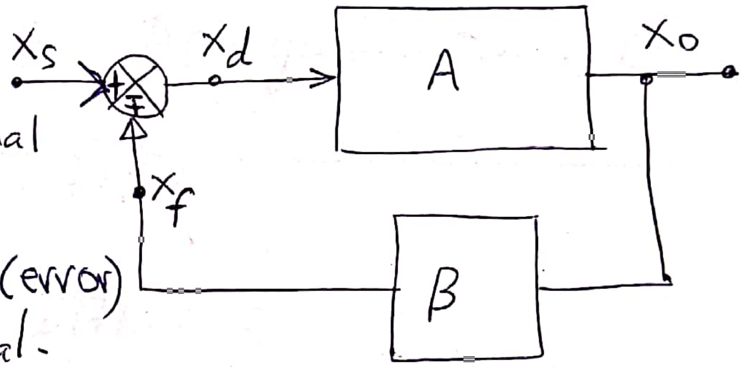
Feedback Amplifiers

F. B is a process by which a portion of the o/p is returned back to the input.

Consider the F.B System shown in Fig. where:



$X_s \rightarrow$ is the external Signal

$X_f \rightarrow$ = = feedback =

$X_d \rightarrow$ = = difference = (error)

$X_o \rightarrow$ = = output Signal.

$A \rightarrow$ = = open-loop gain (gain without F.B) $= \frac{X_o}{X_d}$

$\beta \rightarrow$ = = Feedback ratio. $\rightarrow \beta = \frac{X_f}{X_o}$

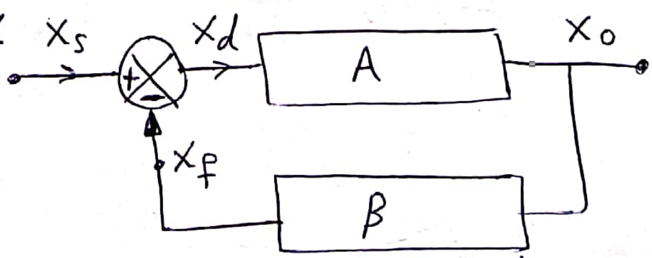
Types of Feedback: According to the relation between X_f and X_o, there are two types of F.B:

(i) If X_f opposes X_s (antiphase) this is called negative feedback and then $X_d = X_s - X_f$.
(reduces X_d)

(ii) If X_f aids X_s (inphase) this is called positive feedback and then $X_d = X_s + X_f$.
(increases X_d)

Negative Feedback (-ve F.B)

In -ve F.B, the following relations are applied:



$X_o = A X_d$, $X_d = X_s - X_f$

$X_f = \beta X_o$, $A_f = \frac{X_o}{X_s}$ where: -ve F.B system.

A_f = Amplifier gain with feedback.

Effect of -ve F.B on Amplifier

The -ve F.B has the following effects:

(a)- Reduce the gain: $A_f = \dfrac{A}{1+\beta A}$.
where:
A = gain without F.B , A_f = gain with F.B
β = F.B factor.

(b)- Extend the Bandwidth:
$$(B.W)_f = B.W\,(1+\beta A).$$
where: $(B.W)_f$ = B.W with F.B
hence -ve F.B decrease f_L and increase f_H
$f_{L_f} = f_L / (1+\beta A)$, $f_{H_f} = \cancel{f_H(1+\beta A)}$
$f_L \Rightarrow$ low cutoff freq; $f_H \Rightarrow$ high cutoff freq.

(c)- Increase Amplifier gain stability
$$\frac{dA_f}{A_f} = \frac{(dA/A)}{1+\beta A} \quad \text{where}$$
(dA/A): fractional change in gain without F.B
(dA_f/A_f): 〃 〃 〃 〃 with F.B

(d)- Reduce Internal noise and nonlinear distortion.
$$X_{n_f} = \frac{X_n}{1+\beta A}, \quad D_f = \frac{D}{1+\beta A} \quad \text{where}$$
X_n = Internal noise without F.B
X_{nf} = 〃 〃 with 〃
D = nonlinear distortion without F.B
D_f = 〃 〃 with 〃

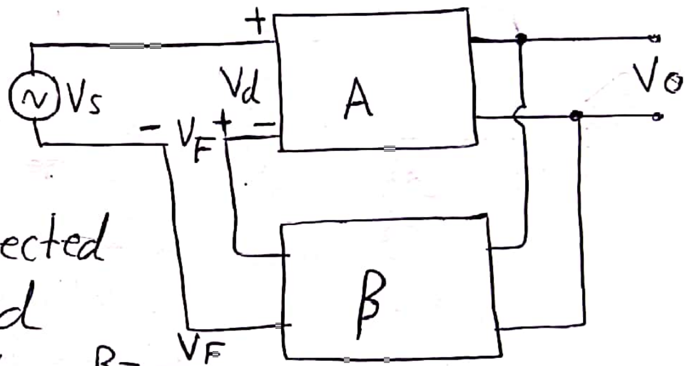
(e)- Decrease or Increase Amplifier impedances:
This effect depends on the type of -ve F.B (Topology) i.e Connection of F.B network to the Amplifier at input and output.

Types of -ve F.B (TOPOLOGY) (Connection)

According to the types of signals X_s and X_o, there are four types of -ve F.B to be applied with the four types of Amplifiers.

① Voltage (o/p) - Series (input): This topology is used with Voltage-Amplifier in which $X_s = V_s$ and $X_o = V_o$, $A = A_v = \frac{V_o}{V_s}$ and the block diagram is shown in Fig.

This Connection increase Z_i and decrease Z_o because the F.B network is connected in series with input and in parallel with output.

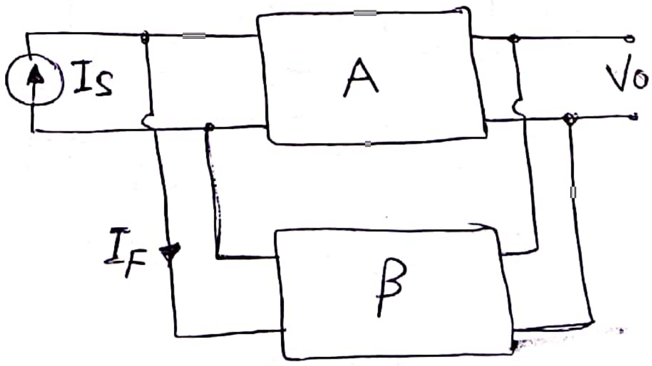


$\beta = \frac{V_F}{V_o}$

$Z_{if} = Z_i(1+\beta A)$, $Z_{of} = \frac{Z_o}{1+\beta A}$, $A_{vf} = \frac{A_v}{1+\beta A}$

② Voltage (o/p) - Shunt (i/p): This type is used with (Transimpedance Amplifier) in which $X_s = I_s$, $X_o = V_o$. So the gain $A = \frac{V_o}{I_s}$ (Ω). the block diagram is shown:

This topology Decrease both Z_i and Z_o where:



$$Z_{if} = \frac{Z_i}{1+\beta A}$$

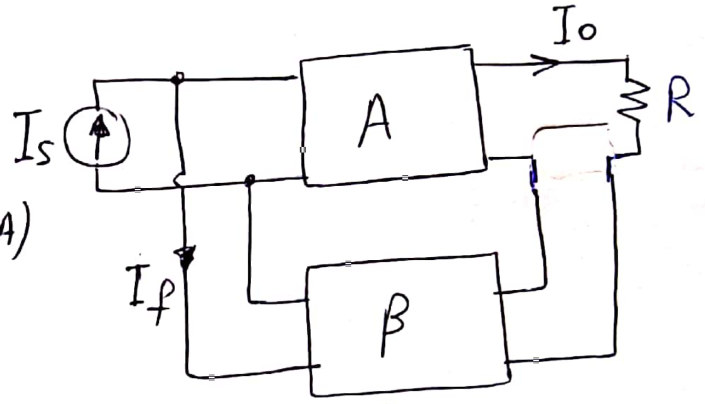
$$Z_{of} = \frac{Z_o}{1+\beta A}$$

$$A = \frac{V_o}{I_s} = R_m\,(\Omega)$$

$$\beta = \frac{I_f}{V_o}\ \mho$$

$$R_{mf} = \frac{R_m}{1+\beta A}$$

③ **Current-Shunt** (o/P Current, i/P Shunt): This type is used with (Current-Amplifier) in which $X_s = I_s$, $X_o = I_o$
so the gain $A = \frac{I_o}{I_s}$, the block diagram is shown:



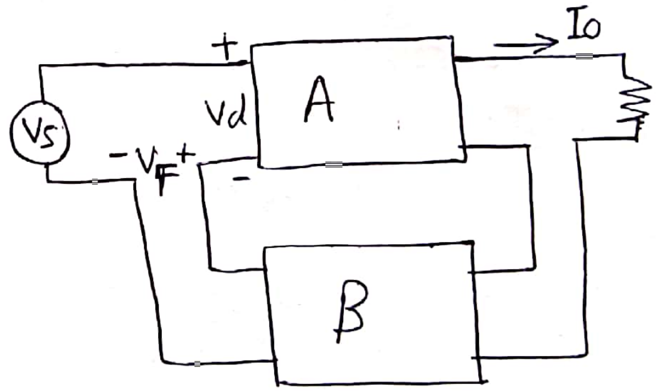
This topology decrease Z_i and increase Z_o

$$Z_{i_f} = \frac{Z_i}{1+\beta A}, \quad Z_{o_f} = Z_o(1+\beta A)$$

$$A = A_I = \frac{I_o}{I_s}, \quad A_{I_f} = \frac{A_I}{1+\beta A}$$

$$\beta = \frac{I_F}{I_o}$$

④ **Current-Series** (o/P Current, I/P Series): This topology is used with (Transconductance-Amplifier) where $X_s = V_s$, $X_o = I_o$
so its gain is $A = \frac{I_o}{V_s} = G_m\,(\mho)$. The block-diagram is shown:



This topology Increases both input and output impedances.

$$Z_{i_f} = Z_i(1+\beta A).$$

$$Z_{o_f} = Z_o(1+\beta A).$$

$$A_f = G_{m_f} = \frac{G_m}{1+\beta A}$$

$$\beta = \frac{V_F}{I_o}\,(\Omega)$$

* NOTES

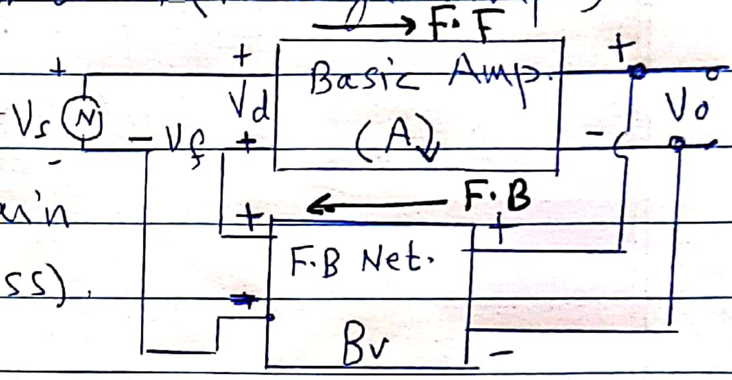
i- The product (βA) is always unitless.

ii- Z_i, Z_o refer to impedances without F.B

iii- Z_{i_f}, Z_{o_f} " " " with -ve F.B

① Voltage-Series or (Shunt-Series) Topology.

This topology is used with (Voltage-Amp.) in which $X_s = V_s$ and $X_o = V_o$ and has a trasfer gain $A = \frac{X_o}{X_s} = \frac{V_o}{V_s}$ (unitless).



In this topology;

* We Sample (take) Voltage (V_o) from o/p and mixe Voltage with V_s.
* A: gain of basic Amp. ($A = \frac{V_o}{V_d}$)
  V_d: error or difference Voltage ($V_d = V_s - V_f$).
  V_f: feedback voltage ($V_f = BV_o$), where
  $B = \frac{V_f}{V_o}$ (F.B factor or F.B ratio).

F.B net. is passive cct and has attenuation ($B < 1$). To derive an expression for the gain with F.B (A_f) then: ① Voltage-gain $A_{vf} = \frac{V_o}{V_s}$

$V_o = A_v V_d \quad , V_d = V_s - V_f \quad , V_f = BV_o$

$V_o = A_v(V_s - V_f) = A(V_s - BV_o) = AV_s - ABV_o$

$V_o + BAV_o = A_v V_s \Rightarrow V_o(1 + BA_v) = A \cdot V_s$

$$\frac{V_o}{V_s} = \boxed{A_{vf} = \frac{A_v}{1 + BA_v}}$$ where

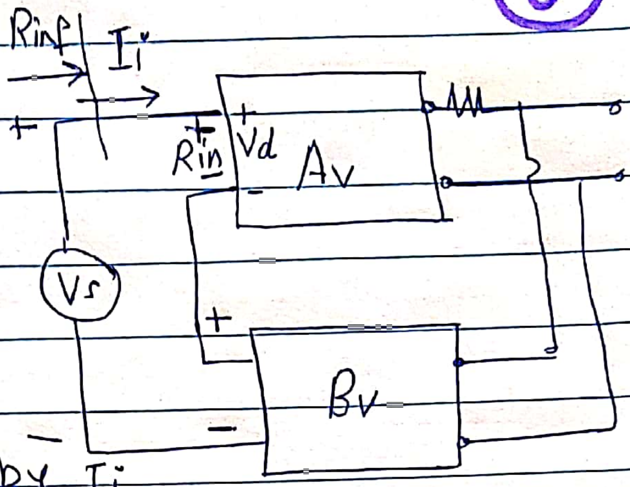
A_v: gain of basic Amp. (without F.B)

A_{vf}: gain of F.B Amp.

B_v: F.B ratio $= \frac{V_f}{V_o}$

* In this topology: A_v, B_v, A_{vf} have No unit i.e (unitless)

(2) Input Resistance: Rin



$V_s = V_d + V_f = V_d + B_v V_o$

$V_o = A_v V_d$

$V_s = V_d + B A_v V_d$

$= V_d (1 + B_v A_v)$

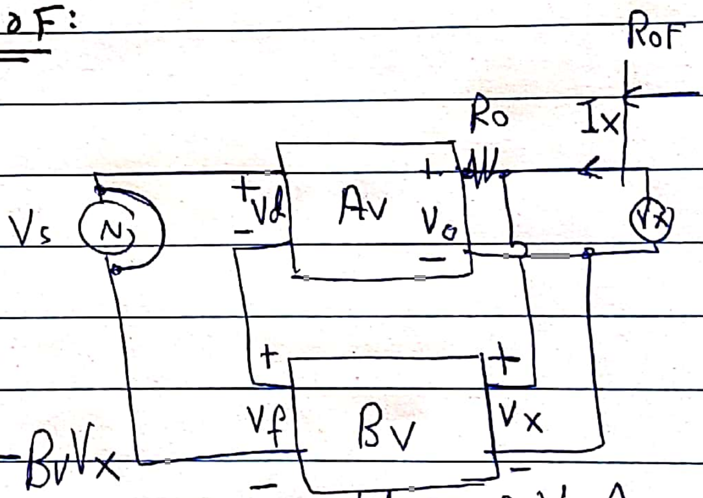
but $R_{in} = \frac{V_d}{I_i}$ divide by I_i

$\frac{V_s}{I_i} = \frac{V_d}{I_i}(1 + B_v A_v)$

$R_{if} = R_{in}(1 + B_v A_v)$

i.e this connection (Series Connection) increase Rin.

(3) Output Resistance R_{oF}:



$R_{oF} = \frac{V_x}{I_x}\Big|_{V_s = 0}$

$I_x = \frac{V_x - V_o}{R_o}$

$V_o = A_v . V_d$

$V_d = V_s - V_f$, $V_f = B_v V_x$.

when $V_s = 0$, $V_d = -V_f = -B_v V_x$

$\therefore I_x = \frac{V_x + B_v V_x A_v}{R_o}$ (because $V_o = A_v . V_d = -B_v V_x A_v$

$\therefore I_x = \frac{V_x (1 + B_v A_v)}{R_o} \rightarrow \frac{I_x}{V_x} = \frac{1}{R_{oF}} = \frac{1 + B_v A_v}{R_o}$

$\therefore R_{oF} = \frac{R_o}{1 + B_v A_v}$ [i.e shunt Connection Reduces Ro]

This means: Series Connection increase Ri or Ro and Shunt Connection decreases Ri or Ro. Where ever it is at input or output.

EXA: a voltage Amp. has: $A_V = 1000$, $R_{in} = 1K\Omega$, $R_o = 2K$
$B.W = 500\,KHZ$ and distortion $D = 100\,dB$. with F.B
* If it is subjected to -ve. F.B with voltage-Series topology. Recalculate its parameters when the F.B ratio $B_v = 0.04$ or 4%?

$$A_{vf} = \frac{A_v}{1+B_v A_v} = \frac{1000}{1+0.04\times100} = \frac{100}{5} = 20$$

$$R_{inf} = R_{in}(1+\beta_v A_v) = 1\,(1+0.04\times100) = 5K\Omega$$

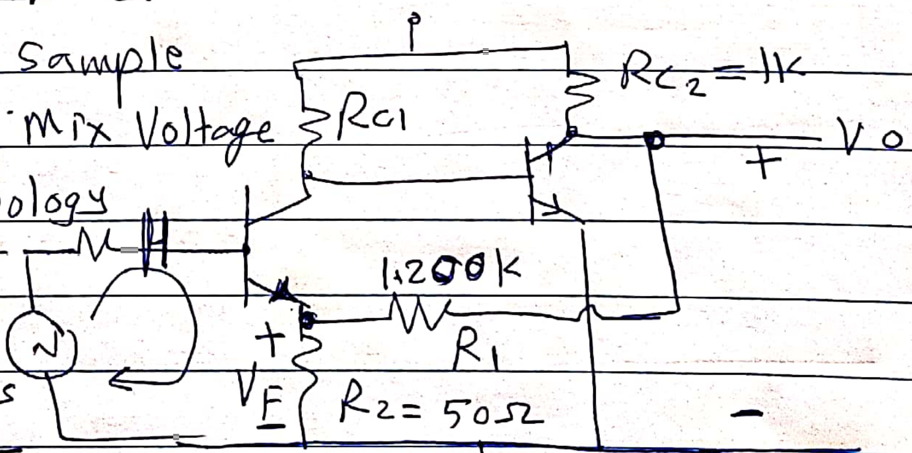
$$R_o = \frac{R_o}{1+\beta_v A_v} = \frac{2K}{1+0.04\times100} = 400\,\Omega$$

$$(B.W)_f = B.W(1+\beta_v A_v) = 500\times5 = 2500\,KHZ$$

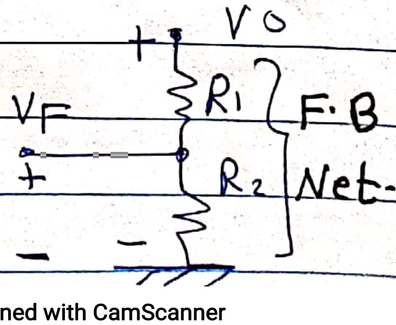
$$D_f = \frac{D}{1+\beta_v A_v} = \frac{100}{1+0.04\times100} = 20\,dB.$$

Voltage-Series in Electronics cct.

In this cct. we sample voltage (Vo) and mix Voltage (Vf) so the topology
* is From o/p voltage → Shunt
* For input we mix voltage (Vf) ∴ Topology is [Voltage-Series]



$$\beta = \frac{V_F}{V_o} = \frac{R_2}{R_1+R_2}$$, (Voltage-divider)



ExA: Given the Amp. has $A_v = 100$, $R_{in} = 5K\Omega$, $R_o = 1K\Omega$, $A_I = -1000$, $B.W = 100KHZ$.
Recalculate A_v, R_{in}, R_o and B.W after applying the F.B shown. (what is the type of Amp).

$$\beta_v = \frac{R_2}{R_1 + R_2} = \frac{50}{1200+50} = 0.04$$

Since the topology is Voltage-Series, then:

$$A_{vf} = \frac{A_v}{1+\beta_v A_v} = \frac{-200}{1+0.04\times100} = \frac{-200}{5} = \boxed{-40}$$

$$1+\beta A = 1+0.04\times100 = \boxed{5}$$

$$A_{If} = \frac{A_I}{1+\beta_v A_v} = \frac{-1000}{1+0.04\times100} = -200$$

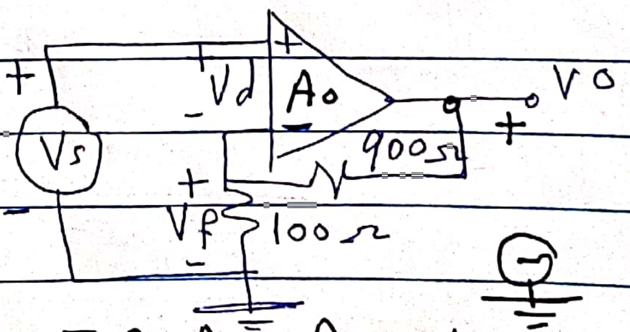
$$R_{inf} = R_{in}(1+\beta_v A_v) = 5(5) = 25K\Omega$$

$$R_{oF} = \frac{R_o}{1+\beta_v A_v} = \frac{1K\Omega}{5} = 200\Omega$$

$$(B.W)_f = B.W(1+\beta_v A_v) = 100\times5 = 500KHZ.$$

The type of Amp. is Voltage-Amp.

* H.W: Identify the topology and Find: β_v, A_{vf}. assume $A_o = 1000$.



* Since we sample Voltage V_o and mix. Voltage V_f, so it is Voltage-Series

$$\beta = \frac{V_F}{V_o} = \frac{100}{100+900} = 0.1$$

$$A_{vf} = \frac{A_v}{1+\beta A_v}, \text{ without F.B } A_v = A_o = 1000$$

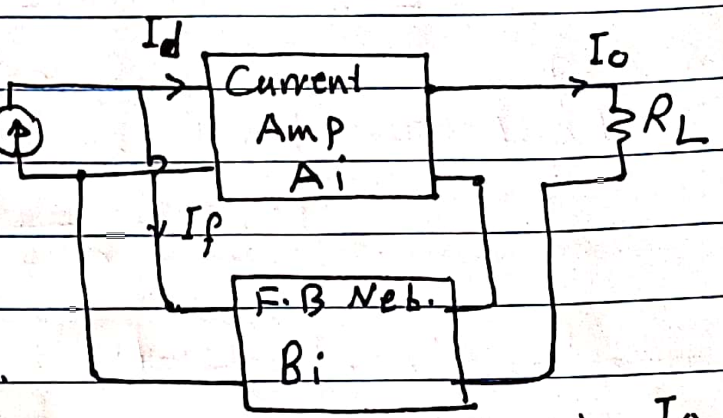
$$\therefore A_{vf} = \frac{1000}{1+0.1\times1000} = 9.9$$

* For Non-Inverting Amp

$$A_v = 1+\frac{R_2}{R_1} = 1+\frac{900}{100} = 10$$

2) Current-shunt Topology:
[Series-shunt]

* $x_o \rightarrow I_o$
$x_f \rightarrow I_f$
$x_s \rightarrow I_s$
$x_d = I_d = I_s - I_f$



* Used with Current Amp.

Transfer gain: $A = A_i \rightarrow$ Current gain (unitless) $= \frac{I_o}{I_d}$

F.B factor: $B = B_i = \frac{I_f}{I_o}$ (unitless)

EXAMPLE:

A current Amp. has the following parameters befor F.B: $A_i = 10^3$, $R_{in} = 10K\Omega$, $R_o = 20K\Omega$, $B.W = 200KHZ$. It is required to make $R_{in} = 1K\Omega$. Identify the required Topology and calculate Amp. parameters with F.B? Find A_{if}, R_{of}, $(B.w)_f$.

* The required topology is Current-shunt.

$$R_{inf} = \frac{R_{in}}{1+B_iA_i} \rightarrow 1K\Omega = \frac{10K}{1+B_iA_i} \rightarrow 1+B_iA_i = 10$$

$$\therefore B_i = \frac{9}{A_i} = \frac{9}{1000} = 0.009$$

$$R_{of} = (1+B_iA_i)R_o = 10\times20 = 200K\Omega$$

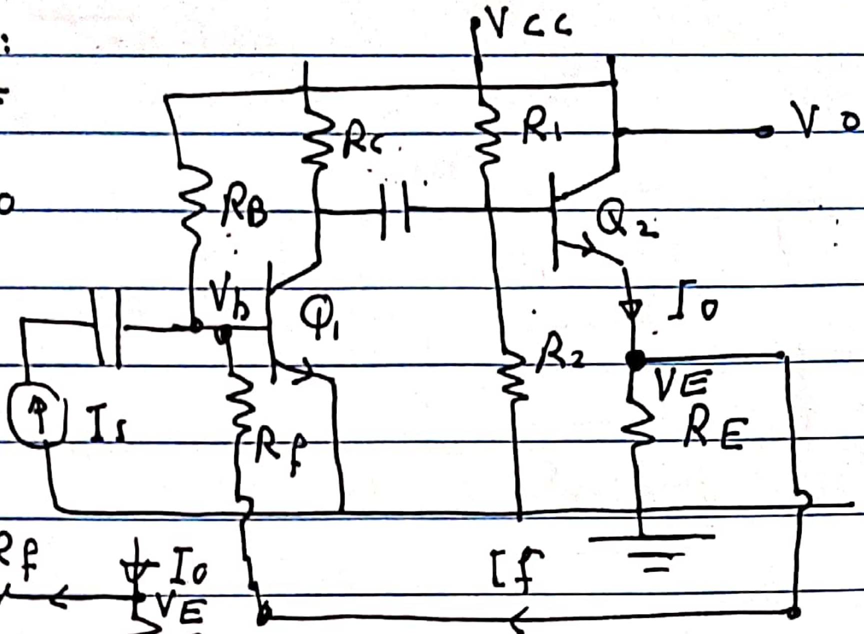
$$A_{if} = \frac{A_i}{1+B_iA_i} = \frac{1000}{10} = 100$$

$$(B.W)_f = (1+B_iA_i)(B.W) = 10\times200 = 2000KHZ = 2MHZ.$$

* If the gain is changed by 20% befor F.B calculate the percentage change in gain after F.B

$$\frac{dA_f}{A_f} = \frac{(dA/A)}{1+B_iA_i} = \frac{20\%}{10} = 2\%$$

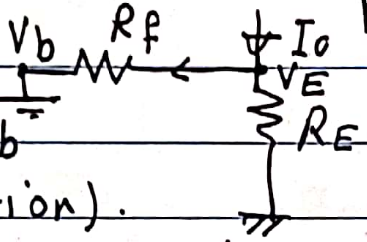
Circuit diagram:



* A portion of I_o (I_f) is returned to input

The F.B factor:

$$B_i = \frac{I_f}{I_o}$$



Since $V_E \gg V_b$ (Amplification).

V_b can be considered ground compared to V_E.

i.e R_E and R_f can be considered in parallel

So current division rule is applied:

$$I_f = \frac{I_o \cdot R_E}{R_E + R_F} \Rightarrow \frac{I_f}{I_o} = B_i = \frac{R_E}{R_E + R_f}.$$

* The above amp. has $R_i = 1K\Omega$, $R_o = 100\,\Omega$ and a gain $A_I = 100$. B.W $= 150KHZ$. a negative F.B is applied with (R_E & R_F). Calculate Amp. parameters when $R_E = 1K\Omega$, $R_F = 99K\Omega$.

Solution: $B_i = \frac{R_E}{R_E + R_F} = \frac{1}{1+99} = 0.01$

$1 + B_i A_i = 1 + 0.01 \times 100 = 2$

$A_{If} = A_I / (1 + B_i A_i) = 100/2 = 50$

$R_{if} = R_i / (1 + BA) = 1/2 = 0.5K\Omega$

$R_{oF} = R_o(1 + BA) = 100 \times 2 = 200\,\Omega$

$(B.W)_f = (B.W)(1 + BA) = 150 \times 2 = 300KHZ.$

3 Voltage-Shunt Topology:

We Sample Voltage and Mix → Current:

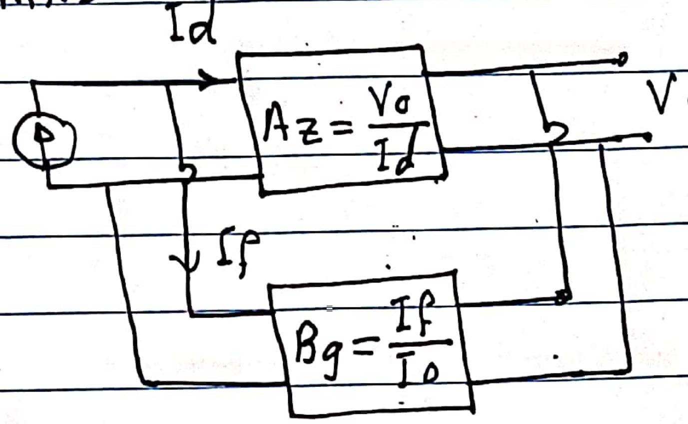
$x_o = V_o$, $x_s = I_s$

$x_d = I_d$, $x_f = I_f$

$A = \frac{V_o}{I_s} = A_z = \Omega$

Transresistance Amp.

$\beta = \frac{I_f}{V_o} = B_g\ (\mho)$



B is connected with A ... shunt i/p, shunt o/p.

So $Z_{if} = \frac{Z_i}{1+\beta A}$, $Z_{of} = \frac{Z_o}{1+\beta A}$.

$$(A_z)_f = \frac{A_z}{1+A_z B_g}$$

EXAMPLE: A transresistance Amp. has $A_z = 1000$, $R_{in} = 5000\,\Omega$, $R_o = 2000\,\Omega$, $(BW) = 20\,KHZ$.

* If a F.B with $B_g = 0.009$ Semins ($\mho$). Calculate Amp. parameters with F.B.

Solution:

$$(A_z)_f = \frac{A_z}{1+\beta A} = \frac{1000}{1+0.009\times 1000} = 100\,\Omega$$

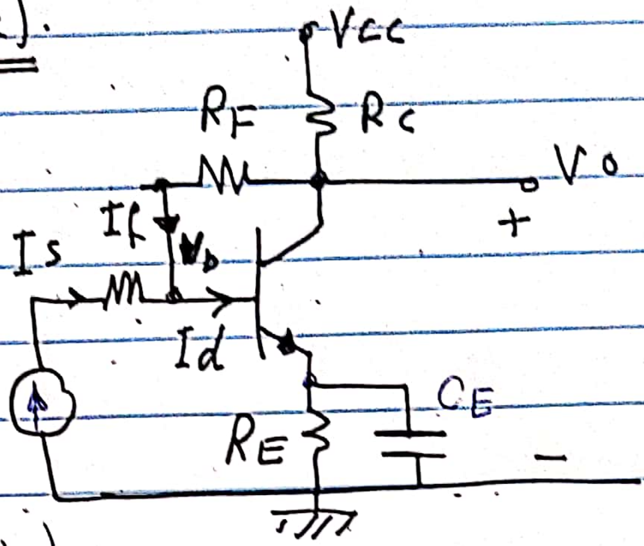
$$(B.W)_f = (B.W)(1+\beta A) = 20\times 10 = 200\,KHZ$$

$$Z_{of} = Z_o/(1+\beta A) = \frac{2000}{10} = 200\,\Omega$$

$$Z_{if} = Z_i/(1+\beta A) = 5000/10 = 500\,\Omega$$

* If the Amp. has a distortion of 80dB after F.B what is the Distortion befor F.B? $D_f = D/(1+\beta A) \rightarrow D = D_f(1+\beta A) = 800\,dB$

Circuit diagram: (Example).



$V_o \gg V_b$ (Amplifier)

$$I_f = \frac{V_o - V_b}{R_F} \Rightarrow I_f \simeq \frac{V_o}{R_f}$$

$$B = \frac{x_f}{x_o} = \frac{I_f}{V_o} = \frac{1}{R_f} \ (℧)$$

$$A = \frac{V_o}{I_s} = A_z. \text{ (Transfer gain).}$$

EXA: For the above cct. the Amp. has a transfer gain $A_z = \frac{V_o}{I_s} = 1000\,\Omega$, $R_{in} = 2K\Omega$, $R_o = 1K\Omega$, Distortion, $D = 50dB$, noise, $X_n = 10\mu V$.
Reclaculate Amp. parameter when $R_f = 250\Omega$.

$B_g = \frac{1}{R_F} = 1/250 = 0.004\,℧$

$1 + BA = 1 + 0.004 \times 1000 = 5$

$(A_z)_f = 1000/5 = 200\,\Omega$

$R_{if} = R_{in}/(1+BA) = 2K/5 = 400\,\Omega$

$R_{of} = R_o/(1+BA) = 1K/5 = 200\,\Omega$

$D_f = D/(1+BA) = 50/5 = 10dB$

$X_{nf} = X_n/(1+BA) = 10\mu V/5 = 2\mu V.$

* Reclaculate A_{z_f}, R_{in_f}, R_{o_f}, $(B.W)_f$, D_f & X_{nf} when $R_f = 2.5\,\Omega$? $B_g = 1/R_F = 0.4$, $1+BA = 401$

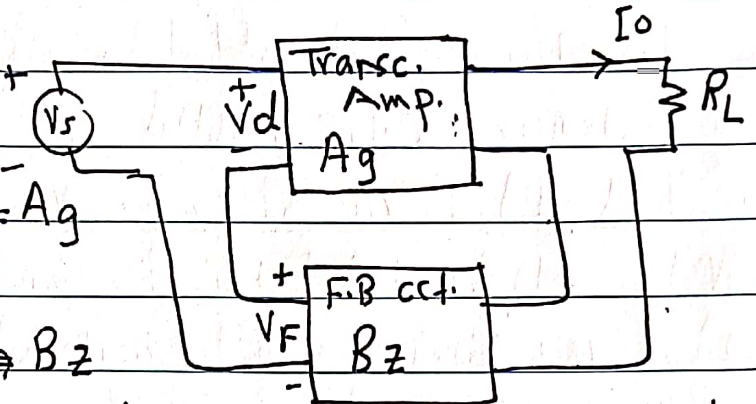
$A_{zf} = A_z/(1+B_g A_z) = \frac{1000}{1+401} = 2.493\,\Omega \simeq 2.5\,\Omega$

Since $BA \gg 1 \Rightarrow A_f = \frac{1}{B}$

$R_{if} =$, $R_{of} =$, $(B.W)_f =$

$D_f =$ $X_{nf} =$

(4) "Current-Series" or "Series-Series" Topology.



$A = \frac{I_o}{V_s} = G_m\ (\mho) = A_g$

$B = \frac{V_F}{I_o} = R\ (\Omega) \Rightarrow B_z$

* This topology is Used With Transconductance Amp.

$$A_{gf} = \frac{A_g}{1 + B_z A_g}\ (\mho)\ \text{Transconductance}$$

* Both Rin and Ro will be increased because F.B cct. is Connected in Series with Basic Amp. from both side input & output. So:

$R_{if} = R_{in}(1 + B_z A_g)$, $R_{oF} = R_o(1 + B_z A_g)$

* $B_z A_g$ has no unite (unitless).

EXAMPLE: A transcondance Amp. has a transfer gain $A_g = 400$ Sem. $(\mho)$, $R_{in} = 1K\Omega$, $R_o = 2K\Omega$, $B.W = 200KHz$ and distortion $D = 100dB$. If a-ve F.B with Current-Series topology is applied with $B_z = 0.01\ \Omega$. Recalculate Amp. parameter After F.B:

Solution:

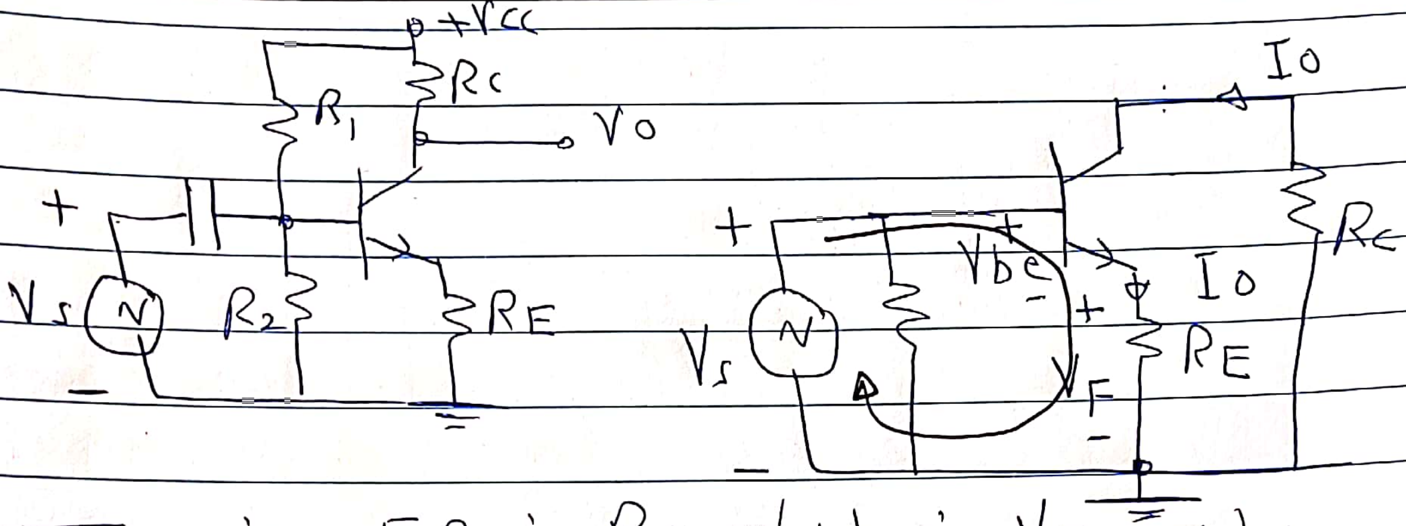
$A_{gf} = A_g / 1+BA$, $B_z \cdot A_g = 0.01 \times 400 = 4$, $(1+BA) = 5$

$\therefore A_{gf} = 400/5 = 80\mho$, $(B.W)_f = 200 \times 5 = 1MH$

$R_{if} = R_i(1+BA) = 1 \times 5 = 5K\Omega$ $D_f = 100/5 = 20dB$

$R_{of} = R_o(1+BA) = 2 \times 5 = 10K\Omega$

Cct. diagram with "Serie-Series" Topology:



* There is a F.B in R_E which is V_F, ~~this~~ V_F opposes V_s ; where $-V_s+V_{be}+V_F=0$
∴ $V_{be}=V_s-V_F$ so −ve F.B.
V_F ~~is~~ $= I_o . R_E$ i.e $V_F \propto I_o$ which is the Current in o/p loop.
* So from o/p we Sample a Current and from input we Mix a Voltage So the topology is "Current Series".

$$\beta = \frac{x_f}{x_o} = \frac{V_F}{I_o} = \frac{I_o . R_E}{I_o} = R_E(\Omega).$$

$$A = \frac{I_o}{V_s} = g_m.$$

EXAMPLE: The above Amp. has $A_g=\frac{I_o}{V_s}=100$ S
$R_i=10K\Omega$, $R_o=1K\Omega$, B.W = 100KHz
* Recalculate Amp. parameters when $R_E=25\Omega$.

