an oscillatory circuit or tank circuit.

A simple oscillatory circuit consists of a capacitor C and inductance coil L in parallel as shown in figure below. This electrical system can produce electrical oscillations of frequency determined by the values of L and C.

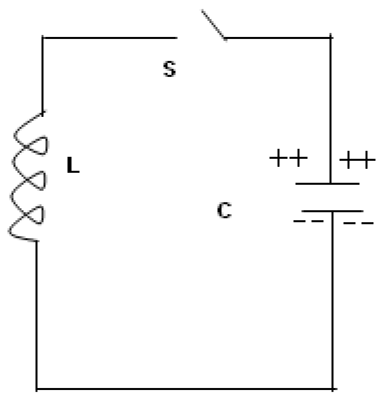


Fig.6.2 (a)

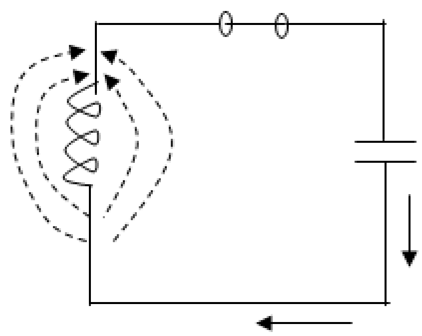


Fig 6.2 (b)

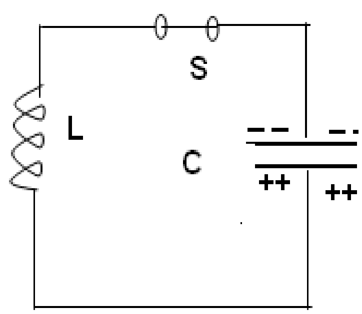


Fig.6.2(c)

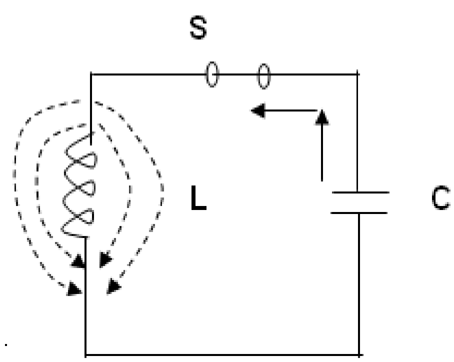


Fig.6.2(d)

Circuit operations- Assume capacitor is charged from a d. c. source with a polarity as shown in Fig.6.2(a).When switch S is closed as shown in Fig6.2(b) the capacitor will discharge through inductance and the electron flow will be in the direction indicated by the arrow. This current flow sets up magnetic field around the coil. Due to the inductive effect, the current builds up slowly towards a maximum value. Circuit current will be maximum when the capacitor is fully discharged. Hence the electrostatic energy across the capacitor is completely converted into magnetic field energy around the coil.

Once the capacitor is discharged, the magnetic field will begin to collapse and produce a counter e.m.f. According to Lenz's law the counter EMF will keep the current flowing in the same direction. The result is that the capacitor is now charged with opposite polarity making upper plate of capacitor –ve and lower plate +ve as shown in Fig 6.2 (c).After the collapsing field has recharged the capacitor, the capacitor now begins to discharge and current now flows in the opposite direction as shown in Fig 6.2(d).

The sequence of charge and discharge results in alternating motion of electrons or an oscillating current. The energy is alternately stored in the electric field of the capacitor C and the magnetic field of the inductance coil L . This interchange of energy between L and C is repeated over and again resulting in the production of Oscillations.

6.5 Damped and Undamped Oscillations

Damped and undamped oscillations are shown in the Figure 6.3. During each oscillation, some energy is lost due to electrical losses (I^2R). The amplitude of the oscillation will be reduced to zero as no compensating arrangement for the electrical losses is provided. The only parameters that will remain unchanged are the frequency or time period. They will change only according to the circuit parameters.

