- Electric Circuit: The closed path followed by an electric current.

$$I = \frac{dQ}{dt} \quad C/s \text{ or Amp}$$

$$P = \frac{dw}{dt}$$

- Electromotive Force: Voltage of an energy source.

$$V = \frac{dw}{dQ}$$

$$P = \frac{dw}{dQ} \cdot \frac{dQ}{dt} = VI$$

$$W = \int_{-\infty}^{t} P\,dt \quad J$$

⇒ Current entering +ve terminal → Absorbing
" leaving " " → Delivering

- Absorbing Power / Delivering Power

When the current is entering the +ve terminal then the element is absorbing power.
When the current is leaving the +ve terminal then the element is ~~leaving~~ delivering power.

1. Active Elements:

i. When an element is capable of delivering power independently for infinite time is active element

~~2. Passive E~~

ii. When an element is having property of internal amplification, it is an active element.

2. Passive Elements:

i. When an element is not capable of delivering energy independently then the element is called passive element.

Eg:- Resistor, Inductor, Capacitor, etc.

a. Resistor: current is directly proportional to applied voltage.

b. Capacitor : $i = C \frac{dv}{dt}$

c. Inductor: $v = L \frac{di}{dt}$

a. Resistor :

$J = \sigma E$ → Ohm's law 1st form

J → current density in amperes per square meter

σ => Conductivity of the substance which is constant for each particular substance.

E → Electric field along the conducting substance in volts per meter.

$$J = \frac{I}{A}$$

$$\frac{I}{A} = \frac{1}{\rho} \cdot \frac{V}{l}$$

$$\frac{I}{A} = \frac{V \cdot l}{RA\,l}$$

$$I = \frac{V}{R}$$

$V = IR$ - Ohm's law 2nd form

$I = GV \rightarrow$ Ohm's Law 3rd form

$$G = \frac{1}{R}$$

$V = R\frac{dQ}{dt} \rightarrow$ Ohm's law 4th form

2. Capacitor:

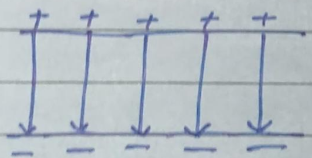


Fig: Electric field lines or lines of force b/w two charged conductors.

$$E = \frac{F}{Q}$$

Area of the plates as A and charge on the top plate be Q

Charge Density $= \frac{Q}{A}$

Acc. to Gauss's Law

$Q = \oint_S D \cos\theta \, ds$

$ds \rightarrow$ Increment of surface

$\theta \rightarrow$ Angle b/w D and ds.

$D \rightarrow$ Flux Density

$Q = D.A$

$D = \varepsilon.E$

$E = \frac{Q}{\varepsilon.A}$

$V = Ed$

$$\boxed{V = \frac{Q}{\varepsilon.A} d}$$

$V = D\,Q$

$D \rightarrow$ elastance $\rightarrow$ reciprocal of Capacitance

~~$C = \frac{Q}{}$~~

$$\boxed{V = \frac{Q}{C}} \Rightarrow \boxed{Q = CV}$$

$$\boxed{C = \frac{\varepsilon A}{d}}$$

$$\frac{dq}{dt} = \frac{c\,dv}{dt}$$

$$\boxed{\begin{aligned} i &= C\frac{dv}{dt} \\ v &= \frac{1}{C}\int_{-\infty}^{t} i\,dt \end{aligned}}$$

$P = Vi$

$$\boxed{P = vC\frac{dv}{dt}}$$

$$W = \int P\,dt = \int VC\frac{dV}{dt}\,dt$$

$$W = \frac{1}{2}CV^2$$

* Linear & Non-Linear Resistors:

When the resistor follows ohm's law it is linear resistor & when the resistor doesn't follow ohm's law it is non-linear resistors.

⇒ Bidirectional → Independent of direction of current.

⇒ when $C = 0$, $\frac{dV}{dt} = 0$] Steady state → Open Circuit
so $i = 0$

⇒ Capacitor doesn't allow sudden change in voltage.

$$i = C\frac{dV}{dt}$$

$dt \to 0$ for sudden change
$i \to \infty$ so it doesn't allow to change voltage suddenly

- Linear Capacitor:
  When capacitance on the capacitor is independent on voltage magnitude then capacitor is called as linear capacitor.

- Non-Linear Capacitor:
  When capacitance on the capacitor is dependent on voltage magnitude then capacitor is called as non-linear capacitor.

3. Inductor:

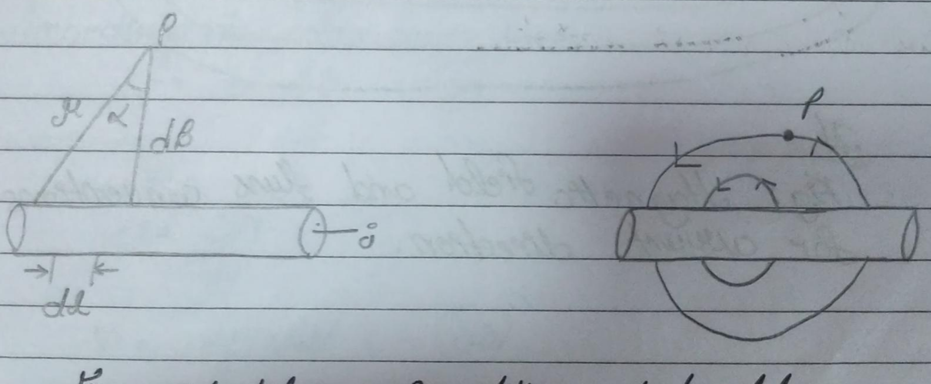


Fig: Identifying Quantities which determine the magnetic field at point P.

classmate
Date
Page

Force per unit magnetic pole.

$$dB = \frac{\mu i \cos\alpha \, dl}{4\pi r^2} \quad - (i)$$

μ = magnetic permeability
i = current

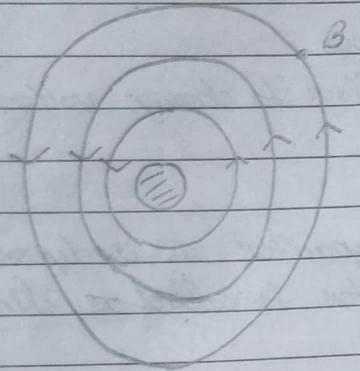


Fig: Cross-section of a current carrying inductor.

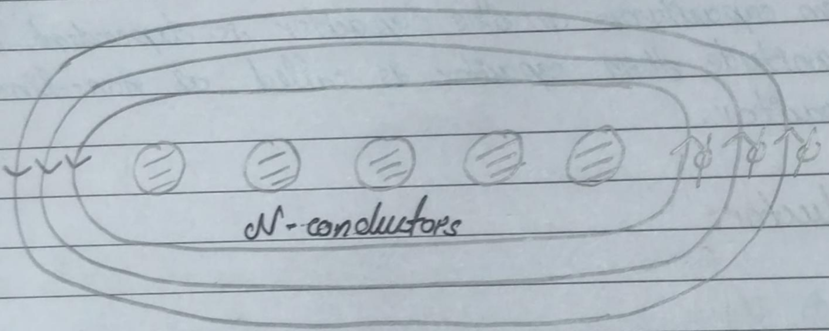


Fig: Magnetic field and flux conventions for current direction.

from (i)

* The magnetic field density ~~from (i)~~ is constant for a constant distance from the current carrying conductor.

The lines of magnetic field density by the lines of magnetic flux is given by

$$\phi = \int_{s} B\cos\theta \, ds \quad - (ii)$$

The total no. of flux linkage

$$\psi = \sum_{j=1}^{N} N_j \phi_j \quad (iii)$$

~~N no of conductors when linked together in a magnetic field there'll be flux linkage.~~

flux linkage is the linking of the magnetic field with the conductors of a coil when the magnetic field passes through the loops of the coil, expressed as a value.

$$\psi = N \int_{s} B\cos\theta \, ds \quad - (iv)$$

According to faraday's law

$$v = K \frac{d\psi}{dt} \quad - (v)$$

$K = 1$

$$v = \frac{d\psi}{dt} \quad - (vi)$$

$$\psi = \int_{-\infty}^{t} v\,dt \quad - (vii)$$

$$q = \int_{-\infty}^{t} i\,dt \quad - (viii)$$

$$\psi = \left[N \int \left(\int \frac{\mu \cos \theta \, dl}{4\pi r^2} \right) ds \right] i \quad \text{- (ix)}$$

ψ and i are inductance parameters

$$\psi = L i \quad - (x)$$

$L \rightarrow$ Self Inductance $\rightarrow$ Both ψ and i have same physical parameters

If current i_1 produces flux linkages ψ_2 in another circuit the parameter is one of the mutual inductance.

$$\psi_2 = M_{21} i_1 \quad - (xi)$$

Substitute (x) in (vi)

So

$$v = \frac{d(Li)}{dt}$$

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

* We can't change current suddenly as

$dt \rightarrow 0$

So $v = \frac{di}{dt}$

So $v \rightarrow \infty$

* In steady state, inductor is short circuit

$dt \rightarrow \infty$

$v = 0$

- **Linear/ Non-Linear Inductance:**

When the inductance of the inductor depends on the current magnitude, it is known as non-linear inductor.

when the inductance of the inductor doesnot depends on the current magnitude, it is known as linear inductor.

- **Types of Resistors:**

i) Fixed Resistors
ii) Variable Resistors.

Fixed resistor
↓
Molded carbon Composition resistor

→ (i) Carbon Clay Composition
→ (ii) Metallized type
→ (iii) Wire Wounded resistor

Q. A resistor has a colour band sequence yellow violet orange and gold. Find the range in which its value must lie so as to satisfy the manufacture's tolerance.

Ans. Yellow → 4
Violet → 7
Orange → 10^3
Gold → ± 5

$(47 \times 10^3) \pm 5\%$
$= 44.65 \times 10^3 - 49.35 \times 10^3$

$2350\ \Omega$

			1st-2nd Band	3rd Band	4th Band
		Black	0	10^0	Gold → ±5%
Bye	Bill	Brown	1	10^1	Silver → ±10%
Bye	Brown	Brown			No color (bare) → ±20%
Rosie	Realised	Red	2	10^2	
off	only	Orange	3	10^3	
Your	Yesterday	Yellow	4	10^4	
Go	Good	Green	5	10^5	
Bristol	Boys	Blue	6	10^6	
Via	Value	Violet	7	10^7	
Great	Good	Gray	8	10^8	
Western	Work	White	9	10^9	

- Type of Capacitor: → offers low impedance to AC & very high imp. to DC

a. Fixed Capacitor
b. Variable Capacitor

Capacitor is used to couple alternating voltage from one circuit to another circuit while at the same time blocking the DC voltage from reaching the next circuit. The capacitor is called as coupling capacitor or blocking capacitor or bypass capacitor.

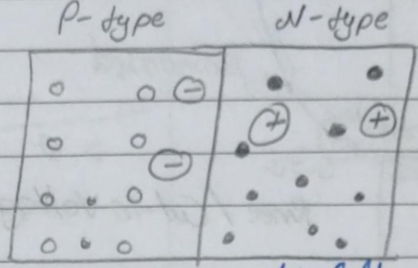
Three types of fixed capacitors:

i. MICA ↳ 5 pF to 10,000 pF
ii. Ceramic ↳ 3 pF to 2 μF
iii. Electrolyte ↳ more than both.

⇒ Capacitance colour code:

1st → Temp. Coefficient
2 → Significant Digits
3 →
4 →
5th → Tolerance

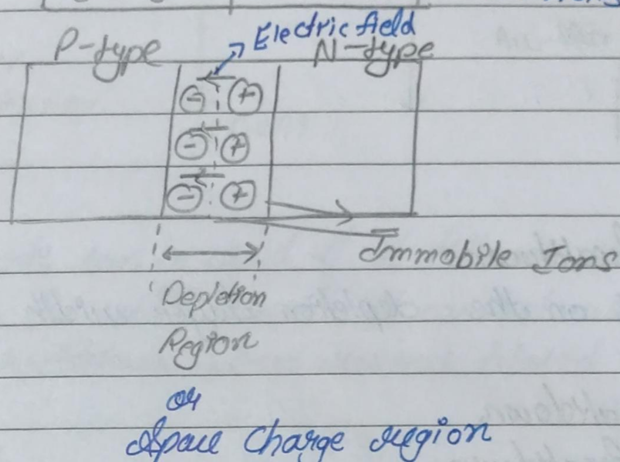
- PN Junction [No external voltage]



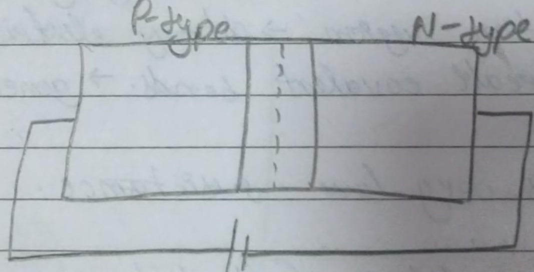
⊕ → +vely charged impurity ions

⊖ → -vely charged impurity ions

o → holes • → electrons

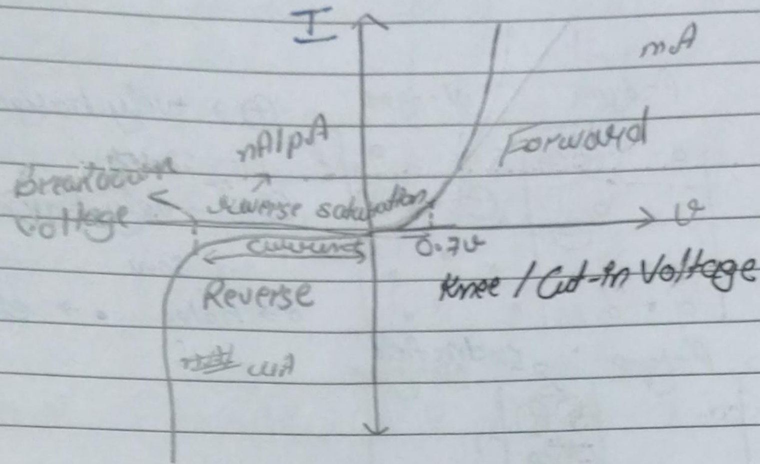


- Forward Bias - PN Junction



classmate
Date
Page

• I-V characteristics of a P-N junction diode:



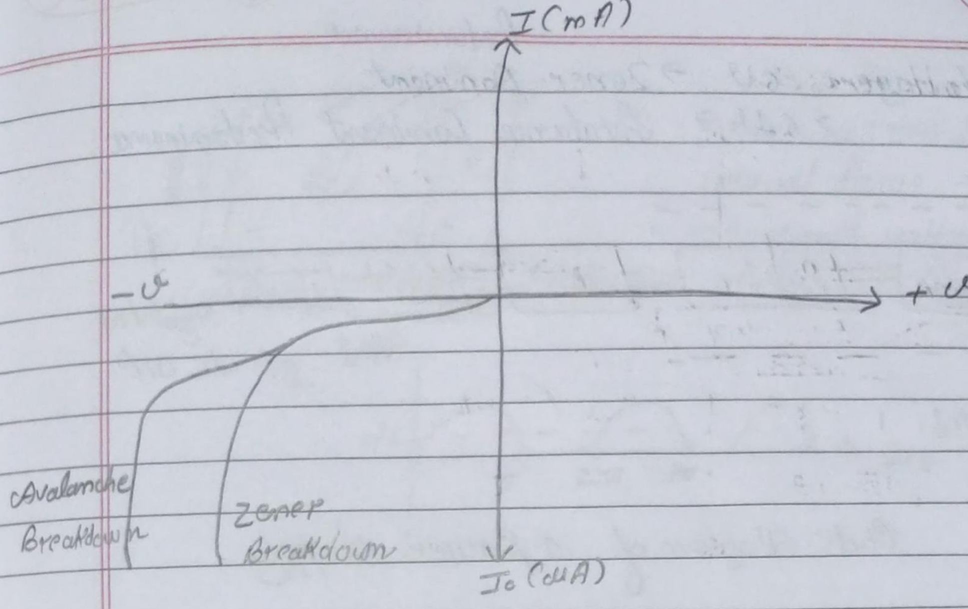
• Junction Breakdown:
It depends on the depletion layer width and the doping label.

1. Zener Breakdown
2. Avalanche Breakdown.

1. Zener Breakdown:
It occurs when semiconductor is highly doped. & we have narrow depletion region → strong electric field → strong enough to break covalent bonds. → generate e⁻- hole pair

Junction has very low resistance.

2. Avalanche Breakdown: (flood of carriers)
Lightly doped → large depletion region → not strong $\vec{E}$ → can't break covalent bonds.
high energy ⟵⟶ increase v of minority carriers.
have ability to break covalent bonds → generate carriers - accelerated by $\vec{E}$ → more collisions → more generation.



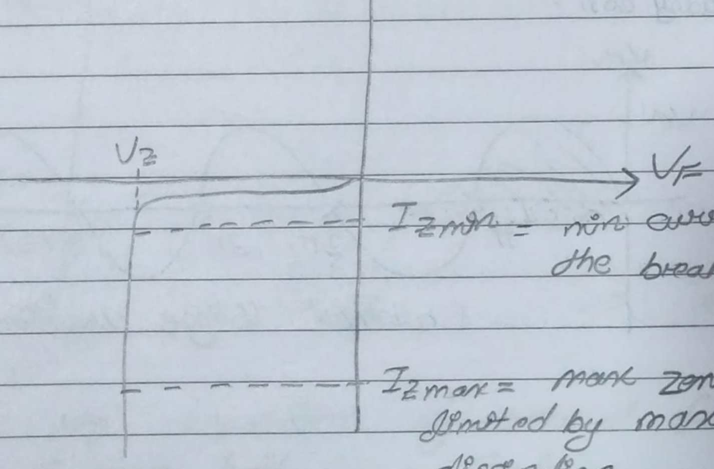
* Ideal diode can be said if it follows:

i. When its forward biased it conducts with 0 resistance → short circuit

ii. Infinite resistance when reverse biased → open circuit

• Zener Diode:

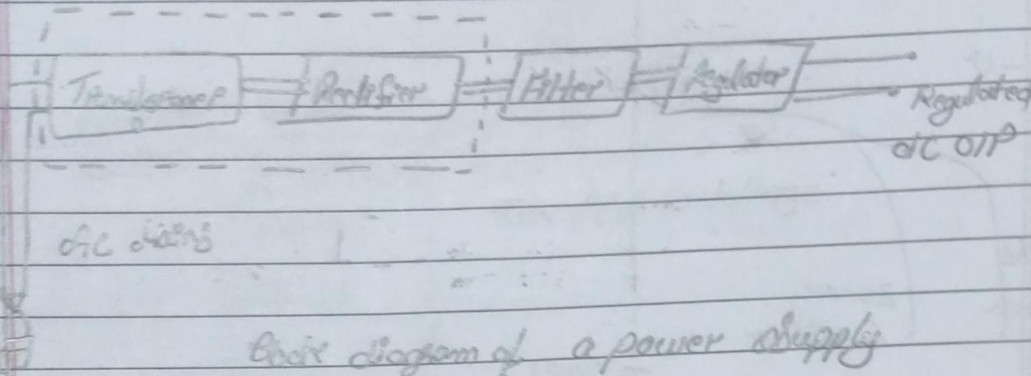
It is a reverse biased heavily doped silicon/germanium P-N junction diode which is operated in the breakdown region where the current is limited by both external resistance.