$A_{gf}=A_g/(1+B_zA_g)$, $1+B_zA_g=1+100\times\frac{1}{25}=5$
∴ $A_{gf}=100/5=20$, $(B.W)_f=100\times5=500KHz$
$R_{if}=R_i(1+BA)=10\times5=50K\Omega$
$R_{oF}=R_o(1+BA)=1\times5=5K\Omega$.

ExA: 2 Given β, R_1, R_2
R_C, R_E

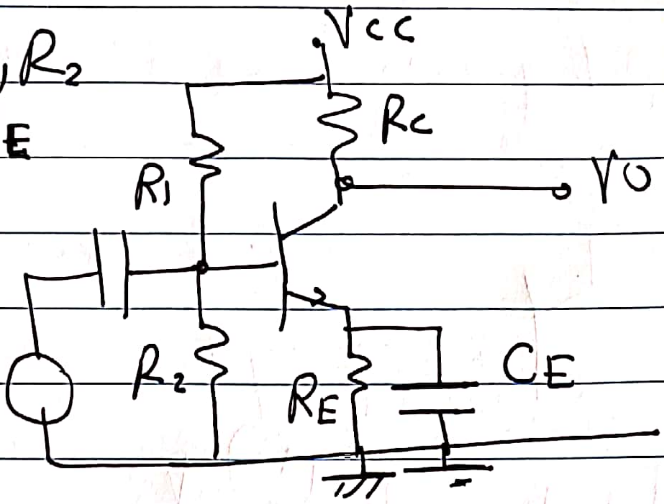
Calculate $\underline{A_V}$, $\underline{R_{in}}$

when C_E:

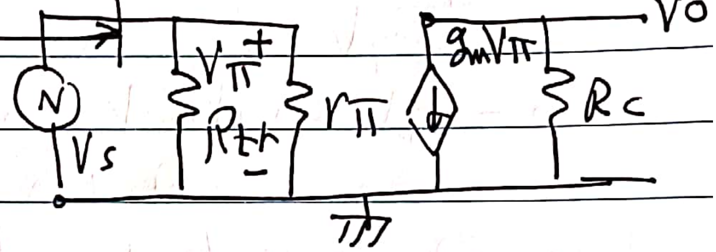
1) exists ✓

2) Removed

and Comment.



1) when C_E is present, it will short out R_E

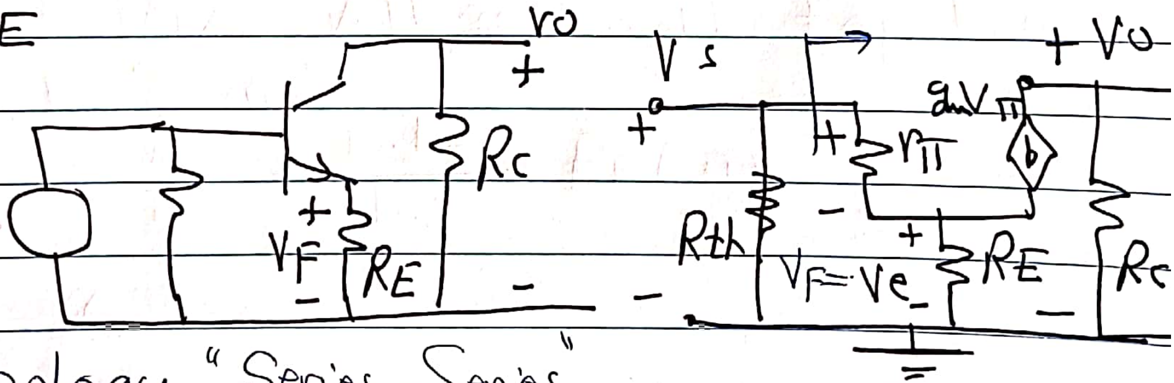


$$A_V = V_o / V_s = \frac{- g_m V_\pi R_C}{V_s}$$

$\therefore A_V = -g_m R_C$ ✓

$R_{in} = R_{th} // r_\pi$ ✓ $\underline{(\text{No } -ve \text{ F.B})}$

2) when C_E is removed a $-ve$ F.B will be ON R_E



with topology "Series_Series"

$A_{VF} = V_o / V_s = -g_m V_\pi R_C / (V_\pi + (\beta+1) I_b R_E)$

$A_{VF} = (- g_m V_\pi R_C) / (V_\pi + (\beta+1) \frac{V_\pi}{r_\pi} R_E)$

$$A_{VF} = \frac{-g_m R_C}{(1 + (\beta+1) \frac{R_E}{r_\pi})} \Rightarrow A_V \rightarrow \text{reduces}$$

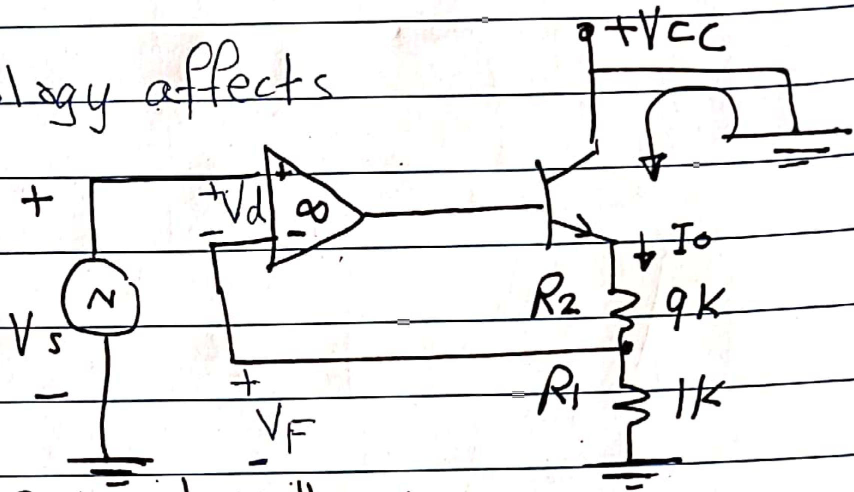
$R_{inf} = [[r_\pi + (\beta+1) R_E] // \cancel{R_{th}}]$ $R_{in} \rightarrow$ Increases

So this F.B decrease $\underline{A_V}$ and Increase $\underline{R_{in}}$

$$\text{"} A_g = \frac{I_o}{V_s} = \frac{g_m V_\pi}{V_\pi + (\beta+1) I_b \cdot R_E} = \frac{g_m V_\pi}{V_\pi + (\beta+1) \frac{V_\pi}{r_\pi} R_E} = \frac{g_m}{1 + \frac{R_E}{r_\pi}(\beta+1)}$$

Examples:

① For the system shown: Identify the topology and determine B??
How does this topology affects A_V, R_{in}, R_o



"Summary of -ve F.B topology".

In all topology: $A_f = \frac{A}{1+BA}$, $(B.W)_f = (1+BA) B.W$, $D_f = \frac{D}{1+BA}$

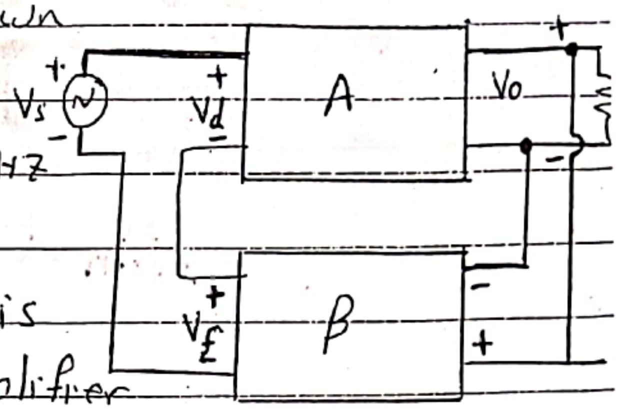
Topology	Amp Type	X_s	X_o	X_f	A	B	Rin_f	Ro_f
Voltage-Series "Shunt-Series"	Voltage Amp.	Vs	Vo	Vf	Av	Bv	$R_{in}(1+BA)$	$\frac{R_o}{(1+BA)}$
Current-Shunt "Series-Shunt"	Current Amp.	Is	Io	If	Ai	Bi	$\frac{R_{in}}{1+BA}$	$R_o(1+BA)$
Voltage-Shunt "Shunt-Shunt"	Transresistance Amp	Is	Vo	If	R_Ω A_z	Bg	$\frac{R_{in}}{1+BA}$	$\frac{R_o}{1+BA}$
Current-Series "Series-Series"	Transconductance Amp.	Vs	Io	Vf	Ag	Bz	$R_{in}(1+BA)$	$R_o(1+BA)$

* In all Topology: $AB \Rightarrow$ No unit (unitless)

Feedback sheet

17

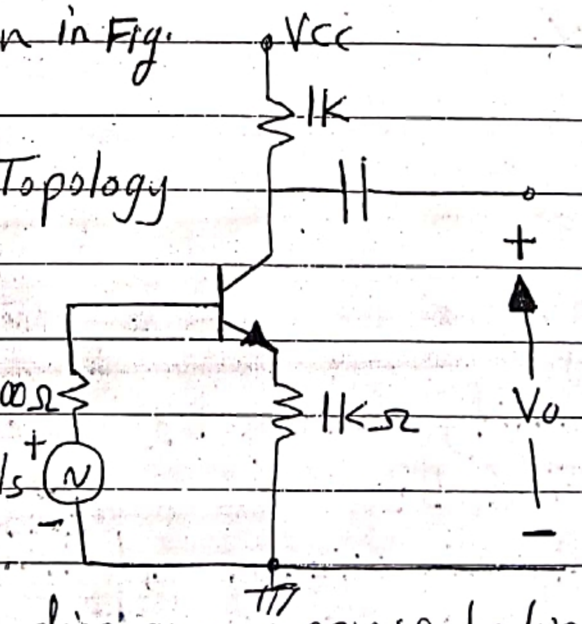
Q1 For the F.B amplifier shown the amplifier has:
$R_i = 1K$, $R_o = 5K$, $f_L = 500HZ$
$f_H = 50KHZ$. $A = 50$ with:
No F.B. If 8% -ve F.B is applied, recalculate the Amplifier parameters? sketch the freq. response with and without F.B?



Q2 A current amplifier has $A_I = 40$ dB, $R_i = 2K\Omega$
$R_o = 1K\Omega$. If it is required to make $R_i = 200\Omega$
(i) What type of -ve F.B is required, draw block diagram
(ii) Recalculate A_I, R_o and find the required β?
(iii) Suggest a F.B network to realize this β?

Q3 For the cct. shown in Fig.

(i) What type and Topology of the F.B?
(ii) How does this F.B affect the input & output impedances.



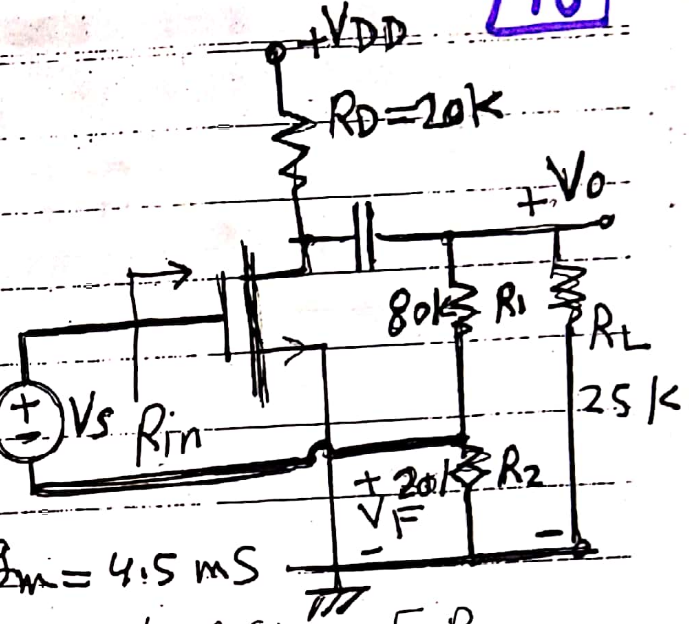
(iii) Draw the block diagram representation for the above F.B.

P.T.O

Q4

Given: $g_m = 4.5\,mS$

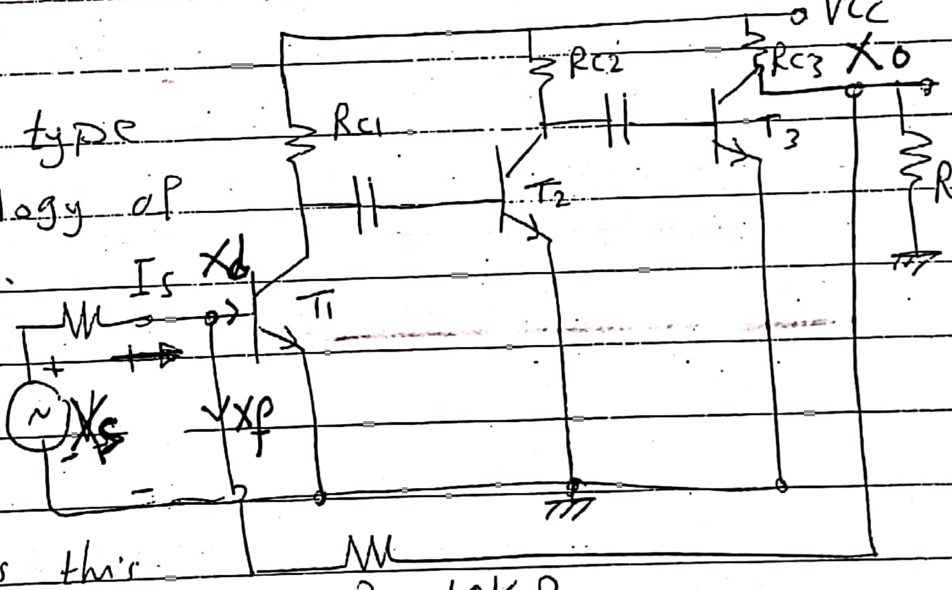
1) Identify F.B Topology
2) Find A_v, R_o, β
   A_{vf}, R_{oF}, R_{in}, R_{inF}
3) If $f_L = 500\,HZ$
   $f_H = 500\,KHZ$



Draw freq. Response befor and After F.B.

Q5: Consider the circuit shown in Fig.

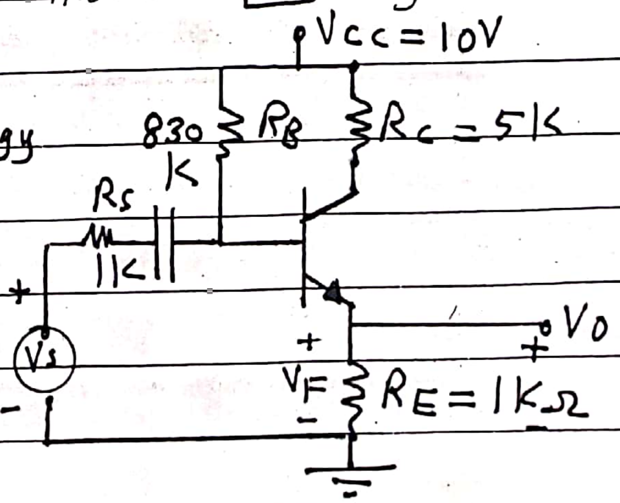
1) Identify type and topology of this F.B.
2) Indicate X_s, X_f, X_d, X_o



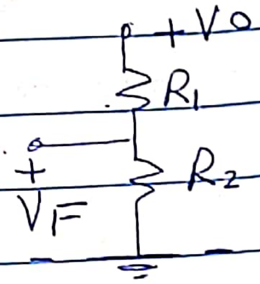
3) How does this F.B affect Z_i & Z_o.
4) Name this Amp. and indicate $\boxed{A}$ type & units, $\boxed{\beta}$ value & unit.

Q6: Identify the topology and Find B?

Estimate Rin without F.B and with F.B?
Sketch Block diagram.



Q_4: The F.B is through R_1 & R_2 where V_F is across R_2. Since the form a Voltage-divider

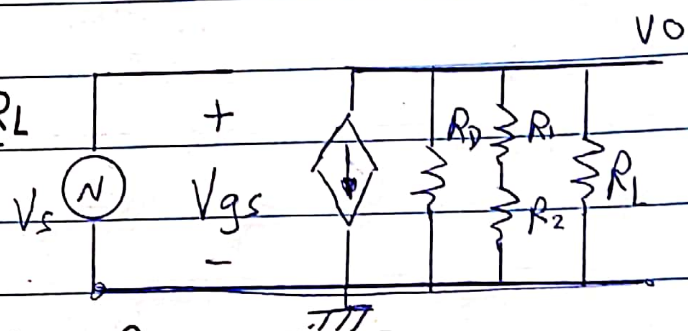


$$V_F = \frac{V_o \cdot R_2}{R_1+R_2} \Rightarrow B = \frac{V_F}{V_o} = \frac{R_2}{R_1+R_2} \quad \underline{VDR}$$

i.e $V_f \propto V_o \Rightarrow$ If $V_o = 0$, $V_f = 0$, No F.B"

So it is voltage from o/p, V_f is mixed in Series with $V_s \Rightarrow$ So it is "Voltage-Series" and Used with "Voltage-Amplifier"

① without F.B:



$$A_v = \frac{V_o}{V_s} = \frac{-g_m V_{gs} (R_D // (R_1+R_2) // R_L)}{V_{gs}}$$

$\therefore |A_v| = g_m (R_D // (R_1+R_2) // R_L)$

$= 4.5 (20 // (100) // 25) = 10 K\Omega$ $\quad g_m = 4.5 mS$

$\therefore |A_v| = 45$ $\quad 4.5 mS \quad R_D = 20K, R_L = 25K$

$R_{in} = \infty$, $R_o = R_D // (R_1+R_2)$ $\quad R_1 = 80K, R_2 = 20K$

$= 16.666 K\Omega$

$f_L = 500 HZ$, $f_H = 500 KHZ$.

with F.B: $B_v = \frac{V_F}{V_o} = \frac{R_2}{R_1+R_2} = \frac{20}{100} = 0.2$

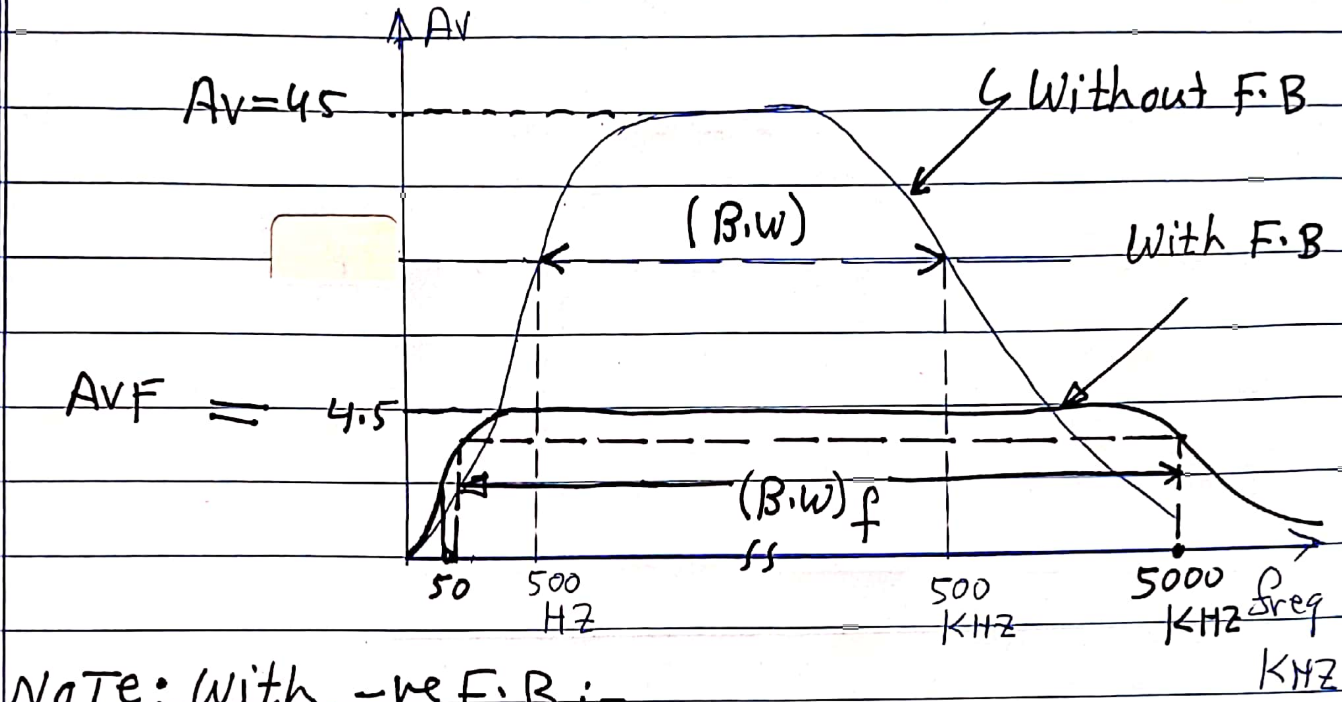
$$A_{vF} = \frac{A_v}{1+B_v A_v} = \frac{45}{1+0.2 \times 45} = 4.5$$

$R_{in_f} = R_{in}(1+B_v A_v) = \infty (10) = \infty$

$R_{oF} = R_o / 1+BA = 16.666/10 = 1.666 K\Omega$

$f_{L_f} = f_L / (1+BA) = 500/10 = 50 HZ$

$f_{Hf} = f_H (1+BA) = 500K \times 10 = 5000 KHZ = 5 MHZ$.



NoTe: With -ve F.B :-

$A_v \rightarrow$ decreases

(B.W) $\rightarrow$ extends (Increases).

* This is True Since Gain x B.W $\approx$ Constant.

Q5: The topology is "Voltage-Shunt"

We Sample from Node $\Rightarrow$ Voltage

& Mix Current $\Rightarrow$ Shunt.

$Z_{inf} = Z_{in}/1+BA$, $Z_{of} = Z_o/1+BA$

Amp: $\rightarrow$ Transresistance Amp.

$A = \frac{V_o}{I_s} = R(\Omega)$, $B = \frac{I_f}{V_o} \approx \frac{1}{R_F} (\mho)$

$X_o \rightarrow V_o$

$X_f \rightarrow I_f$

$X_s \Rightarrow I_s$

$X_d \Rightarrow I_d$

$R_{in}\downarrow$, $R_o\downarrow$

Q6: Topology $\Rightarrow$ Voltage-Series because $V_f \propto V_o$ and If $V_o = 0$, $V_f = 0$. $B = \frac{V_F}{V_o}$ and Since $V_f = V_o$, $B = 1$

* Without F.B, $R_{in} = R_B // r_\pi$ (No R_E), $R_E = 0$

* with F.B $R_{inf} = R_B // (r_\pi + (\beta+1)R_E)$

Since R_E is present and causes -ve F.B, Series $\Rightarrow$ I/p

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Oscillators "Signal Generators"

Oscillator: Feedback Amplifier with +ve F.B produces a periodical A.C output signal with a certain amplitude and a certain freq. without any A.C input signal.

* only D.C voltage is required to biase the Active device in a proper mode.

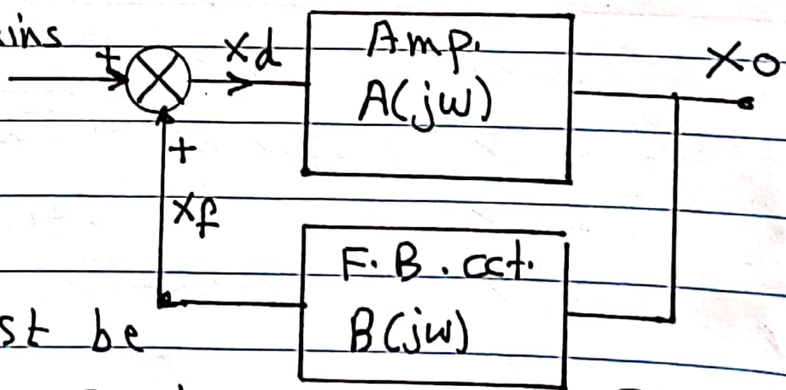
- They can be classified into:

1) Sinusoidal oscillators → produce Sine waves
2) Non-Sinusoidal oscillators which include Traingulare-wave, Square-wave - Sawtooth wave.

"Sinusoidal Oscillators"

F.B Amplifiers Contain:

* Amplifier: which Contains an Active device Such as: BJT, FET or Op-Amp.



* F.B cct.: which must be freq. dependant cct. Such as LC, RC, RL passive cct.

* principle of oscillation: Consider the F.B Amp. with +ve F.B.

$x_o = A(jw) \cdot X_d \quad , X_d = X_s + X_f$ (+ve. F.B)

$X_f = B(jw) X_o$. So: $X_o = A(jw)[X_s + B(jw) X_o]$

$\therefore X_o = A(jw) X_s + A(jw) B(jw) X_o$

$$x_o(1 - A(j\omega)B(j\omega)) = A(j\omega)x_s$$

$$\therefore \frac{x_o}{x_s} = A_f = \frac{A(j\omega)}{1 - A(j\omega)B(j\omega)}$$

Now: If $A(j\omega)B(j\omega) = 1$, then

$\frac{x_o}{x_s} = A_f = \infty$, this means

either $x_o = \infty$ which is impossible since x_o is a certain value

OR $x_s = 0$ which means No input !!!

i.e there is an o/p but No input. which means the system will start giving an o/p but No input i.e Generate an o/p signal

* This happens when $A(j\omega)B(j\omega) = 1$

Since Both are complex function. i.e real + imajinary $A(j\omega) = A\angle\phi$, $B(j\omega) = B\angle\phi$

so $A(j\omega) \& B(j\omega) = 1$ means

$|AB| = 1$, $\angle A + B = 0$ or 360°

which are oscillation conditions or "Barkhusan Condition"

1) $|BA| = 1$ (magnitude condition.

i.e when $|A| = 10$, then $|B| = \frac{1}{10}$ to satisfy $|BA| = 1$. Where A: Amp. gain

B: Attenuation of F.B cct.

2) phase condition: $\angle A + \angle B = 0, 360^\circ$

whe $\angle A$ phase produced by Amp.

$\angle B$ " " : F.B cct.

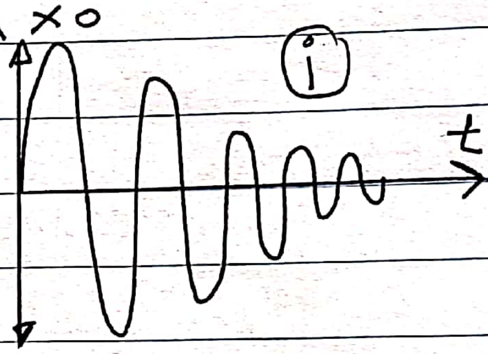
The phase condition can be satisfied when:

i) either both Amp. and B-Net. → Inverting. So A. gives 180° and B gives 180° so the total phase $\angle A + \angle B = 180^\circ + 180^\circ = 360^\circ$

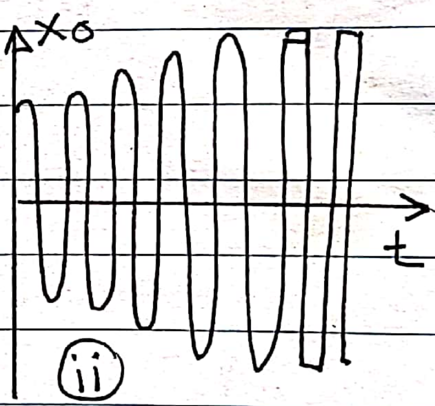
ii) OR both of them are non-inverting i.e giving zero phase: $\angle A + \angle B \Rightarrow \angle 0^\circ + \angle 0^\circ = 0^\circ$.

Consider the following cases: For $|BA|$

i) when $BA < 1$, the oscillation will start but will die out because $A < \frac{1}{B}$ i.e the signal will loss energy more than gain. as show in Fig. i

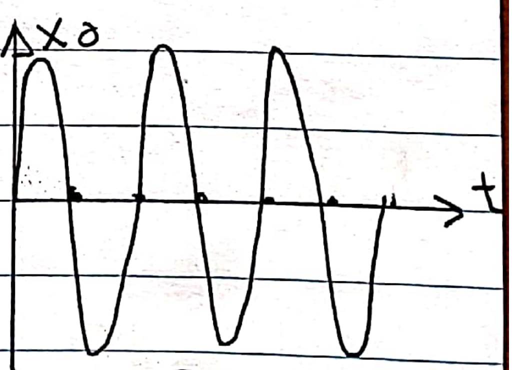


ii) when $BA \gg 1$, the oscillation will start and continu increasing till the cct. will be out of controll because $|BA| \gg 1$ → means the signal will gain more than loss and continu increasing. See Fig. ii



(ii)

iii) when $|BA| = 1$, this is the required condition, here the signal will be maintained oscillating between A and B gain energy from A and loss energy in B by the same ammont giving steady-state output sinusoidal signal with a certain freq. and a certain Amplitude. See Fig. iii

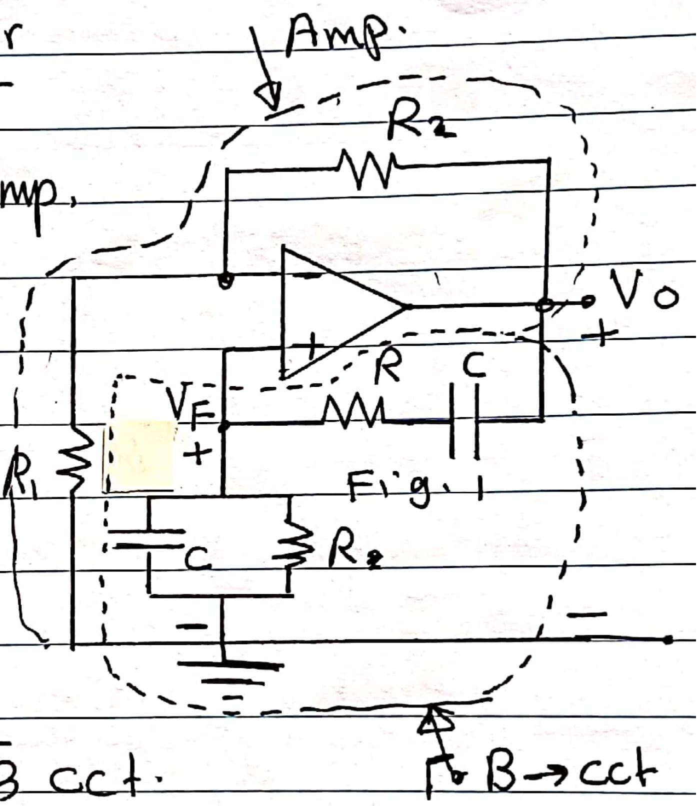


(iii)

RC-Oscillators

Oscillators in which F.B cct. contain R & C element and Amp. can be BJT Amp, FET Amp, Op-Amp.

1) WIEN-Bridge Oscillator



In this oscillator Amp is NON-inverting Amp. which gives $\phi = 0^\circ$ at certain $\omega \rightarrow \omega_o$

F.B cct. must give $\phi = 0^\circ$ at the same value of ω also at $\omega = \omega_o$.

How to derive freq. of oscillations "$\omega_o \Rightarrow f_o$"

* we have to extract F.B cct. and indicate V_o & V_F then find $B = \frac{V_F}{V_o}$.

- Consider the cct. in Fig. 2 which is the F.B cct.

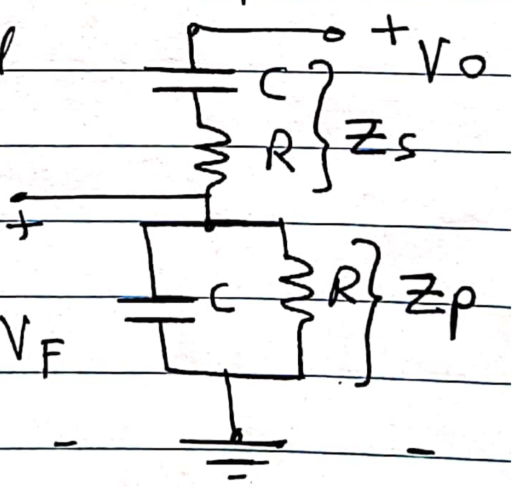


Fig. 2

using VDR: $\frac{V_F}{V_o} = \boxed{B = \frac{Z_P}{Z_p + Z_s}}$

where

$$Z_p = R // \frac{1}{j\omega C} = \frac{\frac{R}{j\omega C}}{R + \frac{1}{j\omega C}}$$

$$Z_p = R/(1 + j\omega CR) \quad , \quad Z_s = R + \frac{1}{j\omega C}$$

$$\& \ B = \frac{R/(1 + j\omega CR)}{R/(1 + j\omega CR) + R + \frac{1}{j\omega C}} \quad (\text{multiply by } 1 + j\omega CR)$$

$$B = \frac{R}{R + (1 + j\omega CR)\left(R + \frac{1}{j\omega C}\right)}$$

$$B = \frac{R}{R + R + \frac{1}{j\omega C} + j\omega CR^2 + R} = \boxed{\frac{R}{3R + j\left(\omega CR^2 - \frac{1}{\omega C}\right)}} \quad \otimes$$

consider eqn. $\otimes$ For $\underline{\underline{B}}$

The F.B cct. will give zero phase when j-term i.e equal zero (i.e $j\left(\omega CR^2 - \frac{1}{\omega C}\right) = 0$

i.e when $\boxed{\omega = \frac{1}{RC}}$ which is ~~called~~ the freq. at which phase condition is satisfied.

$\angle A + \angle B = 0^\circ + 0^\circ = 0^\circ$

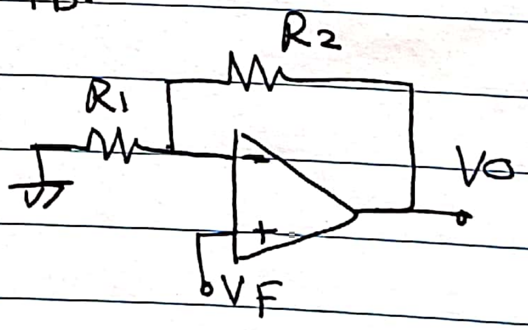
i.e $f = \frac{1}{2\pi RC}$ this is called "<u>frequency of oscillation</u>"

* <u>Now what about magnitude condition.??</u>
* At this freq. i.e when j-term = 0

$$B = \frac{R}{3R} = \frac{1}{3} \quad \left(\text{i.e } |B| = \frac{1}{3} \text{ and } \angle B = 0^\circ\right)$$

To satisfy $|BA| = 1 \quad \therefore |A|_{min} = \frac{1}{|B|} = 3$

we know that for non-inverting Amp:



$A = 1 + \frac{R_2}{R_1} =$

$\therefore \left(1 + \frac{R_2}{R}\right)_{min} = 3$

$\therefore \left(\frac{R_2}{R_1}\right)_{min} = 2 \Rightarrow \boxed{R_2 = 2R_1}$

So to satisfy $|BA| = 1$, we must choose $(R_2/R_1)_{min} = 2$

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Example: Design a WIEN-Bridge Oscillator to oscillate at $f_o = 50KHZ$? the available Capacitors are: $0.01\mu F$?

Solution:

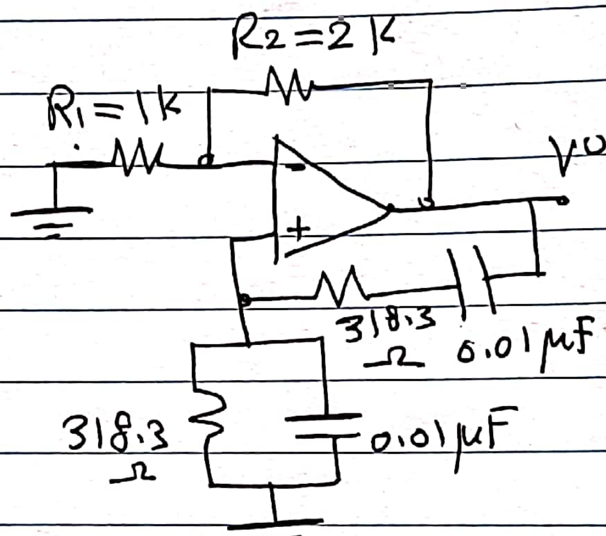
$$f_o = \frac{1}{2\pi RC} \Rightarrow R = \frac{1}{2\pi f_o C} = \frac{1}{2\pi \times 50 \times 10^3 \times 1 \times 10^{-8}}$$

$$\therefore R = \frac{10^3}{\pi} = 318.3\,\Omega$$

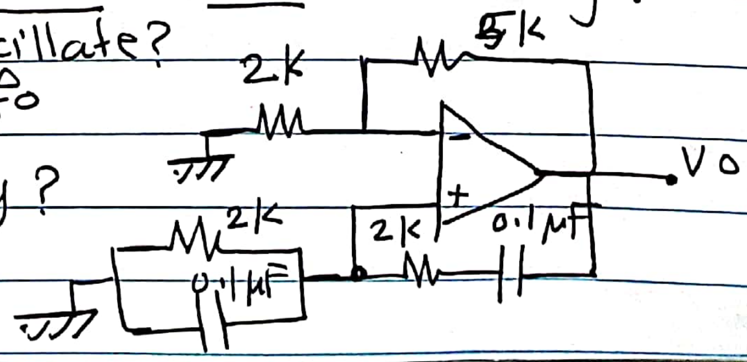
$$\left(\frac{R_2}{R_1}\right)_{min} = 2, \quad R_2 = 2R_1$$

Choose $R_1 = 1K\Omega$

$\therefore R_2 = 2K\Omega$

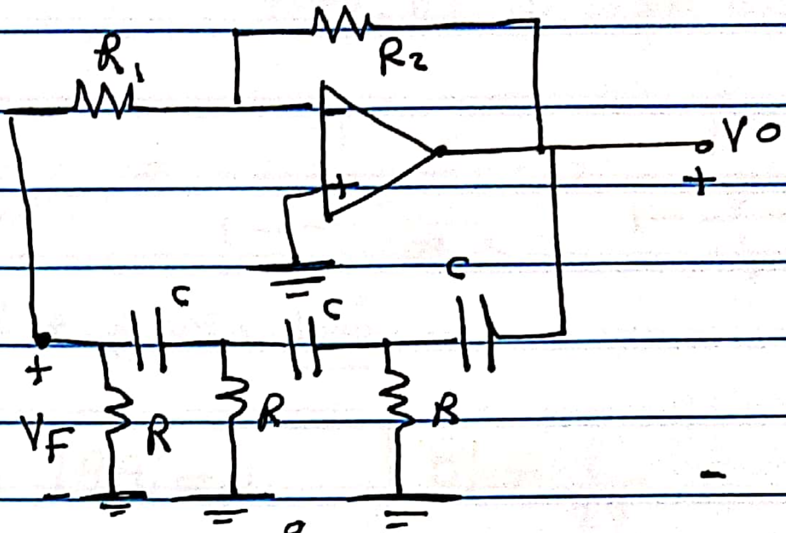


* If we want to replace the NON-inverting Amp. by BJT Amp.
* we must use C.B Amplifier with $A_v = 3$ [Since C.B gives $0°$ and $A_v > 1$]
* If we want to use FET Amp. we must use C.G Amplifier with $A_{v\,min} = 3$ Since it gives $0°$ and $A_v > 1$
* Can we use C.C or C.D and why?
* Can this cct. oscillate?
* If yes Calculate f_o
* If No explain why?