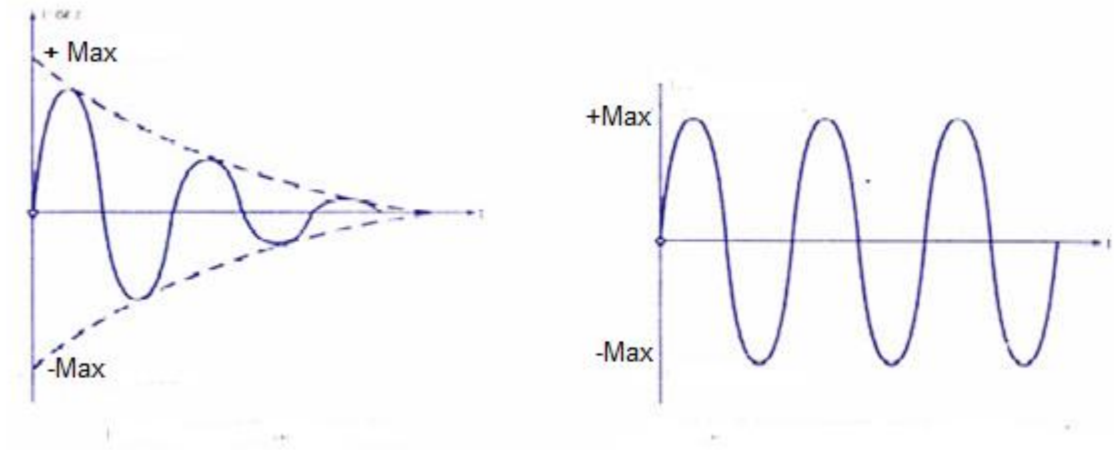


Fig 6.3:Damped and Undamped Oscillations

Undamped oscillations have constant amplitude oscillations. In the harmonic oscillation equation, the exponential factor $e^{-Rt/2L}$ must become unity. That is, the value of the dissipation component in the circuit, R should be zero. If its value is negative, the amplitude goes on increasing with time t. If its value is positive, the amplitude decreases with time t.

The correct amount of undamped oscillations will be obtained only if the correct amount of energy is supplied to overcome the losses at the right time in each cycle. The resulting "undamped oscillations" are called sustained oscillations. Such sustained oscillations or continuous waves are required to be produced by the electronic oscillator circuits.

6.6 Stability

Stability is the ability of a system to remain unchanged over time under stated or reasonably expected conditions of storage and use

Frequency stability

Stability is how close the output frequency stays to its nominal. A very stable oscillator will have an output frequency that does not change. Even if an oscillator is set at an initial frequency, it cannot be maintained throughout. They keep on changing either in a uniform way or sometimes erratically. The term "frequency stability" is used to define the ability of the oscillator to maintain a single fixed frequency as long as possible over a time interval. These deviations in frequency are caused due to variations in the values of circuit features (circuit components, transistor parameters, supply voltages, stray-capacitances, output load etc.) that determine the oscillator frequency.

Amplitude stability

Amplitude of the oscillator is the output voltage, usually expressed in Vpp (peak-to-peak) or Vrms. The amplitude stability is the ability of an oscillator to produce low distortion output The oscillation amplitude is set by gain saturation, usually in the amplifier

6.7 Classification of oscillators

6.7.1 Based on output waveform

Sinusoidal oscillator

Non sinusoidal (triangle,square,sawtooth) oscillator

6.7.2 Based on circuit components

RC oscillator

LC oscillator

Crystal oscillator

6.7.3 Based on operating frequency

Audio frequency (AF) oscillators or Low frequency oscillator

Radio frequency (RF) oscillator Or High frequency oscillator

6.8 Hartley Oscillator

The circuit diagram of Hartley Oscillator is as shown in figure below. It uses two inductors placed across common capacitor C and the center of two inductors are tapped with ground terminal of ckt . The tank circuit is made up of L_1 , L_2 and C and oscillation frequency is given by.

$$f = \frac{1}{2\pi\sqrt{L_T C}} \quad \text{------------------------------ (1)}$$