I_{Zmin} = min current to sustain the breakdown

I_{Zmax} = max Zener current limited by maximum power dissipation.

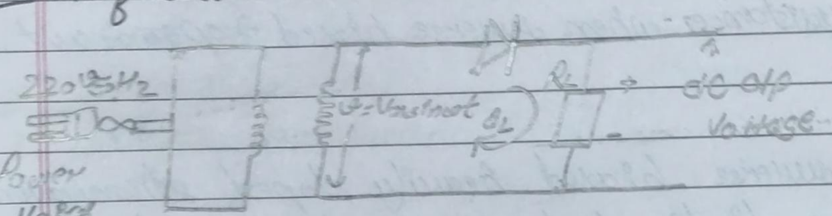
Reverse Voltage < 6V → Zener ~~Dominant~~ Predominance
> 6 V → Avalance ~~Dominant~~ Predominance



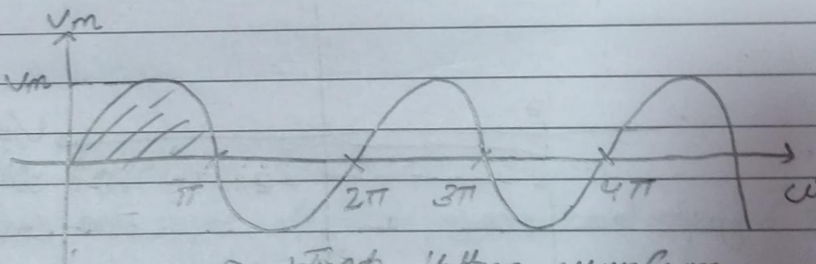
Basic diagram of a power supply

- Rectifiers:

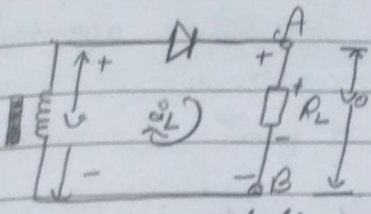
1. Half Wave Rectifier –



Primary is connected to ~~AC~~ power supply → induce current in secondary coil.

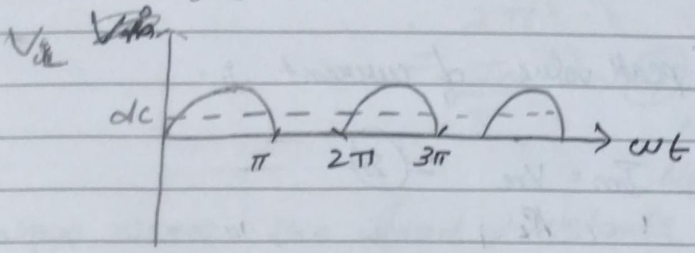


(a) Input Voltage waveform



(a) During +ve half cycle

Diode acts ~~+ve~~ forward bias → current flows → low resistance → very small voltage drop



During reverse bias → no current → no voltage → no graph / current.

- Peak Inverse Voltage:
It will be the maximum voltage ~~induced in secondary coil during reverse biased~~ in which the diode must withstand during the −ve half cycle of input.
$PIV = V_m$. ~~It depr~~

- Output DC Voltage

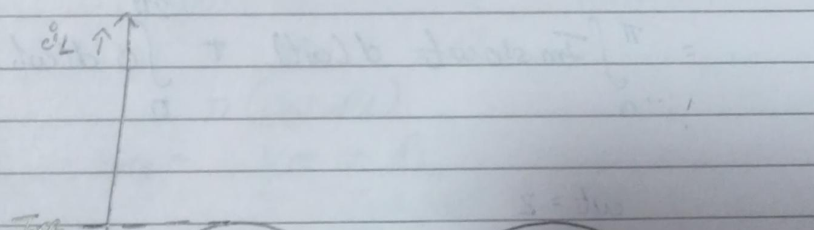


Fig: Waveform of current flowing through R_L in a half wave Rectifier.

classmate

Date

Page

$i_L = I_m \sin \omega t$ – (1)

for $0 \le \omega t \le \pi$

$i_L = 0$

for $\pi \le \omega t \le 2\pi$

I_m = peak value of current i_L.

$$I_m = \frac{V_m}{R_L} \quad -(2)$$

To find the dc or average value of current, we can find the net area under the curve over one complete cycle i.e. for 0 to 2π and divide this area by the base i.e. 2π.

we first integrate & then use eqn. (i) and to find the area.

$$\text{Area} = \int_0^{2\pi} i_L \, d(\omega t)$$

$$= \int_0^{\pi} I_m \sin \omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0 \, d(\omega t)$$

$$\omega t = z$$

$$d(\omega t) = dz$$

$$\text{Area} = \int_0^{\pi} I_m \sin z \, dz + 0$$

$$= 2 I_m \quad -(3)$$

classmate

Date
Page

Average value of the load current

$$I_{avg} = I_{dc} = \frac{\text{area}}{\text{base}}$$

$$= \frac{2I_m}{2\pi}$$

$$= \frac{I_m}{\pi} \quad - (4)$$

Assumptions:-
No resist. in forward bias
Negl. res. in sec. winding

DC voltage across the load resistance R_L,

$$V_{dc} = I_{dc} \times R_L = \frac{I_m}{\pi} \times R_L - (5)$$

If diode res. is not negligible & ~~load~~ diode resistance is comparable to R_L

$$I_m = \frac{V_m}{R_L} \Rightarrow I_m = \frac{V_m}{r_d + R_L}$$

$$V_{dc} = \frac{I_m}{\pi} \times R_L$$

$$= \frac{V_m}{\pi(r_d \times R_L)} \times R_L$$

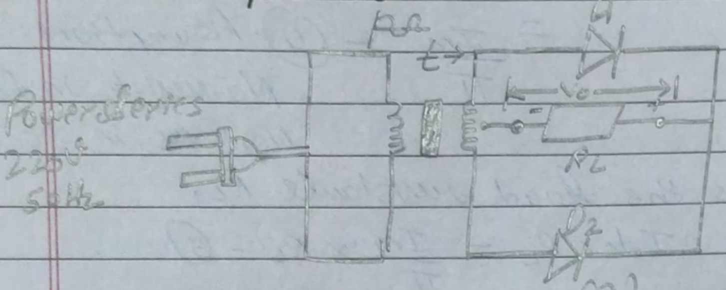
$$V_{dc} = \frac{V_m}{\pi} \times \frac{R_L}{(r_d + R_L)}$$

$$= \frac{V_m R_L}{\pi(r_d + R_L)} = \frac{V_m}{\pi\left(1 + \frac{r_d}{R_L}\right)}$$

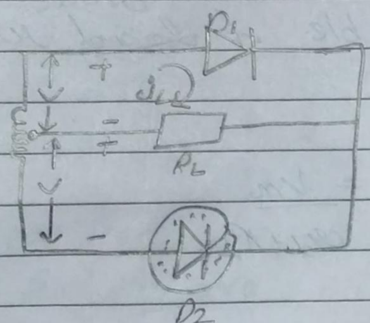
$$= \frac{V_m}{\pi} \quad \left[\text{if } r_d << R_L\right]$$

- Full-Wave Rectifier:
  (1) Centre tap Rectifier
  (2) ~~Rect~~ Bridge Rectifier

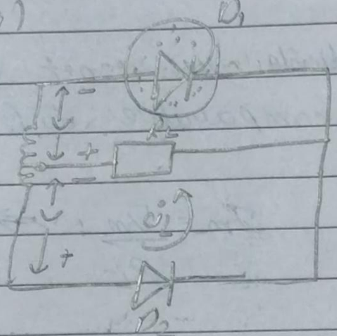
(1) Centre tap Rectifier



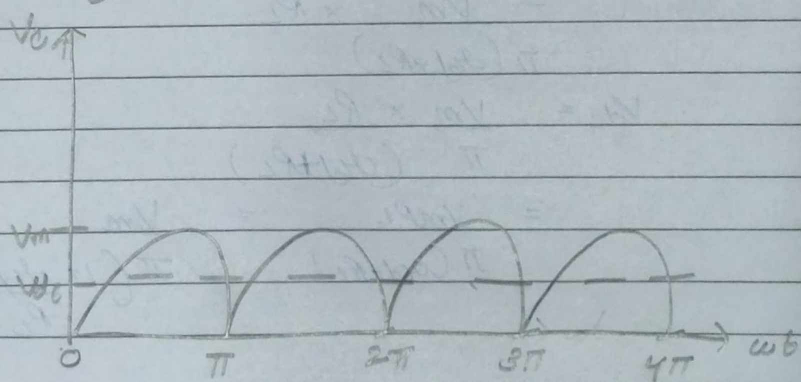
(a)



(b)
+ve half cycle



(c)
-ve half cycle



During the +ve half cycle of secondary voltage the diode D_1 is forward biased and D_2 is reverse biased.

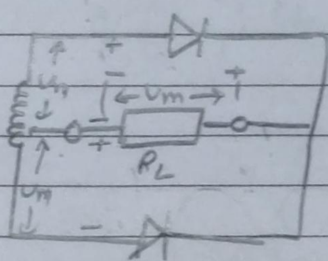
The current flows through the diode D_1 load resistor R_L and the upper half of the winding as shown in the figure no. (b).

During the -ve half cycle diode D_2 is forward biased and D_1 is reverse biased. Then D_2 will conduct.

The load ~~resistor~~ current in (b) & (c) is same.

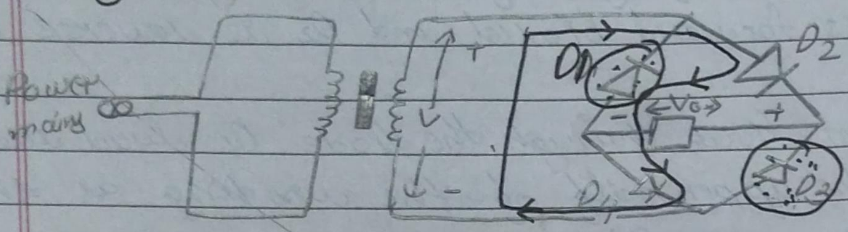
PIV for Center Tap:

$PIV = 2V_m$



The reverse voltage that appears across the non-conducting diode is the summation of the voltage across the load resistor R_L.

2. Bridge Wave Rectifier:

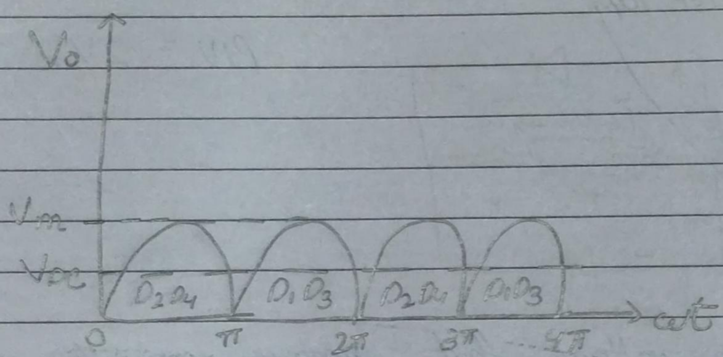


Positive Half Cycle D_2 & D_4 → forward bias → Conduct

D_1 & D_3 → Reverse Bias → Do not conduct

Negative Half Cycle D_1 & D_3 → ~~Re~~ for. bias → Conduct

D_2 & D_4 → reverse bias → Do not conduct



PIV: V_m

* V_m is the max. voltage across secondary winding in bridge wave & V_m is the max. voltage across half the secondary winding in centre tap.

- Output dc voltage in various rectifiers:

$$V_{dc} = \frac{2V_m}{\pi}$$

The output voltage of a full-wave rectifier is described as:

$$V_0 = V_m \sin\omega t \quad 0 \le \omega t \le \pi$$
$$= -V_m \sin\omega t \quad \pi \le \omega t \le 2\pi$$

The average or the dc value of voltage is

$$V_{dc} = \frac{1}{2\pi} \int_0^{2\pi} V_0 \, d(\omega t)$$

$$= \frac{1}{2\pi} \int_0^{\pi} V_m \sin\omega t \, d(\omega t) - \int_{\pi}^{2\pi} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{1}{2\pi} V_m \left[\int_0^{\pi} \cancel{V_m} \sin t \, dt - \int_{\pi}^{2\pi} \sin t \, dt \right.$$

$$\cancel{= \frac{1}{2\pi} \quad -\cos t \; + [\cos t]_{\pi}^{2\pi}}$$

$$= (+2+2) \frac{V_m}{2\pi}$$

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

- Ripple factor:

Ripple factor is a measure of purity of dc output of a rectifier

$$r = \frac{\text{rms value of components of wave}}{\text{average or dc value.}}$$

- **Rectification efficiency:**

It tells us what percentage of total input AC power is converted into dc output power.

$$\eta = \frac{\text{dc power delivered to load}}{\text{ac input power from Transformer } (T_x) \text{ secondary}}$$

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

- **Performance of half-wave rectifier:**

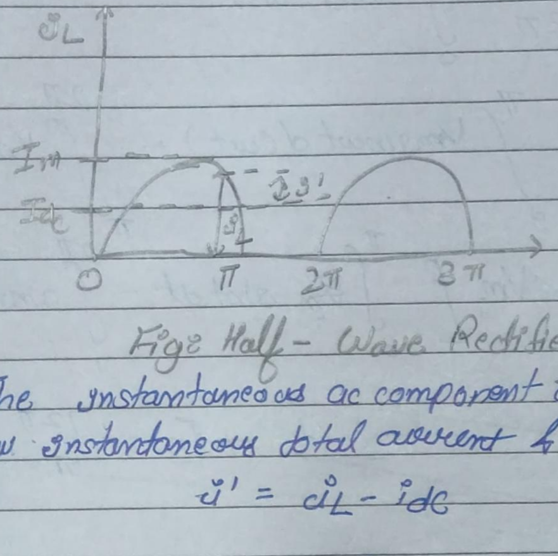


Fig: Half-Wave Rectified current value.

(The instantaneous ac component of current is the difference b/w instantaneous total current & dc current i.e.

$$i' = i_L - i_{dc}$$

$$i_L = I_m \sin\omega t \quad \text{for } 0 \le \omega t \le \pi$$
$$0 \quad \text{for } \pi \le \omega t \le 2\pi$$

⇒ RMS value of current -

The rms or effective value of the current flowing through the load is given by,

classmate

Date

Page

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_L^2\, d(\omega t)}$$

$$= \frac{I_m}{\sqrt{2\pi}}\sqrt{\int_0^{\pi} \frac{1-\cos 2\omega t}{2}}$$

$$= \frac{I_m}{\sqrt{2\pi}}\sqrt{\frac{\pi}{2} - \left[\frac{\sin 2\omega t}{2}\right]_0^{\pi}}$$

$$= \frac{I_m}{2}$$

$$i' = i_L - i_{dc}$$

The rms value of ac component.

$$I'_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (i_L - i_{dc})^2\, d(\omega t)}$$

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

$$r_f = \frac{I'_{rms}}{I_{dc}}$$

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

$$= \sqrt{\frac{I^2_{rms}}{I^2_{dc}} - 1}$$

$$= \sqrt{(1.57)^2 - 1}$$

$$\boxed{r_f = 1.21}$$

- Rectification efficiency of half-wave rectifier:

The dc power delivered to the load,

$$P_{dc} = I^2_{dc} R_L = \left(\frac{I_m}{\pi}\right)^2 R_L$$

The total ac input power is

$$P_{ac} = I^2_{rms}(r_d + R_L)$$
$$= \left(\frac{I_m}{2}\right)^2 (r_d + R_L)$$

So
$$\eta = \frac{P_{dc}}{P_{ac}} = \left(\frac{I_m}{\pi}\right)^2 \times \left(\frac{2}{I_m}\right)^2 \times \frac{R_L}{r_d+R_L}$$

$$= \frac{4}{\pi\left(1+\frac{r_d}{R_L}\right)} \times 100\%$$

$$= \cancel{\frac{P_{dc}}{\pi\left(1+\frac{r_d}{R_L}\right)}} \quad \frac{40.6\%}{1+\frac{r_d}{R_L}}$$

- Performance of full-wave rectifier.