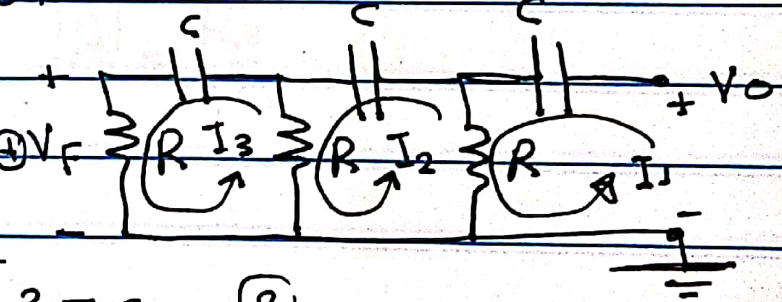
phase-shift oscillator

In this oscillator, the Amp. is inverting Amp. and gives $180°$ and the F.B cct. is three-identical RC Section. at certain freq. (ω) each Section gives $60°$ i.e the total phase-shift of F.B cct is $180°$.



So the total phase-shift around the loop will be $360°$.

Frequency of oscillation.



$$\left(R+\frac{1}{j\omega c}\right)I_1 - RI_2 = V_o \quad \text{— ①}$$

$$\left(2R+\frac{1}{j\omega c}\right)I_2 - RI_1 - RI_3 = 0 \quad \text{— ②}$$

$$\left(2R+\frac{1}{j\omega c}\right)I_3 - RI_2 = 0 \quad \text{— ③}$$

$$V_f = I_3 R \quad \text{— ④}$$

Solve the above eqns to find $B = \frac{V_F}{V_o}$

$$B = \frac{j\omega^3 C^3 R^3}{(6R^2C^2\omega^2 - 1) + j(\omega^3 C^3 R^3 - 5\omega RC)} = \frac{V_F}{V_o}$$

When Real term $= 0$, $6R^2C^2\omega^2 = 1$

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

$$\therefore \omega = \frac{1}{\sqrt{6}RC} = \omega_0 \rightarrow \boxed{f_0 = \frac{1}{2\pi\sqrt{6}RC}}$$

at this freq: freq. of oscillation.

$$B = \frac{\omega^3 R^3 C^3}{\omega^3 R^3 C^3 - 5\omega RC} = \frac{1}{1 - \frac{5}{\omega^2 R^2 C^2}} = \frac{1}{1 - \frac{5}{\frac{1}{6}}}$$

$$\therefore B = -\frac{1}{29}$$ i.e gives $\underline{180^\circ}$

Now to satisfy $|BA| = 1$

$|A_{min}| = 29$.

$|B| = \frac{1}{29}$

$\angle B = 180^\circ$

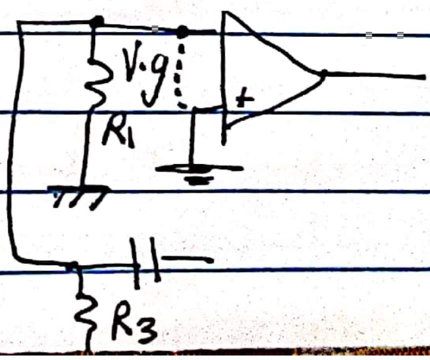
For Inverting Amp.

$$A = -\frac{R_2}{R_1} \Rightarrow \text{i.e } |A| = \frac{R_2}{R_1}$$

$$\therefore \left(\frac{R_2}{R_1}\right)_{min} = 29$$

i.e $\boxed{R_2 = 29 R_1}$

* The last R in RC section is in parallel with R_1 due to Virtual ground concept in op-Amp. So this will affect the Summetry of RC section, So we have to make $(R /\!/ R_1) = R$.



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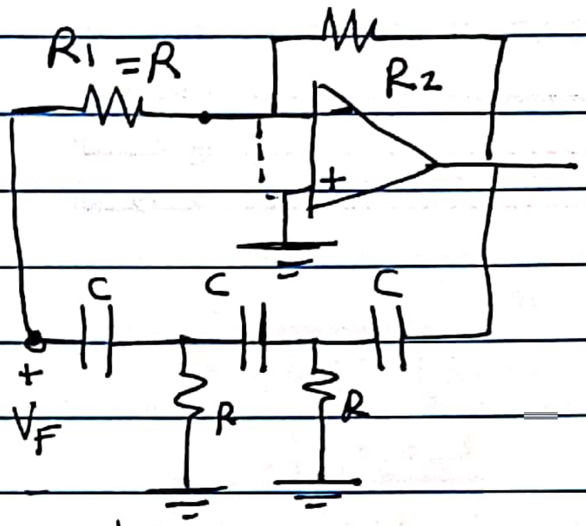
OR We use only R (ONE Resistance) to be as last element in RC-section and work as R_1 and therefore minimize No of Resistance

Ex A: Design a phase-shift Oscillator to produce 20 kHz A.C signal. "Draw the required Comp. Values and draw $V_o(t)$?



* The cct. is shown in Fig.
* For this oscillator $f_o = \dfrac{1}{2\pi\sqrt{6}RC}$ and $|A|_{min} = 29$

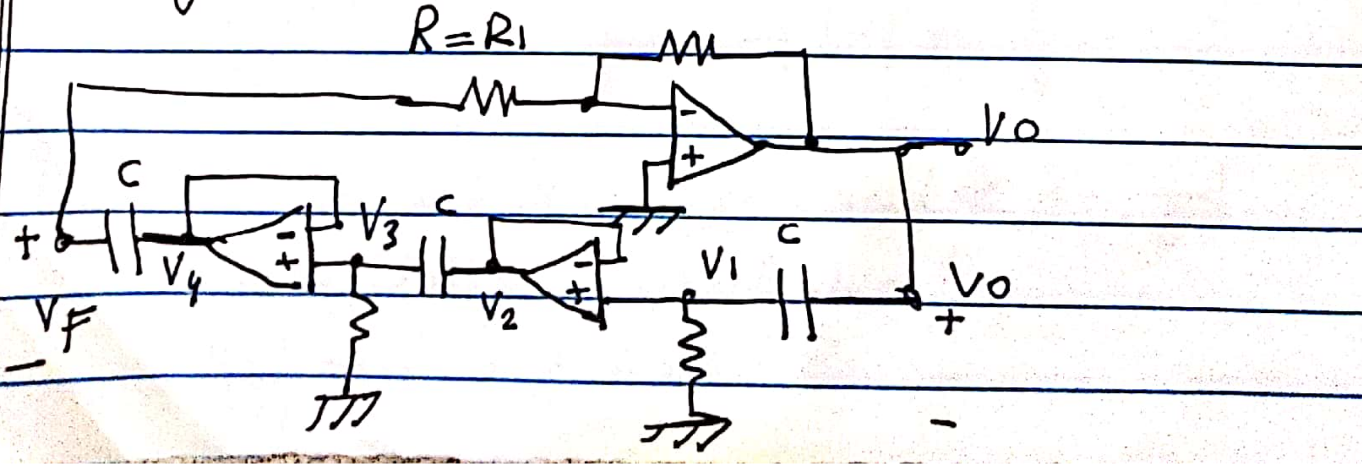
let $C = 0.01\mu F \Rightarrow R = \dfrac{1}{2\pi\sqrt{6} f_o C} =$

$$R = \frac{1}{2\pi\sqrt{6}\times 10^{-8}\times 2\times 10^{4}} = 0.325\,k\Omega$$

$R = R_1 = 0.325\,k\Omega$

$|A| = 29 = \dfrac{R_2}{R_1} \Rightarrow R_2 = 29R_1 = 29\times 0.325 = 9.425\,k\Omega$

* In the previous cct. each RC section loaded the other, to cancel loading effect, a buffer "Voltage follower" can be used as shown.



For this cct.

$$\frac{V_F}{V_0} = B = \frac{V_F}{V_4} \times \frac{V_4}{V_3} \times \frac{V_3}{V_2} \times \frac{V_2}{V_1} \times \frac{V_1}{V_0}$$

but $\frac{V_2}{V_1} = \frac{V_4}{V_3} = 1$

$$\frac{V_1}{V_0} = \frac{V_3}{V_2} \times \frac{V_F}{V_4} = \frac{R}{R + \frac{1}{j\omega c}}$$

So $\frac{V_F}{V_0} = \left(\frac{R}{R+\frac{1}{j\omega}}\right)(1)\left(\frac{R}{R+\frac{1}{j\omega c}}\right)(1)\left(\frac{R}{R+\frac{1}{j\omega c}}\right) = \left(\frac{R}{R+\frac{1}{j\omega c}}\right)^3$

$\therefore \frac{V_F}{V_0} = B = \frac{R^3}{\left(R+\frac{1}{j\omega c}\right)} \frac{1}{\left(R+\frac{1}{j\omega c}\right)^2} = \frac{-j\omega^3 c^3 R^3}{(1+j\omega cR)(1+j\omega cR)^2}$

$$B = \frac{-j\omega^3 R^3 c^3}{(1-3\omega^2 c^2 R^2) + j\omega cR(3-\omega^2 c^2 R^2)}$$

This will give zero phase-shift when real term $= 0$

i.e when $1 - 3\omega^2 c^2 R^2 = 0 \Rightarrow \omega_0 = \frac{1}{\sqrt{3}\,RC}$

$\therefore \boxed{f_0 = \frac{1}{2\pi\sqrt{3}\,RC}}$ freq. of oscillation.

At this freq. $B = \frac{-\omega^2 c^2 R^2}{3 - \omega^2 c^2 R^2}$ Since $\omega_0^2 = \frac{1}{3R^2C^2}$

$\therefore B = \frac{-\frac{1}{3\cancel{R^2 c^2}}\cancel{c^2 R^2}}{3 - \frac{1}{3\cancel{R^2 C^2}}\cancel{c^2 R^2}} = \frac{-\frac{1}{3}}{3-\frac{1}{3}}$

$B = \frac{-1}{9-1} = -\frac{1}{8} \Rightarrow |B| = \frac{1}{8}$

i.e F.B cct will give $\underline{\underline{180^\circ}}$ and $B = \left|\frac{1}{8}\right|$

$\therefore$ To satisfy $|BA| = 1 \Rightarrow |A|_{min} = 8$

i.e $\left|\frac{R_2}{R_1}\right| = 8 \Rightarrow R_2 = 8R_1$

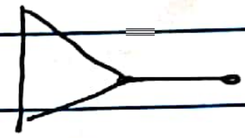
EXA: Design a phase-shift Oscillator to give 30KHZ signal. Draw the cct. diagram and Calculate the required component value.

"Without loading effect" "Three op-Amp. cct"

* For this cct. $f_o = \frac{1}{2\pi\sqrt{3}\,RC}$, $|A|_{min} = 8$

let $C = 0.01\,\mu F$

$$R = \frac{1}{2\pi\sqrt{3} \times 30\times10^{3}\times10^{-8}} = \frac{10^{4}}{6\pi\sqrt{3}} = 0.3K$$

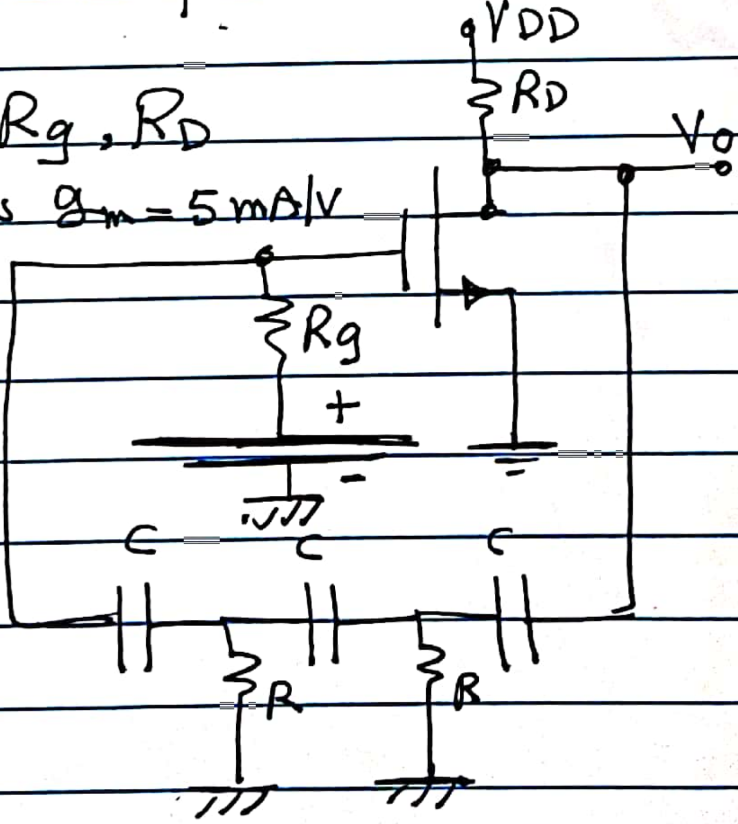


$$\left|\frac{R_2}{R_1}\right| = 8 \Rightarrow R_2 = 8R_1 = 2.448\,K\Omega.$$

* We can replace the Inverting Amp. by:

1. C.E cct in BJT Amp.
2. C.S " in C.S. Amplifier.

EXA: Calculate f_o, R_g, R_D when the MOSFET has $g_m = 5\,mA/V$



$f_o \simeq 65\,KHZ$

$R_g = R = 1K\Omega$

$|A_v| = 29$

$|g_m R_D| = 29$

$R_D = \frac{29}{5} = 5.8\,K\Omega$

$f_o = \frac{1}{2\pi\sqrt{6}\,RC}$

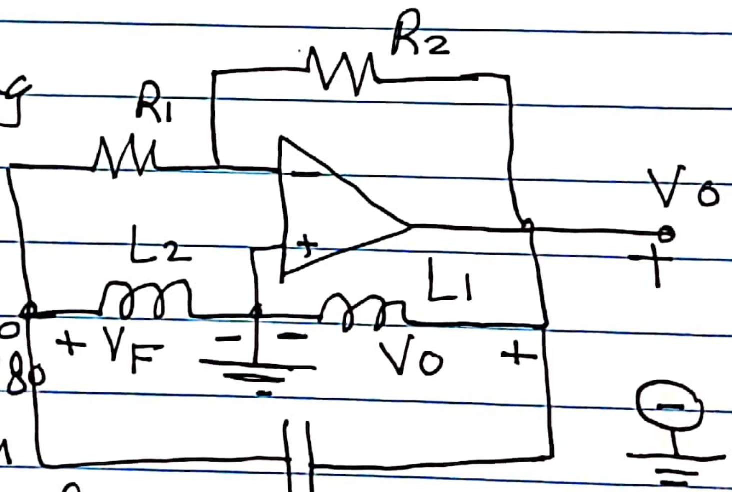
$C = 1nF$, $R = 1K\Omega$

"LC-Oscillators" OR "Tuned-cct. Oscillators"

These oscillators have LC or RL ccts. as F.B ccts. which produce the required phase-shift at resonance and an amp., which can be BJT, FET or Op-Amp" amplifier. that give the required gain and phase.

* For LC-oscillators, there are two main types

1) Hartley Oscillator: This contains two inductors and one capacitor to form the F.B cct. and Amp. to give the required gain: The cct. is shown in Fig.



* The Amp. is inverting which gives $\phi = 180°$ and gain $|A| = \frac{R_2}{R_1}$

* The F.B cct. gives $\phi = 180°$ at resonance and certain attenuation $|B|$. The freq. of Oscilln: can be derived as show:

$$\therefore f_o = \frac{1}{2\pi\sqrt{C(L_1+L_2)}}$$

At resonance the j-term = 0

$$j(\omega L_1 + \omega L_2) + \frac{1}{j\omega C} = 0 \Rightarrow \cancel{j}(\omega L_1 + \omega L_2) = \cancel{-}\frac{1}{\cancel{j}\omega C}$$

$$\therefore \omega(L_1 + L_2) = \frac{1}{\omega C} \Rightarrow \omega^2(L_1+L_2)C = 1$$

$$\therefore \omega_o = \frac{1}{\sqrt{(L_1+L_2)C}} \Rightarrow f_o = \frac{1}{2\pi\sqrt{C(L_1+L_2)}}$$

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$B = \frac{V_F}{V_O} = \frac{jwL_2}{jwL_1} = \frac{L_2}{L_1}$ (VDR)

To satisfy $|BA| = 1 \Rightarrow A = \frac{1}{B} = \frac{L_1}{L_2}$

But $|A| = \frac{R_2}{R_1} \Rightarrow \therefore \boxed{\frac{L_1}{L_2} = \frac{R_2}{R_1}}$

EXA: Design a Hartley oscillator to have $f_o = 100$ KHZ, the minimum gain of the Amp. Not less than 9? the available cap. is 1nF?

$$f_o = \frac{1}{2\pi\sqrt{(L_1+L_2)C}} \Rightarrow (L_1+L_2) = \frac{1}{4\pi^2 f_o^2 C}$$

$$(L_1+L_2) = \frac{1}{4(3.14)^2 \times 10^{10} \times 10^{-9}} = \frac{1}{40 \times 10^{-9} \times 10^{10}} = \frac{1}{400} H = 2.5 \text{ mH}$$

but $\frac{L_1}{L_2} = 9$ (gain) $\Rightarrow L_1 = 10 L_2$

$\therefore 9L_2 + L_2 = 2.5 \Rightarrow L_2 = \frac{2.5}{10} = 0.25$ mH

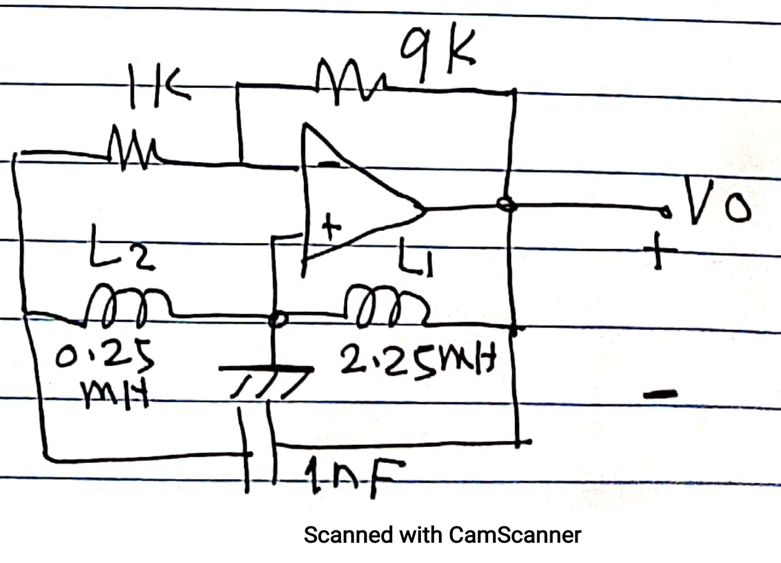
$\therefore L_1 = 2.25$ mH

R_1 & R_2? Since $A = \frac{L_1}{L_2} = 9 = \frac{R_2}{R_1}$

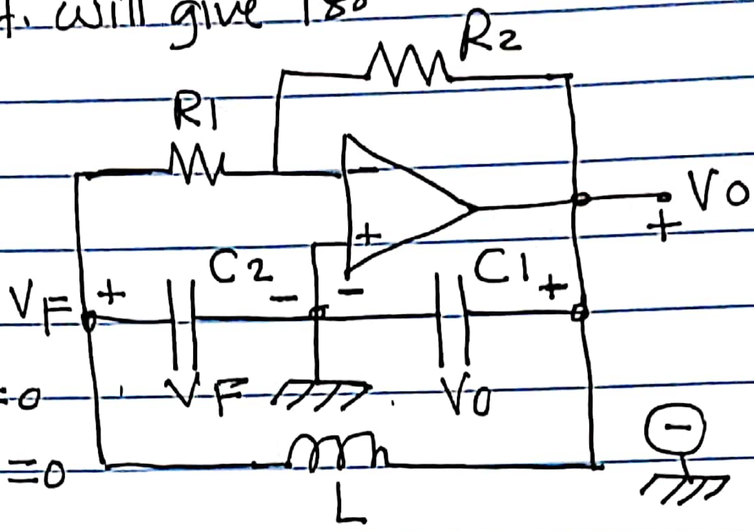
$\therefore R_2 = 9R_1$

let $R_1 = 1K\Omega$

$\therefore R_2 = 9K\Omega$



2) **Colpitts oscillator**: This contains two caps. and one inductor to form the F.B cct. as shown in Fig. The Amp. is inverting which gives 180° and the F.B cct. will give 180° at Resonance.



Consider the LC-cct which has

$$Z = j\omega L + \frac{1}{j\omega C_1} + \frac{1}{j\omega C_2}$$

At Resonance j-term $= 0$

i.e $j\left(\omega L - \frac{1}{\omega C_1} - \frac{1}{\omega C_2}\right) = 0$

$$\therefore \omega L = \frac{1}{\omega C_1} + \frac{1}{\omega C_2}$$

$$\omega^2 = \frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2}\right) \Rightarrow \omega_o^2 = \frac{1}{L\,C_{eq.}}$$

where $C_{eq} = \frac{C_1 \cdot C_2}{C_1 + C_2}$

$$\therefore f_o = \frac{1}{2\pi\sqrt{L \cdot C_{eq.}}} \Rightarrow \therefore f_o = \frac{1}{2\pi\sqrt{L\,C_{eq.}}}$$

$$B = \frac{V_F}{V_o} = \frac{\frac{1}{j\omega C_2}}{\frac{1}{j\omega C_1}} = \frac{C_1}{C_2}$$

To satisfy $|BA| = 1 \Rightarrow |A| = \frac{C_2}{C_1}$.

but For Inverting Amp. $|A| = \frac{R_2}{R_1}$

$\therefore$ we must choose $\left(\frac{R_2}{R_1}\right)_{min} = \frac{C_2}{C_1}$.

EXA 2: Design Colpitts Oscillator to give Sinusoidal Signal at 80KHZ. The gain must NOT exceed 4? The available inductor is 1 μH? draw cct. diagram and o/p signal?

$$f_o = \frac{1}{2\pi\sqrt{L\,C_{eq}}}$$

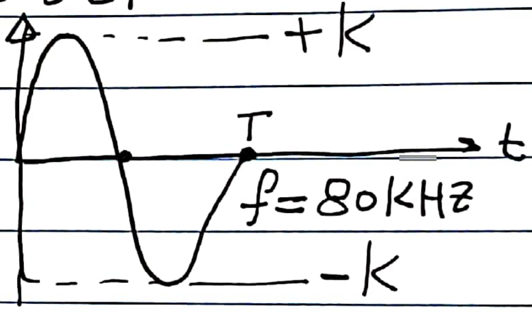
$$C_{eq} = \frac{1}{4\pi^2 L f_o^2} = \frac{1}{40\times64\times10^{8}\times1\times10^{-6}} = 3.9\ \mu F$$

but $A = 4 = \frac{C_2}{C_1} \Rightarrow C_2 = 4C_1$.

$$3.9 = \frac{C_1 \cdot C_2}{C_1 + C_2} = \frac{4C_1^2}{5C_1} = 0.8C_1$$

$$\therefore C_1 = \frac{3.9}{0.8} = 4.875\ \mu F$$

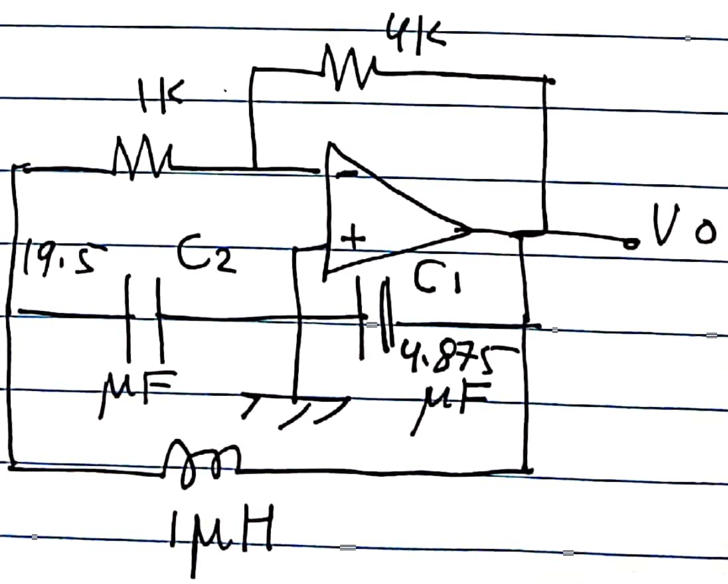
$C_2 = 19.5\ \mu F$



R_2 & R_1?

Since $|A| = \frac{R_2}{R_1} = 4 \therefore R_2 = 4R_1$

let $R_1 = 1K\Omega \Rightarrow R_2 = 4\times1 = 4K\Omega$



"Frequency Stability"

Freq. Stability $= \frac{\Delta f}{f_o}$ ~~where~~ Δf: change in Freq. due to temperature and ageing effect on device and components values.

f_o: designed freq.

* In RC and LC oscillator, the components (R, C, L) values are changed according to temp. and ageing and since freq. of oscillation depends on these values (i.e in RC-oscillator) $\rightarrow f_o = \frac{1}{2\pi RC}$ i.e $f_o \propto \frac{1}{RC}$ and in LC $f_o \propto \frac{1}{LC}$ or $f_o \propto \frac{1}{\sqrt{LC}}$

as Temp. or ageing affect the values of R, C, L the freq of oscillation will be changed.

* For example, If we design an RC oscillator today with $f_o = 50KHZ$, after one year we may find $f_o = 45KHZ$. (due to change in R, C values)

So $f.s = \frac{\Delta f}{f_o} = \frac{50-45}{50} = \frac{5}{50} = 10\%$

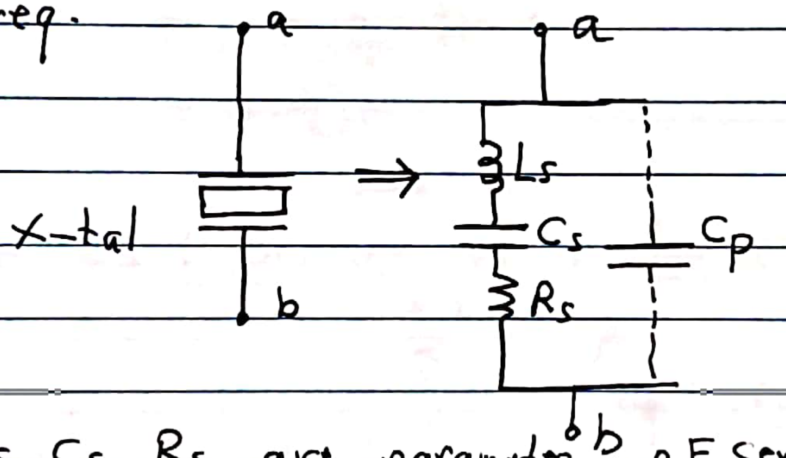
* But in some applications (especially medical applic) we require an oscillator with stable f_o, so we have to use Crystal Oscillator.

which has a very good or Superior freq. Stability compared to RC, LC or RL oscillator.

This will be discussed in the following Section.

Crystal Oscillator

This oscillator is characterized by superior freq. Stability compared to RC and LC oscillator. Also it has high freq. of oscillation. It is using quartz Crystal which is a piezoelectric material. These materials when subjected to an electric field, it will behave as a Series-resonance cct. and oscillate at the resonant freq.



L_s, C_s, R_s are parameters of series-resonance cct. and depend on dimension of quartz-Crystal and polarization.

C_p: Crystal holder cap. (Stray Cap. between electrode)

* This will oscillate at series-resonance freq.

$$f_s = \frac{1}{2\pi\sqrt{L_s \cdot C_s}} \quad \text{(Series-mode)}$$

* with quality factor $Q = \frac{\omega_s \cdot L_s}{R_s}$

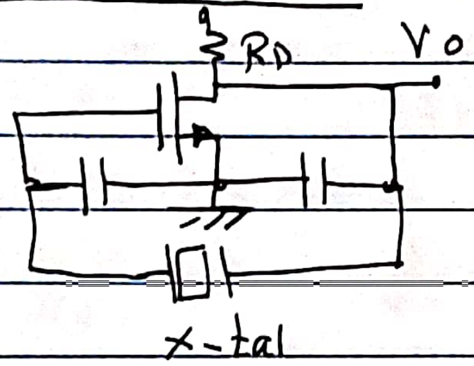
* when C_p is considered it will work in parallel mode $f_p = \frac{1}{2\pi\sqrt{L_s \cdot C_{eq}}}$

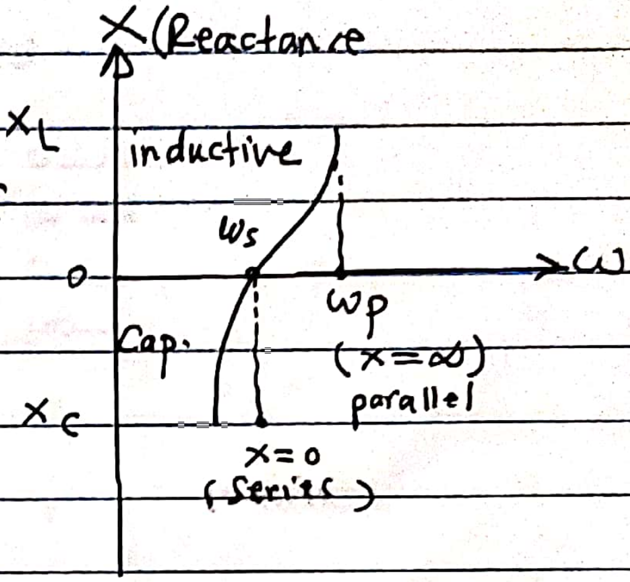
$$C_{eq} = \frac{C_s \cdot C_p}{C_s + C_p}$$

Since the impedance $Z = \sqrt{R_s^2 + j(\omega L - \frac{1}{\omega C})}$ of LRS cct:

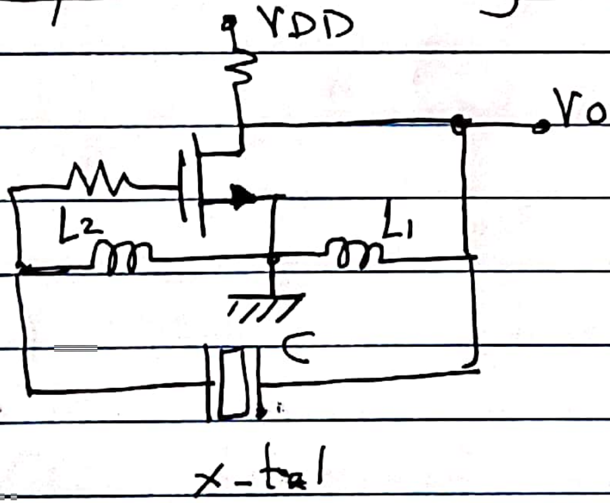
So x-tal can work as inductive or Capacitor

* It can replace the inductor in Colpitts oscillator





oR: as Capacitor in Hartley Oscillator.



In these oscillators the freq. of oscillation depends on Crystal dimension. (C_s, L_s)

* L_s, C_s do not affected by Temp. and aging so f_o is not affected by Temp. and aging and there for they are very stable oscillators.

EXA: a X-tal Qurtze has the following paramters
$L_s = 4H$, $C_s = 0.01\,pF$ and $R_s = 1000\Omega$

1) Calculate f_s and Q?
2) If the crystal has $C_p = 1\,pF$. Calculate f_p?

Solution:

1) $f_o = \frac{1}{2\pi\sqrt{L_s . C_s}} = \frac{1}{2\pi\sqrt{4\times1\times10^{-14}}} = \frac{10^{7}}{2\pi\times2} = \frac{10^{7}}{4\pi}$

$\therefore f_o = 795.774\ KHZ$

$Q = \frac{\omega_s . L}{R_s} = \frac{2\pi\times795.774\times10^{3}}{1000} = 5000$

2) When C_p is considered, then $f_p = \frac{1}{2\pi\sqrt{L C_{eq}}}$.

$C_{eq} = \frac{C_s . C_p}{C_s + C_p} = \frac{0.01\times1}{1+0.01} = 9.9\times10^{-15}\ F$

$f_o = \frac{1}{2\pi\sqrt{4\times9.9\times10^{-15}}} = \frac{10^{7}}{2\pi\sqrt{3.96}} = 799.783\ KHZ$

i.e $f_p > f_s$.

* Since C_s, L_s, R_s depends on Crystal dimension.
So; ~~For~~ each Crystal-oscillator, has a certain-Fixed freq. i.e "It is a Fixed-freq. device" and this is an disadvantages

$\therefore$ Advantages: Very high freq. stability & high freq. of oscillation "KHZ → MHZ" range

* Disadvantages: Fixed-Freq. device
Fragile (سريع الكسر) "handle with care"?.

"NON-Sinusoidal Oscillator" → "Relaxiation Oscillators"

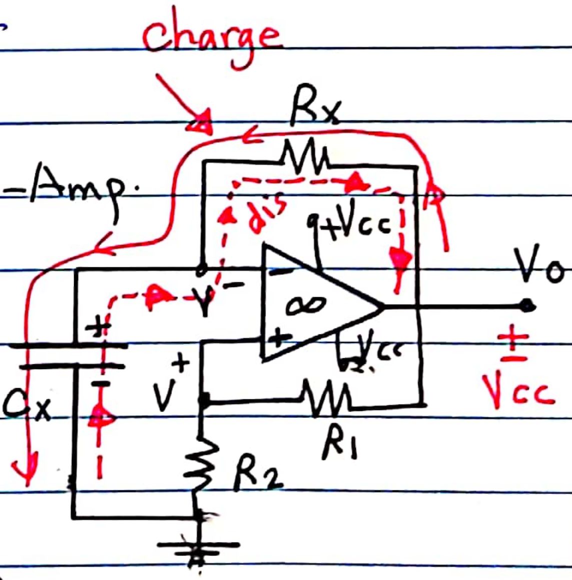
These oscillators produces, Square-Wave, Triangular-Wave Sawtooth Wave and it is based on charging and discharging of capacitor, so the frequency of oscillation depends on charging and discharging time-constant of a Capacitor in the cct.

1) Multivibrators: These produces square-wave o/p and they include:

i) Astable MTV: "has No stable-State" "Free-running"
ii) Monostable MTV: "has one stable-State "ONE shot"
iii) Bistable MTV: "has two stable States

Astable Multivibrator "AMTV"

This can be realized using:
i) Op-Amp. as a Comparator
ii) 555 Timer.

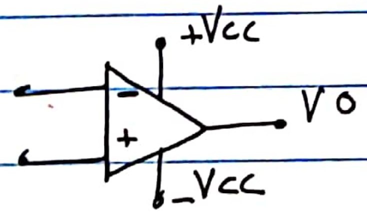


This is based on using the Op-Amp. as a Comparator giving $V_o = \mp V_{cc}$

- when $V^+ > V^- \Rightarrow V_o = +V_{cc}$
- when $V^+ < V^- \Rightarrow V_o = -V_{cc}$

Comparator:

$V_o = A_o(V^+ - V^-)$



For ideal Op-Amp.

$A_o = \infty$, So:

when $V^+ > V^- \Rightarrow V_o = +V_{cc}$, when $V^- > V^+ \Rightarrow V_o = -V_{cc}$.