where $L_T = L_1 + L_2 + 2M$

M= Mutual inductance between L_1 and L_2

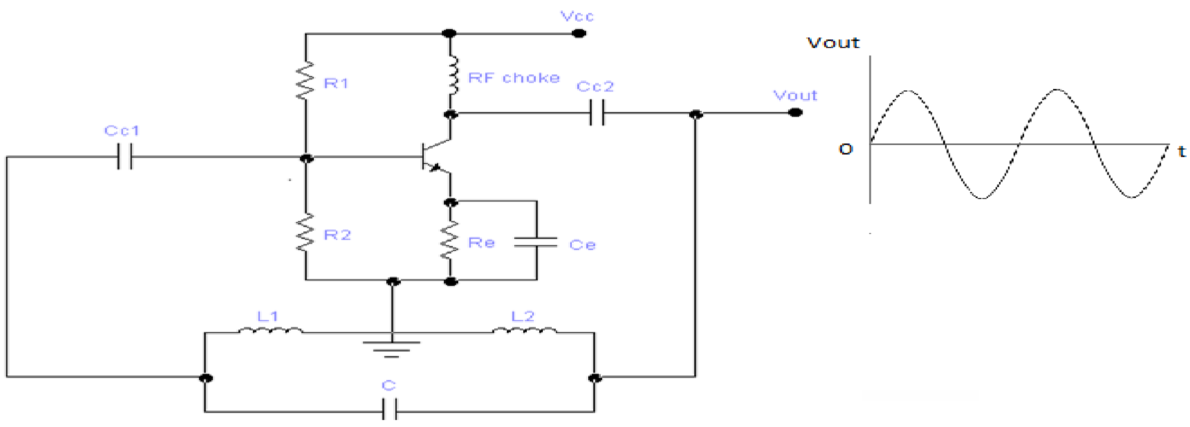


Fig 6.4: Hartley Oscillator

When the circuit is turned ON, the capacitor is charged. When this capacitor is fully charged, it discharges through coils L_1 and L_2 setting up oscillations of frequency determined by expression(1). The output voltage of the amplifier appears across L_2 and feedback voltage across L_1. The voltage across L_1 is 180^0 out of phase with the voltage developed across L_2.A phase shift of 180^0 is produced by the transistor and a further phase shift of 180^0 is produced by L_1-L_2 voltage divider circuit. In this way feedback is properly phased to produce continuous undamped oscillations.

6.9. Colpitt's Oscillator

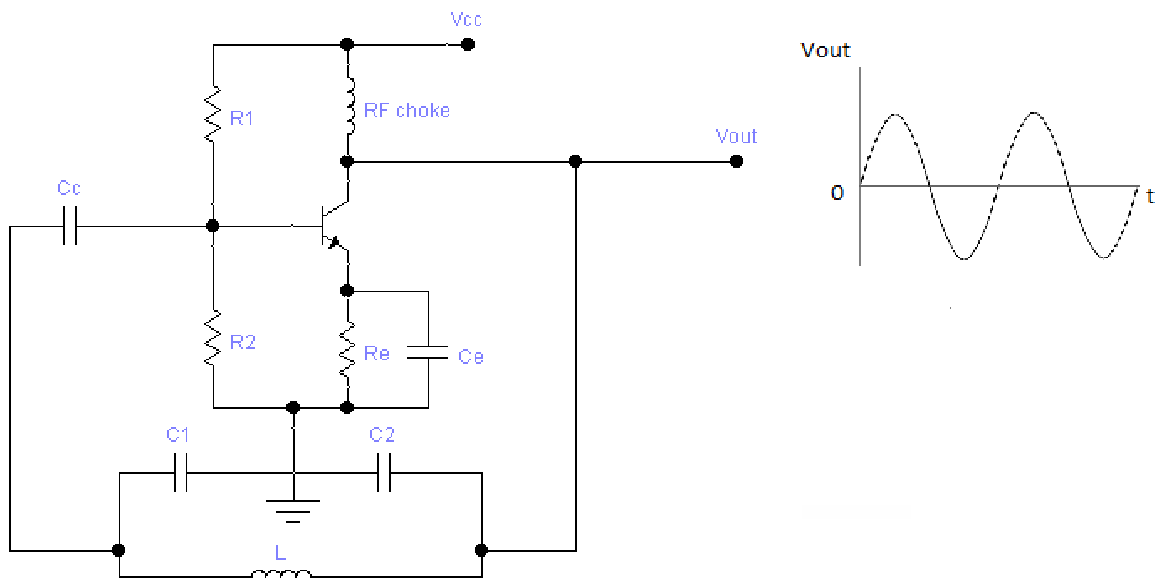


Fig 6.5: Colpitt's Oscillator

The circuit diagram of Colpitt's Oscillator is as shown in figure below. It uses two capacitors placed across common inductor L and the center of two capacitors are tapped with ground terminal of ckt . The tank circuit is made up of C_1 , C_2 and L. The frequency of oscillations is determined by

$$f = \frac{1}{2\pi\sqrt{LC_T}}$$

$$where\ C_T = \frac{C_1 C_2}{C_1 + C_2} \qquad \text{----------------------- (2)}$$

When the circuit is turned ON, the capacitor C_1 and C_2 are charged. The capacitors discharge through L setting up oscillations of frequency determined by expression (2). The output voltage appears across C_2 and feedback voltage is developed across C_1. The voltage across C_1 is 180^0 out of phase with the voltage developed across C_2 (V_{out}). A phase shift of 180^0

is produced by the transistor and a further phase shift of 180^0 is produced by C_1-C_2 voltage divider. In this way feedback is properly phased to produce continuous undamped oscillations.