RMS value of current

$$I_{rms} = \frac{1}{\sqrt{2\pi}}\sqrt{\int_0^{\pi} I_m^2 \sin^2\omega t + \int_{\pi}^{2\pi} I_m^2 \sin^2\omega t}$$

$$= \frac{I_m \times \sqrt{2}}{\sqrt{2\pi}} \int_0^{2\pi} \frac{1-\cos 2\omega t}{2}$$

$$= \frac{I_m}{\sqrt{\pi}} \sqrt{\pi - \frac{\sin 2\omega t}{2}}$$

$$= \frac{I_m}{\sqrt{\pi}} \cdot \frac{I_m}{\sqrt{2}}$$

RMS value of current

$$I_{rms} = \frac{1}{\sqrt{2\pi}} \sqrt{\int_0^{\pi} I_m^2 \sin^2 \omega t}$$

$$= \frac{I_m}{\sqrt{2\pi}} \times \sqrt{\pi}$$

$$= \frac{I_m}{\sqrt{2}}$$

$i' = i_L - i_{dc}$; $i_{dc} = \frac{2I_m}{\pi}$

$I'_{rms} = \cancel{i_L - i} \sqrt{I^2_{rms} - I^2_{dc}}$

$$r = \frac{I'_{rms}}{I_{dc}}$$

$$= \sqrt{\frac{I^2_{rms}}{I^2_{dc}} - 1}$$

$$= \sqrt{\left(\frac{I_m}{\sqrt{2}}\right)^2 \times \frac{\pi^2}{4 I_m^2} - 1}$$

$$= \sqrt{\frac{\pi^2}{8} - 1}$$

$$= 0.482$$

⇒ Rectification efficiency:

$$P_{dc} = I^2_{dc} R_L = \left(\frac{2 I_m}{\pi}\right)^2 R_L$$

Total ac Power $= I^2_{rms} (r_d + R_L)$

$$= \frac{I_m^2}{2} \, r_d + R_L$$

$$\eta = \frac{\frac{4I_m^2}{\pi^2} \times R_L}{\frac{I_m^2}{2}(r_d + R_L)} \times 100 = \frac{8}{\pi^2} \times 100 \times \frac{1}{\frac{r_d}{r_L} + 1}$$

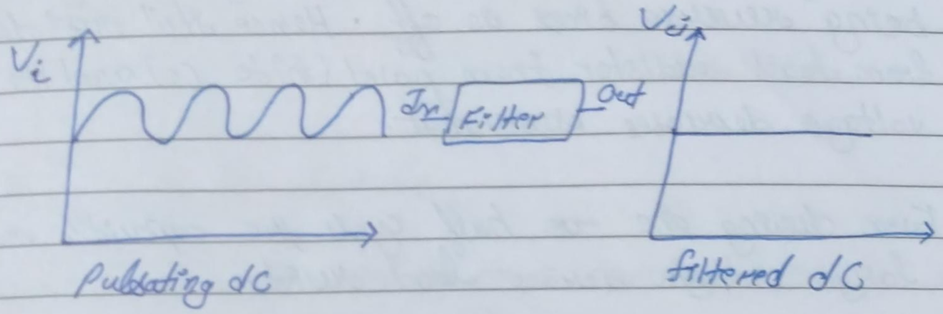
$$= \frac{81.2\%}{1 + \frac{r_d}{R_L}}$$

- Comparison of different rectifiers

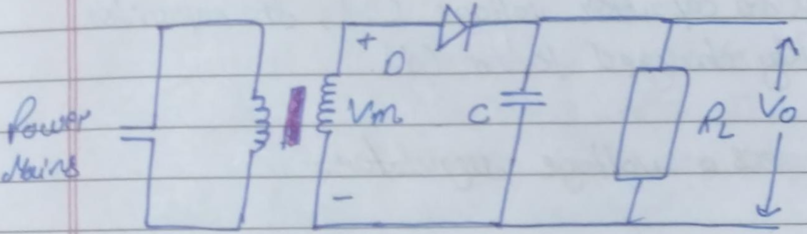
	Half-Wave Rectifier	Full-Wave Rectifiers: i Centre tap	ii Full Wave
1. No. of diodes	1	2	4
2. Tx necessary	No	Yes	~~Yes~~ No
3. Peak Sec. Volt	V_m	$2V_m$	V_m
4. Peak load current (I_m)	$\frac{V_m}{r_d + R_L}$	$\frac{V_m}{r_d + R_L}$	$\frac{V_m}{r_d + R_L}$
5. I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
6. I_{dc}	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
7. r	1.21	0.482	0.482
8. η	40.6%	81.2%	81.2%

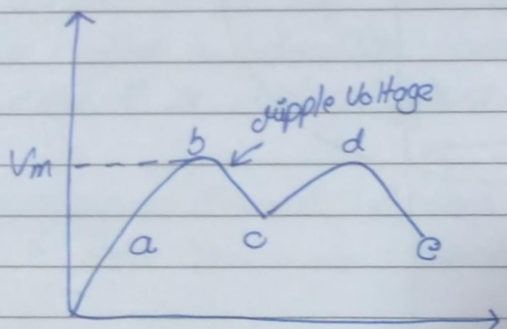
Transformer may be used for isolation even if not required for stepping up or down the input ac.

• Filters:
To minimise the ripple content.



• Shunt Capacitor filter →





∴ When the +ve half cycle of the AC input is applied the diode is in forward bias and hence it'll conduct. So this allows the capacitor to quickly charge upto V_m, i.e. upto (b).

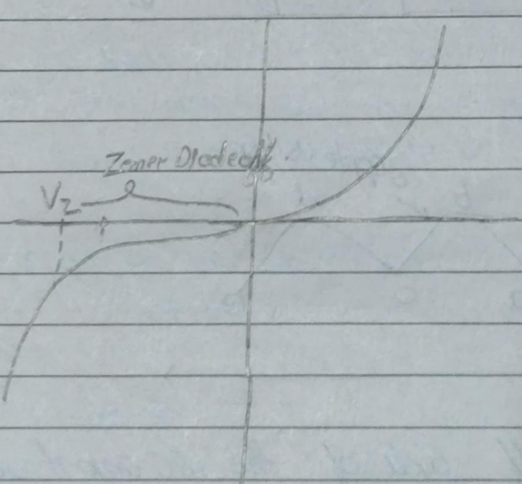
ii) After we fully charge, the capacitor holds the charge till the input ac supply to the rectifier goes negative.

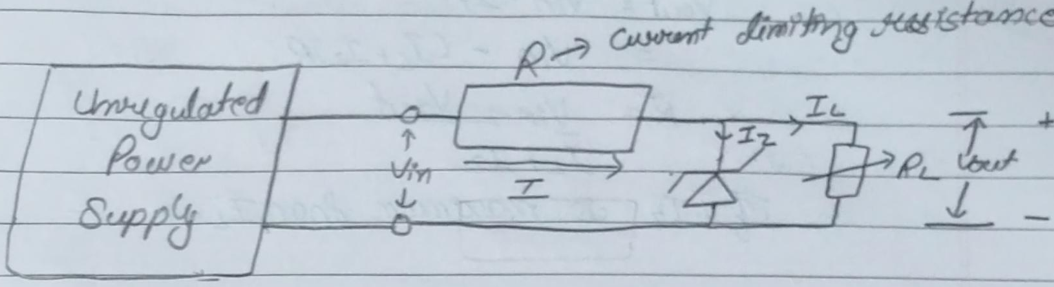
iii) During the -ve half cycle the capacitor attempts to discharge. However, it can't discharge through diode being reverse bias is off. Hence it'll ~~its~~ discharge from load resistor from point (b) to (c) and its voltage decreases somewhat.

iv) Even during the -ve half cycle the capacitor maintains large voltage across load resistor.

v) During the next +ve half cycle when the rectifier voltage exceeds the capacitor voltage (c), the capacitor is again quickly charged to V_m (d).

- Zener diode as a voltage regulator:





$V_{in} \geq V_Z$

$I_{\xi} = I_Z + I_L$

Voltage Regulator is used to keep constancy in the dc voltage

Case 1 Suppose R_L is kept fixed but supply voltage V_{in} is slightly increased.

i The increase in current I will be absorbed by zener diode without affecting I_L.

ii The increase in Vin will be dropped across R thereby keeping Vout constant.

iii On the other hand, if the supply voltage decrease the diode takes a smaller current and voltage drop across R is reduced, thus again keeping Vout constant.

iv When Vin changes I and IR drop changes in such a way as to keep $V_{out} = V_Z$ constant

2. Case II: Vin is fixed but I_L is changed.

i When I_L increases, diode current I_Z decreases thereby keeping I and IR drop constant. In this way Vout remains unaffected.

ii When I_L decrease, diode current I_Z increases thereby keeping I and IR drop constant. In this way Vout remains unaffected.

$$V_{out} = V_{in} - IR$$
$$= V_{in} - (I_L + I_Z)R$$
$$R = \frac{V_{in} - V_{out}}{I_L + I_Z}$$

If I_Z is maximum then $I_L = 0$

$$\text{So } R = \frac{V_{in} - V_{out}}{I_{Z(max)}}$$

- Half Wave Rectifier:

$$\text{Ripple factor} = \frac{1}{2\sqrt{3} f R_L C}$$

- Full wave Rectifier:

$$\text{Ripple factor} = \frac{1}{4\sqrt{3} f R_L C}$$

Q In a centre tap full wave rectifier the load resistance $R_L = 1k\Omega$. Each diode has forward bias resistance of 10Ω. The voltage across half the secondary winding is $220 \sin 314t$ volt. Find

i) Peak value of current

ii) DC / average value of current

iii) Rms value of current.

iv) ripple factor

v) Rectification efficiency.

$v = 220 \sin 100\pi t$

$2\pi f = 100\pi$

$f = 50 hz$

$R_L = 1000 \Omega$

$I_m = \frac{22\cancel{0}}{101\cancel{0}} = 0.217 A$

ii $\frac{2I_m}{\pi} = \frac{2 \times 0.217}{3.14} = 0.138 A$

iii $\frac{0.217}{\sqrt{2}} = 0.15\cancel{3}$

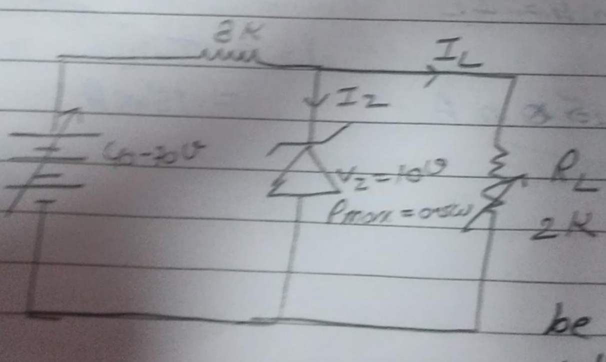
iv ~~0.482~~ $r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$

$= 0.478$

v $\eta = \frac{P_{dc}}{P_{ac}} = \frac{(I_{dc})^2 \times R_L}{I_{rms}^2 \times (R_L + R_d)}$

$\simeq 81.2\%$

Q



Calculate the battery current I, I_Z and I_L in the circuit. How will these values be affected if source voltage increases to 70V.

Neglect zener resistance.

~~Ans~~

$P_{max} = I_Z \cdot V_Z$

$\cancel{0.5 = I_Z \times 10}$

$0.05\,A = I_Z$

$5 \times 10^{-2}\,A = I_Z$

So $\cancel{I = \frac{40}{8 \times 10^{3}}}$

$\cancel{I = 8 \times 10^{-3}\,A}$

$V_{RL} = 30\,V$

So $V = IR$

$\cancel{\frac{30}{3 \times 10^{3}} = I_L}$

$\cancel{15 \times 10^{-3} = I_L}$

$\cancel{I_Z + I_L = I}$

$\cancel{15 \times 10^{-3} \times 5}$

When $V_{in} = 40\,V$

$V_Z = 10\,V$

$30\,V = IR$

$30 = I \times 3 \times 10^{+3}$

$10 \times 10^{-3} = I$

$10\,mA = I$

$\cancel{9.5\,mA = I_L}$

$\cancel{I_Z = 5\,mA}$

$IR = 30\,V$

$\frac{30}{3} \times 10^{-3} = I$

$10\,mA = I$

$i_L = \frac{10}{2000}$

$= 5\,mA$

$i_Z = I - i_L$

$= 5\,mA$

So $V_{in} = 70\,V$

$IR = 60$

$= \frac{60}{3} \times 10^{-3}$

$= 20\,mA$

$i_L = \frac{10}{2000} = 5\,mA$

$i_Z = I - i_L$

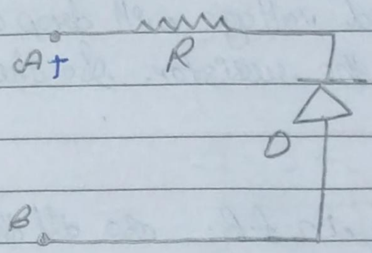
$= 15\,mA$

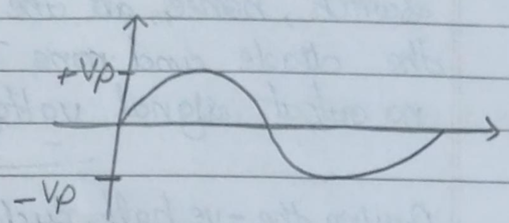
• Clippers and Clampers:

portion of input signal is clipped off

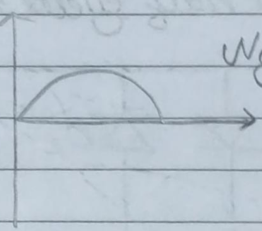
lift up or lift down the input signal to a different dc ~~circuit~~ level.

Clipper circuit:





Input Sine Wave Signal

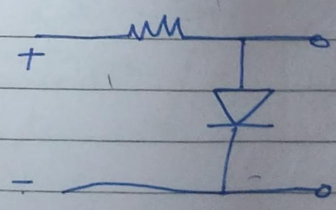


Negative Clipper

When the +ve half cycle of the signal is applied on the clipper A is +ve ~~on~~ wrt B the diode D is reverse biased. Hence it acts as an open circuit.

During the -ve half cycle D is forward biased, hence it acts a closed ~~circuit~~ switch.

Actual -ve clipper:



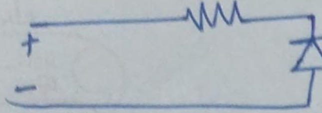
+ve half cycle

f.b. $V_i = V_o$

-ve half cycle

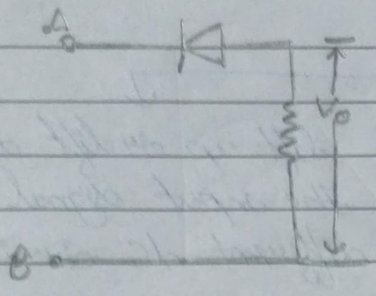
r.b. $V_o = 0$

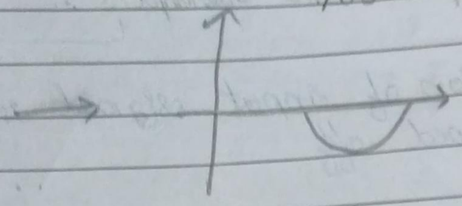
+ve clipper



+ve cycle R.b → $V_o = 0$
-ve cycle f.b → $V_o = +V_i$

Positive Clipper

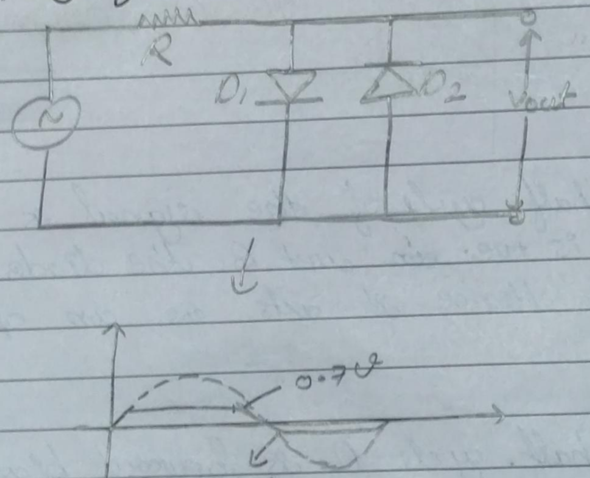


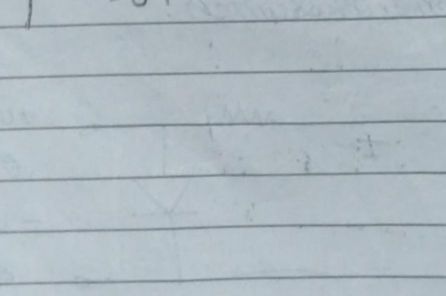


During the +ve half cycle of signal D acts an open switch, hence, all the applied voltage will drop across the diode and none across the resistor. So there's no output signal voltage.

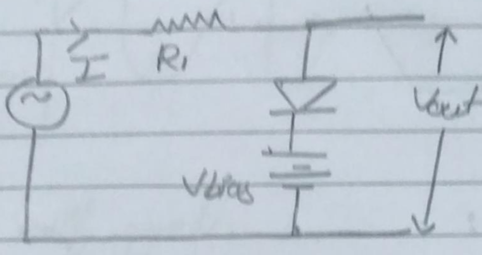
During the -ve half cycle D is in f.B. so all the voltage is across R.

- Clipping of both half cycles:

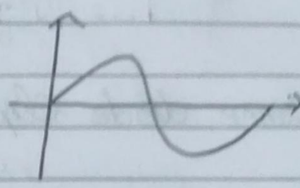




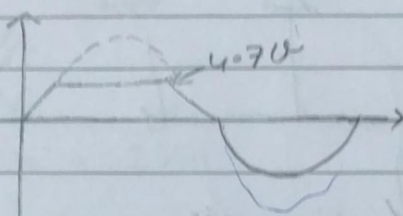
- Bias diode Clipping Circuits :



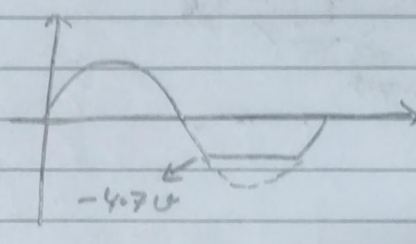
Positive bias diode



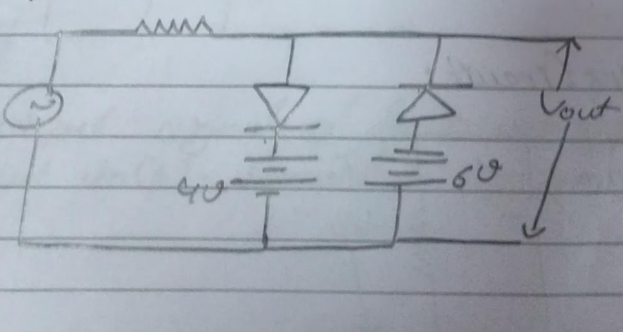
$V_{bias} + V_{diode} \nless V_{AC}$

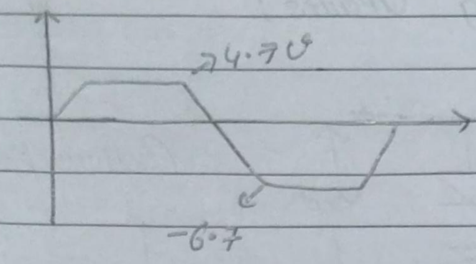


Negative biase

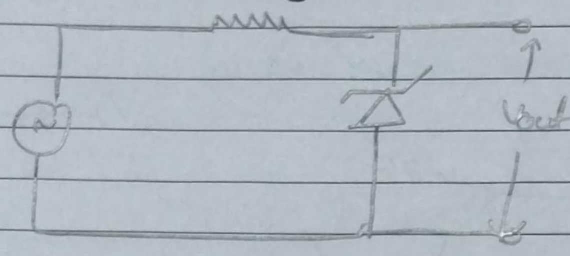


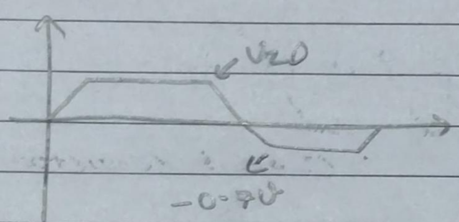
Q find o/p wave form.