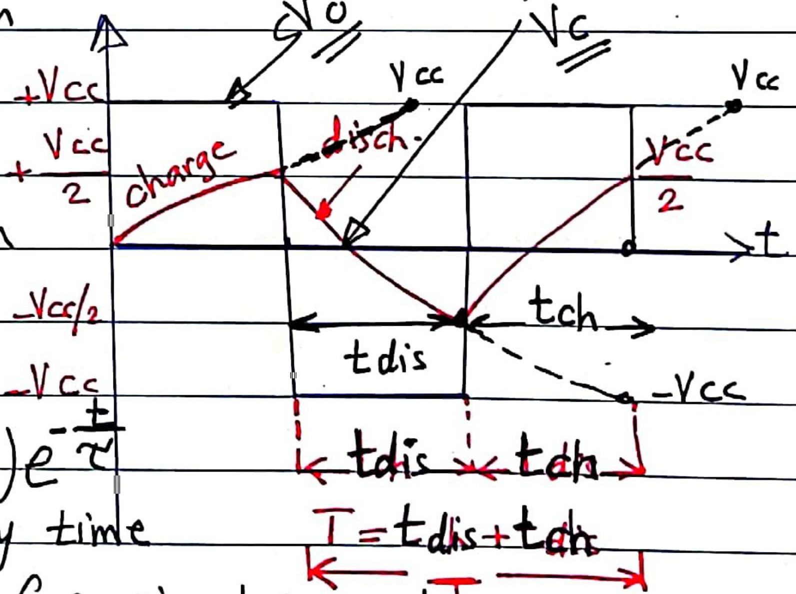
Operation: when we switch-ON D.C power supply The o/p will be either $+V_{cc}$ or $-V_{cc}$.

let us assume $V_o = +V_{cc}$, then $V_F = V^+ = \frac{V_{cc} \cdot R_2}{R_1 + R_2}$

For $R_1 = R_2$, $V^+ = \frac{1}{2} V_{cc}$

- The Cap. C_x will charge with time constant $\tau_x = R_x C_x$
- when C_x try to exceed $\frac{V_{cc}}{2}$, the Comparator will change the state and give $V_o = -V_{cc}$
- Now $V^+ = \frac{-V_{cc} \cdot R_2}{R_1 + R_2}$ and when $R_1 = R_2$, $V^+ = -\frac{V_{cc}}{2}$.
- The capacitor C_x will start discharging aiming $-V_{cc}$ through R_x.
- but when C_x try to exceed $\frac{-V_{cc}}{2}$, the comparator will change the state and give $V_o = +V_{cc}$, i.e back to the first state and the cycle will be repeted

Frequency of oscillation



$T = t_{ch} + t_{dis}$

starting from expression of Cap. Voltage during charging or discharging

$V_c(t) = V_{Final} + (V_{initial} - V_{final}) e^{-\frac{t}{\tau}}$

$V_c(t)$: Cap. Voltage at any time

V_f : final voltage which Cap. aim to reach

" $V_f = \mp V_{cc}$ "

$V_{initial}$: initial Cap. Voltage $\mp \frac{V_{cc}}{2}$ (which C_x start charge or discharge -)

τ : time Constant. $\tau = R_x C_x$.

Charging time.

$$V_c(t) = V_{cc} + \left(-\frac{V_{cc}}{2} - V_{cc}\right) e^{-\frac{t}{\tau}}$$

at $t = t_{ch}$, $V_c(t) = \frac{V_{cc}}{2}$

$$\therefore \frac{V_{cc}}{2} = V_{cc} + \left(\frac{-V_{cc}}{2} - V_{cc}\right)^{-\frac{t_{ch}}{\tau}}$$

$$-\frac{V_{cc}}{2} = -\frac{3}{2} V_{cc}\, e^{-\frac{t_{ch}}{\tau}}$$

$$\therefore 1 = 3 e^{-\frac{t_{ch}}{\tau}} \Rightarrow e^{\frac{t_{ch}}{\tau}} = \frac{1}{3} \Rightarrow t_{ch} = \tau \ln 3$$

$\therefore t_{ch} = 1.1\tau = 1.1\, R_x C_x$

by sammetry $t_{ch} = t_{dis} = 1.1\, R_x C_x$

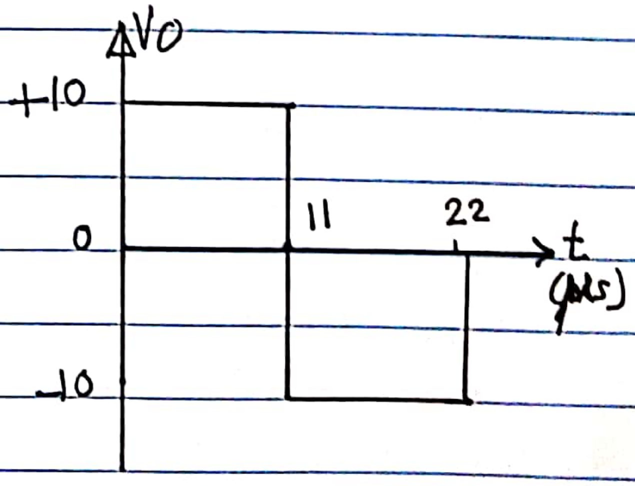
$T = t_{ch} + t_{dis} = 2.2\, R_x C_x$

$$\boxed{\therefore f_o = \frac{1}{2.2\, R_x C_x}}$$

* The o/p will be symmetrical square-wave o/p.

EXAMPLE: For $V_{cc} = \mp 10V$, $R_x = 1K\Omega$, $C_x = 0.01\,\mu F$, $R_1 = R_2 = 1K\Omega$. Calalate f_o & draw $V_o(t)$?

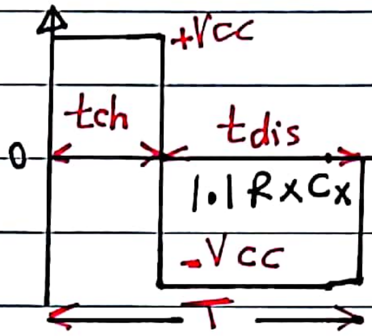
$$f_o = \frac{1}{2.2 \times 10^3 \times 1 \times 10^{-8}} = \frac{10^5}{2.2} = 45.454\ KHZ$$



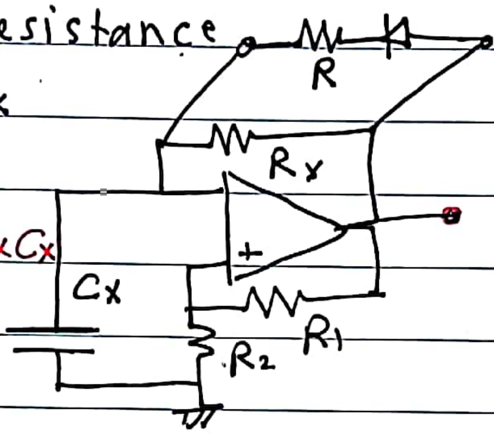
EXA: Design an Astable MTV to produce V_o with amplitude $\mp 15V$ and freq = 40KHZ.
* Use ideal Op-Amp.?

$T = \frac{1}{f} =$

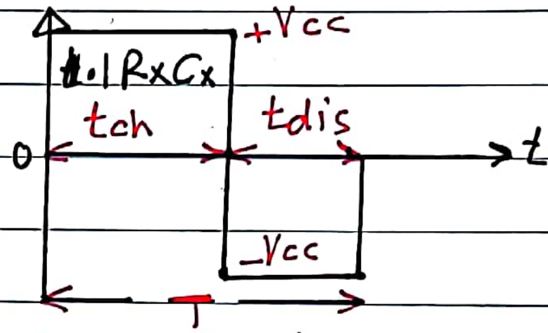
To obtain assymetrical Square-Wave o/p, i.e
"+ve H.C $\gtrless$ -ve H.C
* We have to change charging or discharging time constant.
- To make $t_{dis} > t_{ch}$ →



* We can connect diode with Series resistance
- $R < R_x$

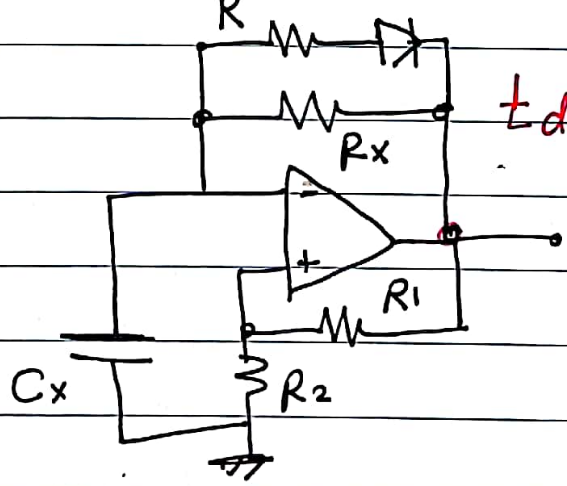


$t_{ch} < 1.1 R_x C_x$



Assymetrical Squar wave

* To make $t_{ch} > t_{dis}$
we can change the direction of diode
$R < R_x$



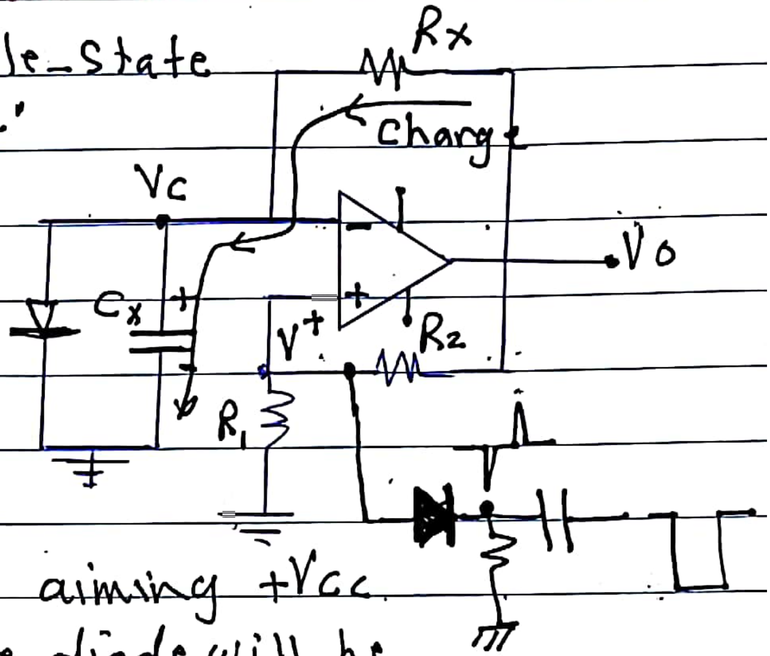
$t_{dis} < 1.1 R_x C_x$

In both cases when Diode is "ON" ⇒ "Short)"
So $R // R_x \Rightarrow < R_x$ which will make t_{ch} or $t_{dis} < 1.1 R_x C_x$ ∴ When Diode is OFF t_{ch} or $t_{dis} = 1.1 R_x C_x$

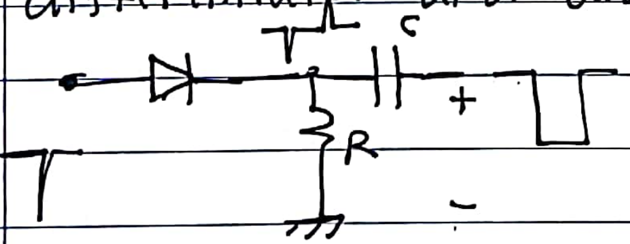
Monostable Multivibrator MMTV

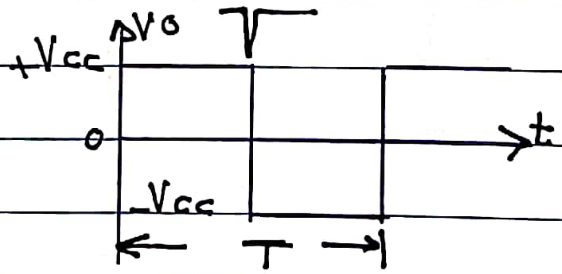
"ONE-Shot" cct.

This cct. has one stable-State "When $V_o = V_{cc}$, $V_c = V^- = V_\gamma$"

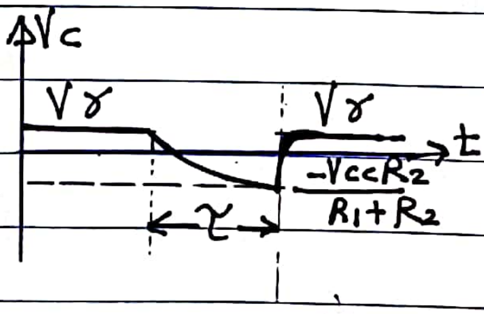


- Assume that, when we Switch-ON, power Supply $V_o = +V_{cc}$, So $V^+ = \frac{V_{cc}R_2}{R_1+R_2}$
For $R_1 = R_2 = R$
$\therefore V^+ = \frac{1}{2}V_{cc}$.
- The Cap. Cx will charge aiming $+V_{cc}$ but when $V_c = V_\gamma$, the diode will be on Fixing $V_c = V^- = V_\gamma$ and the cct. will be in Steady-State. $[V_o = +V_{cc}, V^+ = \frac{1}{2}V_{cc}, V^- = V_\gamma < V^+]$
- Now to change the State of Comparator, we have to make $V^+ < V^-$, this can be, by applying a -ve pulse at ⊕ terminal or through differentiator and diode as shown.





- This will change the state of the Comparator because $V^- > V^+$ and $V_o = -V_{cc}$, $V^+ = -V_{cc}/2$



- The Cap. Cx will Start discharge aiming $-V_{cc}$ but when Cx try to exceed $-V_{cc}/2$, it will chang the state back to Steady State.

So For Full-cycle of output, we requires one pulse "Trigger" i.e we need "one shot" to obtain Full-cycle"

- The duration of the o/p pulse is controlled via R_x, C_x and pulse duration can be calculated as follow:

$V_c(t) = V_f + (V_f - V_{initial})\, e^{-\frac{t}{\tau}}$

Consider the "Qusy - state) [discharg]

$-\frac{V_{cc}}{2} = -V_{cc} + (V_\gamma - (-V_{cc}))\, e^{-\frac{t}{R_x C_x}}$

$\boxed{t_p = T_x \ln\left[\frac{1+(V_\gamma/V_{cc})}{1-B}\right]}$

$B = \frac{R_2}{R_1+R_2}$

For $R_1 = R_2 = R$, $V_\gamma = 0$

$\therefore t_p = R_x C_x \ln 2$

$\therefore 0.5 V_{cc} = (V_\gamma + V_{cc})\, e^{-\frac{t_p}{\tau}}$

$0.5 = \left(1 + \frac{V_\gamma}{V_{cc}}\right) e^{-\frac{t_p}{\tau}}$

For $V_\gamma \ll V_{cc}$

$-0.5 = e^{\frac{-t_p}{\tau}} \Rightarrow t_p = \tau \ln 2 = 0.69 R_x C_x$

$\therefore t_p = 0.69 R_x C_x$ "Pulse duration"

ExA: Design a MMTV to give a puls duration of 2μs and a freq. of 100KHz. Draw $V_o(t)$, let $V_{cc} = \mp 10V$?

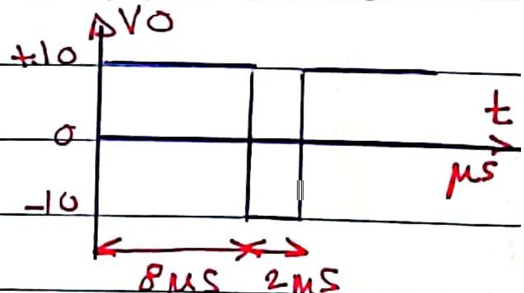
$t_p = 0.69 R_x C_x = 2\mu s$

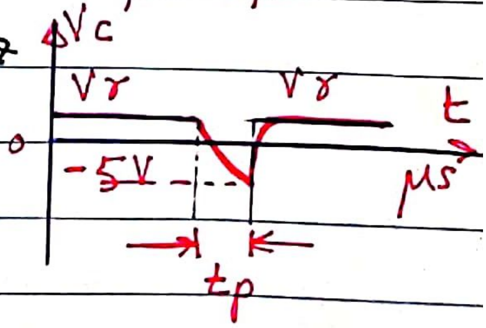
Assume: $C_x = 1nF$ $\therefore R_x = \frac{2 \times 10^{-6}}{0.69 \times 10^{-9}}$

$\therefore R_x = 2.898 K\Omega$

* The Freq. of Trigger must be = 100KHz

let $R_1 = R_2 = 1K\Omega$





Tutorial Sheet ② Oscillator

Q1 Given: $K_n = 2\ mA/V^2$, $V_{TN} = 2V$

Design the cct. shown to oscillate at $f_o = 10KHz$

choose $C = 10nF$

① "Find R & R_D"?

② Draw $V_o(t)$?

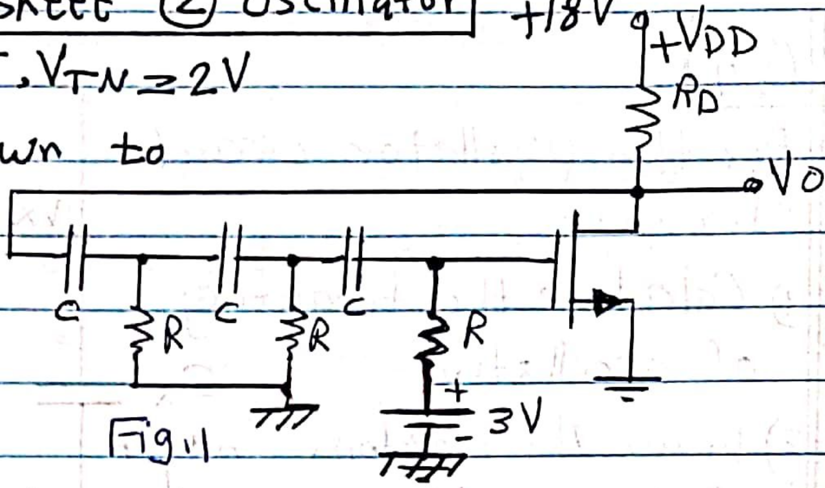


Fig.1

③ Redraw this oscillator using op-Amp.

Q2 Name the oscillator cct. shown in Fig.2 and

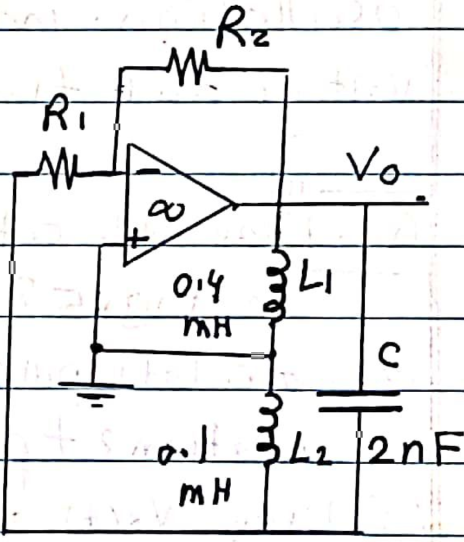
1) Calculate freq. of oscillation and minimum Amp. gain?

2) Calculate R_2 & R_1?

3) Draw $V_o(t)$?

4) what happen when $R_2 = 10R_1$?

Fig.2



Q3 Name the cct. shown in Fig.3 and:

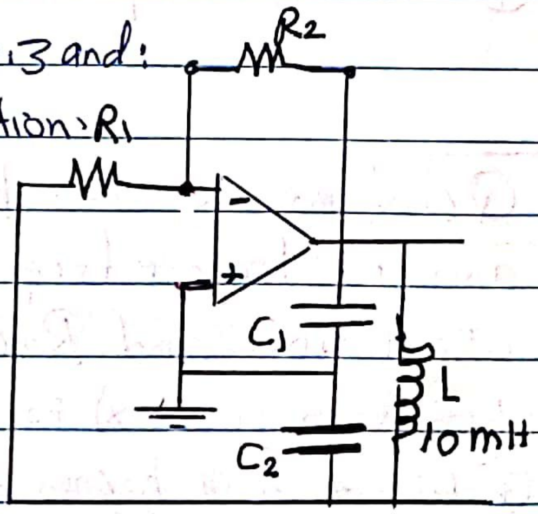
1) Calculate freq. of oscillation.

2) The minimum gain required by the Amp. to start oscillation?

3) Calculate R_1 & R_2?

4) Redraw the cct. using MOSFET Amplifier?

5) Draw $V_o(t)$ for two cycles?



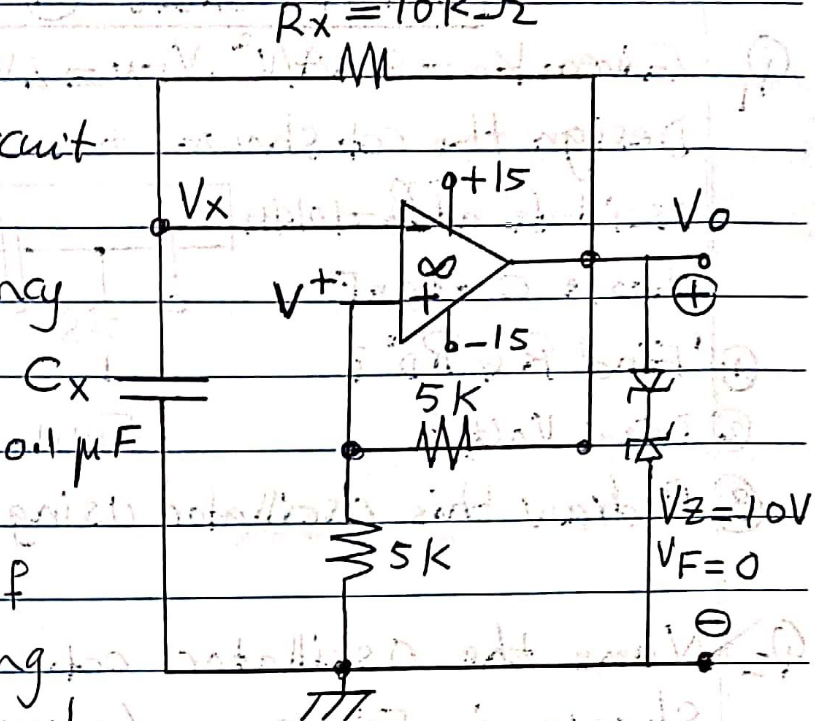
$C_2 = 800pF$, $C_1 = 200pF$

Q4

For the Oscillator circuit shown:

1) Calculate the frequency of oscillation.

2) Draw the Waveform of $V_o(t)$ and $V_x(t)$ for two periodes of oscillation. indicating Voltage and time levels.

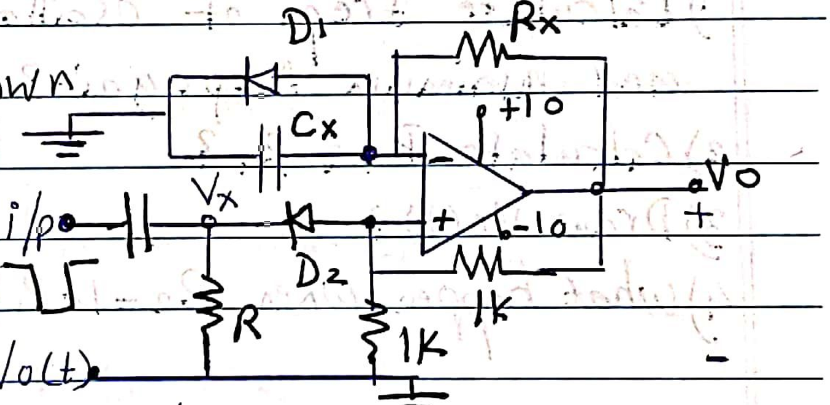


Q5 ① Name the cct. shown in Fig. 5?

② Calculate puls duration? t_p?

③ Draw $V_x(t)$ and $V_o(t)$

④ To have freq = 20KHZ, what must freq. of input puls

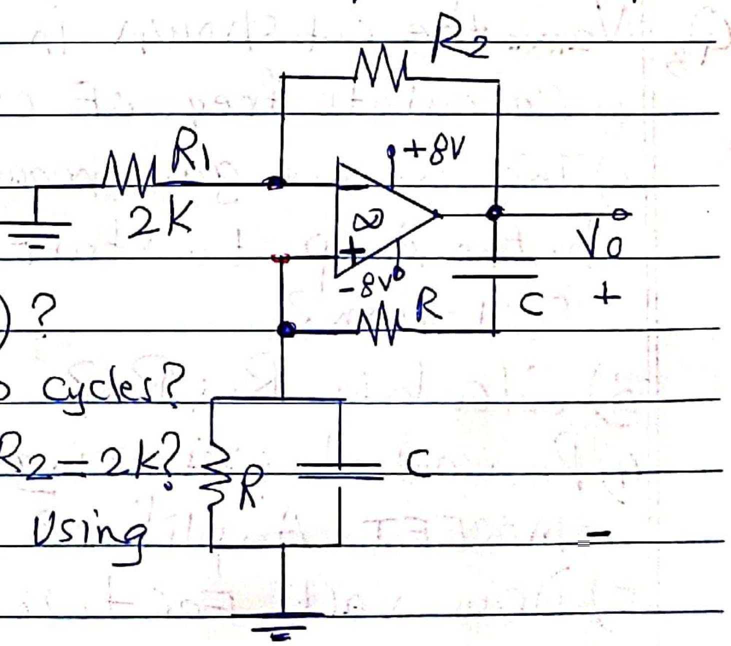


Q6 Name the cct. Shown and ① Calculate freq of oscillation? and $R_2(min)$?

② Sketch $V_o(max)$ For two cycles?

③ what will happen for $R_2 = 2K$?

④ Redraw the Oscillator Using BJT Amp?



"Power Amplifiers"
"Large-Signal Amps"

→ deliverd to Load $\bar{P}_L$

"Convert Some of the D.C power drawn From D.C Sources into A.C power"

* Compared to Small-Signal Amps. power Amps have the following characteristics:

1) Deal with Large Voltage and Current signals.
2) Large Size active devices due to high power rating, heat Sink may be required.
3) Usually, Located as final Stages in electronics system Such as Radio receiver (befor Speaker).
4) Amplify power of the A.C input Signal.
5) The most important parameter is the Conversion effeciency $\eta = \frac{\text{Average A.C Power delivered to load}}{\text{Average D.C power drawn from D.C Source}}$
6) Graphical techniqes is used to calculate the performance. ($\bar{P}_L$), $\bar{P}_s$, $\eta\%$

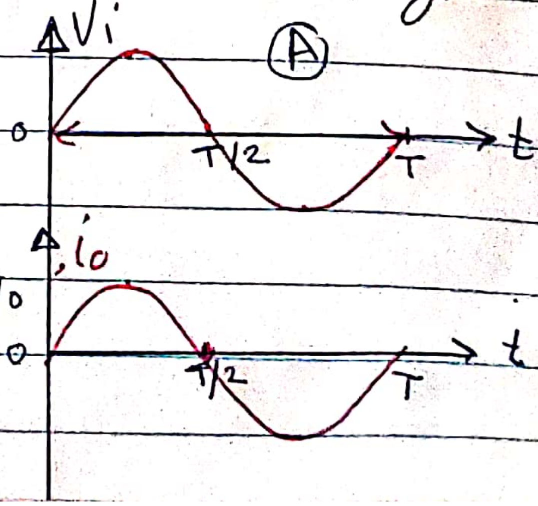
Classification of power Amplifiers

They are classified according to the angle by which the output current and voltage are present of the full input cycle "Conduction angle of the active device".

* The input is Full-Cycle:

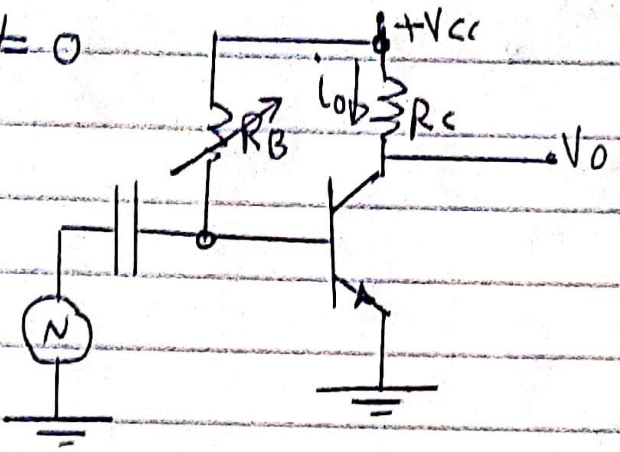
1) Class-A power Amp:

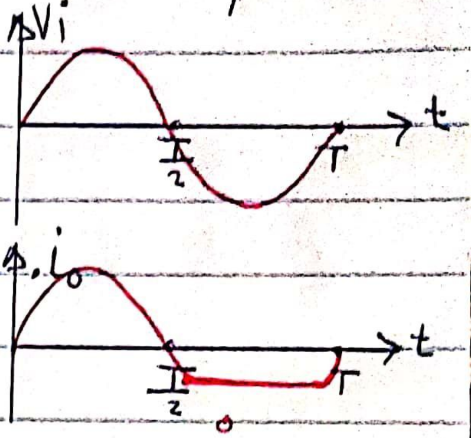
The o/p Current flows for a Complete cycle, i_o is present for 360° full-cycle.



Class-AB:

The o/p is present and the o/p Current flows for more than half-cycle and less than Full cycle $180° < \phi_c < 360°$. The Q-pt is present (Located) Some where between class-A and class-B position
$I_{CQ} \neq 0$



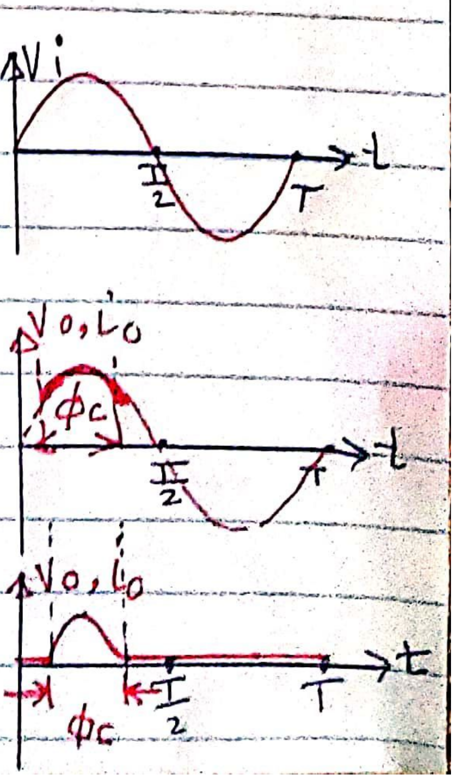


$180° < \phi_c < 360°$

* Normally class-AB is more close to class-B than class-A, practically class-AB is a remedy to aproblem happend , class-B push-pull which is called "crossover-distortion", sloved by biasing Amp. more than Cut-OFF $I_{CQ} \neq 0$. which makes the Amp. works as class-AB.

Class-C Power Amp.

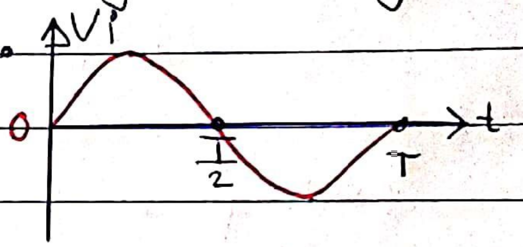
The o/p is present for a small conduction Angle $\phi_c < 180°$
The Q-pt is Located ~~to~~ down the Cut-OFF $I_{CQ} < 0$
It has an application as RF Amp. in Communication. Transmitters
* This class widely used as RF power amp. with high Conversion efficiency.



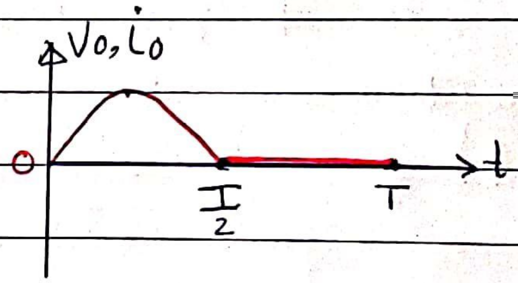
The o/p signal shape depends on the position of the Q-point. For class-A, the optimum position For ~~class~~ Q-pt. is at the center of D.C. Load line.
* The Amp. draws D.C power with or without i/p signal because $I_{CQ} \neq 0$

2) Class-B power Amp.

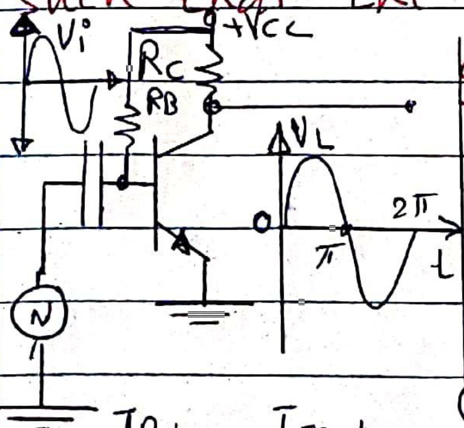
The o/p current flows for a half-cycle and the o/p is present for 180° i.e half-cycle. ideally the Q-pt at Cut-OFF ($I_{CQ} = 0$).



* The Amp. will NOT draw D.C power from V_{CC} for No A.C input signal because $I_{CQ} = 0$ So the D.C power drawn from D.C Source $P_S = I_{CQ} . V_{CC} = 0$

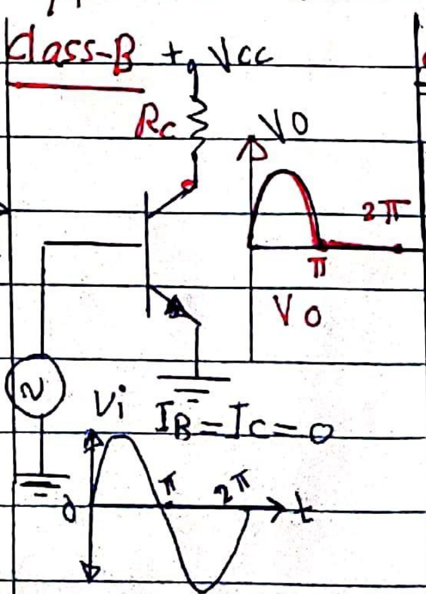


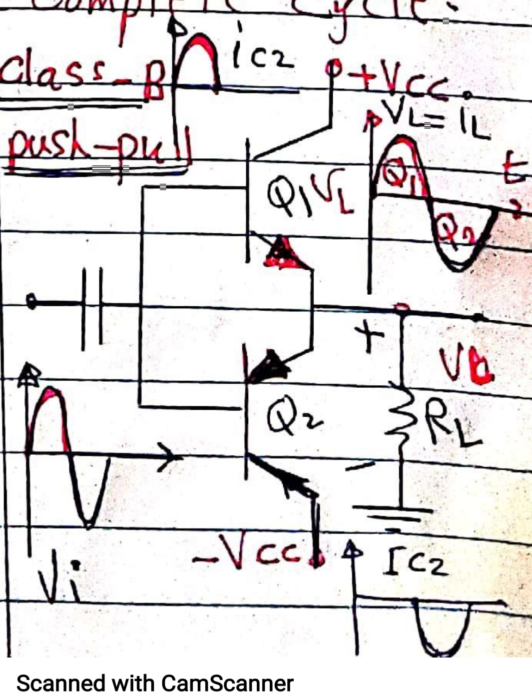
* Normally class-B is used in push-pull arrangment "two transistors are used, one process +ve H.C of Vi and the other to process the -ve half-cycle of Vi such that the o/p will be a Complete cycle.



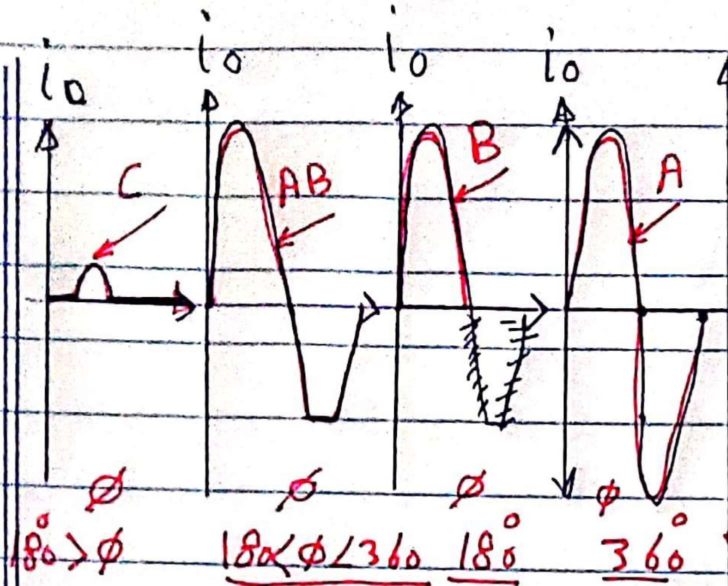
$I_B \neq 0$, $I_{CQ} \neq 0$

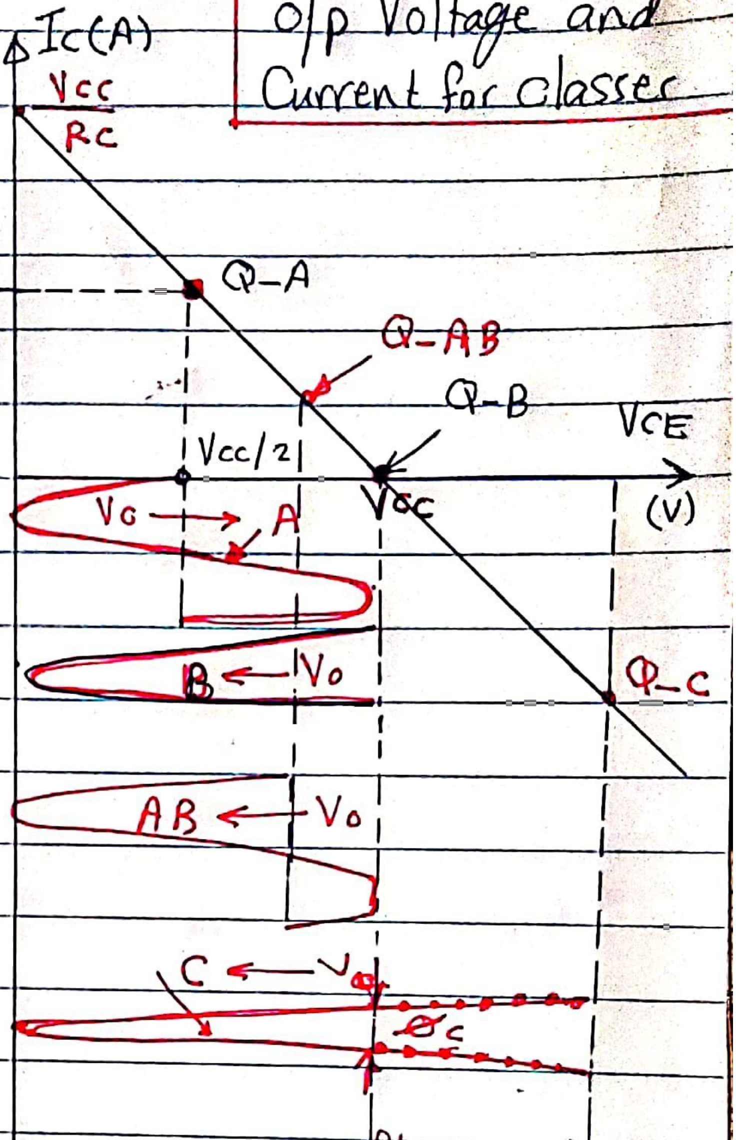
class-A

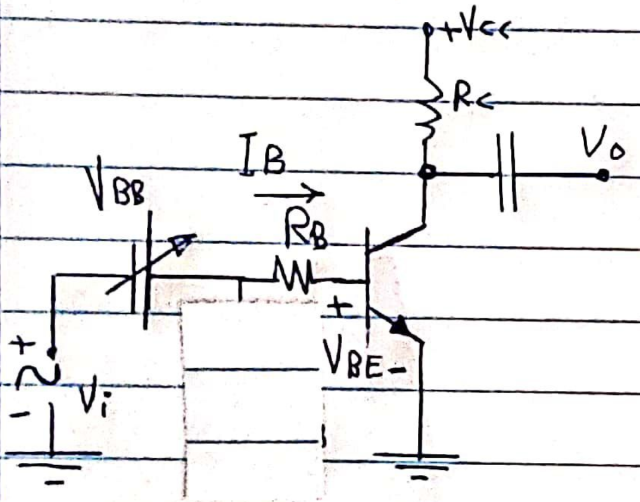




o/p Voltage and Current for classes







$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

① when $V_{BB} > V_{BE}$, the BJT will be in F.A.M, $I_C = \beta I_B$

* The BJT can be biased as class-A or AB
* when $V_{BB} = V_{BE}$, $I_B = 0$, $I_C = 0 \Rightarrow$ Cut OFF.
* when $V_{BB} = 0$ or $V_{BB} < 0$ the BJT will be as class-C mode. Down the Cut OFF mode

In A, B, AB Vi can be Zero

* ~~We~~ No Current flows untill Vi is applied.
* In class-C, the BJT will be ON only in +ve H.C of Vi and only when $V_i > V_{BE}$, which makes $I_B > 0$. So I_B will be > 0 and $I_C > 0$ which will ~~be~~ flow For $< 180^\circ$. for Small Conduction angle $\phi_c < 180^\circ$.
* by Varing V_{BB}, the cct. can be biased as class-A, B, AB or C.

let $V_{CC} = 10V$, $R_C = 10\Omega$, $\beta = 25$, $V_{BE} = 0.6V$
$R_B = 1k\Omega$

$V_{CE} = V_{CC} - I_C R_C$, $I_B = \frac{10 - V_{BE}}{R_B}$, $V_{BB} = V_{BE} + I_B R_B$

* For $V_{CE} = 0$, $I_C = \frac{10}{10} = 1A$
* For $I_C = 0$, $V_{CE} = 10V$
* $\therefore$ D.C L.L points: $(10V, 0)$, $(0V, 1A)$.