Demerits of LC Oscillator

They suffer for frequency instability and poor waveform

They cannot be used to generate low frequencies, since they become too-much bulky and expensive too.

6.10 Quartz crystal

A quartz crystal exhibits a very important property known as the piezoelectric effect. When a mechanical pressure is applied across the faces of the crystal, a voltage which is proportional to mechanical pressure appears across the crystal. That voltage causes distortion in the crystal. Distorted amount will be proportional to the applied voltage and also an alternate voltage applied to a crystal it causes to vibrate at its natural frequency. The equivalent circuit of a quartz crystal is as shown in Fig 6.6.

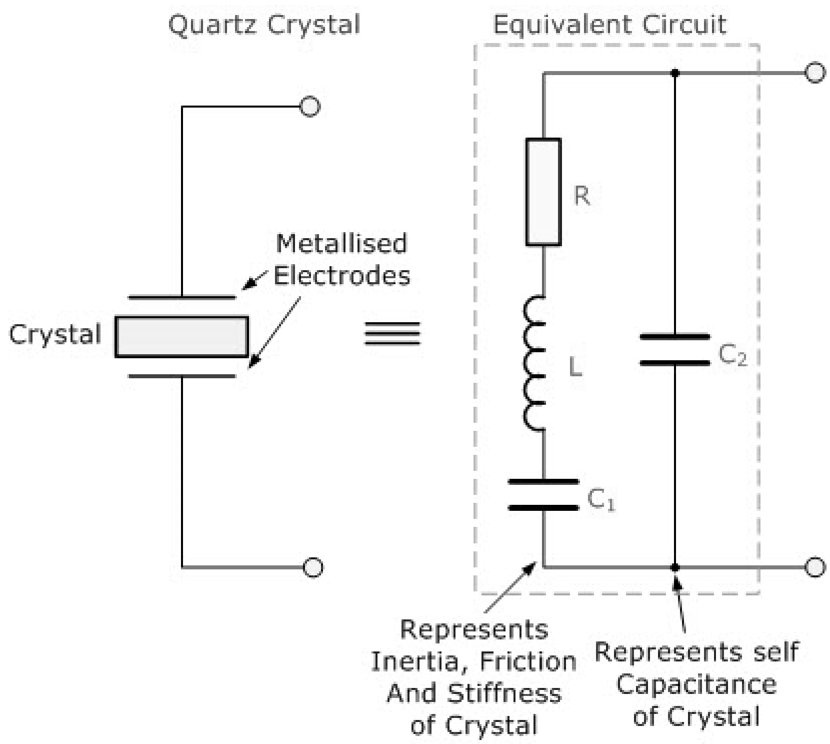


Fig 6.6: Equivalent circuit of Quartz Crystal

6.11 Crystal Oscillator

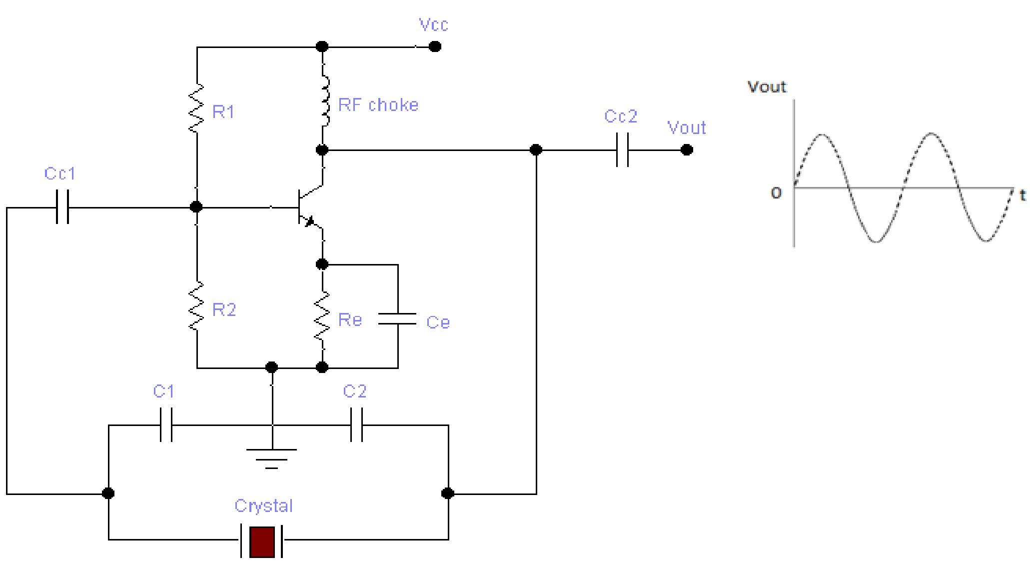


Fig 6.7: Crystal oscillator

Figure 6.7 shows the crystal oscillator circuit diagram. The crystal will act as parallel – tuned circuit. At parallel resonance, the impedance of the crystal is maximum. This means that there is a maximum voltage drop across C_2. This in turn will allow the maximum energy transfer through the feedback network. The feedback is +ve. A phase shift of 180^0 is produced by the transistor. A further phase shift of 180^0 is produced by the capacitor voltage divider. This oscillator will oscillate only at f_p.Where f_p = parallel resonant frequency i.e the frequency at which the vibrating crystal behaves as a parallel resonant circuit.