- Zener diode Clipping:



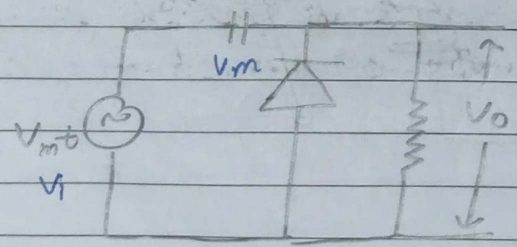


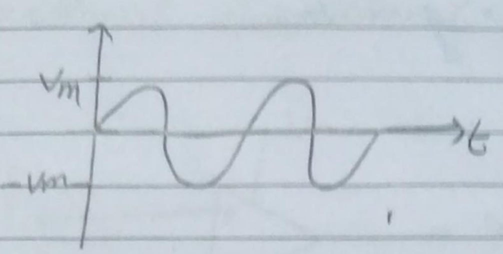
- Clampers:

time constant → $\lambda = CR$

$\lambda >> \frac{T}{2}$, where T = time period of the signal

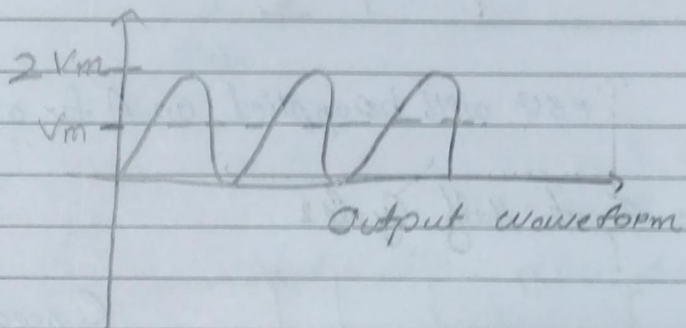
1. Positive Clampers Circuit:

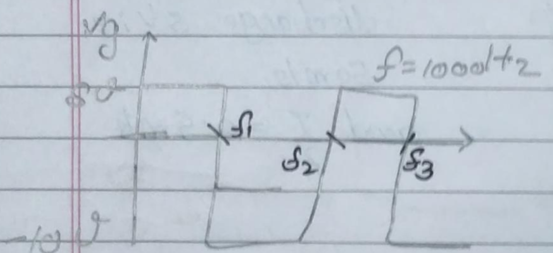


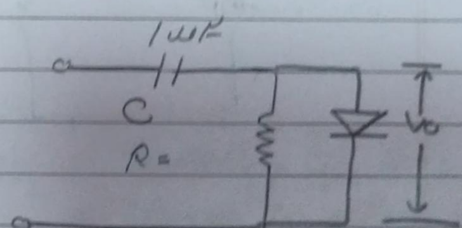


-ve half cycle:
Diode → F.B.
Capacitor → fully charge to +ve Vm.

+ve half cycle:
Diode → R.B.
O/p → $V_i + V_m = 2V_m$







The input signal of fig. (a) is applied to clamper circuit in (b). Draw the o/p waveform of o/p voltage V_o.

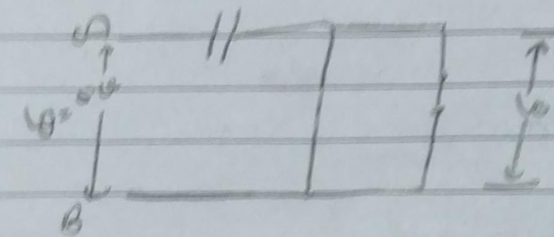
Time period of signal = $\frac{1}{f}$ = 1ms

$\frac{T}{2}$ = 0.5ms

λ = 10ms

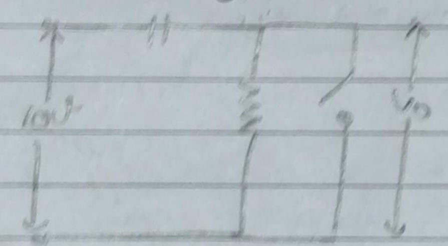
$\lambda >> \frac{T}{2}$

⇒ Positive Input Half-Cycle:



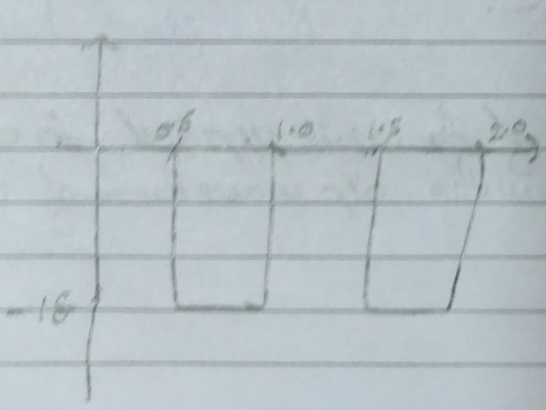
+5V will be applied on A for 0.5ms

⇒ Negative Input Half Cycle:

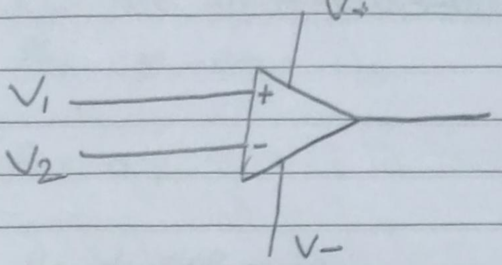


C needs 5λ to discharge 5V i.e. 50ms.

and $\frac{T}{2}$ = 0.5ms



• Operational Amplifier (Op Amp):

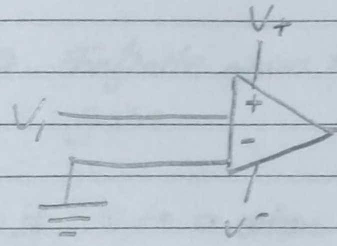


⇒ Two types:

i) Non-Inverting

ii) Inverting

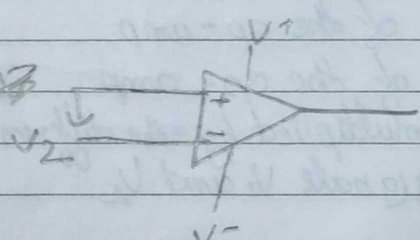
$$V_{out} = \underbrace{A}_{\text{Gain}}(V_1 - V_2)$$



$V_{out} = AV_1$

Non-Inverting Op Amp

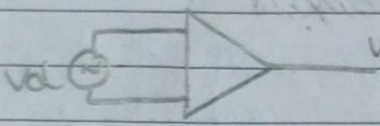
* No change in phase



$V_{out} = -AV_2$

Inverting Op Amp

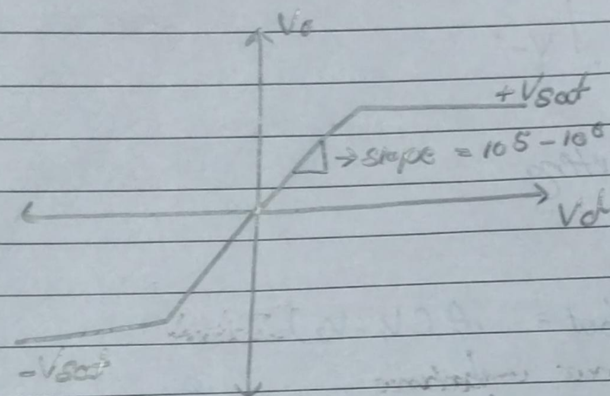
* Change in phase = 180°



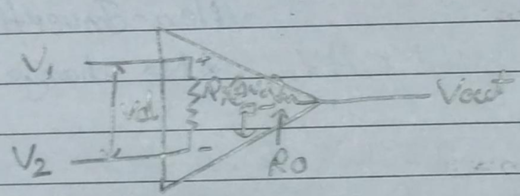
$V_{out} = A\, V_d$

↳ differential i/p V

$A \approx 10^5 - 10^6$



⇒ Equivalent circuit of Op-Amp:



R_i = input impedance of the op-amp
R_o = output impedance of the op-amp
V_{out} = open loop gain multiplied by the difference b/w the input signals V_1 and V_2.

classmate

Date
Page

- Characteristics of an Ideal Op-Amp:

1. $R_i = \infty$, so that the input that is being applied b/w the input terminals will be directly applied to the o/p-amp.

2. $R_o = 0$,

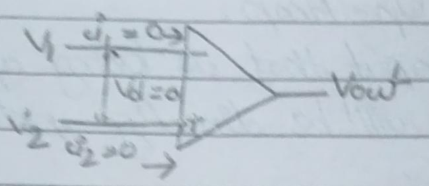
3. Bandwidth = ∞.

4. $A = \infty$

⇒

	Ideal	Practical
1. Infinite Input Impedance	$R_i = \infty$	$M\Omega$
2. Zero o/p Impedance	$R_o = 0$	Ω
3. Infinite open loop gain	$A = \infty$	$10^5 - 10^6$
4. $V_{out} = 0$ when $V_{in} = 0$		mV

$i_1 = i_2 = 0$ as $\Rightarrow R_i$ is ∞



⇒ Op-Amp draws no current at both the input terminals i.e. $i_1 = i_2 = 0$;

⇒ As the gain is infinite the Voltage b/w the inverting and non-inverting terminals is i.e. differential input voltage i.e. $V_d = (V_1 - V_2)$ is essentially zero, for the finite o/p voltage V_o.

- Feedback in Ideal op-amp:

⇒ -ve feedback:

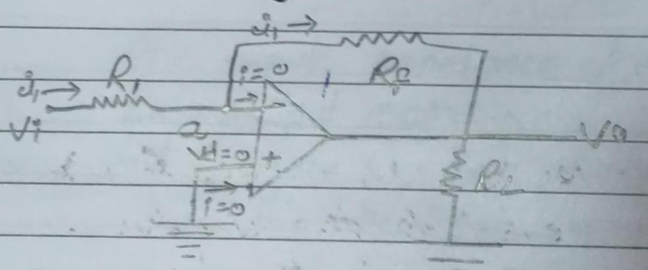
→ 2 basic feedback connection used.

Realistic Assumptions

i. The current drawn by the either of the o/p terminals is negligible.

ii. The differential i/p Voltage b/w non-inverting & inverting input terminal is zero.

⇒ The Inverting Amplifier:



(a) Inverting Amplifier

$$i_1 = \frac{V_i}{R_1}$$

$$V_o = -i_1 R_f = -V_i \frac{R_f}{R_1}$$

Gain of the inverting amplifier (Closed loop gain):

$$A_{CL} = \frac{V_o}{V_i} = -\frac{R_f}{R_1}$$

The nodal eqn. at the node 'a' is

$$\frac{V_a - V_i}{R_1} + \frac{V_a - V_o}{R_f} = 0$$

V_a is the Voltage at node 'a'.

a is grounded, so $V_a = 0$

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

Q Design an amplifier with the gain of -10 and input resistance $10\,k\Omega$.

Ans
$$-10 = \frac{-R_f}{R_1}$$

$$R_1 = 100\,k\Omega$$

Q $R_1 = 10\,k\Omega$, $R_f = 100\,k\Omega$ $V_1 = 1V$. A load of $25\,k\Omega$ is connected to the o/p terminal. Calculate i_1, V_o, i_L and the total current i_o in o/p.

Ans
$$i_1 = \frac{V_i}{R_1} = 10^{-4}A$$

~~$i_L = \frac{V_o}{R_f} = \frac{10}{100 \times 10^{-4}}$~~

$$V_o = \frac{-R_f}{R_1} \times V_i = -10\,V$$

$$i_L = \frac{10}{25\times10^3}$$
$$= \frac{1}{25}\times10^{-2}$$
$$= 4\times10^{-4}$$
$$= 0.4\ mA$$

$$i_T = (0.4+0.1)\,mA$$
$$= 0.5\,mA$$

- **Practical Inverting Amplifier:**

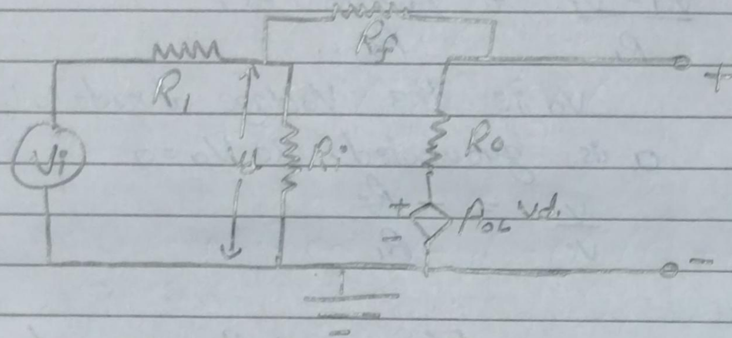


Fig: Equivalent circuit of a practical op-amp inverting amplifier

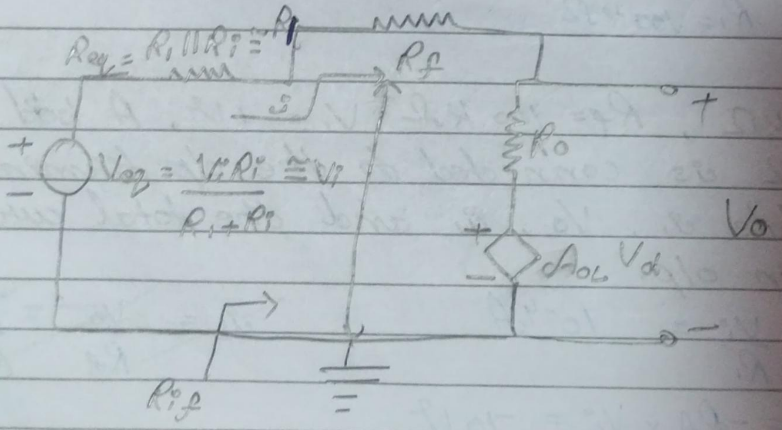


Fig: Simplified circuit by using Thevenin's Equivalent

From the o/p loop:

$$V_o = iR_o + \underset{\substack{\downarrow \\ \text{open loop gain}}}{A_{OL}} V_d \quad - (i)$$

Also

$$V_d + iR_f + V_o = 0 \quad - (ii)$$

Putting the value of V_d from (1) to (2) and simplifying.

$$V_o - iR_o - A_{OL}V_d$$
$$\underline{A_{OL}V_o + iR_fA_{OL} + A_{OL}V_d}$$

$$V_o(1+A_{OL}) + i(R_fA_{OL} - R_o) = 0$$

$$V_o = \frac{(R_o - R_fA_{OL})i}{1+A_{OL}} \quad - (3)$$

$$\frac{V_o - iR_o}{A_{OL}} = V_d$$

$$V_o - iR_o + i$$

Also, the KVL loop eqn.

$$V_i = i(R_1 + R_f) + V_o - (4)$$

Put the value of i from (3) into (4) and solve for closed loop gain,

$$A_{CL} = \frac{V_o}{V_i}$$

$$i = \frac{V_o(1+A_{OL})}{R_o - A_{OL}R_f}$$

$$V_i = V_o \frac{(1+A_{OL})(R_1+R_f)}{R_o - A_{OL}R_f} + V_o$$

$$V_i = V_o\left[\frac{1+A_{OL} + R_o - A_{OL}R_f}{R_o - A_{OL}R_f}\right]$$

$$\frac{V_o}{V_i} = \frac{R_o - A_{OL}R_f}{1+A_{OL}+R_o - A_{OL}R_f}$$

$$\frac{V_o}{V_i} = \frac{R_o - A_{OL}R_f}{1+A_{OL}(1-R_f)+R_o}$$

$$V_i = V_o\left[\frac{R_1+R_f + A_{OL}(R_1+R_f) + R_o - A_{OL}R_f}{R_o - A_{OL}R_f}\right]$$

$$\frac{V_o}{V_i} = \frac{R_o - A_{OL}R_f}{R_1+R_f+R_o+R_1A_{OL}}$$

$$= \frac{R_o - A_{OL}R_f}{R_1(1+A_{OL})+R_o+R_f}$$

If $A_{OL} >> 1$, $A_{OL}R_1 >> R_o+R_f$ and neglecting R_o,

$$A_{CL} = \frac{V_o}{V_i} = -\frac{R_f}{R_1}$$

$\Rightarrow$ Input resistance, R_{if}

$$R_{if} = \frac{V_d}{i}$$

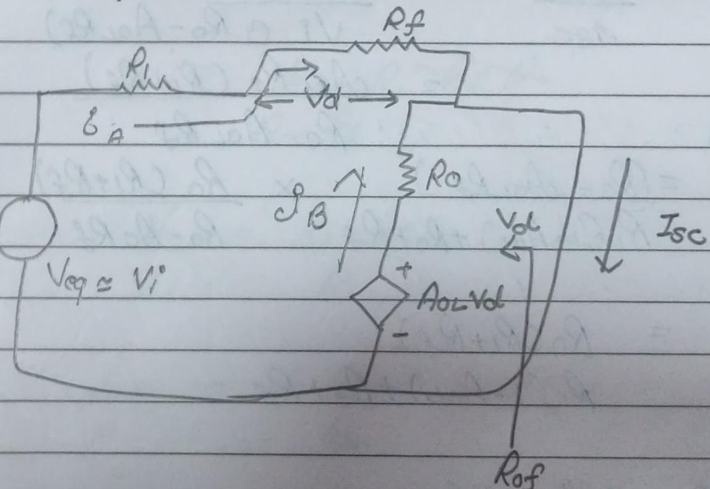
Writing the loop eqn. and solving for R_{if}.

$$V_d + i(R_f + R_o) + A_{OL} V_d = 0$$

$$\frac{V_d}{i}(1 + A_{OL}) = -i(R_f + R_o)$$

$$R_{if} = \frac{V_d}{i} = \frac{(R_f + R_o)}{1 + A_{OL}}$$

$\Rightarrow$ Output impedance, R_{of}



$$i_A = \frac{V_i}{R_1 + R_f} \quad -① $$

$$i_B = \frac{A_{OL} V_d}{R_o} \quad -② $$

$$V_d = -i_A R_f$$

$$i_B = -\frac{A_{OL} i_A R_f}{R_o}$$

$$i_{sc} = i_A + i_B$$

$$= i_A - \frac{A_{OL}\, i_A R_f}{R_o}$$

$$= i_A \left(1 - A_{OL}\frac{R_f}{R_o}\right)$$

$$= \frac{V_i}{(R_1+R_f)} \frac{(R_o - A_{OL}R_f)}{R_o}$$

$$A_{CL} = \frac{V_{oc}}{V_i}$$

$$A_{CL} V_i = V_{oc}$$

$$R_{of} = \frac{V_{oc}}{i_{sc}} = \frac{A_{CL} \cdot V_i R_o (R_1 + R_f)}{V_i (R_o - A_{OL}R_f)}$$

$$= \frac{A_{CL} R_o (R_1+R_f)}{R_o - A_{OL}R_f}$$

$$= \frac{(R_o - A_{OL}R_f)}{R_1(1+A_{OL}) + R_o + R_f} \times \frac{R_o(R_1+R_f)}{R_o - A_o R_f}$$

$$R_{of} = \frac{R_o(R_1+R_f)}{R_1(1+A_{OL}) + R_o + R_f}$$

It can be written as,

$$R_{of} = \frac{\dfrac{R_o(R_1+R_f)}{R_o+R_1+R_f}}{1 + \dfrac{R_1 A_{OL}}{R_o+R_1+R_f}}$$

- The Non-Inverting Amplifier:

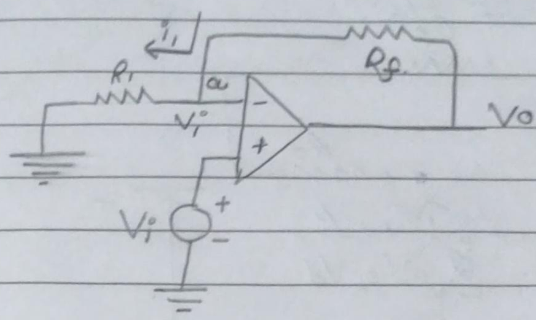


fig. Non-Inverting Amplifier

Two assumptions:

i Input current = 0

ii $V_d = 0$

$$V_i = \frac{V_o}{R_1 + R_f} R_1 \cancel{R_f R}$$

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

$$A_{CL} = 1 + \frac{R_f}{R_1}$$

- Practical Non-Inverting Amplifier:

- Practical Non-inverting Amplifier:

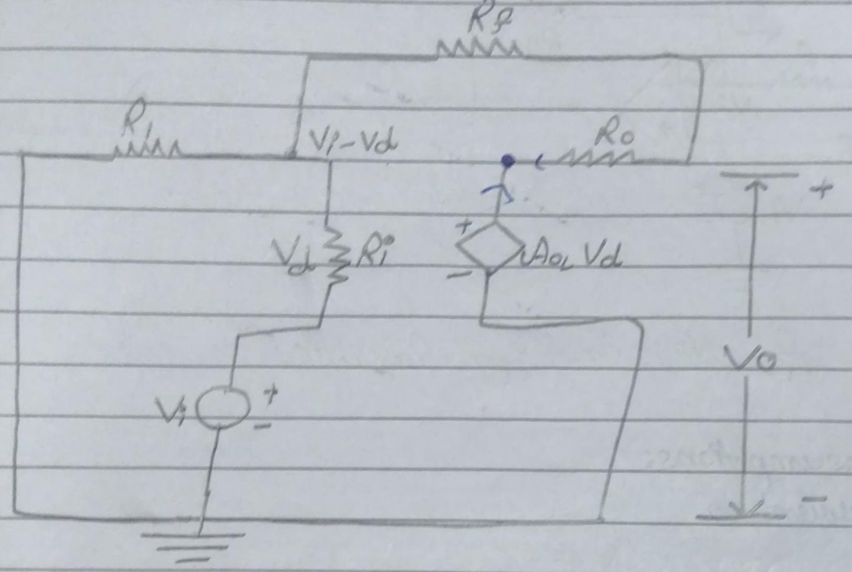


Fig. Equivalent circuit of non-inverting amplifier.