① For ideal class-A: Q-pt $\Rightarrow$ Center of D.C. L.L

i.e: $I_{CQ} = 1/2 = 0.5A$, $V_{CEQ} = \frac{1}{2}V_{CC} = 5V$.

$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{0.5}{25} = 0.02A \Rightarrow 20mA$.

$\therefore V_{BB} = V_{BE} + I_B R_B = 0.6 + 0.02 \times 10^3 = 20.6V$

② For class-B, $I_{CQ} = 0$, $I_{BQ} = 0 \Rightarrow V_{BB} = 0.6V$

$\therefore V_{BB} = V_{BE} = 0.6V$

③ For class-AB, $[0 < I_B < 0.02A]$

let $I_B = 0.01A$

$\therefore V_{BB} = 0.6 + 0.01 \times 10^3 = 10.6V$

④ class-C, $V_{BE} = 0$ or $-ve$

let $V_{BB} = 0$, $I_B = \frac{V_i - V_{BE}}{R_B}$

only when $V_i > 0.6V$

$I_B > 0$, $I_C > 0$

Class-A power Amp.

The o/p is full-cycle, i.e i_c flows for 360° and V_L is present for full-cycle. There are two types of Class-A depending on the position of the Load R_L.

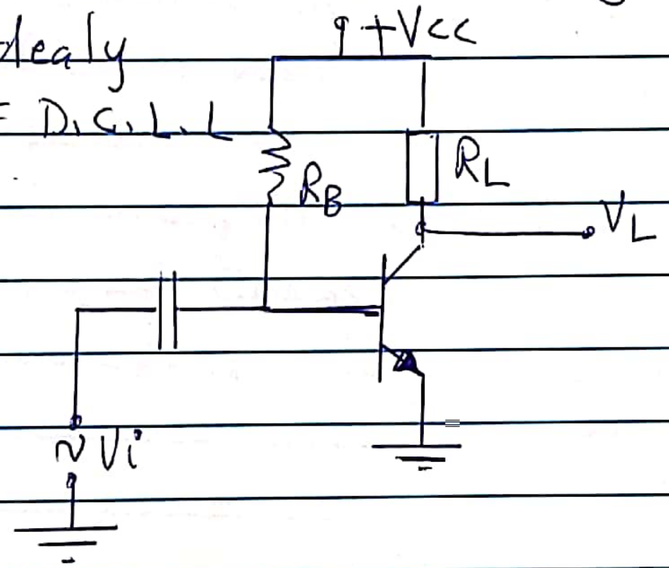
① Direct-coupled (Series-Fed) type:

The load is directy connected between V_{cc} and Collector, as shown in Fig.

- In this class, idealy Q-pt at Center of D.C.L.L

i.e $V_{CEQ} = \frac{V_{cc}}{2}$

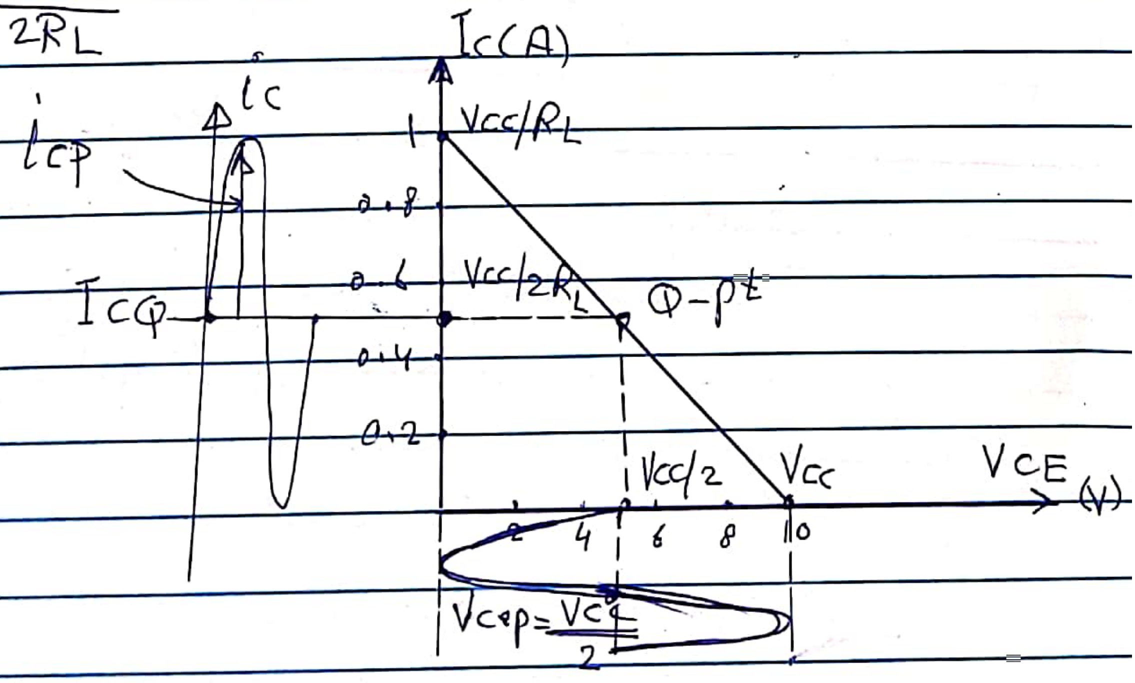
$$I_{CQ} = \frac{V_{cc}}{2R_L}$$



* For Max. output

$V_{cep} = V_{cc}/2$

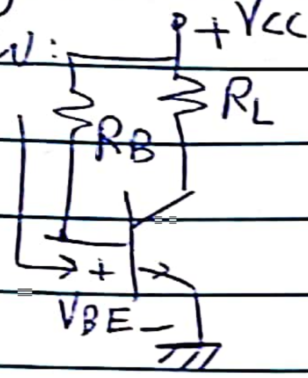
$i_{cp} = \frac{V_{cc}}{2R_L}$



Average D.C input power drawn from Vcc

$\overline{P_S} = V_{CC} \cdot I_{CQ}$

where I_{CQ} is from D.C Analysis and Can be obtained as follow:

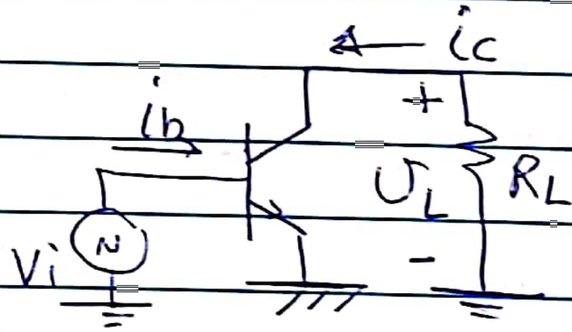


$V_{CC} + I_B R_B + V_{BE} = 0$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} - I_{BQ}$$

$I_{CQ} = \beta I_{BQ}$

The average A.c power delivered to load $\overline{P_L}$ is obtained when an A.c input Signal is applied which will produce A.c base Current i_b which will produce A.c Collector Current $i_c = \beta i_b$ and causes A.c Voltage on the load $V_L = i_c \cdot R_L$



$$\overline{P_L} = i_{L(rms)} \cdot V_{L(rms)}$$

$$= i^2_{L(rms)} \cdot R_L$$

$$= \frac{V^2_{L(rms)}}{R_L}$$

In terms of peak or peak-peak Value

$i_{L(rms)} = i_{Lp}/\sqrt{2}$, $V_{L(rms)} = V_{Lp}/\sqrt{2}$

So $\overline{P_L} = (i^2_{Lp} R_L)/2$ or $\overline{P_L} = \dfrac{V^2_{Lp}}{2R_L}$

OR $\overline{P_L} = \dfrac{V_{Lp} \cdot i_{Lp}}{2}$

The Conversion efficiency $\% = \dfrac{\overline{P_L}}{\overline{P_S}} \times 100 \%$

The difference between $\bar{P}_s$ and $\bar{P}_L$ is the power dissipated in the transistor and R_L which is in the form of heat.

In R_L: $P_D = I_{CQ}^2 R_L$.

In transistor: $\bar{P}_{D(trans)} = \bar{P}_s - P_L - I_{CQ}^2 R_L$

Maximum Conversion efficiency:

This happen when Q-pt. at Center of D.C.L.L, $V_{CEQ} = V_{CC}/2$, $I_{CQ} = V_{CC}/2R_L$

$\bar{P}_s = V_{CC} \cdot I_{CQ}$.

$V_{CP} = V_{CC}/2$, $I_{CP} = V_{CC}/2R_L$

$$\bar{P}_L = \frac{V_{CP} \cdot I_{CP}}{2} = \frac{V_{CC} \cdot V_{CC}}{8R_L} = \frac{V_{CC}^2}{8R_L}.$$

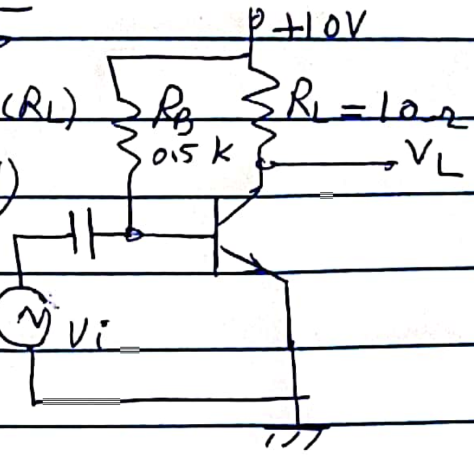
$\bar{P}_s = V_{CC} \cdot I_{CQ}$ ~~$\Rightarrow$ but~~ $I_{CQ} = \dfrac{V_{CC}}{2R_L}$

$$\bar{P}_s = \frac{V_{CC}^2}{2R_L}$$

$$\eta = \frac{\bar{P}_L}{\bar{P}_s} \times 100\% = \frac{\frac{V_{CC}^2}{8R_L}}{\frac{V_{CC}^2}{2R_L}} \times 100\%$$

$$\eta = \frac{V_{CC}^2}{8R_L} \times \frac{2R_L}{V_{CC}^2} \times 100\% = 25\% = \eta_{max}$$

EXA: Given $V_{BE} = 0.6V$, $\beta = 25$

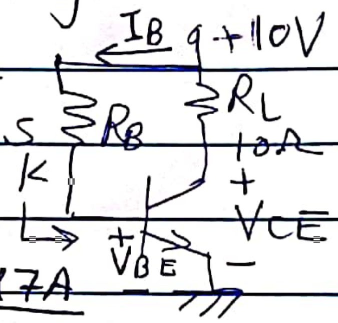


1) Calculate I_{BQ}, I_{CQ}, $P_{D(tran)}$, $P_{D(R_L)}$ and $\overline{P_s}$. (without I/p signal)

2) If an A.c i/p is applied and cause a peak base current of $\dot{i}_{bp} = 16mA$. Calculate $\overline{P_s}$, $\overline{P_L}$, $\eta\%$ and $P_{D(R_L)}$ and $P_{D(tran)}$.

3) Sketch D.C.L.L and A.C.L.L, indicate Q-pt and collector current and V_{CE} swings.

4) What is $\dot{i}_{bp}$ which gives max $\eta\%$?



1) $-10 + I_B R_B + V_{BE} = 0$

$\therefore I_B = \dfrac{10 - 0.6}{0.5} = 18.8\,mA$

$I_{CQ} = \beta I_B = 25 \times 18.8 = 470mA = 0.47A$

$V_{CE} = 10 - I_C R_C = 10 - 0.47 \times 10 = 5.3V$

$\overline{P_s} = V_{cc} \cdot I_{CQ} = 10 \times 0.47 = 4.7$ Watt.

$P_{D(R_L)} = I_{CQ}^2 R_L = (0.47)^2 \cdot 10 = 2.209W$

$P_{D(tra)} = I_{CQ} \cdot V_{CEQ} = 0.47 \times 5.3 = 2.491W$

* All $\overline{P_s}$ is dissipated in R_L and tran. (In the form of heat).

2) $\overline{P_s} = I_{CQ} \cdot V_{cc} = 0.47 \times 10 = 4.7W$

$\overline{P_L} = \dot{i}_{c(rms)}^2 R_L = \dfrac{\dot{i}_{cp}^2 \times R_L}{2}$

$\dot{i}_{cp} = \beta \dot{i}_{bp} = 25 \times 16mA = 0.4A$

$\therefore \overline{P_L} = \dfrac{(0.4)^2}{2} \times 10 = 0.8W$

$\eta = \dfrac{\overline{P_L}}{\overline{P_s}} \times 100\% = \dfrac{0.8}{4.7} \times 100\% = 17\%$

$P_D(R_L) = I_{CQ}^2 R_L = (0.47)^2 \times 10 = \underline{2.209 \text{ Watt}}$

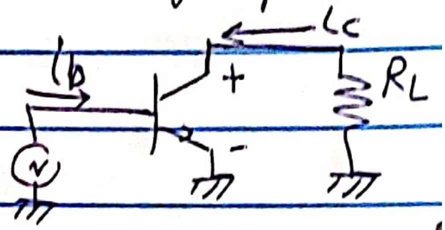
i.e $P_D(R_L) \longrightarrow$ does NOT change.

$P_D(\text{tran}) = \bar{P}_S - P_D(R_L) - \bar{P}_L = 4.7 - 2.209 - 0.8$

$P_D(\text{tran}) = 1.691 \text{ Watt}$

& $P_D(\text{tran})$ is reduced from $2.491 \Rightarrow 1.691$ Watt by the amount of $\bar{P}_L$ which is 0.8W

i.e when A.C signal is applied: Some of $P_D(\text{tran})$ is converted to an A.C average power delivered to Load.



$-V_{CC} + I_C R_C + V_{CE} = 0$

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

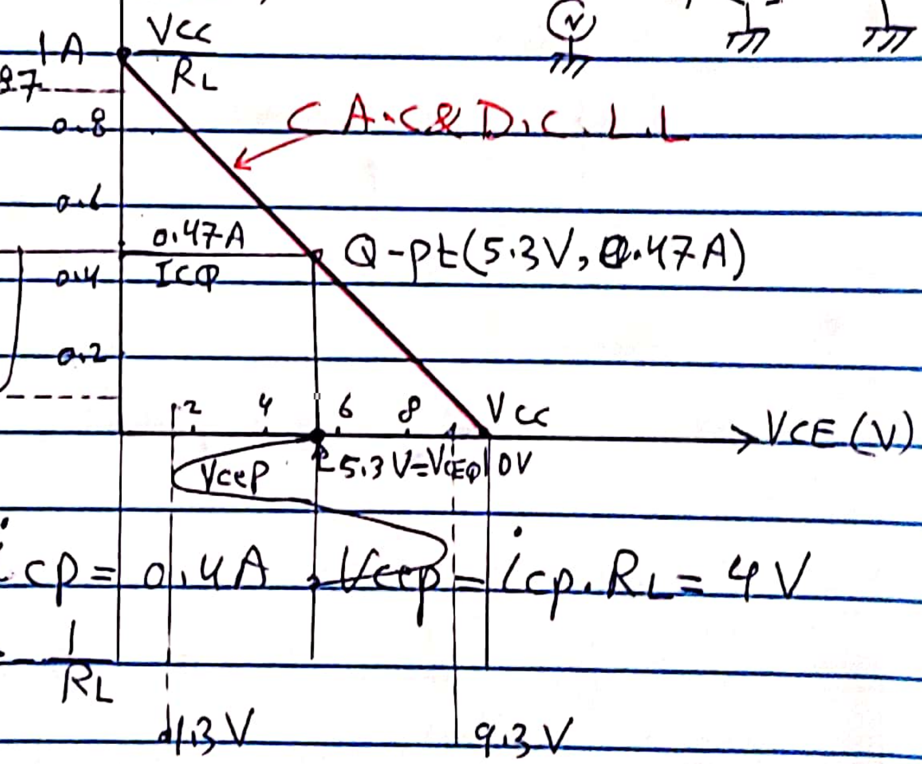
i) For $I_C = 0$

$V_{CE} = 10V$

$P_1(10V, 0)$

ii) For $V_{CE} = 0$

$I_C = \frac{10}{10} = 1A$



$P_2(0, 1A)$, $i_{cp} = 0.4A$, $V_{cep} = i_{cp} \cdot R_L = 4V$

Slope of D.C.L.L $= -\frac{1}{R_L}$

A.C.L.L: $v_{ce} = -i_c R_L \rightarrow$ slope $= -\frac{1}{R_L}$

D.C.L.L & A.C.L.L have the Same slope $= -\frac{1}{R_L}$

4) For η_{max}, $i_{cp} = \frac{1}{2} i_{cmax} = \frac{1}{2} \times 1 = 0.5A$

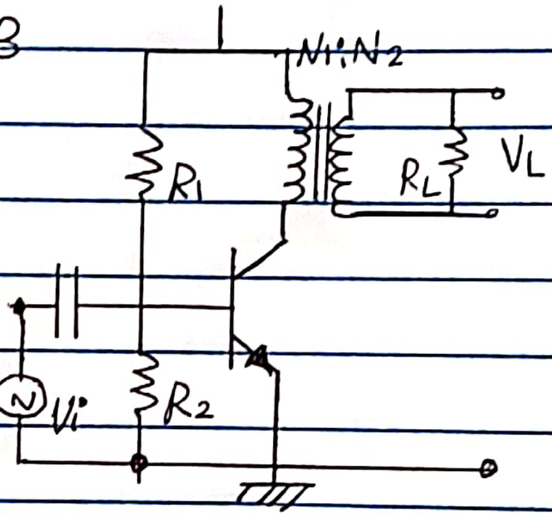
(Q-pt. must be at Center of D.C.L.L & $i_{cp} = \frac{1}{2} \frac{V_{CC}}{R_L}$)

$i_{bp} = i_{cp}/\beta = 0.5/25 = 20mA$

ii) Class-A transformer Coupled P.A:

In this type, the load is connected at the secondary of a transformer, so for the same $\overline{P_S}$ there is No $I_{CQ}^2 R_L$ i.e $\overline{P_L}$ will increase or less $\overline{P_S}$ is required for the same $\overline{P_L}$ ["Compared to direct Coupled type" which meas higher conversion efficiency].

- The cct. diagram is shown in Fig.



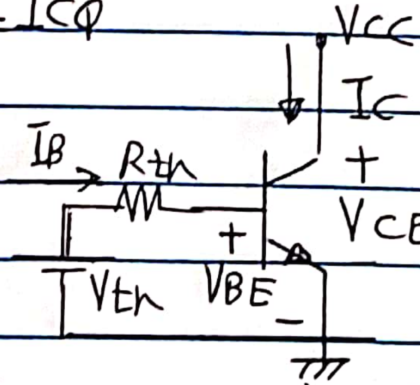
* For given $V_{cc}, R_1, R_2, V_{BE}, \beta$

D.C. Analysis gives:

Assume ideal primary coil with series resistance $R_s = 0$

$V_{th} = \dfrac{V_{cc} R_2}{R_1 + R_2}$, $R_{th} = R_1 // R_2$

$I_B = \dfrac{V_{th} - V_{BE}}{R_{th}}$, $I_C = \beta I_B = I_{CQ}$

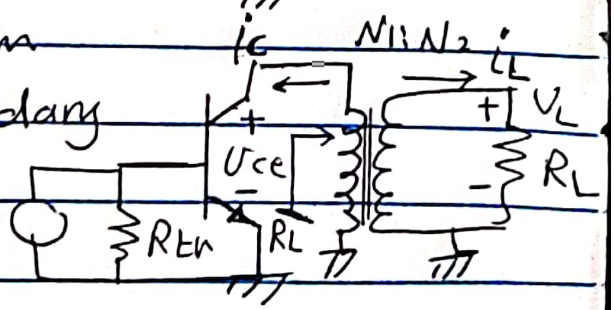


$V_{CE} = V_{cc}$.

$\overline{P_S} = V_{cc} \cdot I_{CQ} = \overline{P_D}$(trans).

For A.C Analysis:

$\overline{P_L}$ can be calculated from primary side or from secondary side.



* From secondary side

use: R_L, i_L, V_L

Scanned with CamScanner

$$\overline{P_L} = i_{L(rms)} \cdot V_{L(rms)} = \frac{i_{Lp}}{\sqrt{2}} \times \frac{V_{Lp}}{\sqrt{2}} = \frac{V_{Lp} \cdot i_{Lp}}{2}$$

oR $\overline{P_L} = i^2_{L(rms)} R_L = \frac{i^2_{Lp}}{2} R_L$

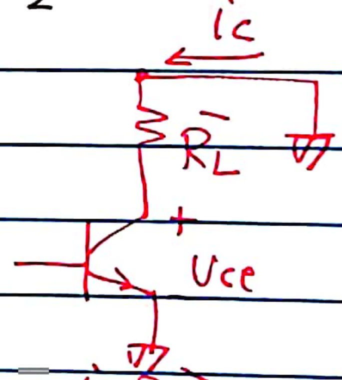
oR $\overline{P_L} = \frac{V^2_{Lp}}{R_L} = \frac{V^2_{Lp}}{2R_L}$

* From primary side: use $i_c, V_{ce}, \overline{R_L}$
where $\overline{R_L}$ is A.C reflected resistance seen from primary $\overline{R_L} = \left(\frac{N_1}{N_2}\right)^2 R_L = a^2 R_L$
where $\left(\frac{N_1}{N_2}\right)$: transformer turn-ratio

$$\overline{P_L} = i_{c(rms)} \cdot V_{ce(rms)} = \frac{i_{cp}}{\sqrt{2}} \frac{V_{cep}}{\sqrt{2}} = \frac{i_{cp} \cdot V_{cep}}{2}$$

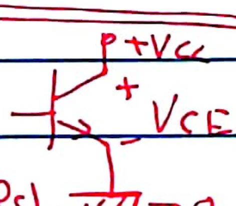
oR $\overline{P_L} = i^2_{c(rms)} \overline{R_L} = \frac{i^2_{cp}}{2} \overline{R_L}$

oR $\overline{P_L} = \frac{V^2_{cep(rms)}}{\overline{R_L}} = \frac{V^2_{cep}}{2\overline{R_L}}$



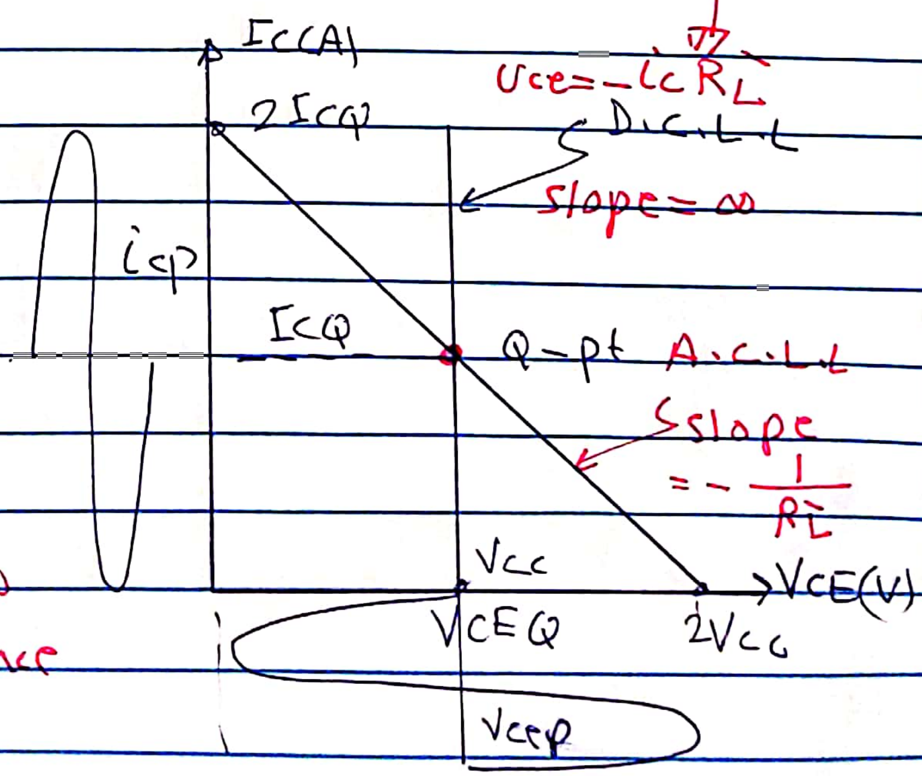
$V_{ce} = -i_c \overline{R_L}$

D.C. & A.C. L.L



$-V_{cc} + I_c(R_s) + V_{CE} = 0$

For $I_c = 0$
$V_{CE} = V_{cc}$
For $V_{CE} = 0$
$I_c = \frac{V_{cc}}{R_s} = \frac{V_{cc}}{0} = \infty$
"R_s = Series resistance of primary coil"



At Q-pt. A.C & D.C L.L are intersected, so it satisfied both A.C & D.C lines. At Q-pt.

$V_{CEQ} = V_{CC} - I_{CQ} \cdot \bar{R_L}$, $I_{CQ} = \frac{V_{CC}}{\bar{R_L}}$, $\bar{R_L} = \frac{V_{CC}}{I_{CQ}}$

To Find Intersections of A.C.L.L on I_C & V_{CE} axis: (For V_{CE} axis) :-

$\bar{V_{CE}} = V_{CEQ} + \Delta V_{CE}$

Slope of A.C.L.L $= \frac{1}{\bar{R_L}} = \frac{\Delta I_C}{\Delta V_{CE}}$, $\Delta V_{CE} = \Delta I_C \bar{R_L}$

but $\Delta I_C = I_{CQ} \Rightarrow \Delta V_{CE} = I_{CQ} \bar{R_L}$ and

$I_{CQ} \bar{R_L} = V_{CC} \Rightarrow \therefore \bar{V_{CE}} = V_{CC} + V_{CC} = 2V_{CC}$

(For I_C axis): $\bar{I_C} = I_{CQ} + \Delta I_C$

$\Delta I_C = \frac{\Delta V_{CE}}{\bar{R_L}} = \frac{V_{CC}}{\bar{R_L}} = I_{CQ}$.

$\therefore \bar{I_C} = I_{CQ} + I_{CQ} = 2 I_{CQ}$.

$\therefore$ Max intersections are: $2V_{CC}$ & $2 I_{CQ}$.

Max. Conversion efficiency η_{max}?

$\eta = \frac{\bar{P_L}}{\bar{P_S}} \times 100\%$, $\bar{P_L} = \frac{V_{LP}^2}{2\bar{R_L}}$

P_L will be Max. when $V_{LP} = V_{LP(max)} = V_{CC}$ "See A.C.L.L".

$\therefore \bar{P}_{L(max)} = \frac{V_{CC}^2}{2\bar{R_L}}$

and $\bar{P_S} = V_{CC} \cdot I_{CQ} = \frac{V_{CC} \cdot V_{CC}}{\bar{R_L}} = \frac{V_{CC}^2}{\bar{R_L}}$

$\therefore \eta_{max} = \frac{\bar{P}_{L(max)}}{\bar{P_S}} \times 100\%$

$= \frac{V_{CC}^2 / 2\bar{R_L})}{V_{CC}^2/\bar{R_L}} \times 100\% = 50\%$

$\therefore \eta_{max} = 50\%$ [When $V_{CEQ} = V_{CC}$, $V_{cep} = V_{CC}$]

Ex A: A class-A transformer-coupled power Amp. deliver a Max. Load power of 4W to 8Ω load. If the BJT has $\beta = 20$, $V_{BE} = 0.6V$ and $V_{CC} = 20V$.

1) Calculate $(\frac{N_1}{N_2})$ of the transformer.
2) The Value of R_B.
3) Transistor ratings (I_{Cmax}, V_{CEmax}, $P_{D(max)}$).
4) Sketch D.C & A.C. L.L with i_C & V_{CE} swings.

For max. operation: $\eta_{max} = 50\% = \frac{\bar{P_L}}{\bar{P_S}}$

~~$\bar{P_S} = \eta_{max} \cdot P_{L(max)} = 0.5$~~

$$\bar{P_S} = \frac{P_{L(max)}}{\eta_{max}} = \frac{4W}{0.5} = 8W$$

$$\bar{P_S} = V_{CC} \cdot I_{CQ} \Rightarrow I_{CQ} = \frac{\bar{P_S}}{V_{CC}} = \frac{8}{20} = 0.4A$$

$$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{0.4}{20} = 0.02A$$

$$R_B = \frac{V_{CC} - V_{BE}}{I_B} = \frac{20 - 0.6}{0.02} = \frac{19.4V}{0.02} = 970\,\Omega$$

$$(N_1/N_2) = a = \sqrt{\frac{\bar{R_L}}{R_L}} \quad (\bar{R_L} = a^2 R_L)$$

$$\bar{R_L} = \frac{V_{CC}}{I_{CQ}} = \frac{20V}{0.4} = 50\,\Omega$$

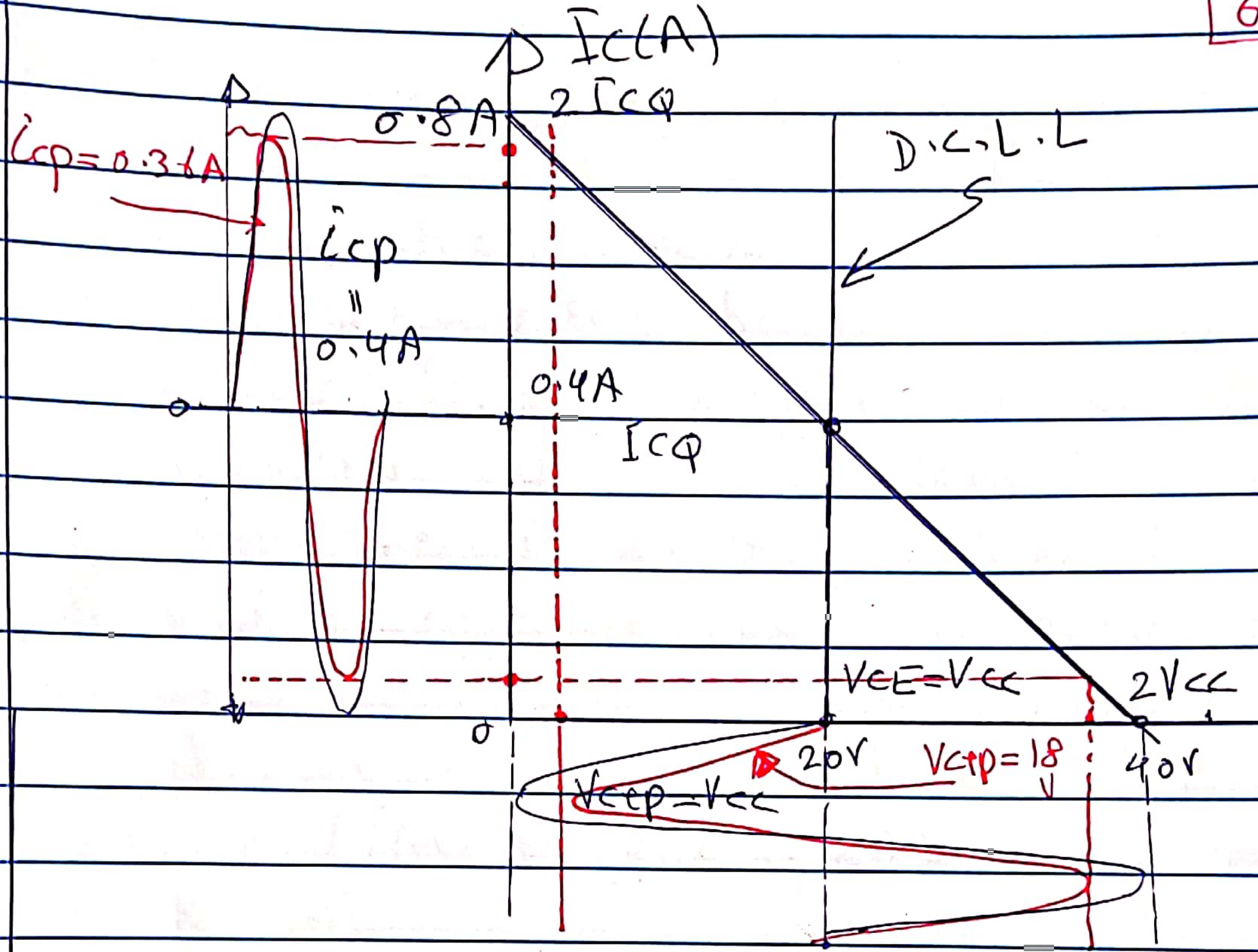
$$\therefore a = \frac{N_1}{N_2} = \sqrt{\frac{50}{8}} = 2.5$$

$I_{Cmax} = 2I_{CQ} = 0.8A$, $V_{CEmax} = 2V_{CC} = 40V$

$P_{D(max)} = \bar{P_S} - \bar{P_L} = 8 - 4 = 4W$

For No A.C Signal $\bar{P_D} = \bar{P_S} = 8W$.

(Worst Case P_D on BJT).