Advantages

It has higher order of frequency stability

The Q-factor of the crystal is very high.

Disadvantages

It can be used in low power circuits.

The frequency of oscillations cannot be changed appreciably.

6.12 RC Phase Shift Oscillator

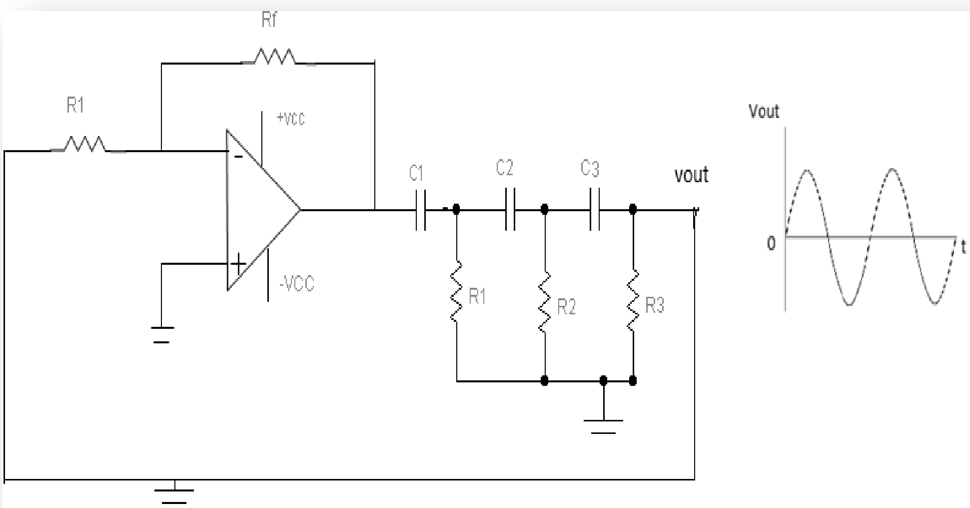


Fig 6.8: RC phase shift Oscillator

It consists of op- amplifier and a RC phase shift circuit. The RC phase shift circuit consists of three sections R_1C_1, R_2C_2, and R_3C_3.At some particular frequency f_0 the phase shift in each RC section is 60^0 so that the total phase shift produced by the RC network is 180^0. The frequency of oscillation is given by

$$f_o = \frac{1}{2\pi RC\sqrt{2N}} \quad \text{-------------------------------------} \ (3)$$

f_o is the Output Frequency in Hertz

R is the Resistance in Ohms

C is the Capacitance in Farads

N is the number of RC stages

When N=3 , $f_O = \frac{1}{2\pi RC\sqrt{6}}$

When the circuit is switched ON it produces oscillations of frequency determined by equation(3). The output of the amplifier is feedback to RC feedback network. This network produces a phase shift of 180^0 and the transistor gives another 180^0 shift. Thereby total phase shift of the output signal when fed back is 360^0

Merits

They do not require inductor thereby reduce the cost.

They are quite useful in the low frequency range where tank circuit oscillators cannot be used.