$\cancel{V_i + V_d = 9R_1}$

$$\frac{V_i - V_d}{R_1} + \frac{V_d}{R_i} + \frac{V_i - V_d - V_o}{R_f} = 0$$

$$(V_i - V_d)Y_1 + V_d Y_i + (V_i - V_d - V_o)Y_f = 0$$

$Y \rightarrow$ Admittance

or

$$-(Y_1 + Y_i + Y_f)V_d + (Y_1 + Y_f)V_i = Y_f V_o \quad - (1)$$

$$(Y_1 + Y_f)V_i - Y_f V_o = V_d(Y_1 + Y_f - Y_i)$$

$$\Rightarrow V_i Y_1 - V_d Y_1 + V_d Y_i + V_i Y_f - V_d Y_f - V_o Y_f = 0.$$

$$\Rightarrow V_d [Y_i - Y_1 - Y_f].$$

$$\Rightarrow - V_d[-Y_i + Y_1 + Y_f] + V_i[Y_1 + Y_f] - V_o Y_f.$$

At output node: KCL

$$Y_f (V_i - V_d - V_o) + (A_{OL} V_d - V_o) Y_o = 0$$

$$-V_o (Y_f + Y_o) + Y_f V_i + V_d (-Y_f + A_{OL} Y_o) = 0 \quad -(2)$$

$$-V_o (Y_f + Y_o) + Y_f V_i = V_d (-A_{OL} Y_o + Y_f)$$

$$(Y_1 + Y_f - Y_i)(-V_o (Y_f + Y_o) + Y_f V_i) = (Y_1 + Y_f) V_i - Y_f V_o$$

$$(Y_1 + Y_f - Y_i)(-V_o Y_f - Y_o V_o + Y_f V_i) = Y_1 V_i + Y_f V_i - Y_f V_o$$

$$- V_o Y_f Y_1 - Y_o V_o Y_1 + Y_f V_i Y_1 - V_o Y_f^2 - Y_o V_o Y_f + Y_f^2 V_i + Y_i V_o Y_f + Y_i Y_o V_o - Y_f V_i Y_i - Y_1 V_i - Y_f V_i + Y_f V_o = 0$$

$$V_o (-Y_f Y_1 - Y_o Y_1 - Y_f^2 - Y_o Y_f + Y_i Y_f + Y_o Y_i + Y_f) + V_i (Y_f Y_1 + Y_f^2 - Y_f Y_i - Y_1 - Y_f) = 0$$

$$\frac{V_o}{V_i} = Y_f Y_1 + Y_o Y_1$$

$$A_{CL} = \frac{V_o}{V_i} = \frac{A_{OL} Y_o (Y_1 + Y_f) + Y_f Y_i}{(A_{OL}+1) Y_o Y_f + (Y_1 + Y_i)(Y_f + Y_o)} \quad (3)$$

If $A_{OL} \to \infty$

$$A_{CL} = \frac{Y_o (Y_1 + Y_f)}{Y_o Y_f}$$

$$A_{CL} = 1 + \frac{Y_1}{Y_f}$$

$$A_{CL} = 1 + \frac{R_f}{R_1}$$

Q In the circuit of non-inverting amplifier $R_1 = 5K\Omega$, $R_f = 20K\Omega$ and $V_i = 1V$. A load resistor of $5K\Omega$ is connected at the output. Calculate V_o, A_{CL}, the load current and the output current i_o.

Ans

$$\frac{V_o}{V_i} = 1 + \frac{20}{5}$$

$$V_o = 5V$$

$$A_{CL} = 5$$

$$i_L = \frac{V_o}{R_L} = \frac{5}{5 \times 10^3} = 1mA$$

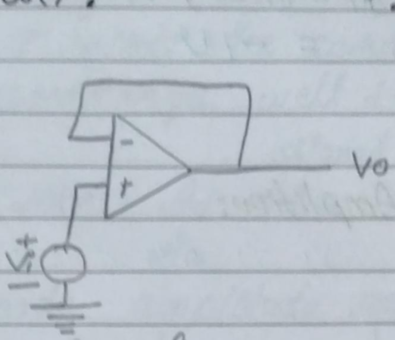
$$i_1 = \frac{V_i}{5 \times 10^3} = \frac{1}{5} = 0.2 \times 10^{-3} = 0.2mA$$

$$i_o = i_L + i_1 = 1.2mA$$

- Voltage follower:

$R_1 = \infty$

$R_f = 0$

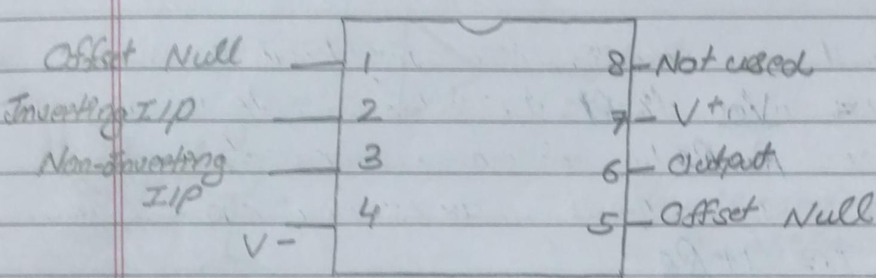


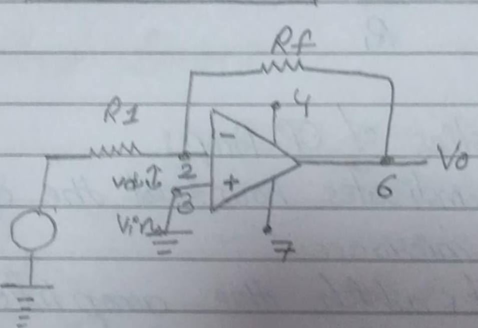
$A_{CL} = \frac{V_o}{V_i} = 1$ as $V_o = V_i$

Output signal follows the input signals.

Ideal Non-Inverting Amplifier

- Inverting Amplifier:





Vi. $\frac{V_2 - V_i}{R_1} + \frac{V_2 - V_o}{R_f} = 0$

$V_2 = 0$

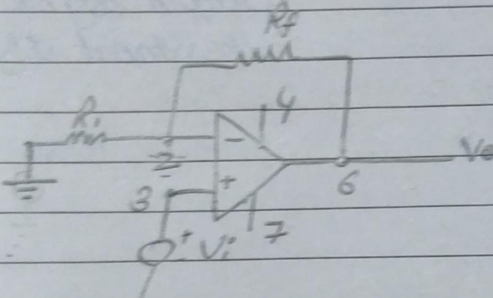
$\frac{V_i}{R_1} = \frac{-V_o}{R_f}$

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

$\Rightarrow$ $V_{in} = 100$, $R_f = 10$, $R_1 = 1k\Omega$, $V_0 = ?$

$$V_0 = -\frac{10 \times 100}{10^3} = -1V$$

$\Rightarrow$ Non - Inverting Amplifier:



$$V_i = \frac{V_0}{R_1 + R_f} \cdot R_1$$

$$\frac{V_0}{V_i} = 1 + \frac{R_f}{R_1}$$

- Basic characteristics of OP-Amp:

1. Slew Rate: ~~It indicates how fast the op-Amp output changes to V per microsec.~~
Maximum rate at which the amplifier o/p can change in V/µs (micro sec)

$$S = \frac{\Delta V_{out}}{\Delta t}$$

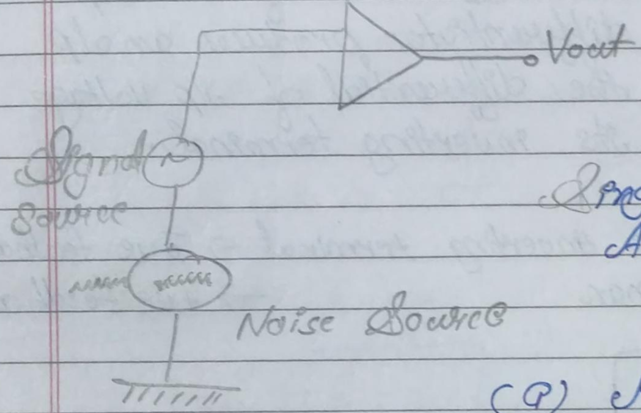
2. Common Mode Rejection Ratio:

How much it rejects the common mode input & how ~~CMRR = Vd~~ well it amplifies the differential input signal.

$$CMRR = \frac{A_d}{A_c} = \infty$$

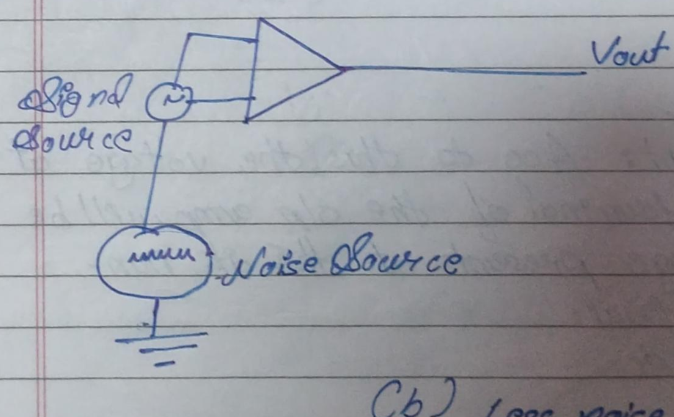
In common mode amplitude remains same in i/p & o/p. & are in phase

Differential Mode → $-V_i = +V_2$ i.e. out of phase.



Single-ended Amplifier

(a) More noise as the Noise + Signal Source is input



Differential

(b) Less noise as the Amplifier rejects the common mode input i.e. the noise source

3. **Offset Voltage:**
Difference b/w the inverting & non-inverting voltage.
Ideally it is zero.

4. **Bandwidth:**
It can amplify any frequencies without any loss.
Ideally it is ∞.

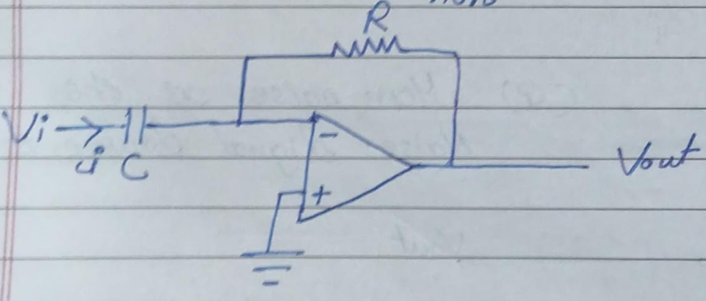
• **Applications of op-Amp:**

1. **Differentiator:**

i. It is an electronic circuit which produces an o/p equal to the first derivative of the i/p.

ii. An op-amp based differentiator produces an o/p which is equal to the differential of i/p voltage that is applied to its inverting terminal.

If o/p is fed back to inverting terminal → -ve feedback
non → +ve feedback



Virtual Short Concept: Acc to this, the voltage at the inverting i/p terminal of the o/p amp will be equal to the voltage present at ~~the~~ its non-inverting i/p terminal.

~~$V_i = 0$~~

$i = \frac{dq}{dt}$

$q = CV$

$i = \frac{dCV}{dt}$

$i = C\frac{dV}{dt}$

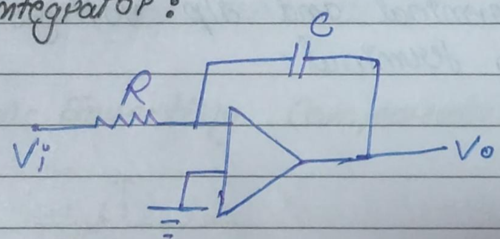
$\frac{Cd(0 - V_i)}{dt} + \frac{0 - V_0}{R} = 0$

$V_0 = -RC\frac{dV_i}{dt}$

If $RC = 1sec$

$V_0 = -\frac{dV_i}{dt}$ (- is out of phase)

2. Integrator:



$-\frac{V_i}{R} + \frac{Cd(0 - V_0)}{dt} = 0$

$-\frac{V_i}{R} = C\frac{dV_0}{dt}$

$-\frac{1}{RC} V_i\, dt = dV_0$

$V_0 = -\frac{1}{RC}\int V_i\, dt$

If $RC = 1s$, $V_o = -\int V_i\,dt$ (Out of phase)

3. Comparator:

An electronic circuit that'll compare the two inputs and give o/p after comparison.

They're of two types:

1. Inverting
2. Non-Inverting

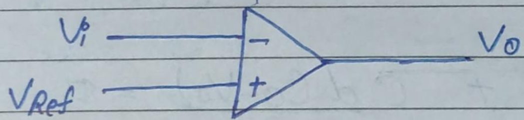
⇒ Inverting Comparator:

Reference Voltage: It is created in circuit to create a reference.

I/p ~~in~~ voltage → Inverting Terminal

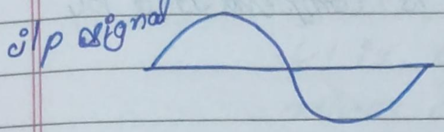
Ref. voltage → Non-Inverting Terminal

An inverting comparator is an op-Amp based comparator for which a reference voltage is applied to its non-inverting terminal and i/p voltage is applied to its inverting terminal.

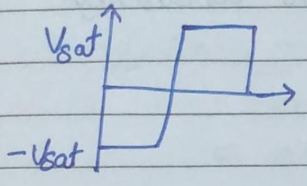


~~⇒ If V_{in} is greater than V_{ref} than the voltage at the o/p ~~is at~~ will give rise to +ve saturation level i.e. V_{sat} and vice-verse.~~

~~The o/p value of an inverting comparator will be -Vsat for which the Vin ≮ Vref.~~



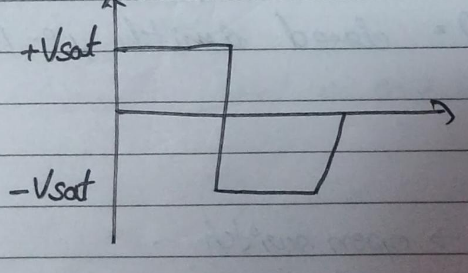
During +ve half cycle o/p is $-V_{sat}$



During the +ve half cycle of the sinusoidal i/p signal the Voltage present at the inverting terminal > 0 V i.e. Vin > Vref, hence the o/p value of the inverting comparator will $-V_{sat}$. and vice-versa.

* O/p changes whenever it crosses 0 V.

⇒ Non-Inverting Comparator:

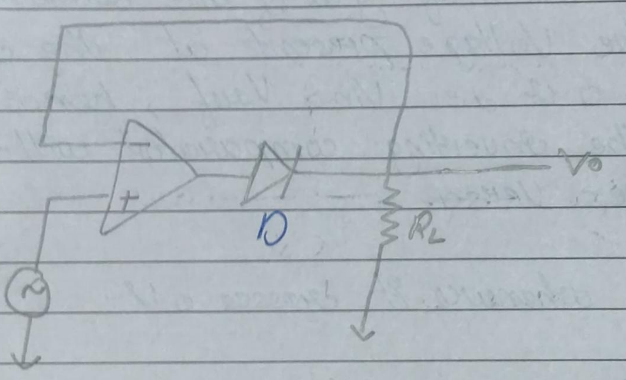


In +ve half cycle
Vin > Vref → Vsat
-ve half cycle
Vin < Vref → -Vsat

* Precision Rectifier (Superdiode):

We use it to get rectified o/p (ac to dc) without loss of any signal.
The voltage drop across diode is compensated by op-amp.

When $V_{in} >> V_{threshold}$ then only diode is conducting.
(like 0.7)



(1) V_{in} is +ve, $V_{in} > 0$
D in F.B. so D = closed switch i.e. D is buffer.
$V_{in} = V_0$.