EXA 2: For the same R_B (From previous example) Calculate $\overline{P_L}$, $\eta\%$, P_D when the input signal causes a peack collector current of 0.36A? [Sketch i_c & V_{ce}]

* For the same ($R_B = 970\,\Omega$, $I_B = 20mA$, $I_{CQ} = 0.4A$

so $\overline{P_s} = 0.4 \times 20 = 8W$

$$\overline{P_L} = \frac{i_{cp}^2}{2} R_L = \frac{(0.36)^2}{2} \times 50 = 3.24\,W$$

$$\eta = \frac{3.24}{8} \times 100\% = 40.5\%$$

$$P_D(\text{trans}) = \overline{P_s} - \overline{P_L} = 8 - 3.24 = 4.76\,W$$

$$V_{cep} = i_{cp} \cdot R_L = 0.36 \times 50 = 18V$$

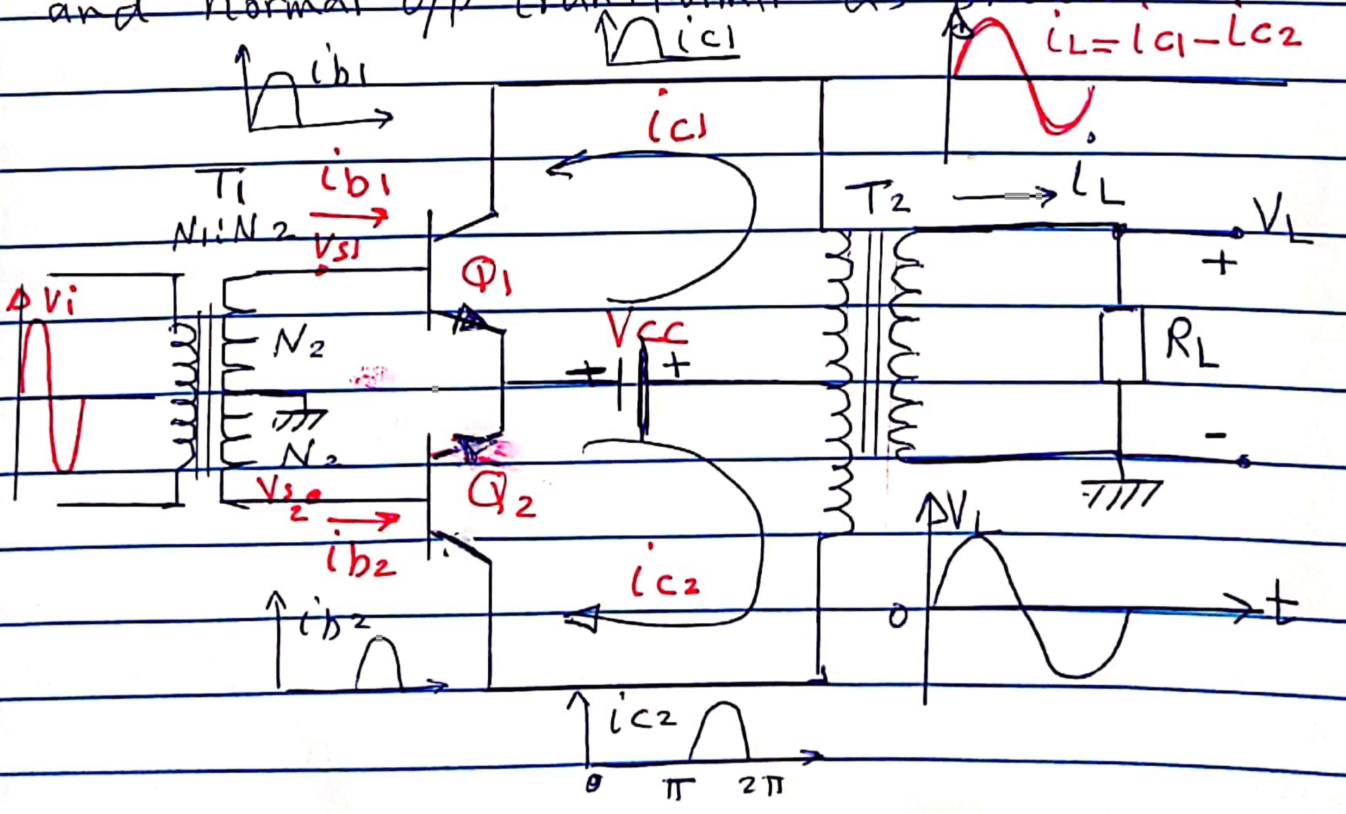
Class-B push-pull power Amplifier

In this P.A, two transistors are used. ONE For processing +ve H.C of the A.C input and the other to process the -ve H.C. because the Q-pt is at cut-off ($I_{CQ}=0$) i.e No $\overline{P_s}$ For No V_s.
The transistor will draw $\overline{P_s}$ from D.C Souce only when there is an A.C i/p signal. i.e compared to class-A, less $\overline{P_s}$ is required for the same $\overline{P_L}$, So the conversion efficiency is high. The transistors can be of the same type or different types (PNP & NPN) or (n-channel & p channel).

"Transformer-coupled, class-B push-pull power Amp"

(*) "Using Same type of transistors"

* This type must use i/p center-tapped Trans. and normal o/p transformer as shown"



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"Transformer-coupled, Class-B push-pull power Amp"

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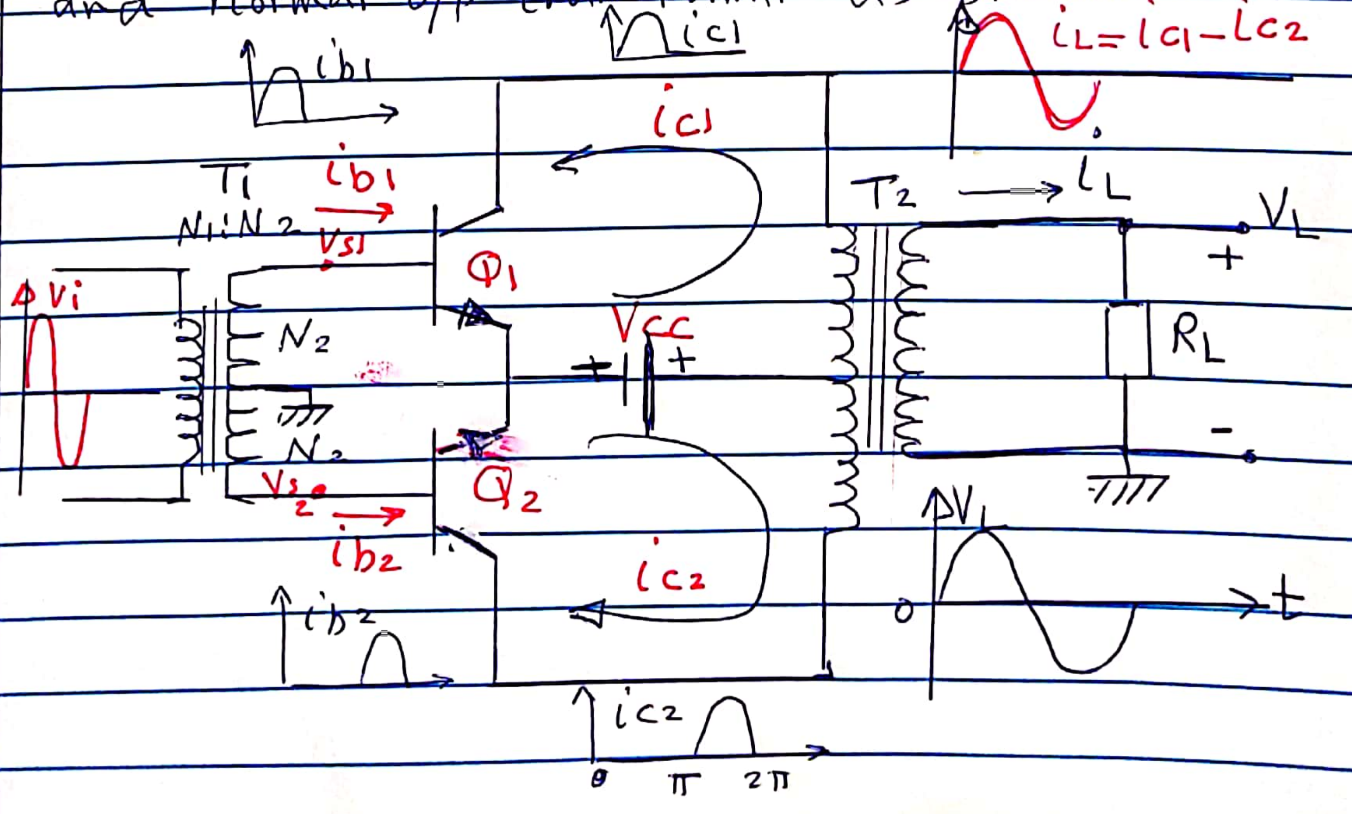
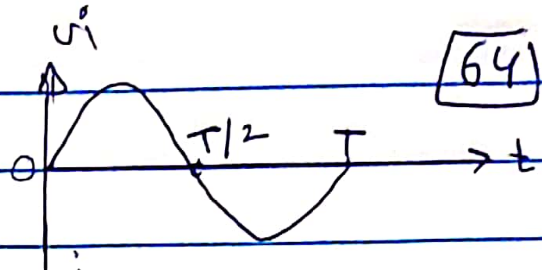


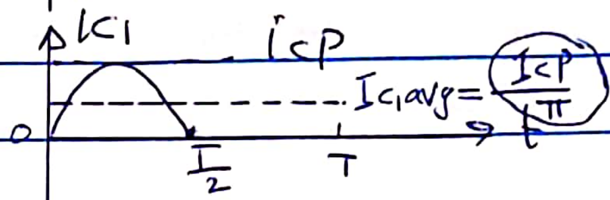
The waveforms of v_i, i_{c_1}, i_{c_2}, i_L and v_L are shown:



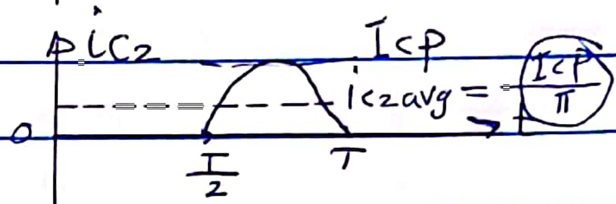
$I_{cp_1} = I_{cp_2} = \frac{V_{cep}}{\bar{R_L}}$

where $\bar{R_L} = a^2 R_L$

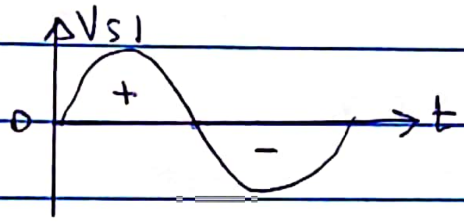
$\bar{R_L}$: A.C reflected Resistance

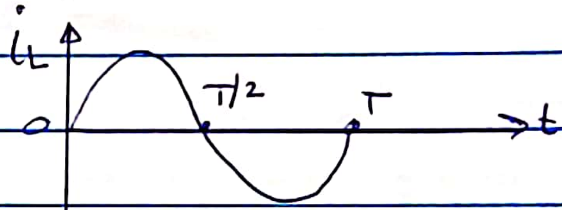


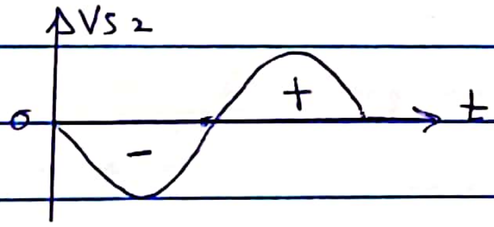
(*) Due to the presence of center-taped transformer T_1, $V_{s2} = -V_{s1} = \frac{N_2}{N_1} V_i$

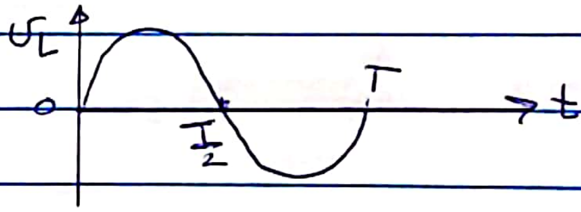


So









① During +ve H.C of V_i, V_{s1} is +ve, Q_1 is ON, $Q_2 \rightarrow$ OFF (V_{s2} is −ve). i_{c_1} will flow in through $+V_{cc}$ and Q_1, $\bar{P_s} = V_{cc} \cdot I_{c_1 avg}$

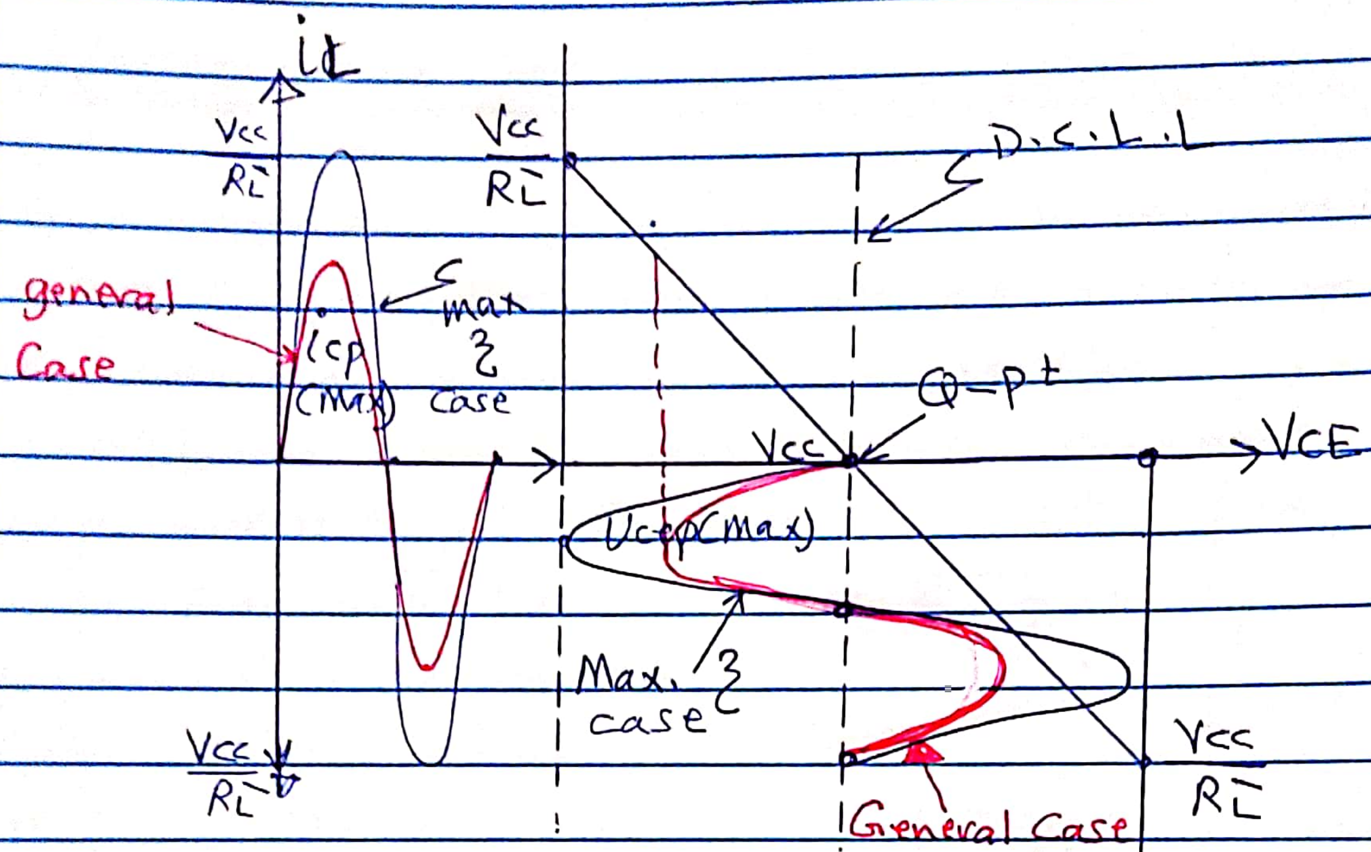
where $I_{c_1 p} = \frac{V_{cep}}{\bar{R_L}}$, $I_{c_1 avg} = \frac{I_{cp}}{\pi}$

$\bar{P_{s_1}} = V_{cc} \frac{I_{cp}}{\pi}$

② During −ve H.C of V_i, $V_{s1} \Rightarrow$ −ve, $V_{s2} \Rightarrow$ +ve So $Q_1 \rightarrow$ OFF, $Q_2 \rightarrow$ ON, i_{c_2} will flow in V_{cc} and Q_2. $\bar{P_{s_2}} = V_{cc} \cdot I_{c_2 avg} = \frac{I_{cP}}{\pi} V_{cc}$.

③ During a Full-Cycle of V_i, $\bar{P_s}$ average drawn from V_{cc} is: $\bar{P_s} = \bar{P_{s1}} + \bar{P_{s2}} = 2V_{cc} \frac{I_{cP}}{\pi}$

D.C & A.C Load line:



For Max. η, $V_{cep} = V_{cc} \rightarrow \bar{P}_s = 2V_{cc}\frac{I_{cp}}{\pi}$

$$I_{cp} = \frac{V_{cc}}{R_L} \rightarrow \therefore \boxed{\bar{P}_s = \frac{2V_{cc}^2}{R_L \pi}}$$

$$\bar{P}_L = \left(\frac{V_{cep}}{\sqrt{2}}\right)^2 \frac{1}{R_L} = \frac{V_{cep}^2}{2R_L} \rightarrow \bar{P}_{L(max)} = \frac{V_{cc}^2}{2R_L}$$

$$\eta_{max} = \frac{P_{L(max)}}{\bar{P}_s} = \frac{\cancel{V_{cc}^2}}{2\cancel{R_L}} \times \frac{\pi \cancel{R_L}}{2\cancel{V_{cc}^2}} = \frac{\pi}{4} \times 100\%$$

$\eta_{max} = 78.5\%$ [when $V_{cep} = V_{cc}$]

P_D For each transistor $= \frac{\bar{P}_s - \bar{P}_L}{2}$.

$\boxed{P_D \approx 0.2 P_{L(max)}}$ For each transistor.

Complementary class-B push-pull power Amp.

Both input and o/p transformers can be eliminated using complementary transistors (PNP & NPN) or (n-channel & P-channel). the cct. is shown in in Fig.

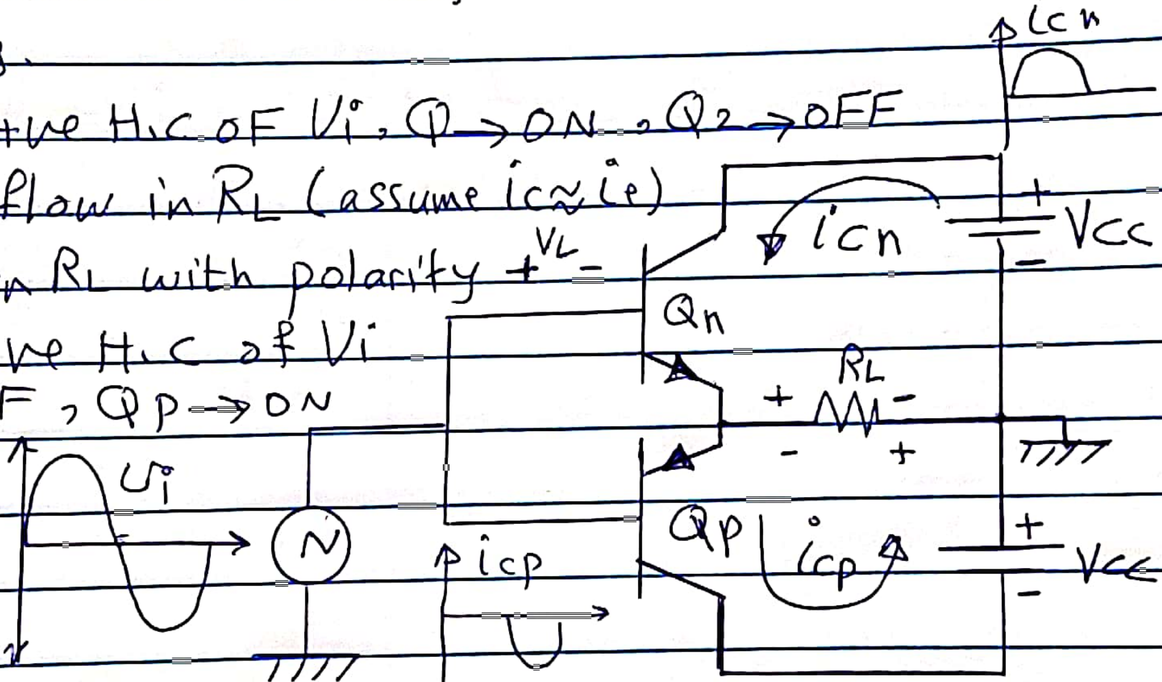
(1) For +ve H.C of V_i, $Q_1 \rightarrow ON$, $Q_2 \rightarrow OFF$

i_{cn} flow in R_L (assume $i_c \approx i_e$)

$v_L = i_{cn} R_L$ with polarity $+ \overset{v_L}{} -$

(2) For -ve H.C of V_i

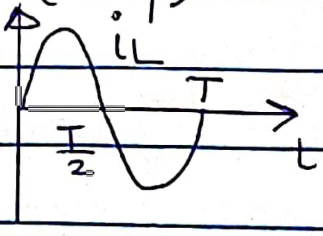
$Q_n \rightarrow OFF$, $Q_p \rightarrow ON$



i_{cp} will flow in R_L causing v_L with polarity $- v_L +$

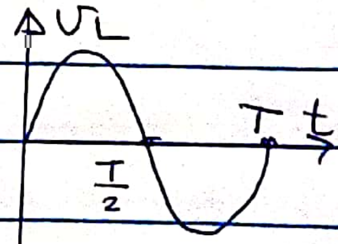
(3) For a Full cycle of v_i, $i_L = i_{cn} + (-i_{cp})$

$\therefore i_L = i_{cn} - i_{cp}$ will be of the form



v_L will be of the Same form of i_L i.e v_L and i_L are inphase

* Note that v_L & v_i are inphase because the cct. is Common Collector



$v_o \approx V_i = V_L$

* when Q_n is ON, $\bar{P}_{S(+)} = V_{cc} \cdot I_{cn(avg)}$.

$I_{cn(avg)} = \frac{I_{cp}}{\pi}$, $I_{cp} = I_{ep} = \frac{V_{LP}}{R_L}$

* When Q_p is ON, we draw $\overline{P_s}(-) = -V_{cc}(I_{cp(avg)})$

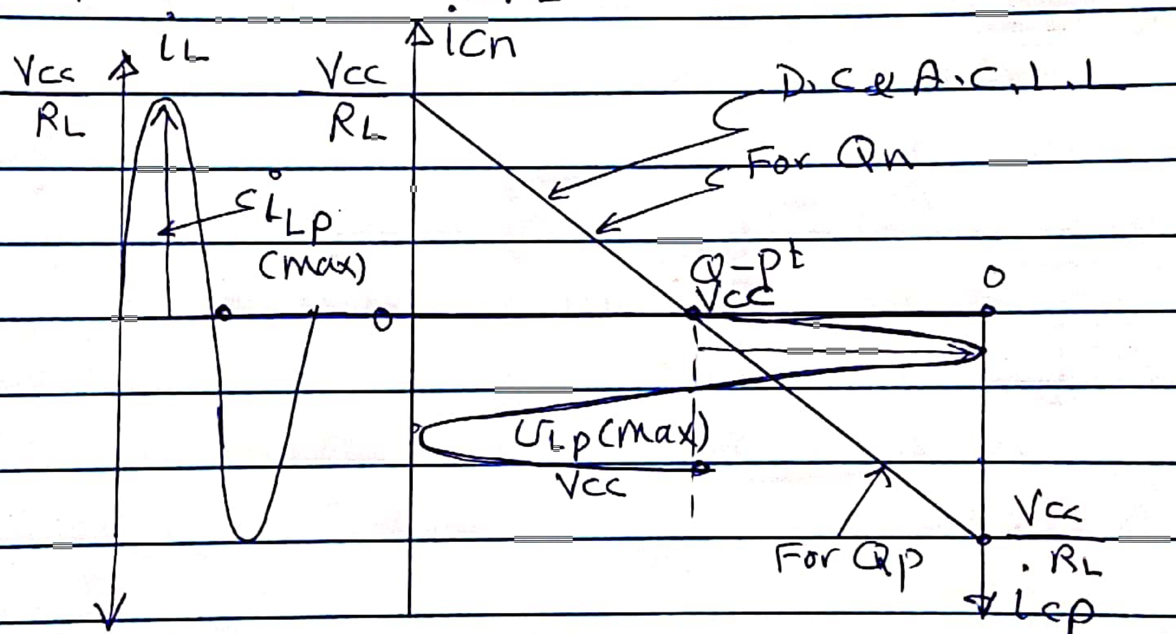
$I_{cp(avg)} = \frac{I_{cp(peak)}}{\pi} \Rightarrow I_{cp(peak)} = \frac{V_{Lp}}{R_L}$

So $\overline{P_s}(-) = +V_{cc}\frac{I_{cp(peak)}}{\pi}$

For Full cycle of Vi: $\overline{P_s} = \overline{P_s}(+) + \overline{P_s}(-) = \frac{2I_{c(peak)}}{\pi}V_{cc}$

Since v_L is a complete cycle.

$\overline{P_L} = \left(\frac{V_{Lpeak}}{\sqrt{2}}\right)^2/R_L = \frac{V_{Lpeak}^2}{2R_L}$



$\overline{P_L}(max)$ is obtained when $V_{Lp} = V_{cc}$

or $\overline{P_L}(max) = \boxed{V_{cc}^2/2R_L}$

and Since $\overline{P_s} = 2V_{cc}\frac{I_{c(peak)}}{\pi}$, $I_{c(peak)} = \frac{V_{cc}}{R_L}$

$\therefore \overline{P_s} = \frac{2V_{cc}V_{cc}}{\pi R_L} = \frac{2V_{cc}^2}{\pi R_L}$

$\therefore \eta_{max} = P_{L(max)}/\overline{P_s} = \frac{\cancel{V_{cc}^2}}{2\cancel{R_L}} \times \frac{\pi \cancel{R_L}}{2\cancel{V_{cc}^2}} = \frac{\pi}{4} \times 100\%$

$\therefore \eta_{max} = 78.5\%$ [when $V_{Lp} \approx V_{cc}$ and $V_{ip} \approx V_{Lp} = V_{cc}$]

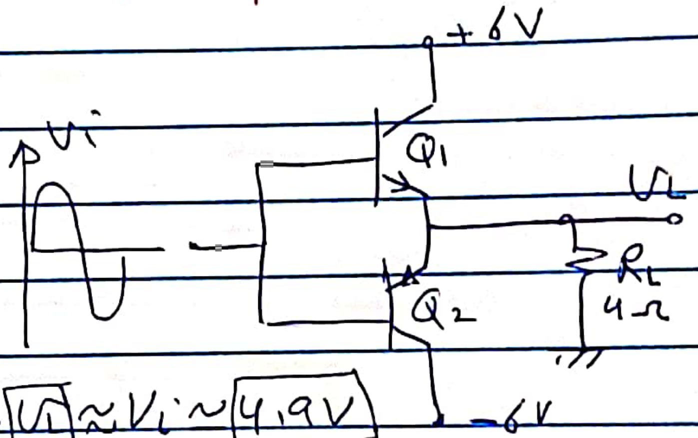
In general $\eta = \frac{V_{LP}}{V_{cc}} \times \frac{\pi}{4}\%$ [Valid For both types]

When $V_{Lp} = V_{cc} \rightarrow \eta = \eta_{max} = \frac{\pi}{4} \times 100\% = 78.5\%$

*NOTE: This cct. is emitter follower, So $v_L = v_i$ ***

EXA: A class-B output stage with complementary transistors is biased with $V_{cc} = \mp 6V$ and deliver 3W to 4Ω load. calculate:

1) peak input voltage, $\overline{P_s}$, $\eta\%$, P_D (each tr.).
2) sketch D.C & A.C L.L with v_{ce} & i_c swings.
3) what is the peak input voltage required to give η_{max}



① $\overline{P_L} = \frac{V_{Lp}^2}{2R_L}$

$V_{Lp} = \sqrt{2\overline{P_L}R_L} = \sqrt{2\times3\times4}$

$V_{Lp} \simeq 4.9V$

and since $A_v \simeq 1$ (C.C), $\boxed{V_{L}} \approx V_i \approx \boxed{4.9V}$

$\overline{P_s} = \frac{2I_{cp}}{\pi} \times V_{cc}$, $I_{cp} = i_{Lp} = \frac{V_{Lp}}{R_L} = \frac{4.9}{4} = 1.225A$

$\therefore \overline{P_s} = \frac{2\times1.225}{\pi} \times 6 = 4.68\ W$

$\eta = \frac{\overline{P_L}}{\overline{P_s}} \times 100\% = \frac{3}{4.68} \times 100\% = 64.1\%$

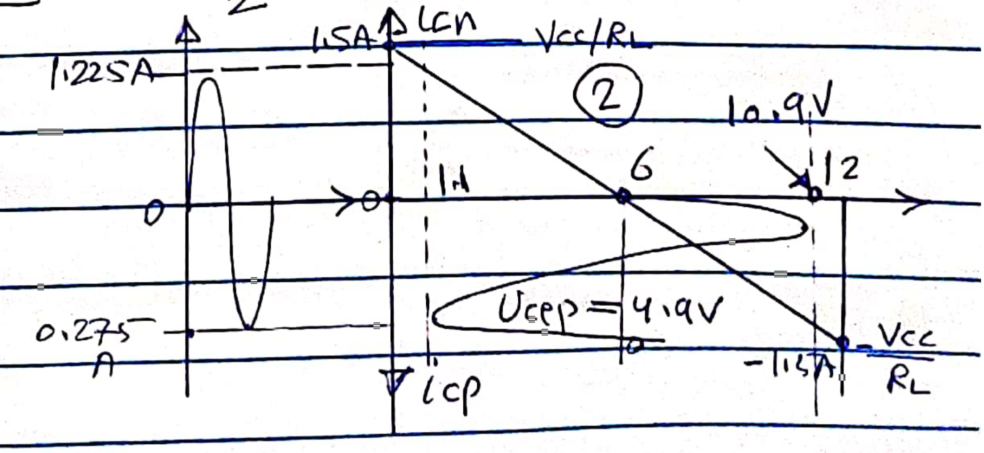
$P_{D(each)} = \frac{\overline{P_s} - \overline{P_L}}{2} = \frac{4.68 - 3}{2} = 0.84\ W$

③ For η_{max}

$V_{Lp} = V_{cc} = 6V$

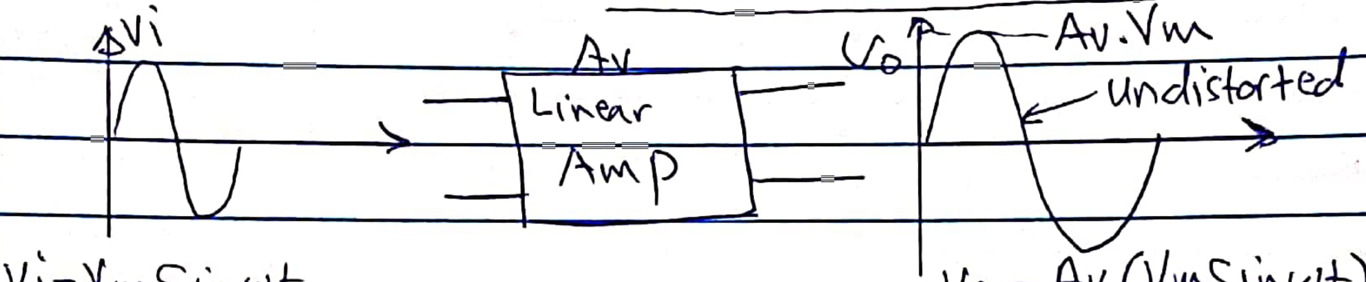
but $V_{ip} \simeq V_{Lp}$

$\therefore V_{ip} = 6V$

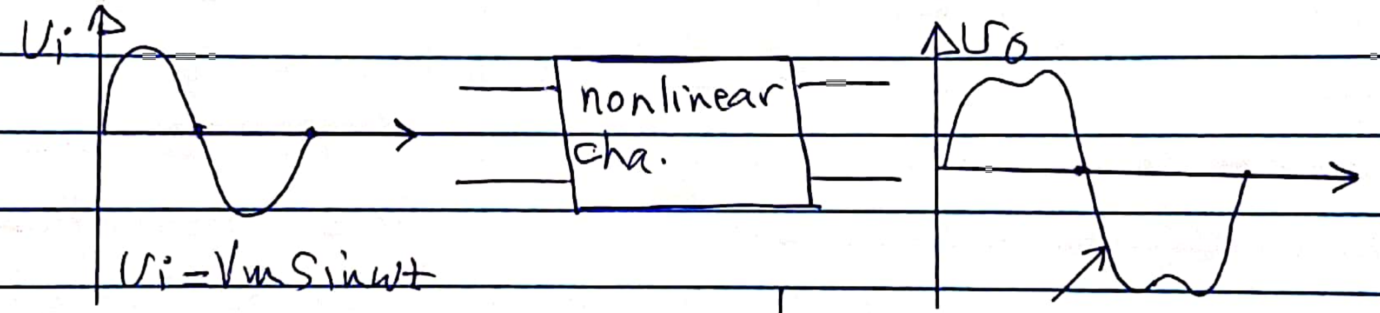


"Distortion in power Amplifiers"

Distortion: Deformation in the signal due to nonlinear characteristics of the transistor and this is called nonlinear distortion.



$V_i = V_m \sin\omega t$ $\qquad V_o = A_v(V_m \sin\omega t)$



distorted Signal

$V_o(t) = B_0 + B_1 \sin\omega t + B_2 \sin 2\omega t + B_3 \sin 3\omega t + B_n \sin n\omega t$ eqn.

For the distorted Signal:

B_0: D.C component $f = 0$

B_1: Amplitude of fundemental frequency (ω)

B_2: Amp. of 2nd Harmonics (2ω)

B_3: " " 3rd Harmonic (3ω)

B_n: " " nth Harmonics $(n\omega)$

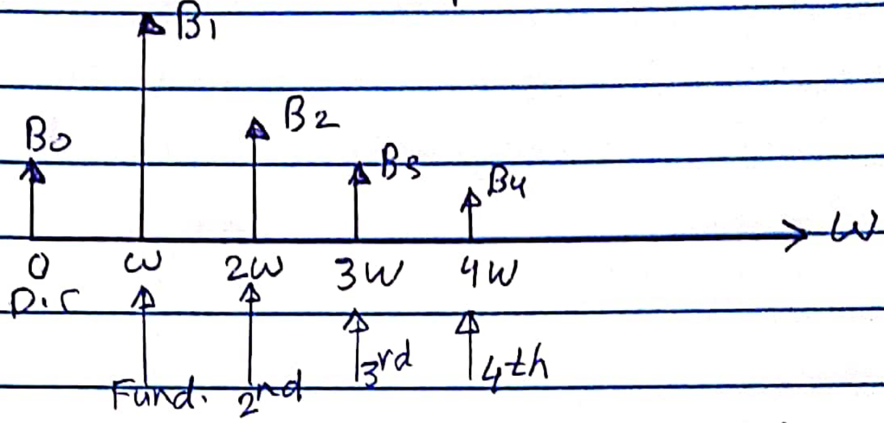
$D_2 = \frac{B_2}{B_1}$ (2nd Harmonics distortion)

$D_3 = \frac{B_3}{B_1}$ (3rd " ")

$D_n = \frac{B_n}{B_1}$ (n^{th} harmonic distortion)

Total Harmonic distion $T.H.D = \sqrt{D_2^2 + D_3^2 + \dots + D_n^2}$

Spectrum of distorted Signal



ExA: The o/p voltage of a certain power is given by:

$V_o(t) = 2 + 8\sin 2\pi \times 10^3 t + 6\sin 4\pi \times 10^3 t + 2\sin 6\pi \times 10^3 t$

1) calculate 2nd and 3rd Harmonic and T.H.D (V)

2) Sketch the Spectrum of V_o.

Compared to eqn. x [general eqn. for distorted signal]

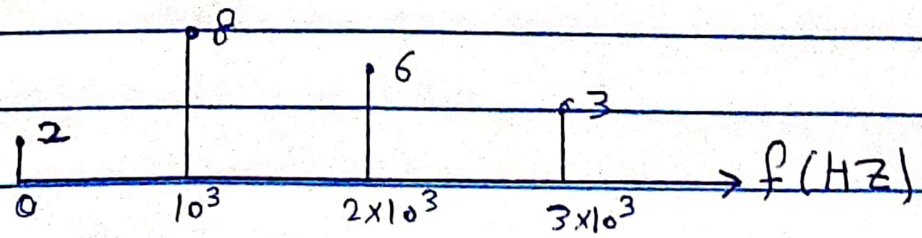
$B_0 = 2V$ (d.c), $B_1 = 8V$ (fundemental)

$B_2 = 6V$ (2nd Harmonics), $B_3 = 2V$ (3rd Harmonic)

So: $D_2 = \frac{B_2}{B_1} = \frac{6}{8} \times 100\% = 75\%$

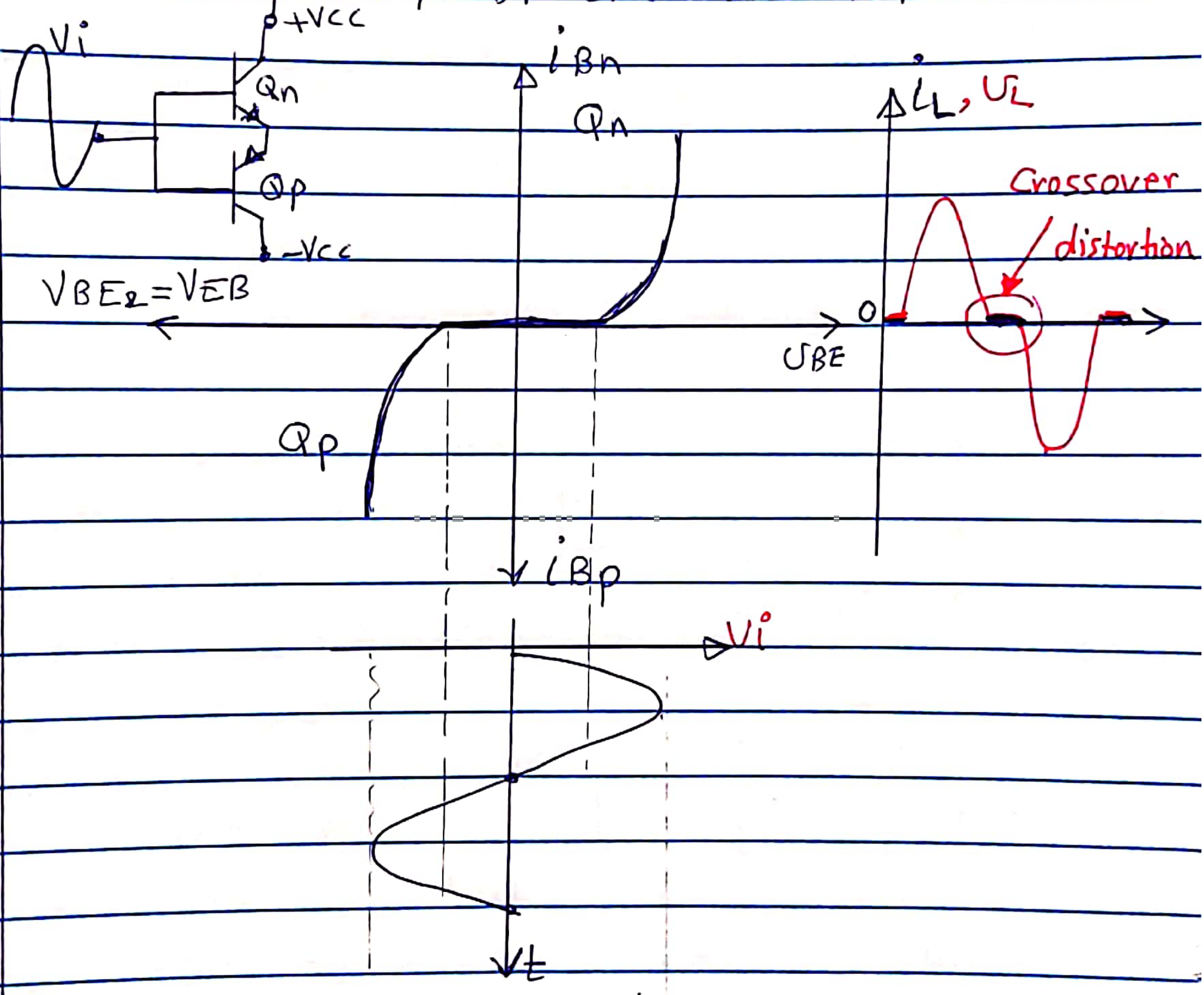
$D_3 = \frac{B_3}{B_1} = \frac{2}{8} \times 100\% = 25\%$

$T.H.D = \sqrt{(0.75)^2 + (0.25)^2} = \sqrt{0.625} = 79\%$



Crossover distortion

This type of distortion happens only in class-B power Amp. because its Q-pt is at Cutoff. It is due to finite voltage VBE of the transistor and causes dead zone on the input c/c of the transistor.



this distortion can be eliminated by cancelling the effect of VBE. this can be achieved by applying a D.C voltage on the bases of transistor equal and opposite to VBE.