They provide constant output and good frequency stability for all audio frequency signals.

Demerits

It is difficult to start oscillations.

The circuit requires a large number of components.

They cannot generate high frequencies and are unstable as variable frequency generators.

6.13 Wein Bridge oscillator

The Wien Bridge oscillator is a two-stage RC coupled amplifier circuit that has good stability low distortion at its resonant frequency. The Wien bridge oscillator op-amp is used as the oscillator circuit and it is working like a non inverting amplifier. The Wien Bridge oscillator is a two-stage RC coupled amplifier circuit that has good stability low distortion at its resonant frequency

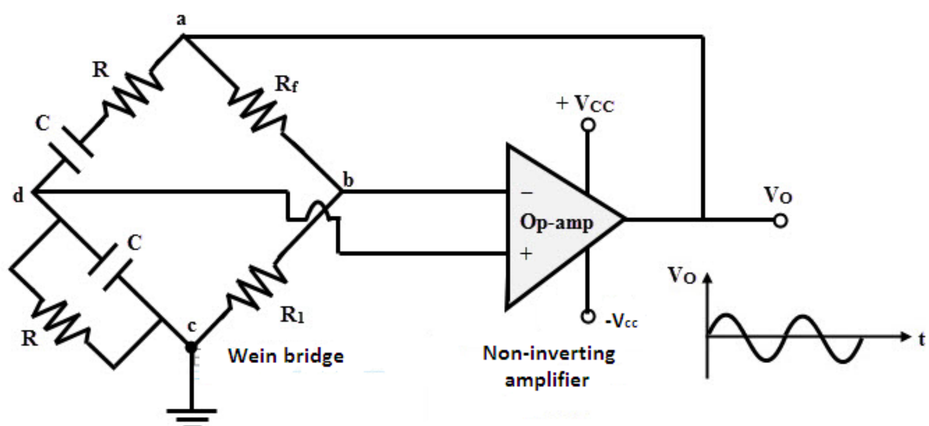


Fig 6.9 Wein Bridge Oscillator

Due to the advantages like good frequency stability, very low distortion and ease of tuning, a Wien bridge oscillator becomes the most popular audio frequency range signal generator circuit. This type of oscillator uses RC feedback network so it can also be considered as RC oscillator.

The main difference between the general oscillator and Wien bridge oscillator is that in an oscillator, amplifier stage introduces 180 degrees phase shift and additional 180 degrees phase shift is introduced by feedback network so as to obtain the 360 degrees or zero phase shift around the loop to satisfy the Barkhausen criteria.

The Figure 6.9 shows a widely used type of Wien bridge oscillator. The operational amplifier is used in a non inverting configuration and feedback form a voltage divider network. The resistances R1 and Rf forms the part of the feedback path which determines or facilitates to adjust the amplifier gain.The output of op-amp is connected as input to the bridge at points a and c while the output of the bridge at points b and d are connected to the input of op-amp.A portion of the amplifier output is feedback through the voltage divider network (a series combination of resistor and capacitor) to the positive or non-inverting terminal of the amplifier.Second portion of the amplifier is feedback to the inverting or negative terminal of the amplifier through the impedance of magnitude 2R.

If the feedback network elements are chosen properly, the phase shift of the signal input to the amplifier is zero at certain frequency. Since the amplifier is non-inverting which introduce zero phase shift plus the feedback network zero phase shift, the total phase shift becomes zero around the loop hence the required condition of oscillations.

Therefore the Wien bridge oscillator works as a sine wave generator whose frequency of oscillations is determined by R and C components.

The gain of amplifier = $1+\frac{R_f}{R_1}$

To satisfy conditions for sustained oscillations $A_V\beta = 1$ the gain of amplifier must be min 3.

$$\left(1 + \frac{R_f}{R_1}\right) \geq 3$$

If $\frac{R_f}{R_1} > 2$

The frequency of oscillation $f_o = \frac{1}{2\pi RC}$

Features

By varying capacitors simultaneously, by mounting them on single shaft, different frequency range can be obtained.

Perfect sine wave output is possible

It is used in AF range of 20 Hz to 20 KHz

Frequency stability is poor.

More number of components are used which increases the cost.

Applications

It is used to measure the audio frequency.
Wien bridge oscillator designs the long range of frequencies
It produces sine wave.

https://www.youtube.com/watch?v=aJAZHPqEUKU

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