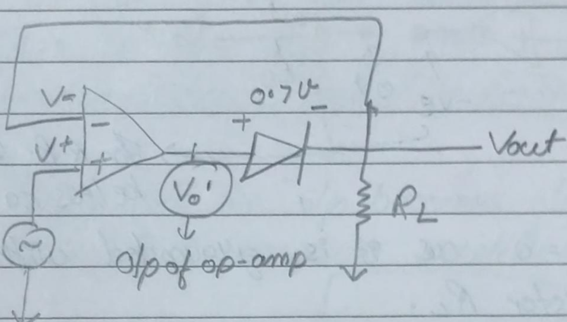
(2) V_{in} is -ve, $V_{in} < 0$
D in R.B., so D → open switch.
$V_0 = 0$

Effective Voltage Drop across Diode:

$$V_F' = \frac{V_F}{A_{OL}}$$

where V_F is Voltage drop across the diode
V_F' is effective forward voltage drop across the diode.

$$V_F' = \frac{0.7}{10^5}$$
$$\simeq 0V \text{ (approx.)}$$



$$V_{out} = V_o' - 0.7\,V$$

$$V_o' = V_{out} + 0.7\,V$$

$$V_o' = A_{OL}(V^+ - V^-)$$

$$A_{OL}(V^+ - V^-) = V_{out} + 0.7$$

$\cancel{A_{OL}(V_d) - 0.7 = V_{out}}$

$\cancel{A_{OL} >> 0.7}$

So $V_{in} = V_{out}$

$$\frac{V_{out} + 0.7}{A_{OL}} = V^+ - V^-$$

$A_{OL} >> 0$

$V^+ - V^- \approx 0$

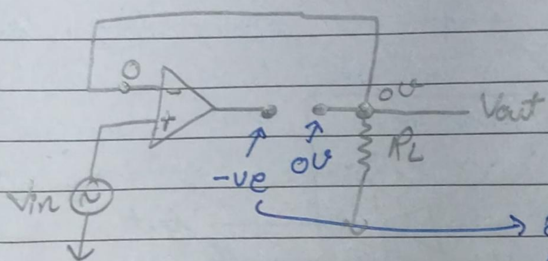
$V^+ = V^-$

The implies that the i/p at the +ve terminal will be equal to the -ve terminal. (& -ve terminal is connected to o/p)
so

$V_{out} = V_{in}$

Note: The diode will conduct only when the applied i/p voltage is greater than zero.

⇒ -ve input signal:

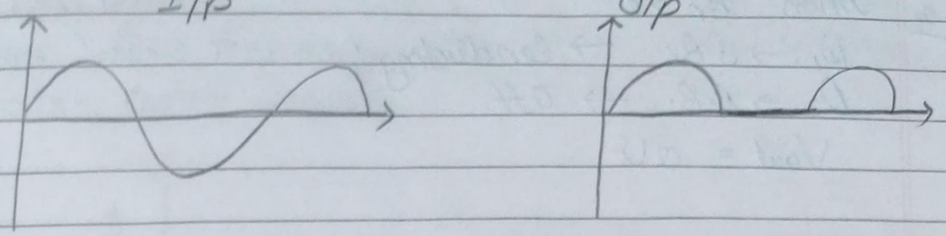


In R.B. so o/p would be less so 0 atn then -ve o/p

$V_{out} = 0$ as it is grounded with the load resistor R_L.

V at -ve terminal = 0. (as its connected to Vout)
(* Can apply virtual short concept)

This is only possible whenever the applied i/p voltage in the diode is -ve

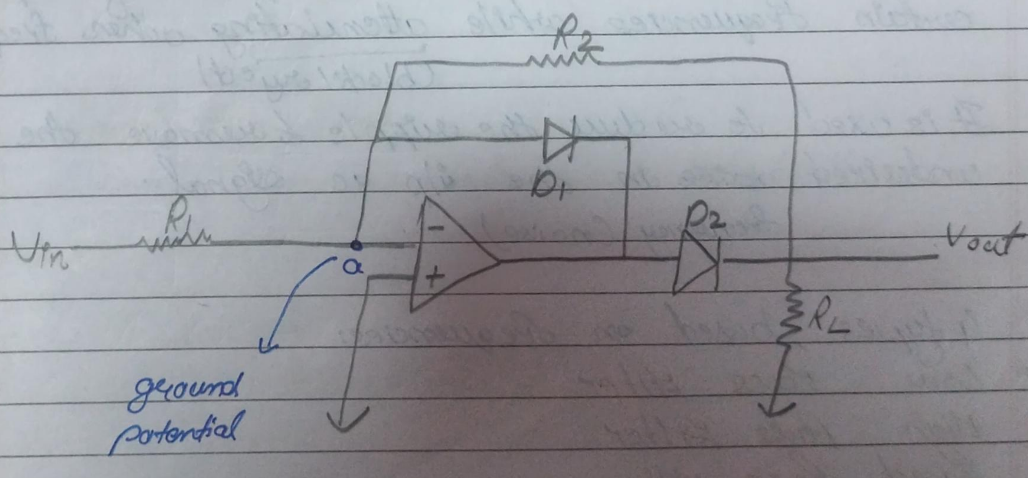


Whenever $V_{in} < 0$ then the o/p of op-amp will be in $-V_{sat}$.
And this will be open-loop configuration.

Whenever the i/p becomes +ve at that time the op-amp needs to come out from the $-V_{sat}$ (negative saturation voltage) i.e. it'll ~~have~~ take some time to have $+V_{sat}$. This is fine for low frequencies.
~~There'll be no delay in low frequencies.~~

At high frequencies the o/p becomes distorted. So we use modified precision rectifier. To avoid the $-V_{sat}$ we use

- Modified Precision Rectifier:



1. When $V_{in} > 0$
   $D_1 \rightarrow$ F.B. $\rightarrow$ Conducting
   $D_2 \rightarrow$ R.B. $\rightarrow$ Off
   $V_{out} = 0V$

2. $V_{in} < 0$
   $D_1 \rightarrow$ off
   $D_2 \rightarrow$ conducting
   $V_{out} = -\frac{R_2}{R_1} V_{in}$

⇒ Let us assume D_1 is conducting
⇓
O/p is fedback to the I/p.

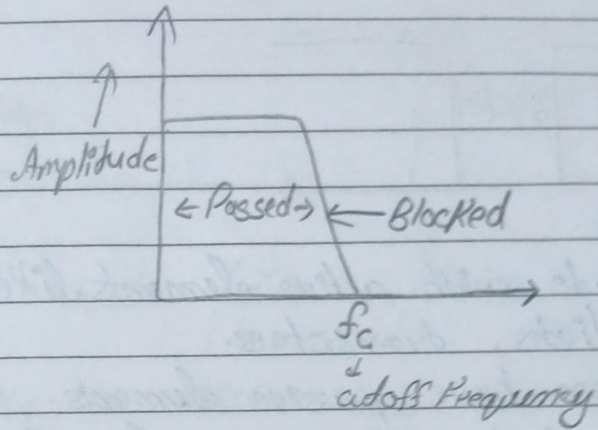
At the 'a' node we can apply virtual ground concept $V_a = 0$.

- Filters:
A filter is a circuit which is capable of amplifying certain frequencies while attenuating other frequencies.
(block/reject)
It is used to reduce the ripple & remove the undesired ~~noise~~ in the i/p ac signal.
frequency (noise)

⇒ 4 types, based on frequencies:
1. Low Pass Filter
2. High Pass Filter
3. Band Pass Filter
4. Band Reject Filter

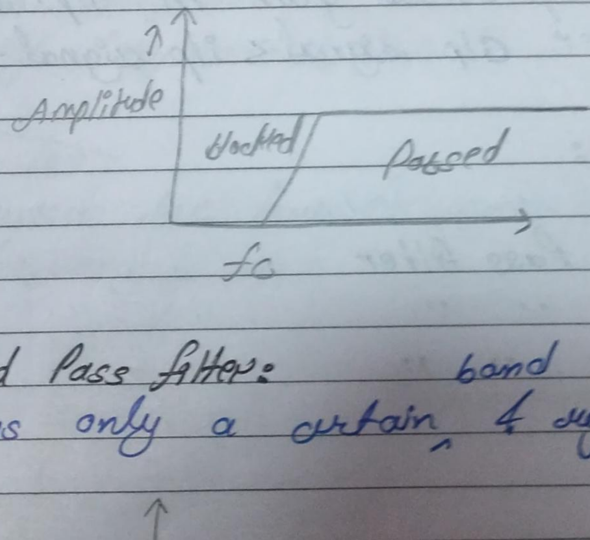
1. Low Pass Filter:

Allows low frequency signals & rejects high frequency
(ohz- cutoff frequency).



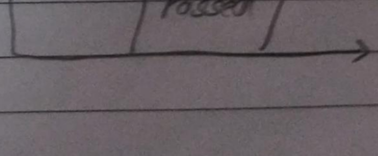
2. High Pass filter:

Allow high frequency & rejects low frequency.
~~(cutoff frequency → ......)~~ $(f > f_c)$

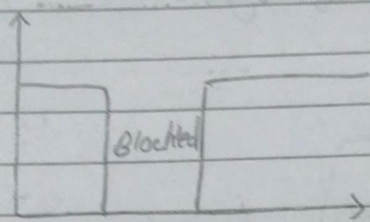


3. Band Pass filter:

Allows only a certain band & reject other.



4. Band Reject filter:
Rejects only a certain band & accept others.



⇒ Active filter: Made with active elements like op-amp, diodes, transistors.
Can have passive elements.

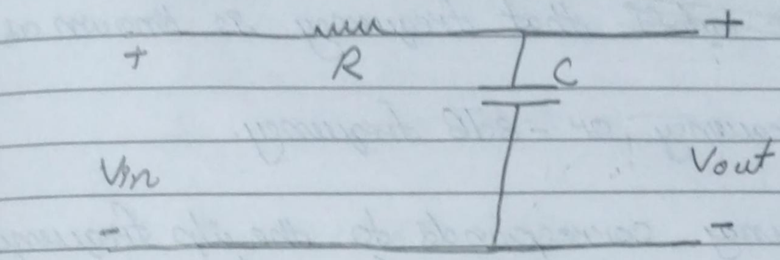
⇒ Passive filter: Made with passive elements like resistor, capacitor (not inductor bcs of huge energy loss).

* Active filter provides gain in i/p signal.
Passive filter o/p signal < i/p signal.

1. Passive filter:
Types:
a. RC Low Pass filter
b. RL " " "
c. RLC " " "

⇒ ~~RC Low~~

⇒ RC low pass filter:



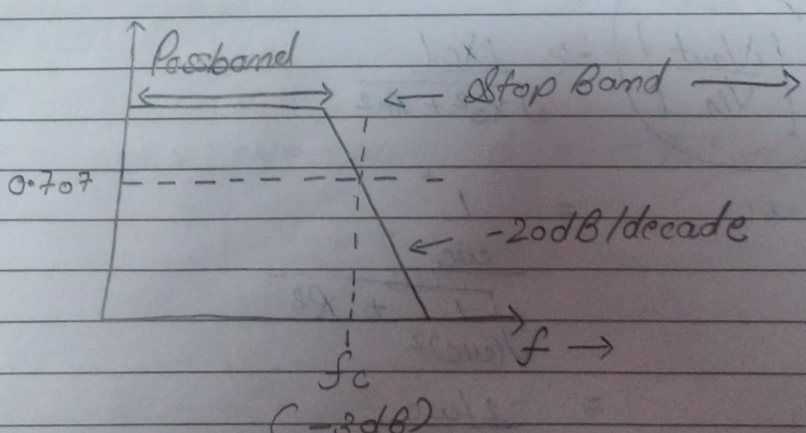
$$V_{out} = \left(\frac{X_C}{X_C + R}\right) V_{in}$$

X_C is resistance of capacitor which varies with frequency.

$$|X_C| = \frac{1}{\omega C}$$

i) At low frequencies, $X_C \uparrow$, $V_{out} = V_{in}$
ii) At high frequencies, $X_C \downarrow$, $V_{out} = 0$

~~i.e. at low~~
It passes the low frequency signal & rejects the high frequency.



classmate

Date

Page

⇒ The frequency at which o/p is 0.707 or $\left(\frac{1}{\sqrt{2}}\right)$ times i/p, ~~its the cutoff~~ that frequency is known as cutoff frequency or -3dB frequency.

⇒ -3dB frequency corresponds to the i/p frequency that causes the o/p signal to drop by -3dB ~~related~~ relative to the i/p signal.

$$V_0 = \frac{1}{\sqrt{2}} V_i$$

⇒ The magnitude changes to -20 whenever the frequency changes to tenfold / decade.

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

$$V_{out} = \left(\frac{X_C}{X_C + R_C}\right) V_{in}$$

Transfer function ←

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{|X_C|}{\sqrt{X_C^2 + R_C^2}}$$

$$= \frac{\frac{1}{\omega C}}{\sqrt{\frac{1}{(\omega C)^2} + R^2}}$$

$$= \frac{1/\omega C}{\frac{\sqrt{1 + R^2 \omega^2 C^2}}{\omega C}}$$

$$\frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1+R^2\omega^2c^2}}$$

$$\frac{1}{2} = \frac{1}{1+R^2\omega^2c^2}$$

$$2 = 1+R^2\omega^2c^2$$

$$1 = R^2 \times 4\pi^2 f^2 c^2$$

$$\frac{1}{4R^2\pi^2c^2} = f^2$$

$$\boxed{\frac{1}{2\pi RC} = f_c}$$

If f_c ↑ the o/p signal ↓ and phase will change.

$$\boxed{\phi = -\tan^{-1}(\omega CR)} \Rightarrow \text{Phase}$$

$\Rightarrow$ $\omega = 0$, $\phi = 0°$ i.e. o/p in phase with i/p

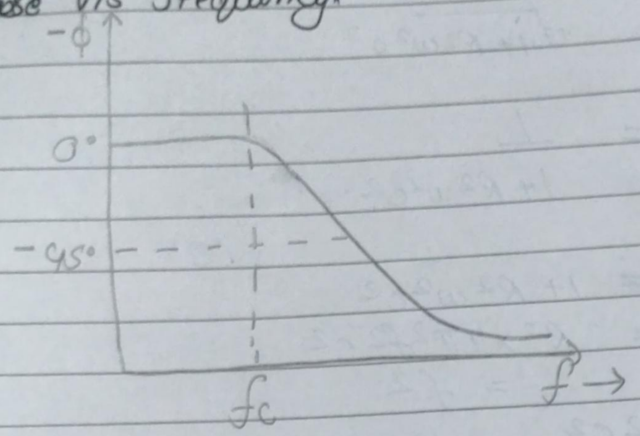
At f_c, $\omega = \omega_0 \Rightarrow \phi = -\tan^{-1}\left(\frac{2\pi \times RC}{2\pi RC}\right)$

$$\phi = -\tan^{-1}(1)$$

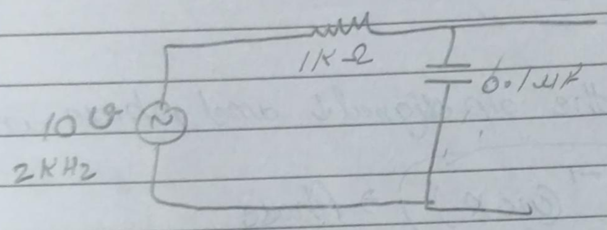
$$\phi = -45°$$

$\omega = \infty$, $\phi = -90°$; o/p lags i/p with 90°

Phase V/s frequency.



Q find −3dB frequency and o/p voltage at 2KHz.



$$\frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1+R^2\omega^2C^2}}$$

$$\frac{1}{2} =$$

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

$$= \frac{1}{2 \times 3.14 \times 10^3 \times 10^{-6}}$$

$$= \frac{1}{6.28 \times 10^{-3}}$$

$$= \frac{1000}{6.28}$$

$$= 1.59\ KHz$$

$$V_o = \left(\frac{X_C}{X_C + R}\right) V_{in}$$

$X_C = \cancel{1592356.6}$ $\quad X_C = 796.17$

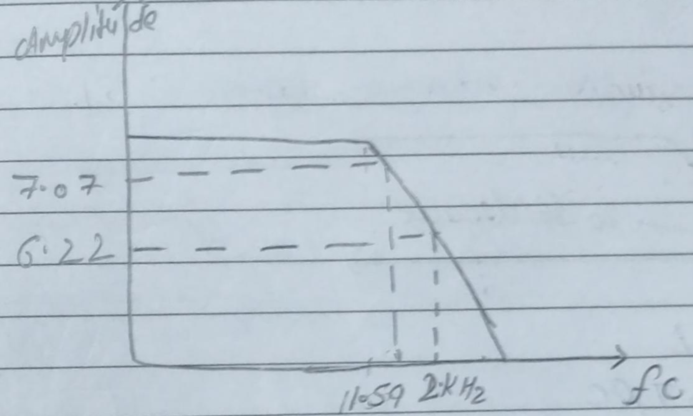
$X_C = 1.59\ M\Omega$

$$V_0 = \left(\frac{796}{796+1000}\right) \times 10 \qquad V_0 = \left(\frac{|X_C|}{\sqrt{X_C^2+R^2}}\right) \cdot V_{in}$$

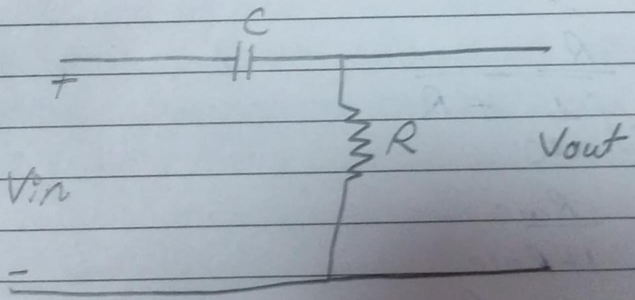
$$V_0 = \frac{796}{\sqrt{633616+10^6}} \cancel{\times 10} \times 10$$

$$= \frac{796}{1278.12} \times 10$$

$$= 6.227 \text{ V}$$



- RC High Pass Filter:

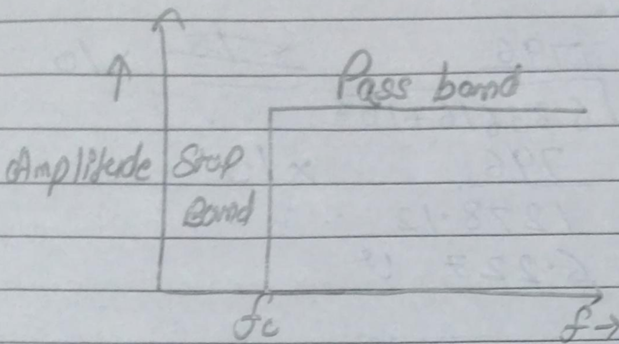


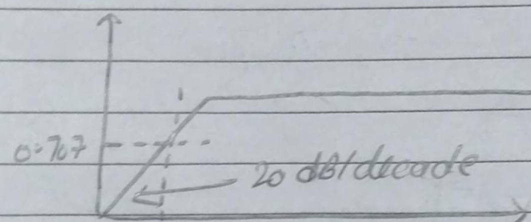
$$V_{out} = \left(\frac{R}{X_C+R}\right) V_{in}$$

$$|X_C| = \frac{1}{\omega C}$$

i. At $\omega = 0$, $|X_C| = \infty$, $V_o = 0$

ii. At $\omega = \infty$, $|X_C| = 0$, $V_o = V_{in}$





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

$$V_o = \frac{1}{\sqrt{2}} V_{in}$$

$$\frac{1}{\sqrt{2}} = \frac{R}{\sqrt{\frac{1}{\omega C} + R}}$$

$$\frac{1}{2} = \frac{R\omega C}{1 + R\omega C}$$

$$2R\omega C = 1 + R\omega C$$

$$R\omega C = 1$$

$$2\pi f RC = 1$$

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

As $f_c \uparrow$ o/p signal ↑ and phase will also change.