This makes ~~class~~ the Amp. biased at $I_{CQ} > 0$ i.e class-AB practically either using D.C sources or using diode of the Same type of the transistors as shown in Figs.

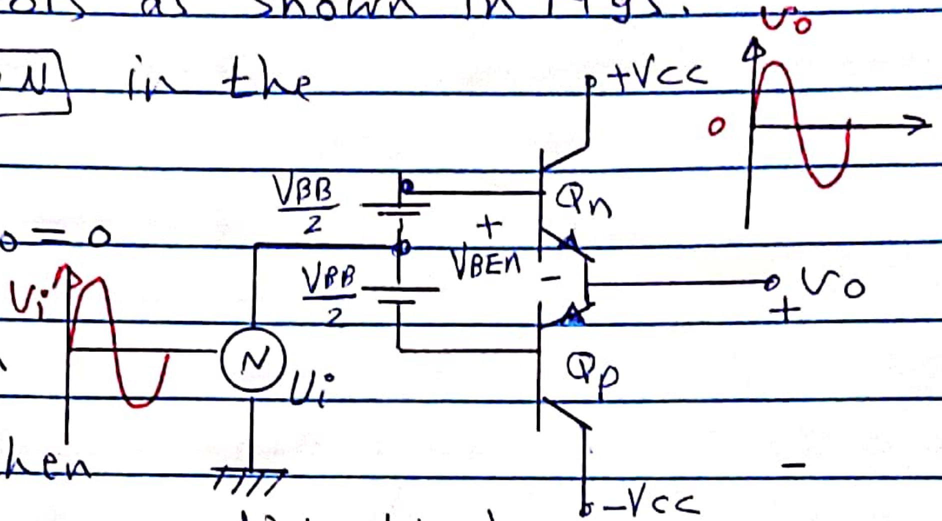
When Q_n is $\boxed{ON}$ in the +ve H.C of V_i

$V_i - \frac{V_{BB}}{2} + V_{BE_n} + V_o = 0$

$V_o = V_i + \frac{V_{BB}}{2} - V_{BEn}$

If $\frac{V_{BB}}{2} = V_{BEn}$, then

$V_o = V_i$ (No crossover distortion).



* D_1 & D_2 must be matched with transistors

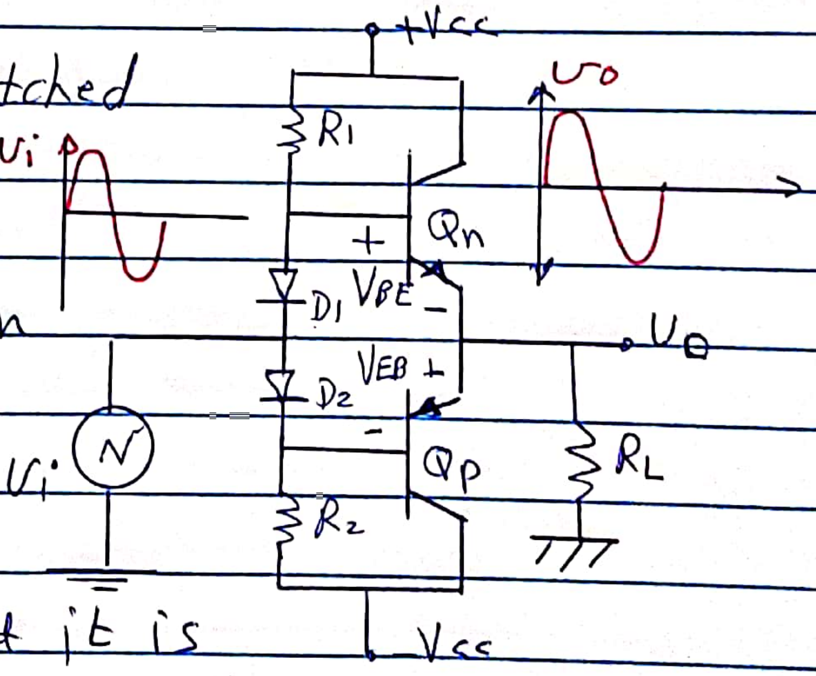
$V_{\gamma 1} = V_{\gamma 2} = V_{BEn} = V_{EB}$

* In this modification

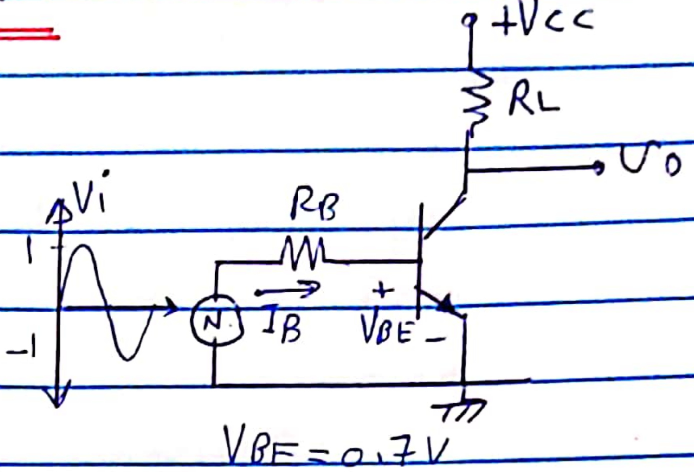
$I_B > 0$, $I_C > 0$

i.e the cct. is NOT class-B.

It is class-AB but it is very close to class-B than class-A.



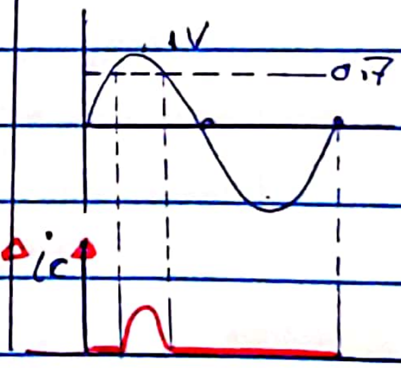
Class-C power Amplifier:



1) The Q-pt. is down the CutoFF. i.e the transistor Conducts For < 180° (Small Conduction angle Normaly < 90°.

The BJT will be FW in +ve H.C and $I_B = \frac{V_i - V_{BE}}{R_B}$

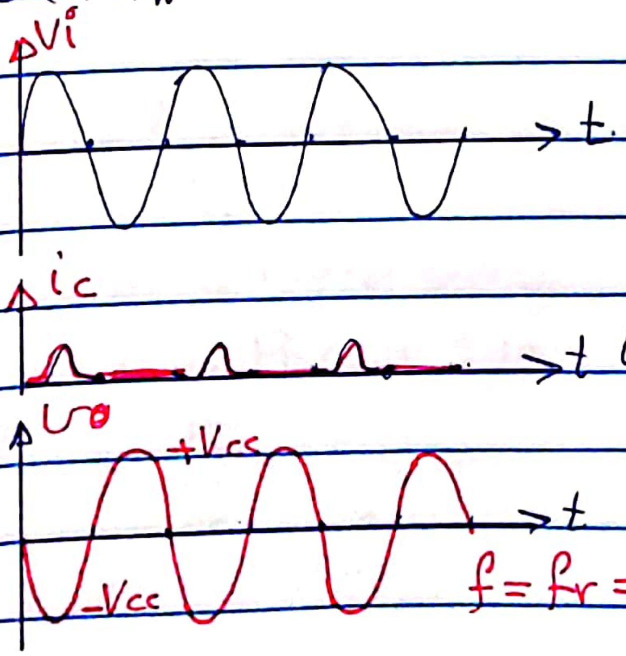
* It is ON when $V_i > V_{BE}$

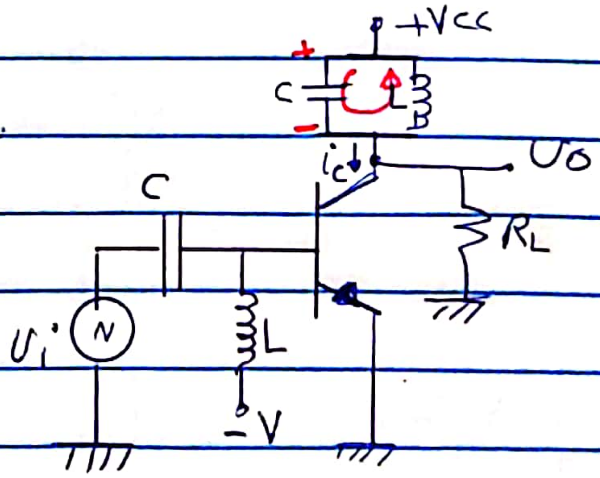


2) The o/p Current is less than half cycle. i.e it is distorted Signal which is full of harmonics

3) practically the load is a parallel tuned cct. its resonance freq. is the fundemental frequency of the input Signal.

* For aperiodical Vi, ic will have the form





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

When the form of i_c is a pulse form, the parallel tuned cct. has a characteristic called "flywheel effect" which is when it is excited by a pulse current, it will oscillate and give a sinusoidal o/p signal at resonant freq $f_r = \frac{1}{2\pi\sqrt{LC}}$ with amplitude $\mp V_{cc}$. "due to charging and discharging of the capacitor).

For a certain load, the average load power $\overline{P_L}$ is given by $\overline{P_L} = \frac{V_{cc}^2}{2R_{eff}}$

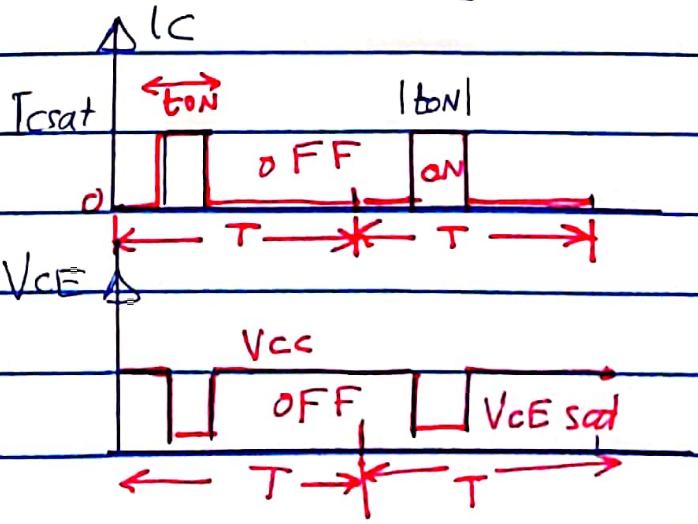
where R_{eff}: parallel combination of R_L and parallel tuned cct resistance.

* In class C, the transistor works as switch "ON & OFF" "Saturation & CutoFF)

when it is ON: (Saturation: $I_c = I_{c(sat)}$
$V_{CE} = V_{CE(sat)}$

when it is OFF $[I_c = 0, V_{CE} = V_{cc}]$

When transistor is in Sat.



$P_{D(ON)} = I_{c(sat)} V_{CE(sat)}$

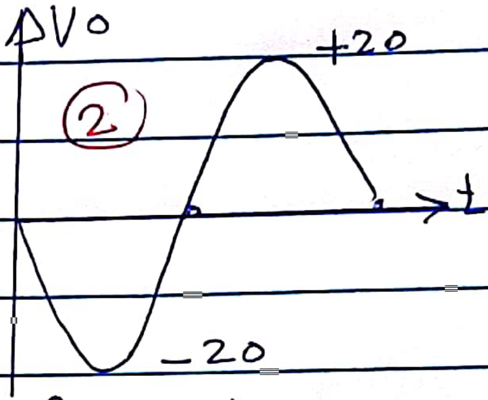
$P_{D(avg)} = P_{D(ON)} \frac{t_{on}}{T}$

$\overline{P_s} = \overline{P_L} + P_{D(avg)}$.

$\eta = \frac{\overline{P_L}}{\overline{P_s}} \times 100\%$.

EX: A class-C power Amplifier has an input of $f = 100\,KHZ$, the BJT has $V_{CE(sat)} = 0.3V$ and $I_{C(sat)} = 0.2A$ and its on for 2μs. If $V_{cc} = 20V$, the effective Resistance is 50Ω

1) Calculate $\overline{P_L}$, $\overline{P_s}$ and $\eta\%$.
2) Sketch $V_o(t)$.
3) Calculate L, C required (i.e design the tuned cct. required to process the input signal).



$f = 100\,KHZ$

1) $$\overline{P_L} = \frac{V_{cc}^2}{2R_{eff}} = \frac{400}{2\times 50} = 4W$$

$$\overline{P_s} = \overline{P_L} + P_{D(avg)}$$

$$P_{D(avg)} = P_{D(ON)}\frac{t_{on}}{T} = I_{C(sat)} \cdot V_{CE(s)} \frac{t_{on}}{T}$$

$$T = \frac{1}{f} = \frac{1}{10^5} = 10\,\mu s$$

$$P_{D(avg)} = 0.2 \times 0.3 \frac{2}{10} = 0.012W$$

$$\overline{P_s} = 4 + 0.012 = 4.012\,W$$

$$\eta = \frac{4}{4.012} \times 100\% = 99.7\%$$

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

let $C = 1\,pF$

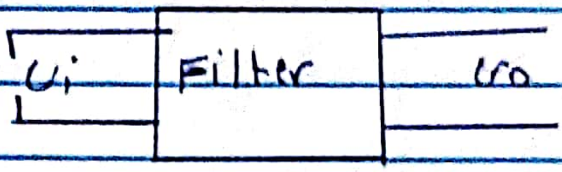
$$\therefore L = \frac{1}{4\pi^2 f_r^2 C} = \frac{1}{4\times 10 \times 10^{10} \times 10^{-12}} = 2.5\,H.$$

Scanned with CamScanner

Active Filters:

Filter: It is a selective circuit allows a certain band of frequency to pass and this band is called passband and reject other band which is called stopband or reject band.

- It must contain freq. dependant element, mainly capacitance.



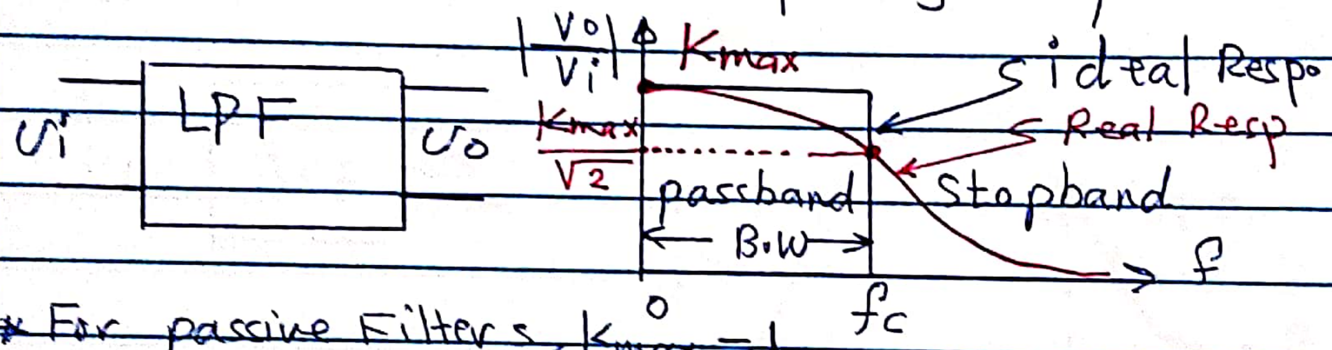
- Filters are classified into: passive Filters and Active Filters. A comparision between them is presented in the following table

Passive Filter	Active Filter
1) Contains only passive elements (R, C, L)	1) Contain passive and active element (R, C, L) + BJT, MOSFET or Op-Amp
2) No power supply is needed (No PS on device) "No power consumption"	2) D.C power supply is required to bias the active devices, power consumption happen.
3) No Amplification "No gain is achieved	3) Gain is achievable due to Active device
4) Can't be integrable So it is NOT Compatible with modern electronics systems.	4) Can be made as an IC "Integrated cct" So it can be Compatible with modern electronic system.

Filter Classification According to passband:

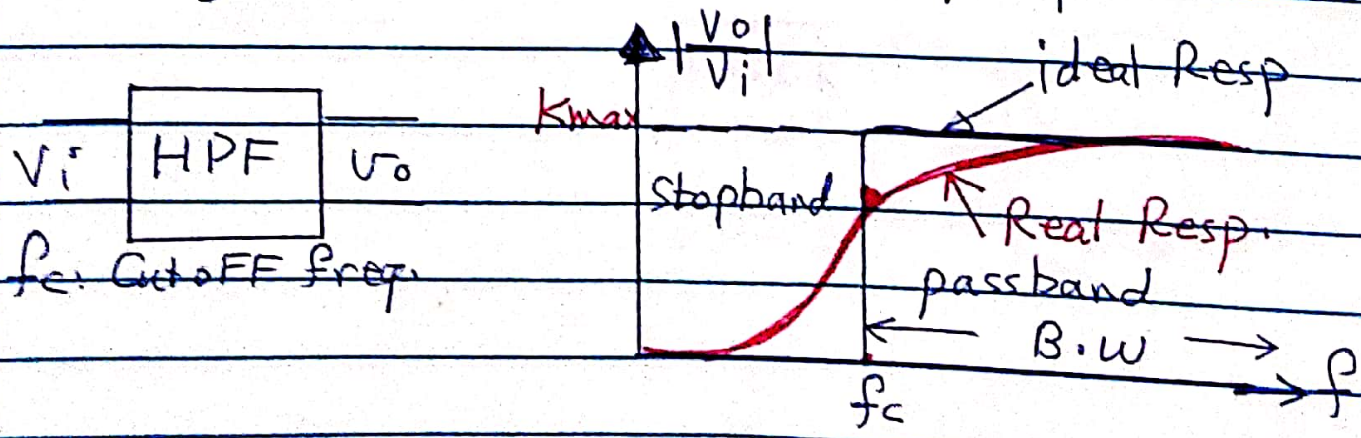
~~They are classified into:~~

1) Low pass Filter: (LPF): This type allows low freq. band to pass [its bandwidth extends from ($0 \rightarrow f_c$) where f_c is called CutoFF freq and rejects frequencies above f_c as show in its frequency Response



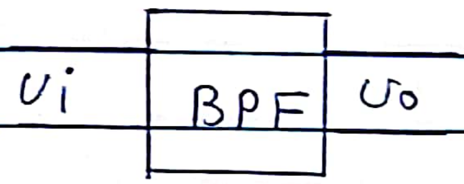
* For passive Filters, $K_{max} = 1$
* " Active " , $K_{max} > 1$
* f_c: CutoFF frequency: the frequency at which the value of $\left|\frac{V_o}{V_i}\right|$ drops to $0.707\,K_{max} = \frac{K_{max}}{\sqrt{2}}$

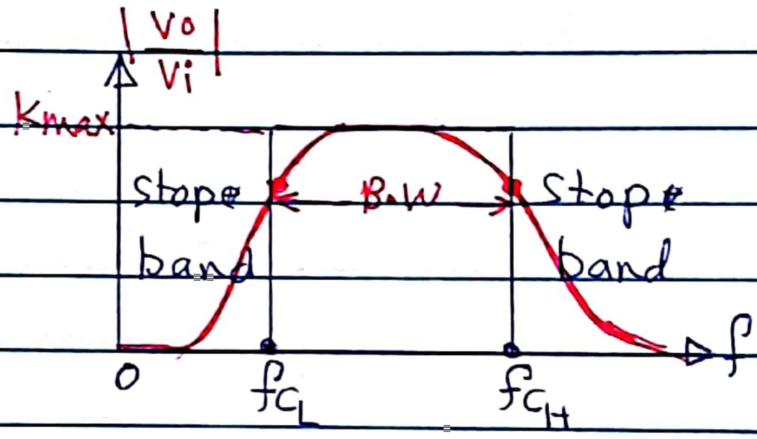
2) High-pass Filters (HPF): This type allows high freq. band to pass [its bandwidth extends from ($f_c \rightarrow \infty$) where f_c is called CutoFF freq.] and rejects other bands. its freq. Resp. is shown



3) Bandpass Filter (BPF)

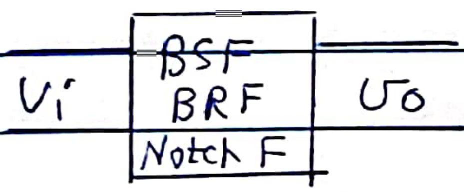
This type allows a certain band of freq to pass extending from (f_{c_L} → to f_{c_H}) over a bandwidth of $B.W = f_{cH} - f_{cL}$ where f_{cL} → low cutoff freq and f_{cH} → high cutoff freq. and reject frequencies band ($0 \to f_{c_L}$) and $f_{c_H} \to \infty$ as shown in the frequency Response shown.

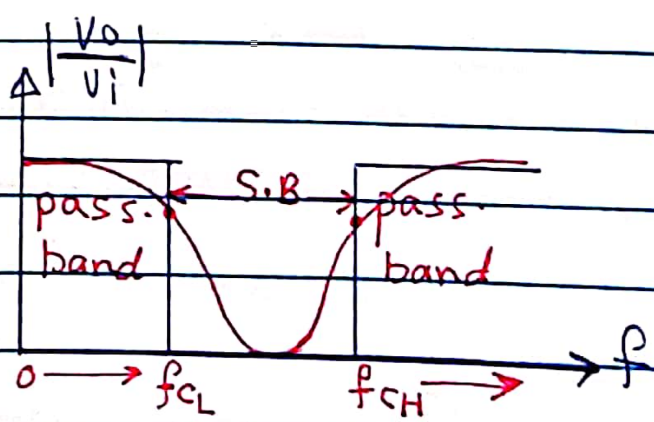




4) Bandstop or Bandreject Filter "BSF" or "BRF"

This type rejects a certain bands of frequency ($f_{c_L} \to f_{cH}$) and allows ($0 \to f_{c_L}$) and ($f_{cH} \to \infty$) over a bandwidth (from $0 \to f_{c_L}$ and $f_{c_H} \to \infty$)
This's also called "Notch Filter"





Filter Transfer function:

It represents the ratio of $\frac{V_o(s)}{V_i(s)} = H(s) = \frac{N(s)}{D(s)}$

Filter order: : The highest power of (S) in the denominator D(S), i.e D(S) indicate Filter order.

* If the highest power is (1) Such as $H(s) = \frac{5}{S+2}$ it is 1^{st} order.
* If the highest power is (2) Such that: $H(s) = \frac{5}{S^2+2S+1}$ it is 2^{nd} order.
* If the highest power is (3) Such that: $H(s) = \frac{4}{S^3+2S^2+0.5S+1}$ it is 3^{rd} order
* If it is: $H(s) = \frac{K}{S^n + S^{n-1} + S^{n-2} + \cdots + 1}$ it is n^{th} order

* N(S) indicate type of Filter:

1) If N(S) = Constant (Ko) → N(S) = 5 → LPF
2) " " $= K \cdot S$ → 4S → N(S) = 5S → BPF
3) " " $= K_1 S^2 + K_2$ → $N(S) = 2S^2+3$ → BSF
4) " " $= KS^2$ → $N(S) = 4S^2$ → HPF

EXA: Name type and order of the following T.F

1) $H(s) = \frac{2}{S+3}$ → 1^{st} order LPF
2) $H(s) = \frac{4S}{S^2+2S+1}$ → 2^{nd} order BPF
3) $H(s) = \frac{2S^2}{S^2+2S+1}$ → 2^{nd} order HPF
4) $H(s) = \frac{5S^2+3}{S^3+2S^2+S+1}$ → 3^{rd} order BSF

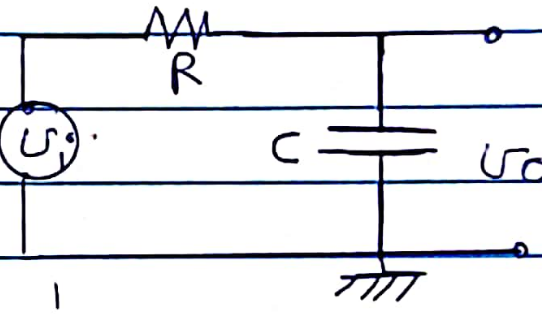
First Order Filters

~~These Filters have one (S) in the D(s) of the transfer function and Since each (S) represent Single Capacitor ($X_C = \frac{1}{j\omega C} = \frac{1}{SC}$). they Contain Single Capacitor~~

1) Passive Filter representation:

~~They are consisting of (R and C) and as follow:~~

a) Low-pass filter:

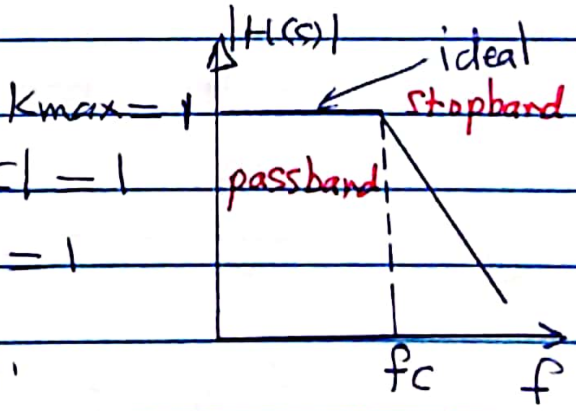


$$H(S) = \frac{V_o}{V_i} = \frac{\frac{1}{SC}}{\frac{1}{SC} + R}$$

$$H(s) = \frac{1}{1 + sRC} \rightarrow |H(s)| = \frac{1}{1 + |(\omega RC)|}$$

Compare to: $H(S) = \frac{K_{max}}{1 + |\omega RC|}$. to Find f_c, then

$$|H(s)| = \left|\frac{V_o}{V_i}\right| = \frac{K_{max}}{\sqrt{2}}.$$

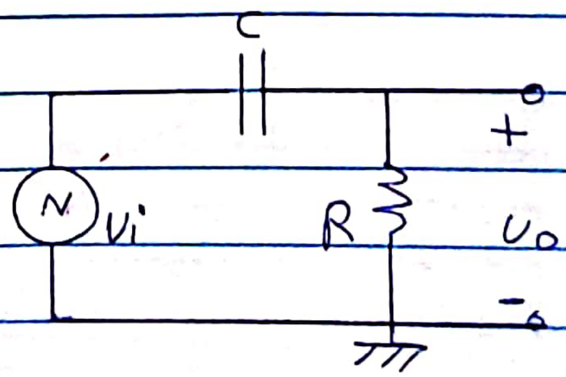


this will happen when, $|\omega RC| = 1$

$\therefore |\omega_c RC| = 1 \Longrightarrow |2\pi f_c RC| = 1$

$\therefore \boxed{f_c = \frac{1}{2\pi RC}}$ CutoFF freq.

b) high-pass filter:



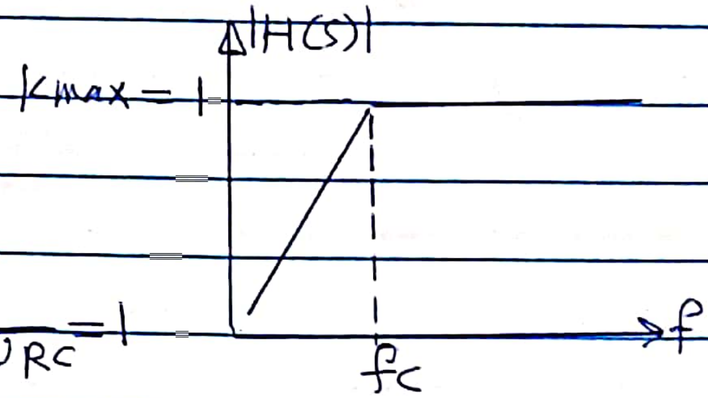
to obtain high-pass Filter Use $C \rightarrow R$ and $R \rightarrow C$ transformation the cct. is shown in Fig.

$$H(s) = \frac{V_o}{V_i} = \frac{R}{R + \frac{1}{SC}} = \frac{1}{1 + \frac{1}{SCR}} = \frac{1}{1 + \frac{1}{jwRC}}$$

$$H(s) = \frac{K_{max}}{1 + \frac{1}{jwRC}}$$

$$\left|\frac{V_o}{V_i}\right| = \frac{K_{max}}{1 + \left|\frac{1}{wRC}\right|}$$

$$\left|\frac{V_o}{V_i}\right| = \frac{K_{max}}{\sqrt{2}} \quad \text{when} \quad \frac{1}{wRC} = 1$$



i.e when $W = \frac{1}{RC} \Rightarrow W_c$

$\therefore f_c = \frac{1}{2\pi RC}$ (CutoFF freq).

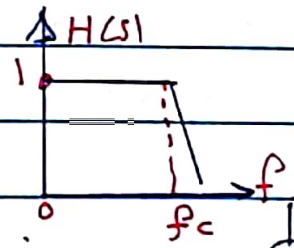
2) Active Filter Representation.

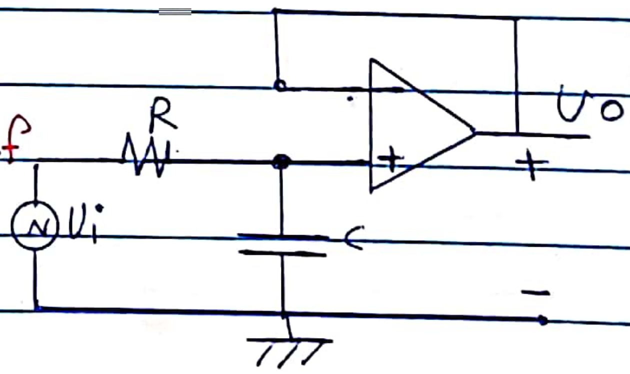
a) Low-pass Filter

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

and $K_{max} = 1$

because the cct. is Voltage follower with $A_V = 1$



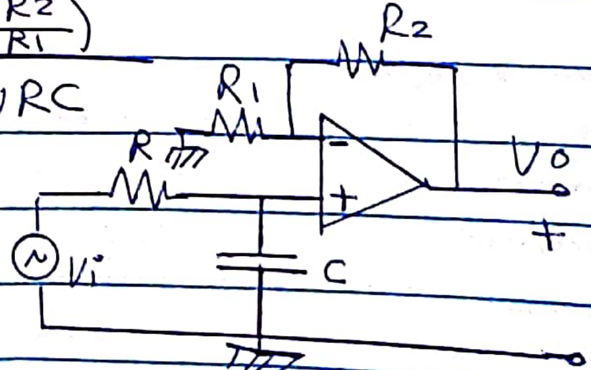


To have a gain, We Can use the op-Amp. as noninverting Amp. as shown

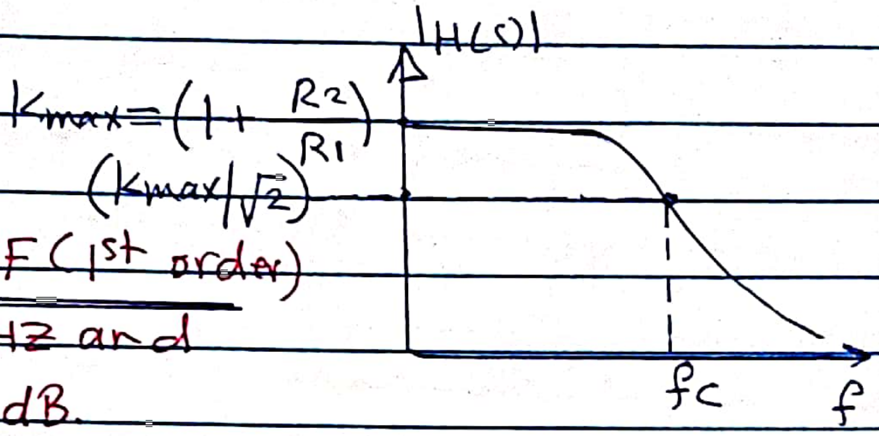
in this case $H(s) = \frac{(1 + \frac{R_2}{R_1})}{1 + jwRC}$

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

$$K_{max} = 1 + \frac{R_2}{R_1}$$



In this case the Response will be:



EXA: Design a LPF (1st order) to have $f_c = 2KHZ$ and a Max. gain = 20dB.
1) (Calculate R_1, R_2, R, C) 2) Sketch the Bode Plote.

$$f_c = \frac{1}{2\pi RC} = 2KHZ., \text{ choose } C = 0.1\mu F$$

$$\therefore R = \frac{1}{2\pi C f_c} = \frac{1}{2\pi \times 1 \times 10^{-7} \times 2 \times 10^{3}} = \frac{10^4}{4\pi}$$

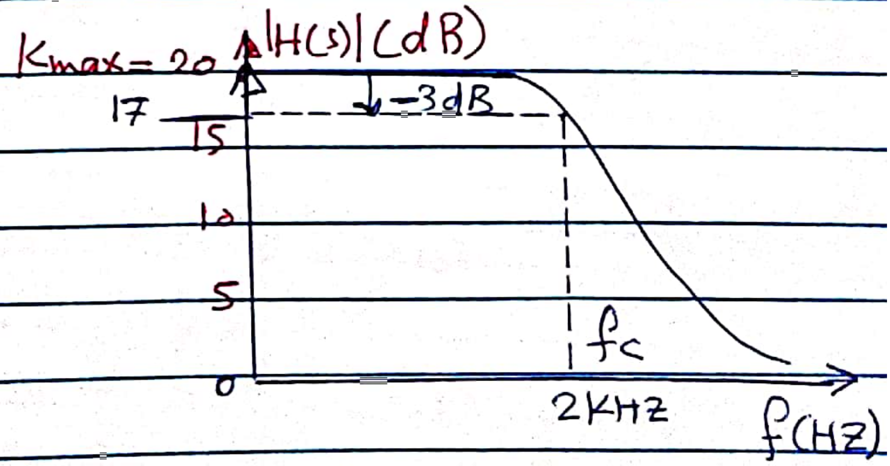
$$\therefore R = 795.8\,\Omega$$

$$K_{max} = 20dB = 20\log\left|\frac{V_o}{V_i}\right| \rightarrow \log\left|\frac{V_o}{V_i}\right| = \frac{20}{20} = 1$$

$$\therefore \left|\frac{V_o}{V_i}\right| = 10^{1} = 10 = 1 + \frac{R_2}{R_1} \rightarrow \frac{R_2}{R_1} = 9$$

$$\therefore R_2 = 9R_1 \Longrightarrow \text{let } R_1 = 1K\Omega$$

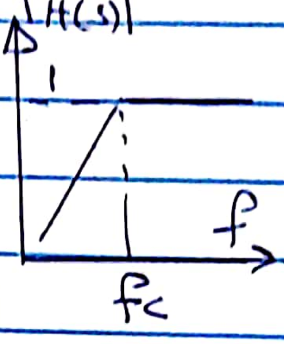
$$\therefore R_2 = 9K\Omega$$

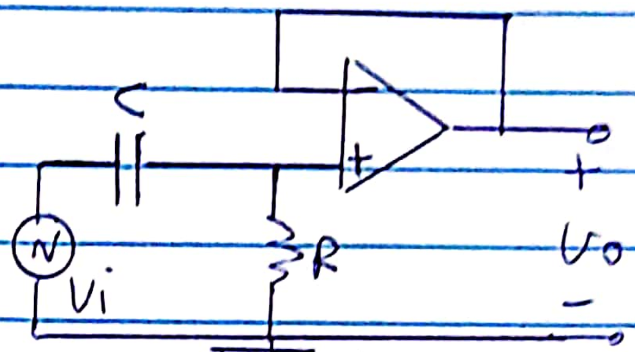


Bode Plote or "frequency Response"

b) High-pass filter:

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



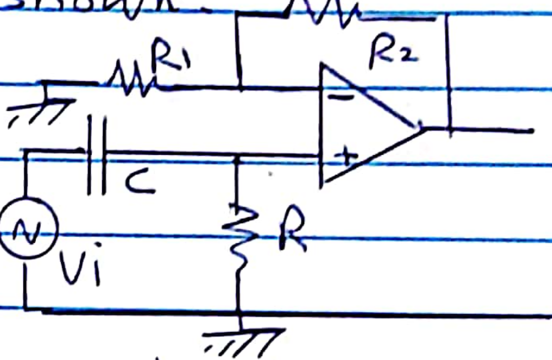


$K_{max} = 1$

Since $A_v = 1$

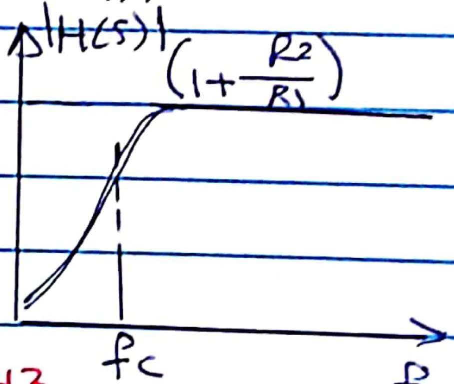
* To have a gain, we must use the Op-Amp as Noninverting Amp. as shown.

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



but the max gain will be $K_{max} = \left(1 + \frac{R_2}{R_1}\right)$

and the transfer function will be: $H(s) = \dfrac{\left(1+\frac{R_2}{R_1}\right)}{1 + \frac{1}{sRC}}$



EXA: Design a 1st order HPF to have $A_v = |H(s)| = 20$, $f_c = 5\,KHZ$.