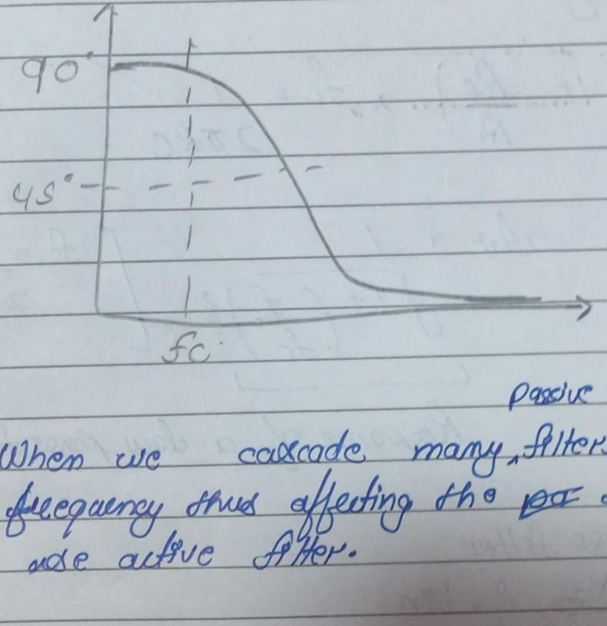
$$\Rightarrow \boxed{\phi = \tan^{-1}\left(\frac{1}{\omega CR}\right)}$$

At $\omega = 0$, $\phi = 90^\circ$ → o/p leads i/p by 90°

$\omega = \infty$, $\phi = 0$

$\omega = \omega_c$, $\phi = 45^\circ$

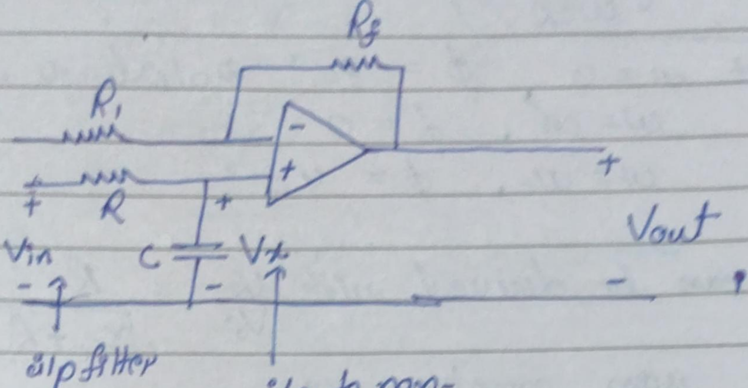
** Phase can be derived with $\frac{V_o}{V_i} = \frac{R}{\sqrt{X_c + R}}$ by using complex $\omega C j$.



Passive

* When we cascade many filters it'll effect the cutoff frequency thus affecting the ~~pa~~ load. That's why we use active filter.

· Active Low Pass filter & High Pass filter:



$$A_v = \left(1 + \frac{R_f}{R_1}\right), \quad f_c = \frac{1}{2\pi RC}$$

$$\left|\frac{V_o}{V_i}\right| = A_v \times \underbrace{\frac{1}{\sqrt{1+\left(\frac{f}{f_c}\right)^2}}} \quad \left[f_c = \frac{1}{2\pi RC}\right]$$

Response of a low pass filter

for a low pass filter

$$V_o = \left(\frac{X_c}{X_c + R}\right) \cdot V_{in}$$

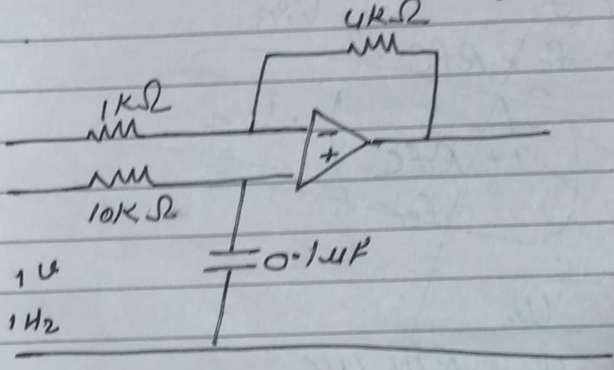
Multiply the numerator and denominator by ωc.

$$V_o = \frac{X_c}{X_c+R}\cdot V_{in} \Rightarrow \frac{1}{1+\omega cR}\cdot V_{in} \Rightarrow \frac{1}{1+2\pi f CR}\cdot V_{in}$$

$$= \frac{\frac{1}{2\pi CR}}{\frac{1}{2\pi CR}+f}\cdot V_{in} = \frac{f_c}{f_c+f}\cdot V_{in} \Rightarrow \frac{1}{1+\frac{f}{f_c}}\cdot V_{in}$$

$$\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1+\left(\frac{f}{f_c}\right)^2}}$$

Q. Find the cutoff frequency of the given filter.



Ans

$$A_v = 1+\frac{R_f}{R_1} = 5$$

$$\cancel{\frac{1}{\sqrt{2}} = 5\times\frac{1}{\sqrt{1+\left(\frac{f}{f_c}\right)^2}}}$$

$$f_c = \frac{1}{2\pi RC} = 159\,Hz$$

$$V_o = 5\times\frac{1}{\sqrt{1+\left(\frac{1}{159}\right)^2}}\times 1$$

$V_0 = 4.99 \simeq 5\ V$

⇒ Active high pass filter.

$$V_0 = \frac{R}{X_C + R} \cdot V_{in}$$

$$V_0 = \frac{R}{\frac{1}{\omega C} + R} \cdot V_{in}$$

$$\frac{V_0}{V_{in}} = \frac{R}{1 + R\omega C}$$

$$\frac{V_0}{V_{in}} = \frac{R}{1 + 2\pi f RC}$$

$$\frac{V_0}{V_{in}} = \frac{\frac{R}{2\pi RC}}{\frac{1}{2\pi f CR} + f}$$

$$= \frac{R}{2\pi RC}$$

$$= \frac{\frac{R}{2\pi RC}}{\frac{1}{2\pi CR} + f}$$

$$= \frac{Rf_c}{f_c + f}$$

$$\frac{V_0}{V_{in}} = \frac{R}{1 + \frac{f}{f_c}}$$

$V_0 =$

- Active high pass filter:

$$\frac{V_o}{V_i} = \frac{R}{X_C + R} = \frac{R}{\frac{1}{\omega C} + R}$$

$$= \frac{R\omega C}{1 + R\omega C}$$

$$= \frac{R\omega C \times \omega_c}{\omega_c + R\omega C \times \omega_c} = \frac{\frac{R\omega C}{2\pi f_c}}{\frac{1}{2\pi f_c} + \frac{R\omega C}{2\pi f_c}} = \frac{R\omega C \times 2\pi}{2\pi}$$

$$= \frac{R\omega C \times \frac{2\pi}{2\pi RC}}{\omega_c \frac{2\pi}{2\pi RC} + \frac{R\omega C \times 2\pi}{2\pi RC}}$$

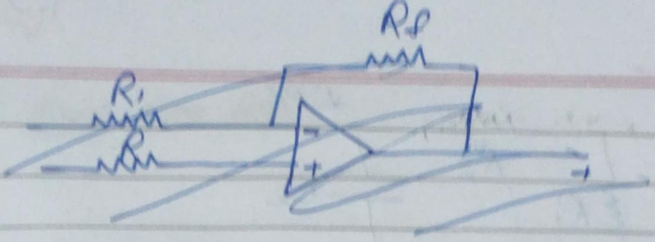
$$= \frac{\omega}{\omega_c + \omega}$$

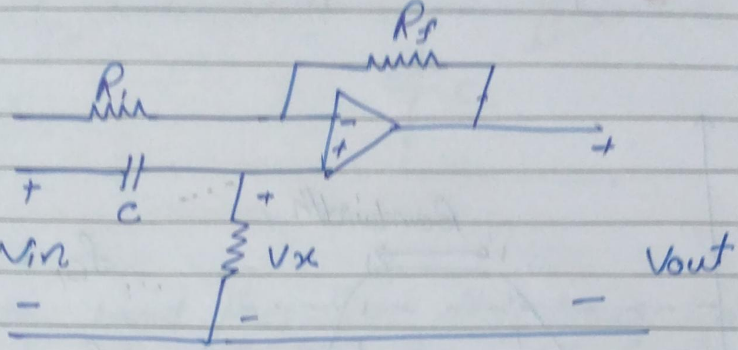
$$= \frac{f}{f_c + f}$$

$$V_o = \left(\frac{\frac{f}{f_c}}{1 + \frac{f}{f_c}} \right) \cdot V_{in}$$

$$\left| \frac{V_o}{V_i} \right| = \frac{(f/f_c)}{\sqrt{1 + \left(\frac{f}{f_c}\right)^2}} \Bigg\}$$ Response of high pass filter

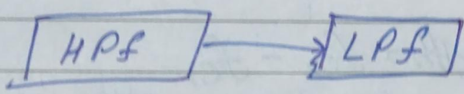
So $$V_o = A_v \times \frac{f/f_c}{\sqrt{1 + \left(\frac{f}{f_c}\right)^2}}$$

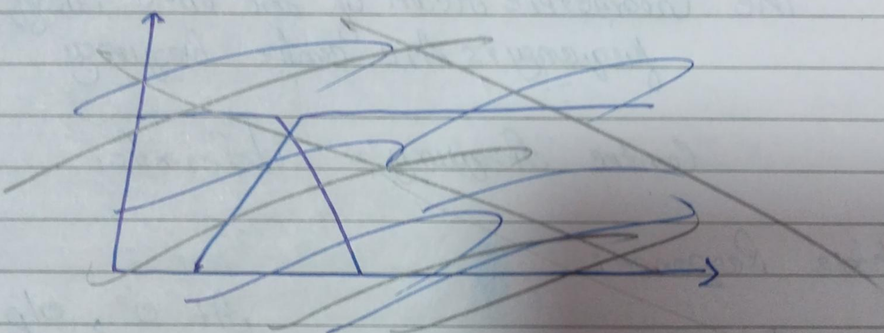


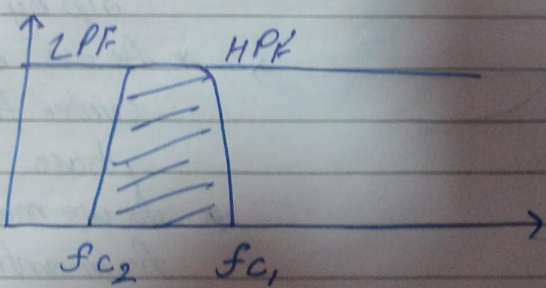


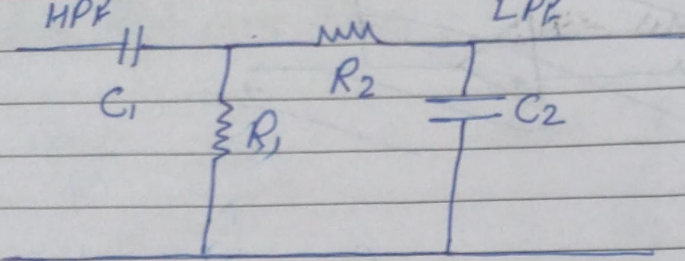
- Band Pass filter:

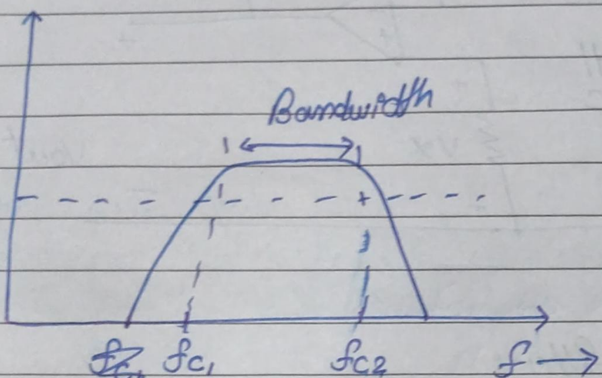
Cascade high pass & low pass filter.











f_{C_1} = Low cut-off frequency

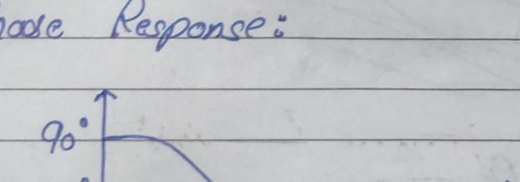
f_{C_2} = High cut off freq.

Bandwidth $= f_{C_2} - f_{C_1}$

The Geometric Mean of the two cutoff frequency is the centre frequency

Centre frequency $= \sqrt{f_{C_2} \times f_{C_1}}$

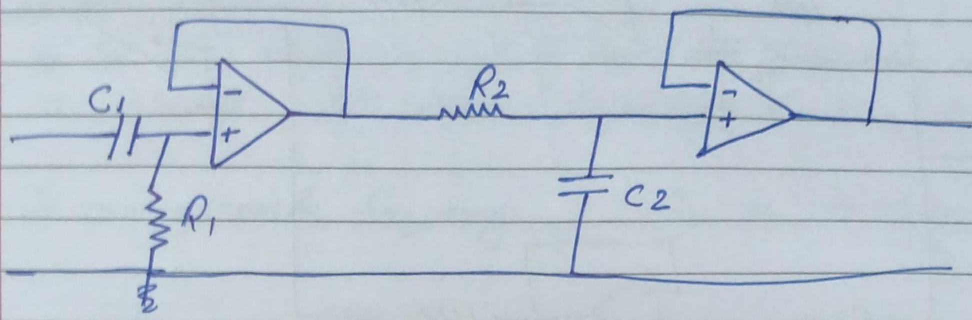
Phase Response:



At 0°, o/p leads i/p by 90°

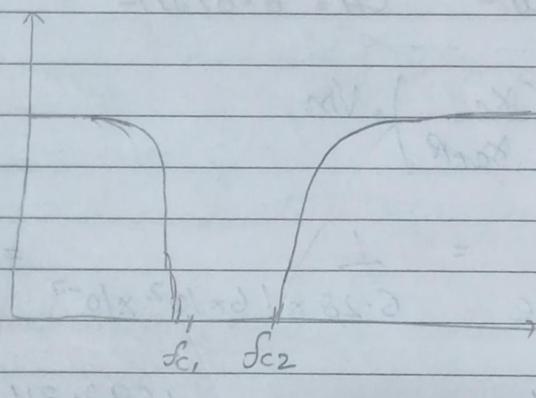
* As we move towards centre frequency the phase response ↓.
* As we move away from centre frequency o/p will lag the i/p. & at ∞ o/p lags by 90°

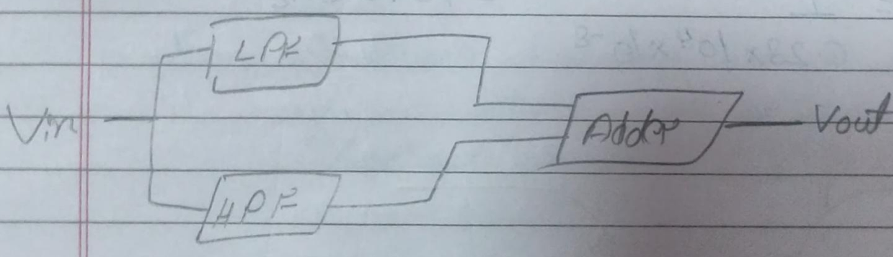
→ Active Band Pass filter:



* In passive band pass filter they have higher input impedance thus affecting the cutoff frequency and distorting the i/p signal.

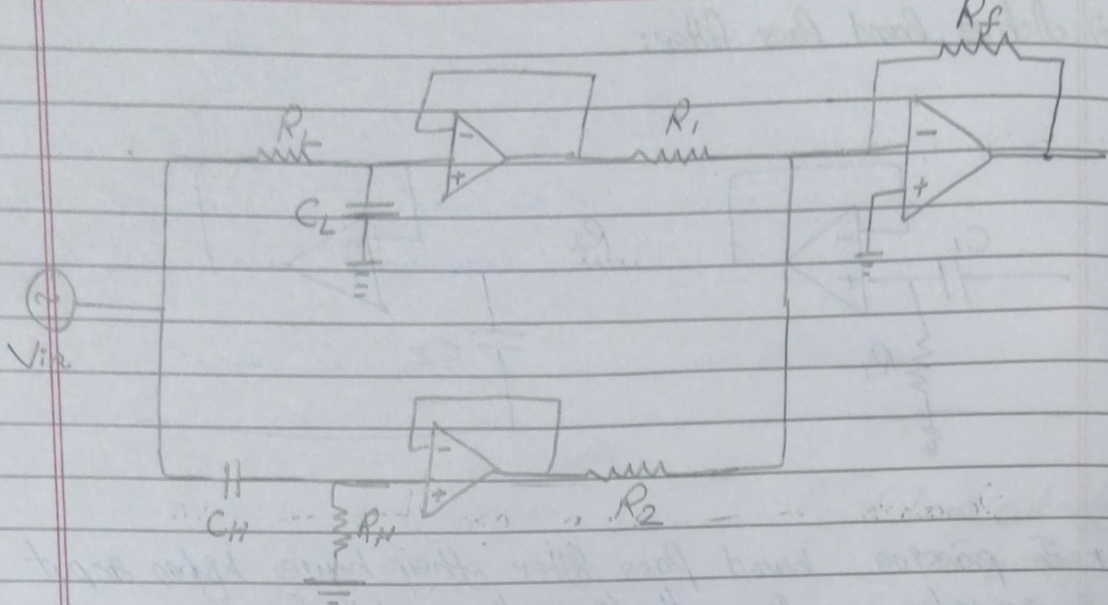
• Band-Stop/Reject Filter:





classmate

Date ____
Page ____



Q find the band stop filter for the given values:

$R_L = 1.6\ K\Omega$ $\quad R_1 = 1K\Omega$ $\quad R_2 = 1K\Omega$

$R_H = 10K\Omega$ $\quad R_F = 1k\Omega$

$C_L = 0.1\mu F$ $\quad C_H = 0.01\mu F$

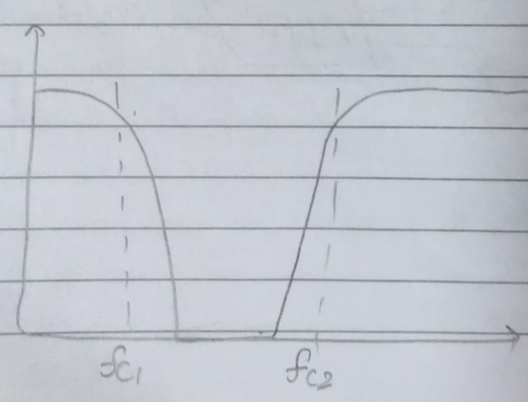
Ans

$$V_{out} = \left(\frac{X_C}{X_C + R}\right) \cdot V_{in}$$

$=$

$$(f_c)_L = \frac{1}{2\pi RC} = \frac{1}{6.28 \times 16 \times 10^2 \times 10^{-7}} = 995.2\ Hz$$

$$(f_{cH}) = \frac{1}{6.28 \times 10^4 \times 10^{-8}} = 1592.3\ Hz$$



$f_2 - f_1 = 5\,kHz$

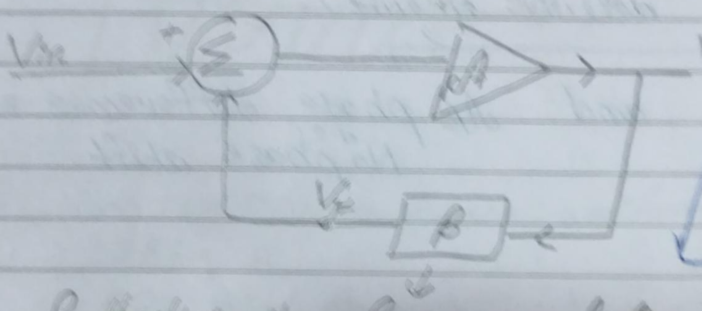
- Oscillators:

i. It is an electronic circuit used to generate an o/p ac signal with desired frequency from a dc signal.

ii. It can generate frequency of few Hz to GHz

DC signal → Oscillator → AC o/p with desired frequency

iii. Oscillator is an amplifier with positive feedback.

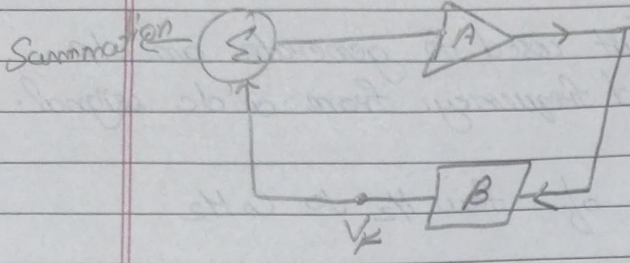


$V_f = \beta \cdot V_o$
$V_f = A\beta V_{in}$

feedback circuit ⇒ frequency selective circuit

β = feedback fraction i.e. it is what fraction of o/p signal will be given to i/p of feedback circuit

When there's no i/p signal there'll be still oscillations in o/p. due to thermal noise.

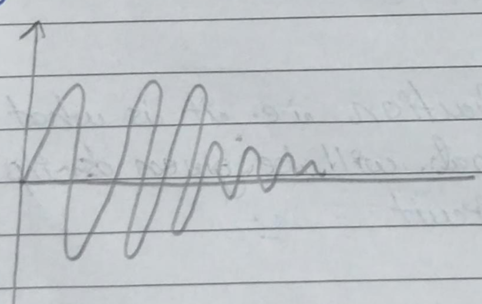


$A\beta$ is the loop gain & o/p depends on this $A\beta$.

Only particular frequency will be selected on basis of $A\beta$. Only some signal with particular frequency will be passes through frequency selective circuit.

$A\beta = 1$ and $A\beta$ phase difference $= 0$
i.e. No phase shift.

If $A\beta < 1$



If $A\beta < 1$, over a period of time, oscillation will die out i.e. damping.

$A\beta = 0.9$

$V_{in} = 2V$

$V_F = A\beta V_{in} = 1.8$

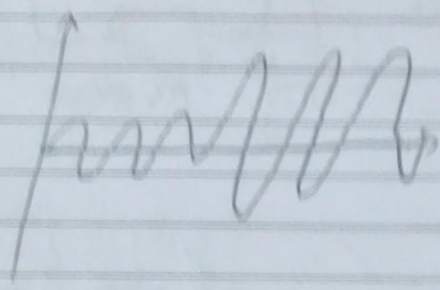
$V_F = 1.8 \times 0.9 = 1.62$

$V_F = 1.62 \times 0.9 = 1.458$

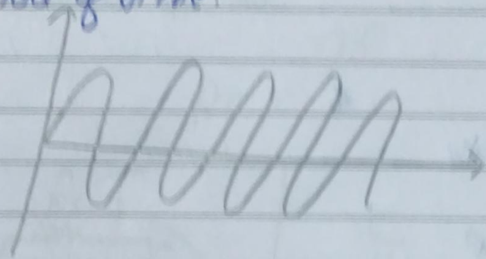
Over a period of time it keeps on decreasing thus will die out over a period of time.

ii) If AB > 1

it keeps on increasing



iii) If AB = 1, the oscillation is sustained for the period of time.



The two criteria to have uniform oscillation:

|AB| = 1 } Barkhausen
∠AB = 0° (Phase Diff = 0) } Criteria

* feedback circuit can be made of RC, RL or RLC components

→ Types of ~~feed~~ oscillator based on feedback circuit:

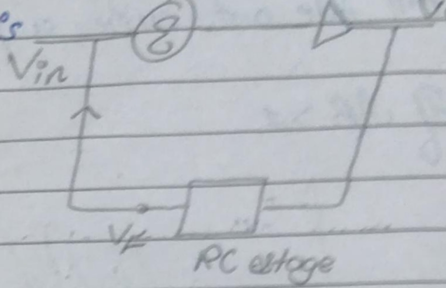
i. RC
ii. RL
iii. Crystal oscillator
} Sinusoidal oscillation

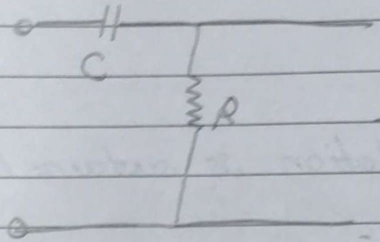
iv. Relaxation oscillator → non-sinusoidal oscillation

- RC Phase Shift oscillator :

i) ~~RC~~ The no feedback o/p is of 180°. i.e. phase shift = 180°

ii) RC circuit should reduce 180° phase shift for sustain ability.





→ HPF aka Phase lead circuit as o/p leads the i/p signal

$$\frac{V_o}{V_{in}} = \frac{R}{R - jX_c} \quad \&$$

$$\frac{V_o}{V_{in}} = \frac{R}{R - \frac{j}{\omega C}}$$

$$\frac{V_o}{V_{in}} = \frac{R\omega C}{R\omega C - j} = \frac{1}{1 - \frac{j}{R\omega C}}$$

$$\angle\phi = -\tan^{-1}\left(-\frac{1}{\omega CR}\right)$$

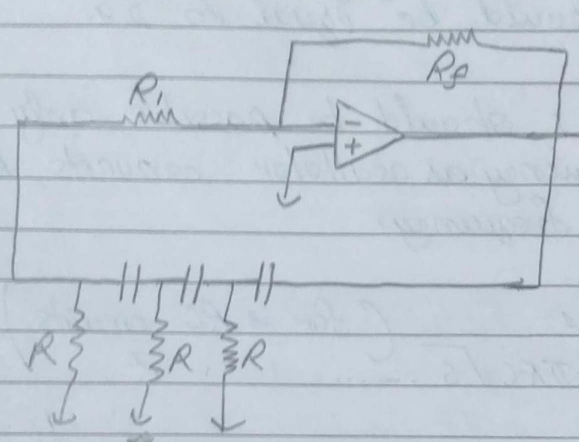
$$\angle\phi = \tan^{-1}\left(\frac{1}{\omega CR}\right)$$

$$\angle\phi = \tan^{-1}\left(\frac{X_c}{R}\right)$$

X_c very small $\angle\phi = 0°$

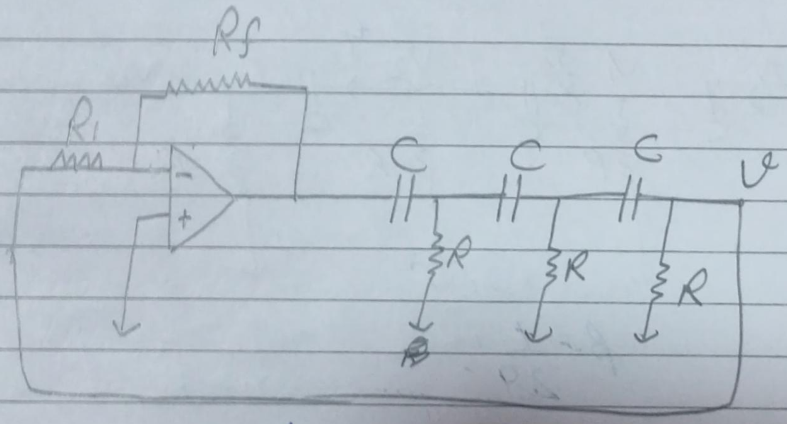
$R = 0, \angle\phi = 90°$

So we cascade two RC circuits to get 180° ∠ ϕ
This is theoretically correct but in actual we use three RC phase shift.



Practically one RC gives 60° phase diff.
so three RC = 180°

OR



↓

$\angle A\beta = 0$

⇒ $\beta = \frac{1}{29}$ i.e. the attenuation (loss of signal) produced by the feedback circuit (for this circuit) -RC

So $A = 29$

⇒ In RC phase shift oscillator, the attenuation introduced by feedback oscillator is 1/29.

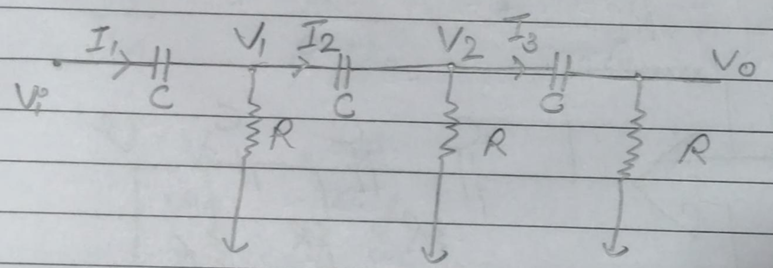
⇒ In order to get the unity gain the gain i.e. provided by op-amp should be equal to 29.

* $\angle A\beta = 0$ & $A\beta = 1$ should be possible only at a particular frequency as oscillator converts DC to AC with desired frequency.

$$f = \frac{1}{2\pi RC\sqrt{6}} \quad \left(\text{for 3 RC circuits}\right)$$

$$f = \frac{1}{2\pi RC\sqrt{2n}}$$, n is the no. of Phase lead circuit

⇒



$$\beta = \frac{1}{29}$$

i.e. $\frac{V_o}{V_i} = -\frac{1}{29}$

Proof:

At node V_2,

$$V_2 = (-jI_3X_C) + V_o$$

$$V_o = I_3 R$$

$$I_3 = \frac{V_o}{R}$$

$$V_2 = \left(-j \frac{V_0}{R} X_C\right) + V_0$$

$$X_C = \frac{1}{\omega C}$$

$$V_2 = \left(-j \frac{V_0}{R} \frac{1}{\omega C}\right) + V_0$$

$$V_2 = V_0 - j \frac{V_0 . 1}{R\omega C} \times \frac{j}{j}$$

$$V_2 = V_0 + \frac{V_0}{jR\omega C}$$

$$V_2 = V_0 \left[1 + \frac{1}{j\omega RC}\right]$$

Apply KCL at V_2,

$$I_2 = \frac{V_2}{R} + I_3$$

$$I_2 = \frac{V_0}{R}\left[1 + \frac{1}{j\omega RC} + 1\right] \quad \left[\because I_3 = \frac{V_0}{R}\right]$$

$$I_2 = \frac{V_0}{R}\left[2 + \frac{1}{j\omega CR}\right]$$

At node V_1

$$V_1 = V_2 + \frac{I_2}{j\omega C}$$

$$= V_0\left[1 + \frac{1}{j\omega CR}\right] + \frac{V_0}{R}\left[\frac{2}{j\omega C} + \frac{1}{j\omega CR} \times \frac{1}{j\omega C}\right]$$

$$= V_0\left[1+\frac{\cancel{j}1}{j\omega CR}+\frac{2}{j\omega CR}-\frac{1}{\omega^2C^2R^2}\right]$$

$$V_1 = V_0\left[1+\frac{3}{j\omega CR}-\frac{1}{\omega^2C^2R^2}\right]$$

Applying KCL at V_1

$$I_1 = \frac{V_1}{R} + I_2$$

$$I_1 = \frac{V_0}{R}\left[1+\frac{3}{j\omega CR}-\frac{1}{\omega^2C^2R^2}\right]+\frac{V_0}{R}\left[2+\frac{1}{j\omega CR}\right]$$

$$= \frac{V_0}{R}\left[3+\frac{4}{j\omega CR}-\frac{1}{\omega^2C^2R^2}\right]$$

$$V_i = V_1 + \frac{I_1}{j\omega C}$$

$$= V_0\left[1+\frac{3}{j\omega CR}-\frac{1}{\omega^2C^2R^2}\right]+\frac{V_0}{R}\left[3+\frac{4}{j\omega CR}-\frac{1}{\omega^2C^2R^2}\right]\times\frac{1}{j\omega C}$$

$$= V_0\left[1+\frac{3}{j\omega CR}-\frac{1}{\omega^2C^2R^2}+\frac{3}{j\omega CR}-\frac{4}{\omega^2C^2R^2}-\frac{1}{j\omega^3C^3R^3}\right]$$

$$V_i = V_0\left[1+\frac{6}{j\omega CR}-\frac{5}{\omega^2C^2R^2}-\frac{1}{j\omega^3C^3R^3}\right]$$

classmate

Date ____

Page ____

$\cancel{B}$ $Img = 0$

$$\frac{6}{\omega CR} - \frac{\cancel{6}}{\omega^3 C^3 R^3} = 0$$

$$6 = \frac{1}{\omega^2 C^2 R^2}$$

$$\omega = \cancel{RC}\ \frac{1}{RC\sqrt{6}}$$

So $f = \dfrac{1}{2\pi RC\sqrt{6}}$

So $Img = 0$

So

$$\cancel{V_i = V_0 \left[1 - \frac{5}{\frac{6R^2C^2}{R^2C^2}} \times R^2C^2 \right]}$$

$$\cancel{V_i = V_0 \left[\right.}$$

$$V_i = V_0 \left[1 - \frac{5}{\frac{1}{6R^2C^2}} \times R^2C^2 \right]$$

$$V_i = V_0 \left[1 - 30 \right]$$

$$\frac{V_0}{V_i} = \frac{-1}{29}$$

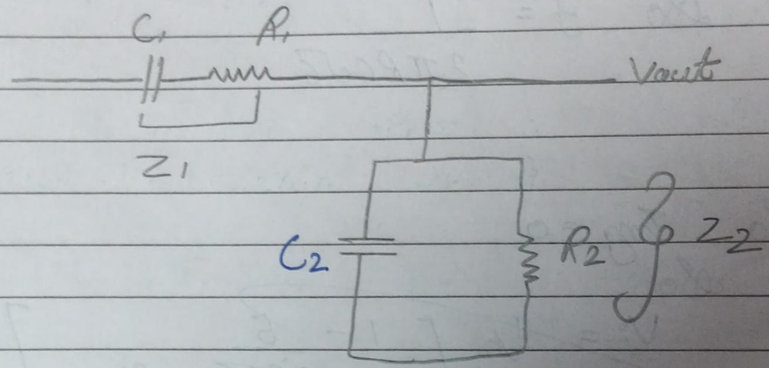
CLASSMATE

Date
Page

- Wein Bridge ~~Frequency~~ Oscillator:

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

$$\beta = \frac{1}{3}$$



$$V_0 = \frac{Z_2}{Z_1 + Z_2} \cdot V_{in}$$

$$Z_2 = R_2 \parallel \frac{1}{j\omega C_2} \Rightarrow \frac{\frac{R_2}{j\omega C_2}}{R_2 + \frac{1}{j\omega C_2}}$$

$$Z_1 = R_1 + \frac{1}{j\omega C_1}$$

$$\frac{R_1 j\omega C_1 + 1}{j\omega C_1} \qquad \frac{R_2}{R_2 j\omega C_2 + 1}$$

$$\frac{V_o}{V_{in}} = \frac{\frac{R_2}{R_2 j\omega C_2 + 1}}{\frac{R_2}{R_2 j\omega C_2 + 1} + \frac{R_1 j\omega C_1 + 1}{j\omega C_1}}$$

$$= \frac{\frac{R_2}{R_2 j\omega C_2 + 1}}{\frac{R_2 j\omega C_1 - R_1 R_2 \omega^2 C_1 C_2 + R_2 j\omega C_2 + R_1 j\omega C_1 + 1}{(R_2 j\omega C_2 + 1)(j\omega C_1)}}$$

$$\frac{V_o}{V_i} = \frac{R_2 j\omega C_1}{R_2 j\omega C_1 - R_1 R_2 \omega^2 C_1 C_2 + R_2 j\omega C_2 + R_1 j\omega C_1 + 1}$$

$$\frac{V_o}{V_i} = \frac{R_2 j\omega C_1}{1 - \omega^2 R_1 R_2 C_1 C_2 + j\omega [R_2 C_2 + R_2 C_1 + R_1 C_1]}$$

~~$R_1 C_1$~~ ~~We know that phase shift = 0~~

~~$R_2 j\omega C_1$~~ ~~So $1 - \omega^2 R_1 R_2 \omega^2 C_1 C_2 =$~~

As phase shift = 0

So $1 - \omega^2 R_1 R_2 C_1 C_2 = 0$

$$1 = \omega^2 R_1 R_2 C_1 C_2$$

$$\omega^2 = \frac{1}{R_1 R_2 C_1 C_2}$$

$$\omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

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

$$\frac{V_o}{V_i} = \frac{R_2C_1}{R_1C_1 + R_2C_2 + R_2C_1}$$

If $R_1 = R_2$ and $C_1 = C_2$

$$\frac{V_o}{V_i} = \frac{R.C}{3RC}$$

$$\boxed{\beta = \frac{V_o}{V_i} = \frac{1}{3}}$$

- **Multivibrator:**

It is an electronic oscillator that produces non-sinusoidal oscillations like triangular, square, etc.

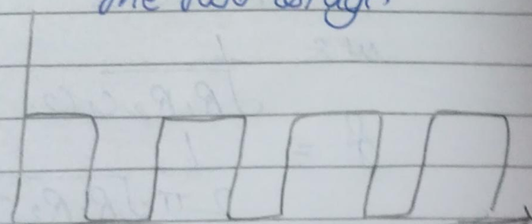
~~It~~ Two state solid devices: Two reference voltages in a device.

It is used to implement two state solid devices.

Three types:

1. Astable
2. Monostable
3. Bistable

Astable: o/p will keep on changing b/w the two states i.e. o/p not stable at any of the two stage.



555 IC timer is a type of relaxation oscillator for generating stabalised square o/p waveform of either a fixed frequency of upto 500 KHz or varied ~~due to~~ duty cycles from 50 to 100%.