Sol: $f_c = \frac{1}{2\pi RC} = 5\,KHZ$, let $C = 0.01\,\mu F$

$\therefore R = \frac{1}{2\pi C f_c} = \frac{1}{2\pi \times 10^{-8} \times 5 \times 10^{3}} = \frac{10^4}{\pi}$

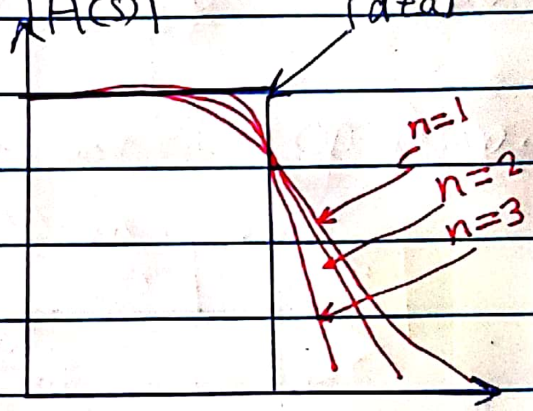
$\therefore R = 3.183\,KHZ$.

$|H(s)| = 20 = 1 + \frac{R_2}{R_1}$, $\frac{R_2}{R_1} = 19$

let $R_1 = 1\,K\Omega$ $\therefore R_2 = 19\,K\Omega$.

2nd Order Filters

These Filters have a sharper (Steep sided) response compared to 1st order. In general as Filter order increase, the response will be sharper. For example, look the response shown For a LPF with different order:



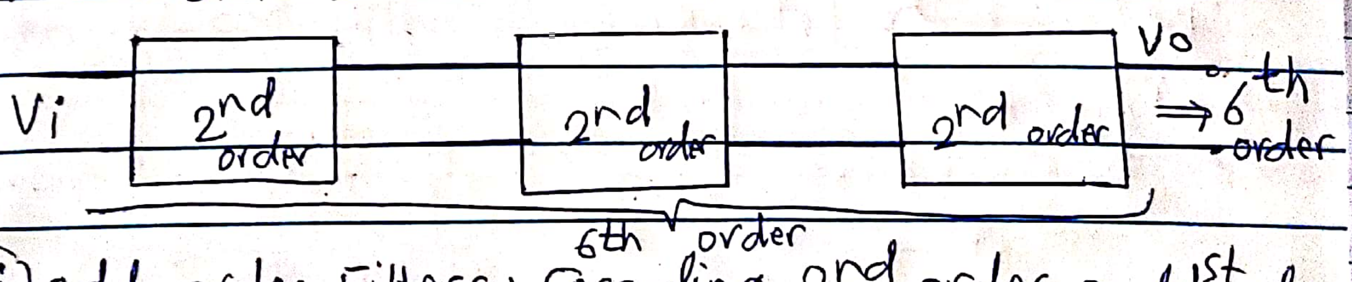
* As Filter order Increase the response will be closer to ideal response.

*n: Filter order.

* The basic building block is the 2nd order filter
* High-order Active filters can be obtained:

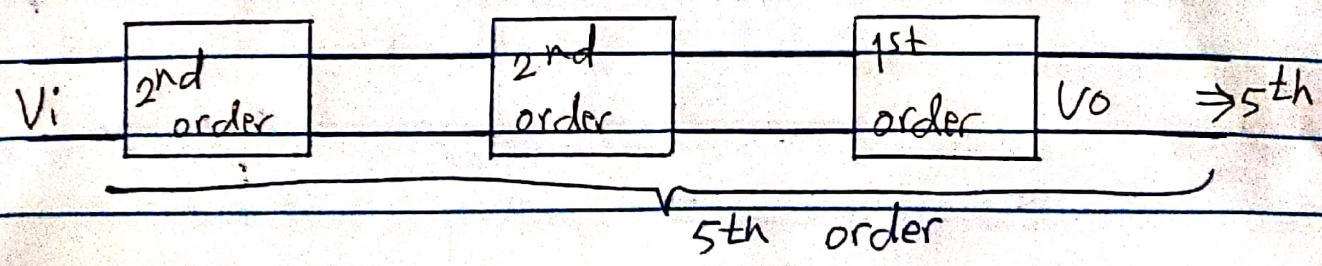
① by cascading 2nd order filters and 1st order Filters where:

(i) Even-order Filters: by cascading 2nd order only. For example 6th order, using three 2nd order filter in cascade:



(ii) odd order Filters: cascading 2nd order and 1st order

For EX: 5th order



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* In Cascading, We require many (Large No of) Op-Amp.

(2) Using different well-known configurations such as:

(i) Multiple-loop -ve F.B configuration: MLNFB.

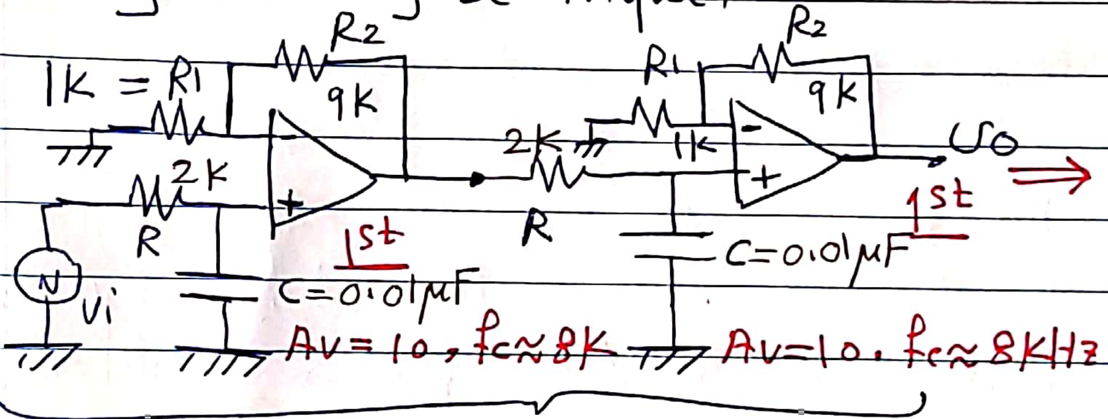
(ii) Follow the leader configuration: "FL"

(iii) Leap-Froge configuration.

* In this technique, we require less No of passive and Active elements.

* For example to realize 2nd order LPF with a certain gain:

: Using cascading technique.

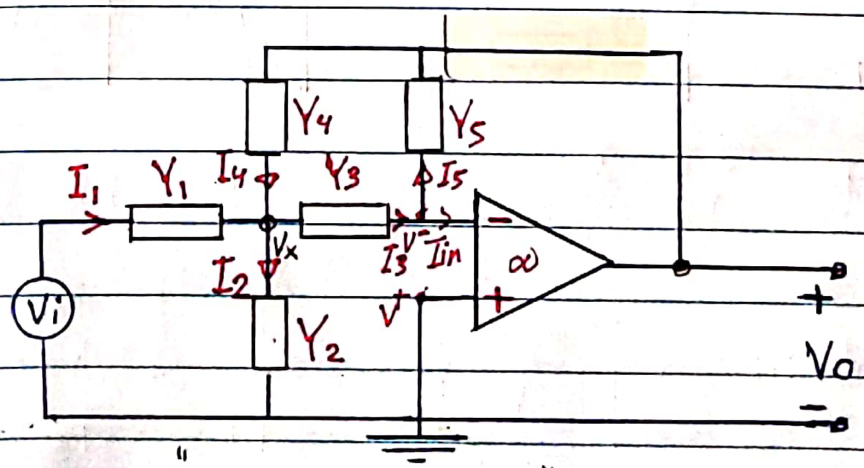


2nd order
$f_c \simeq 8KHz$
$A_v = 100$

* It is required to use: 2-op-Amp, 2 cap, 6 Resistors

2nd order using multiple-loop configuration

General 2nd Filter "Using MLNFB Configuration.



* This cct. can realize 2nd order LPF, HPF or BPF by the proper choice of the Components "Y"

"ideal Op-Amp" $A_o = \infty$, $I_{in} = 0$, $V^+ = V^- = 0$

We can derive an expression for the transfer function $H(s) = \frac{V_o}{V_i}$ by writting KCL at node ⓧ

$I_1 + I_4 = I_2 + I_3$

$(V_i - V_x)Y_1 + (V_o - V_x)Y_4 = V_x . Y_2 + (V_x - V^-)Y_3$ —— ①

at node ⊖ KCL yields:

$I_3 = I_{in} + I_5$ —— ② $\rightarrow Y_3(V_x - V^-) = I_{in} + (V^- - V_o)Y_5$

but $I_{in} = 0$, $V^- = V^+ = 0$ (ideal op-Amp).

$V_i Y_1 - V_x(Y_1 + Y_2 + Y_3 + Y_4) + V_o Y_4 = 0$ —— ①̄

$Y_3 V_x = -V_o Y_5$ —— ②̄

$\therefore V_x = \frac{-V_o Y_5}{Y_3}$ —— ③

Sub. ③ in ①̄ yields:

$V_i Y_1 + \left[\frac{Y_5}{Y_3}(Y_1 + Y_2 + Y_3 + Y_4) + Y_4\right] V_o = 0$

$V_o \left[Y_5(Y_1 + Y_2 + Y_3 + Y_4) + Y_4 Y_3\right] = -Y_1 Y_3 V_i$

$$\therefore \frac{V_o}{V_i} = H(s) = \frac{-\overset{G_1}{Y_1}\overset{G_3}{Y_3}}{\overset{SC}{Y_5}(\underset{G}{Y_1} + \underset{SC}{Y_2} + \underset{G}{Y_3} + \underset{G}{Y_4}) + \underset{G}{Y_3}\underset{G}{Y_4}} \quad ⓧ$$

① To realize 2nd order LPF $\left(H(s) = \frac{k}{S^2 + S + C}\right)$

we must choose Y_1 and $Y_3 \Rightarrow$ Resistance $\rightarrow G_1 \& G_3$

$Y_5 \rightarrow$ Capacitor $\Rightarrow C_5$, $Y_4 \rightarrow$ Resistor $\rightarrow G_4$

and $Y_2 \rightarrow$ Capacitor $\rightarrow C_2$, then, SC_2

$$H(s) = \frac{(-G_1 G_3)}{\underbrace{S^2 C_5 C_2}_{S^2} + \underbrace{S C_5 (G_1 + G_3 + G_4)}_{S} + \underbrace{G_3 G_4}_{C}} \quad ④$$

To make the above in the form $H(s) = \frac{K_o}{S^2 + KS + K}$

Divide numarator $N(S)$ and denominator $D(S)$ by C_2C_5 and Sub: $G=\frac{1}{R}$

$$H(S) = \frac{\left(-\frac{1}{R_1R_3C_2C_5}\right)}{S^2+S\frac{1}{C_2}\left(\frac{1}{R_1}+\frac{1}{R_3}+\frac{1}{R_4}\right)+\frac{1}{R_3R_4C_2C_5}} \quad (5)$$

Compare the above eqn. with Standered 2nd order system equation:

$$H(s) = \frac{S^2+\frac{\omega_{oz}}{Q_z}+\omega_{oz}^2}{S^2+\frac{\omega_{op}}{Q_p}+\omega_{op}^2}$$

where ω_{oz} and Q_z → Frequency and quality factor of zero.

ω_{op} and Q_p → freq. and quality factor of poles.

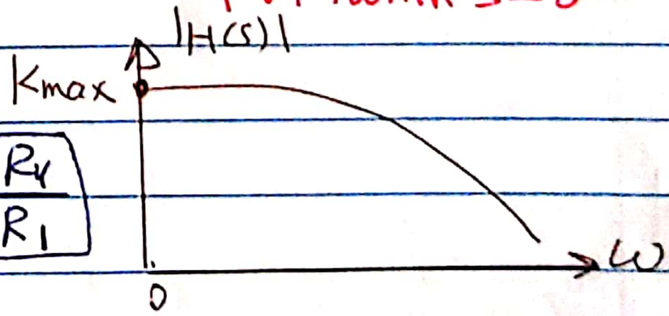
consider eqn. (5) it is 2nd order LPF with cutoff frequency:

$$\omega_c=\omega_o=\frac{1}{\sqrt{R_3R_4C_2C_5}}$$ cutoff freq.

* To Find Max. gain: $K_{max}=\left|\frac{V_o}{V_i}\right|$ when $s=0$

So when we Subst. $S=0$ in eqn. (5)

$$|H(s)| = \frac{\cancel{R_3}R_4\cancel{C_2C_5}}{R_1\cancel{R_3}\cancel{C_2C_5}} = \boxed{\frac{R_4}{R_1}}$$

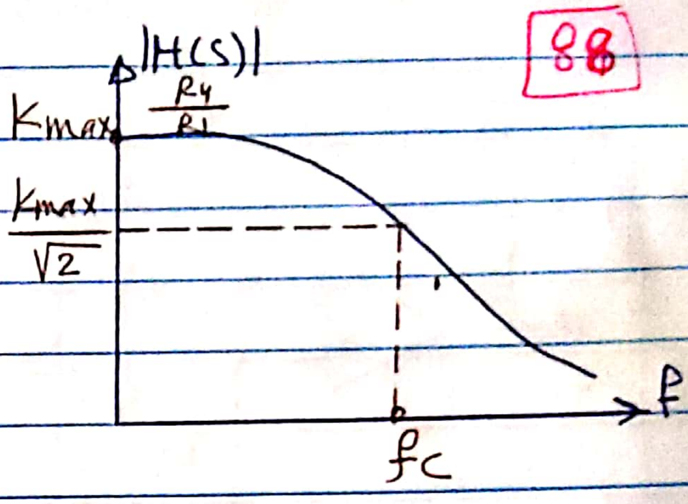


∴ This 2nd order LPF has: $f_c=\frac{1}{2\pi\sqrt{R_3R_4C_2C_5}}$, $K_{max}=\frac{R_4}{R_1}$

For equal cap. design, $C_2=C_5=C$

$$f_c = \frac{1}{2\pi C\sqrt{R_3 R_4}}.$$

and its response is shown in Fig.



Notice the Max. gain is $\frac{R_4}{R_1}$.

EXA: Design a 2nd order LPF with a Max. gain = 40 dB and CutoFF freq = 2 KHz.

$K_{max} = 40\,dB = 20\log\frac{V_o}{V_i} \Rightarrow \log\frac{V_o}{V_i} = 2$

$\therefore \left|\frac{V_o}{V_i}\right| = 10^2 = 100 = K_{max}$

$K_{max} = \frac{R_4}{R_1}$, assume $R_1 = 2\,K\Omega$, $R_4 = 50\,K\Omega$

$\therefore R_1 = 2\,K\Omega$, $R_4 = 50\,K\Omega$

* Assume equal Cap. design and choose $C_2 = C_5 = C$

choose $C = 0.01\,\mu F$.

From f_c expression: $R_3 R_4 = \frac{1}{4\pi^2 C^2 f_c^2}$

$\therefore R_3 R_4 = \frac{1}{4\times(3.14)^2\times10^{-16}\times4\times10^{6}} = \frac{1}{4\times10\times10^{-16}\times4\times10^{6}}$

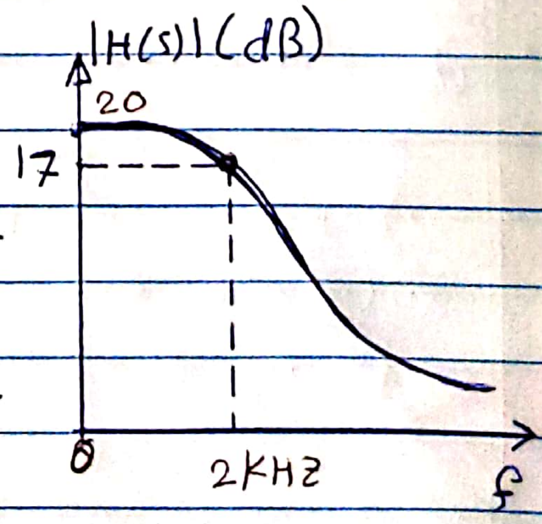
$\therefore R_3 R_4 = \frac{10^9}{16} = 62.5\times10^{6}\,\Omega$

but $R_4 = 50\,K\Omega$

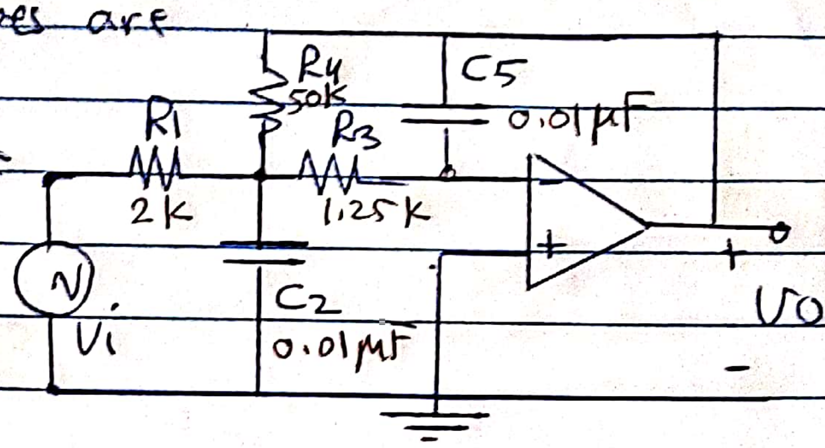
$\therefore R_3 = \frac{62.5\times10^{6}}{5\times10^{4}} = 1.25\,K\Omega$

$\therefore R_1 = 2\,K\Omega$, $R_4 = 50\,K\Omega$

$R_3 = 1.25\,K\Omega$, $C_2 = C_5 = 0.01\,\mu F$



all Resistor Values are in KΩ range which is desirable For design.



(2) Realization of HPF

This Filter can be obtained by C→R and R→C transformation OR looking at eqn. ④ and choose the components Y such that the H(s) will have a Form $H(s) = \frac{s^2}{s^2 + s + c}$

Which means Y_1 & Y_3 must be Capacitors to give sC_1, sC_3 → $s^2C_1C_3$, Y_4 → Capacitor sC_4, Y_2 and Y_5 → Resistors → G_2 and G_5

then:

$$H(s) = \frac{-s^2C_1C_3}{s^2C_3C_4 + G_5(C_1+C_3+C_4)s + G_5G_2}$$

$$= \frac{-(C_1/C_4)s^2}{s^2 + \frac{G_5(C_1+C_3+C_4)s}{C_3C_4} + \frac{G_5G_2}{C_3C_4}} \quad (6)$$

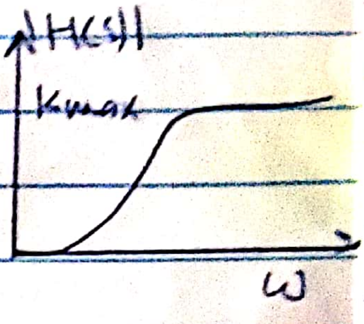
Compare to standered 2^{nd} order system eqn.

$$H(s) = \frac{s^2 + (\omega_{oz}/Q_z)s + \omega_{oz}^2}{s^2 + \frac{\omega_{op}}{Q_p}s + \omega_{op}^2}$$

$\therefore \omega_o^2 = \frac{1}{R_5R_2C_3C_4} \longrightarrow f_c = \frac{1}{2\pi\sqrt{C_3C_4R_2R_5}}$

$K_{max} = \left|\frac{V_o}{V_i}\right|_{s=\infty}$, divide $N(S)$ & $D(S)$ by S^2

then subs. $S=\infty$, will result in:



$$|H(S)| = K_{max} = \frac{C_1}{C_4}$$

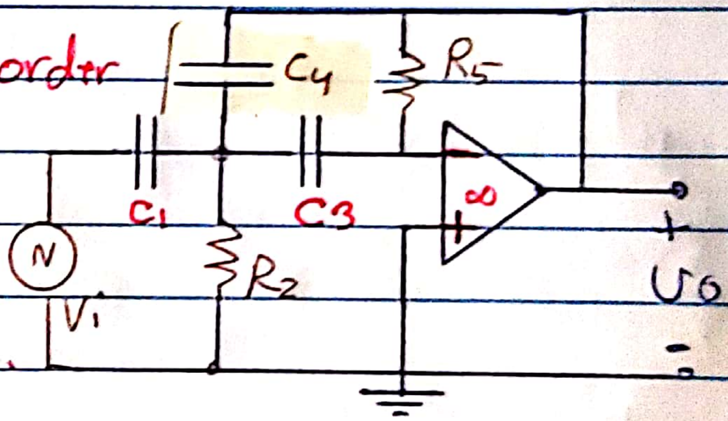
∴ For this 2^{nd} order HPF:

$$f_c = \frac{1}{2\pi\sqrt{R_2R_5C_3C_4}} \quad \text{(CutoFF freq)}$$

and Max. gain $K_{max} = \frac{C_1}{C_4}$

and the cct. is

EXA2: Design a 2^{nd} order HPF to have:
$f_c = 20KHZ$, and
a Max. gain $K_{max} = 10$.
- Sketch freq. Response.



Since $K_{max} = C_1/C_4 = 10$

∴ $C_1 = 10C_4$, let $C_4 = 0.1\,\mu F$

∴ $C_1 = 10 \times 0.1 = 1\,\mu F$.

$f_c = 1/2\pi\sqrt{R_2R_5C_3C_4}$ ⇒ For equal Resistors design $R_2 = R_5 = R$

$$f_c = \frac{1}{2\pi R\sqrt{C_3C_4}}, \text{ let } R = 1K\Omega = R_2 = R_5 = 1K$$

$$C_3C_4 = \frac{1}{4\pi^2R^2f^2} \Rightarrow C_3 = \frac{1}{4\pi^2R^2f_c^2C_4}$$

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but $C_4 = 0.1\mu F$

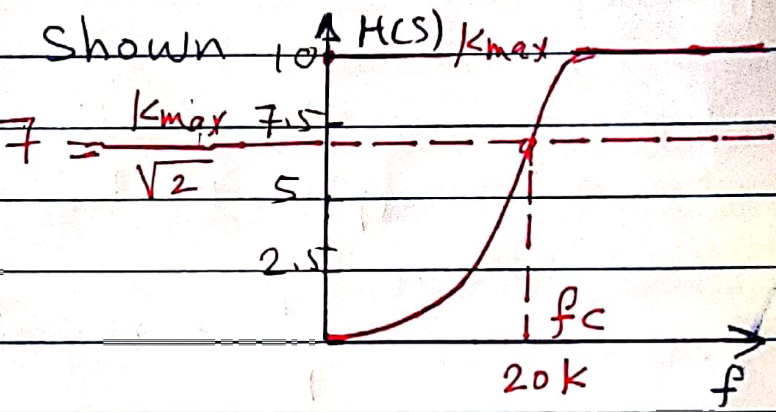
$$C_3 = \frac{1}{4\times10\times(10^3)^2\times(2\times10^4)^2\times10^{-7}} = \frac{10^{-8}}{16} = 0.625\,nF$$

So the designed Components Values:

$R_2 = R_5 = 1k\Omega$

$C_1 = 1\mu F$, $C_4 = 0.1\mu F$, $C_3 = 0.625\,nF$

and the response is shown in Fig.



3 Realization of 2nd order BPF

Consider equation ⓧ, to realize BPF, it must have ~~a~~ transfer function of the form $H(s) = \frac{S}{S^2+S+C}$

So we have to choose Y_1 and Y_2 of different type such that $Y_1 Y_3 \Rightarrow$ Contain S

either $Y_1 \to G_1$ & $Y_3 \to SC_3$ OR $Y_1 \to SC_1$ & $Y_3 \to G_3$

let $Y_1 \to G_1$, $Y_3 \to SC_3$, So $Y_5 \to G_5$, $Y_2 \to G_2$ and $Y_4 \to G_4$: this choise will result in:

$$H(s) = \frac{-G_1 C_3 S}{C_3 C_4 S^2 + G_5(C_3+C_4)S + G_5(G_1+G_2)}$$

Divide $N(S)$ & $D(S)$ by C_3C_4 will result in:

$$H(S) = \frac{(-G_1/C_4)\,S}{S^2 + G_5\left(\frac{C_3+C_4}{C_3C_4}\right)S + G_5\frac{(G_1+G_2)}{C_3C_4}} \qquad (7)$$

Compare eqn. ⑦ with standered 2^{nd} order System eqn:

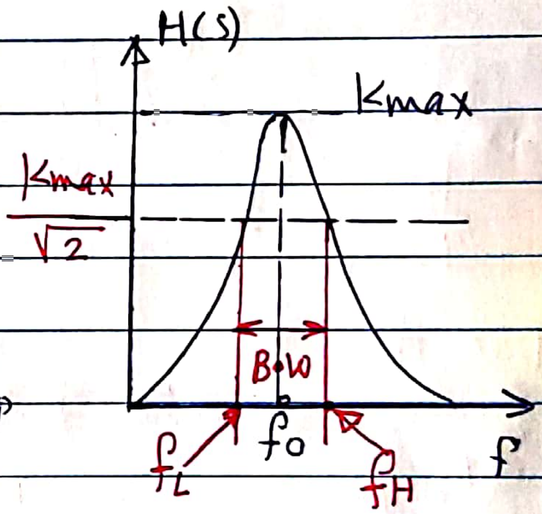
$$H(s) = \frac{s^2 + \frac{\omega_{oz}}{Q_z} s + \omega_{oz}^2}{s^2 + \frac{\omega_{op}}{Q_p} s + \omega_{op}^2}$$

The center freq ω_{op} is: $\omega_o = \frac{1}{\sqrt{C_3 C_4 R_5 R_{eq}}}$

where $R_{eq} = R_1 // R_2$.

Using equal-cap. design $C_3 = C_4 = C$

$$\therefore f_o = \frac{1}{2\pi C \sqrt{R_5 R_{eq}}}$$



The Max. Gain Kmax, can be derived as

$$K_{max} = \left| \frac{V_o}{V_i} \right|_{s=\omega_o=\omega}$$

From eqn. ⑦ s^2 will cancel ω_{op}^2

$$|H(s)| = [G_1/C_4] \Big/ \frac{C_3+C_4}{C_3 C_4} G_5$$

$$|H(s)| = \frac{G_1}{\cancel{C_4}} \times \frac{C_3 \cancel{C_4}}{G_5(G_4+G_3)} = \boxed{\frac{G_1 C_3}{G_5(C_3+C_4)}} \text{ passband gain}$$

For equal cap design $C_3 = C_4 = C$

$$\therefore \text{Max. gain} = \frac{R_5 \cdot C}{R_1 \; 2C} = \boxed{\frac{R_5}{2R_1}}$$

the selectivity $Q = \frac{f_o}{B.W}$ can be derived as follow:

From eqn. ⑦ $$\frac{\omega_{op}}{Q_p} = \frac{G_5(C_3+C_4)}{C_3 C_4} = \frac{2G_5 \cdot C}{C}$$

$$\boxed{B.W = \frac{2}{R_5 C}}$$

Using the idea: $Q = \frac{Q}{\omega_0} \cdot \omega_0$

where $\omega_0 = \frac{1}{C\sqrt{R_5 R_{eq}}}$ ~~and~~ OR $\omega_0 = \sqrt{\frac{G_5(G_1+G_2)}{C_3 C_4}}$

and $\frac{\omega_0}{Q} = \frac{G_5(C_3+C_4)}{C_3 C_4}$

∴ $Q = \frac{C_3 C_4}{G_5(C_3+C_4)} \cdot \sqrt{\frac{G_5(G_1+G_2)}{C_3 C_4}}$

For $C_3 = C_4 = C \rightarrow \boxed{Q = \frac{1}{2}\sqrt{\frac{G_1+G_2}{G_5}}} = \boxed{\frac{1}{2}\sqrt{\frac{R_5}{R_{eq}}}}$

$\left(R_{eq} = \frac{R_1 \cdot R_2}{R_1+R_2}\right)$

∴ For BPF realization:

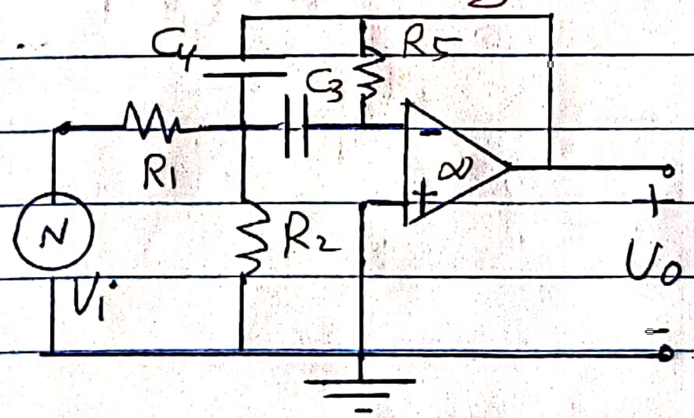
(1) $f_o = \frac{1}{2\pi C\sqrt{R_5 R_{eq}}}$ center freq.

(2) $\frac{\omega_0}{Q} = \frac{2}{R_5 \cdot C}$

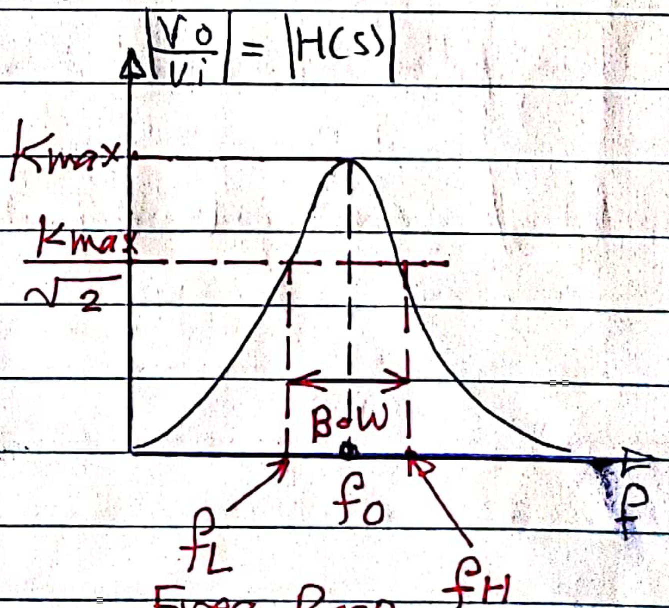
(3) Max. gain = passband gain $K_{max} = \frac{R_5}{2R_1}$

(4) Selectivity $Q = \frac{1}{2}\sqrt{\frac{R_5}{R_{eq}}}$

and the circuit is as shown in Fig.



cct- diagram



Freq. Resp.

EXA: Design a 2^{nd} order BPF Filter to have a passband gain $= 10$. Center freq $= 20KHZ$ and Selectivity $Q = 10$. Sketch the freq. Response. "The available cap. is $1nF$". $\boxed{94}$

From eqn: $\frac{\omega_o}{Q} = \frac{2}{R_5 \cdot C} \rightarrow R_5 = \frac{2Q}{\omega_o \cdot C} = \frac{2 \times 10}{2\pi \times 2 \times 10^4 C}$

$$R_5 = \frac{2 \times 10}{2\pi \times 2 \times 10^4 \times 10^{-9}} = \frac{2 \times 10}{4\pi \times 10^{-5}} = 159.155 K\Omega$$

$$K_{max} = \frac{R_5}{2R_1} \Rightarrow R_1 = \frac{R_5}{2K_{max}} = \frac{159.155}{2 \times 10}$$

$$R_1 = 7.957 K\Omega$$

$$f_o = \frac{1}{2\pi C\sqrt{R_5 R_{eq}}} \Rightarrow R_{eq} = R_1 // R_2 = \frac{1}{4\pi^2 C^2 R_5}$$

OR From Q expn. $Q = \frac{1}{2}\sqrt{\frac{R_5}{R_{eq}}}$

$$R_{eq} = \frac{R_5}{4Q^2} = \frac{159.155}{4 \times 100} = 0.397 K\Omega = \frac{R_1 R_2}{R_1 + R_2}$$

$$\therefore R_2 = \frac{R_1 \cdot R_{eq}}{R_1 - R_{eq}} = \frac{7.957 \times 0.397}{7.957 - 0.397} = 0.412 K\Omega$$

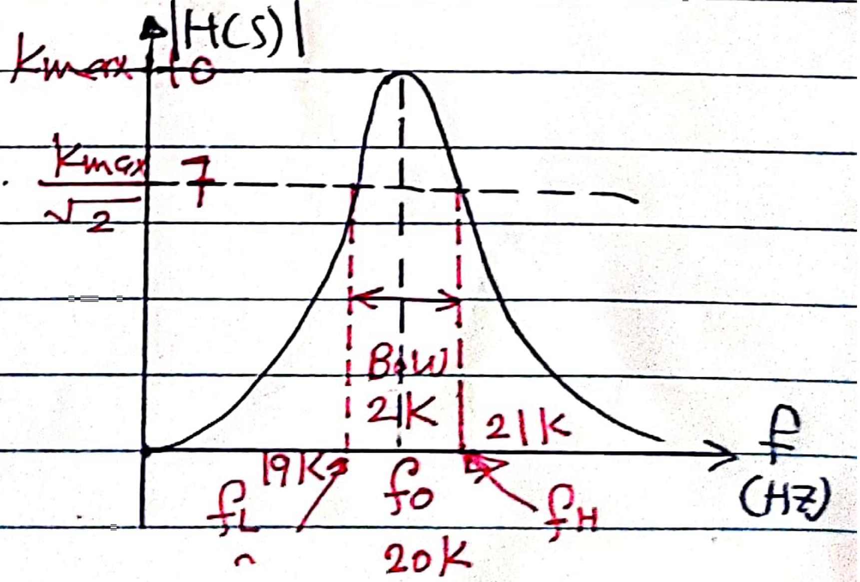
$B.W = \frac{f_o}{Q} = \frac{20}{10} = 2 KHz$

$f_L = f_o - \frac{B.W}{2}$

$= 20 - \frac{2}{2} = 19 KHZ$

$f_H = f_o + \frac{B.W}{2}$

$= 20 + \frac{(2)}{2} = 21 KHZ$



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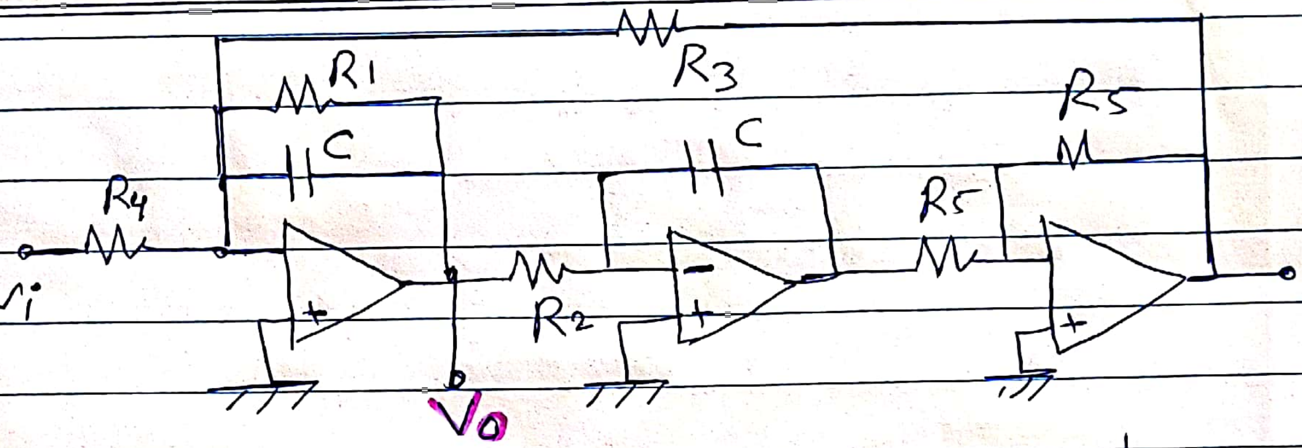
Tow-Thomas Biquad "BP/LP" 2nd order Filter



The transfer function $H(s) = \frac{V_o}{V_i} = \frac{-\frac{1}{CR_4}S}{S^2 + \frac{1}{R_1C}S + \frac{1}{R_2R_3C^2}}$

So it is a 2nd order BP Filter for the output indicated.

For $R_2 = R_3 = R$, then: $H(s) = \frac{-\frac{1}{R_4C}S}{S^2 + \frac{1S}{R_1C} + \frac{1}{R^2C^2}}$

compare to standered 2nd order system eqn.

$D(s) = S^2 + \frac{\omega_o}{Q}S + \omega_o^2$

$\therefore \omega_o = \frac{1}{RC} \Rightarrow f_o = \frac{1}{2\pi CR}$

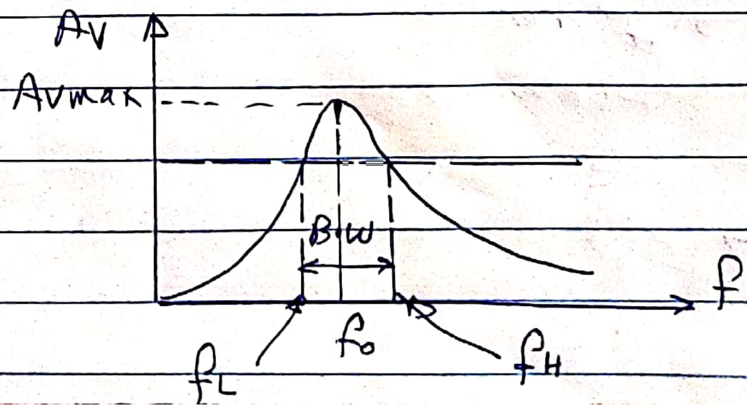
Max. gain $|A_{V(max)}| = |H(s)|_{s=\omega_o} = \frac{1}{R_4C} \times \frac{R_1C}{1}$

$\therefore |A_{V(max)}| = \frac{R_1}{R_4}$

$Q = \frac{Q}{\omega_o} \times \omega_o = \frac{R_1C}{1} \times \frac{1}{RC} = \frac{R_1}{R}$

$f_H = f_o + \frac{B.W}{2}$

$f_L = f_o - \frac{B.W}{2}$



EXA: Design a 2nd order BPF to have $f_0 = 10KHZ$, $Q = 50$ and $A_{V(max)} = 100$ sketch freq. Response. (use $C = 0.01\mu F$).

$$f_0 = \frac{1}{2\pi RC} \Rightarrow R = \frac{1}{2\pi f_0 C} = \frac{1}{2\pi \times 10^4 \times 10^{-8}}$$

$$\therefore R = \frac{10^4}{2\pi} = 1.592K\Omega = R_2 = R_3$$

$$Q = \frac{R_1}{R} \longrightarrow R_1 = Q.R = 50 \times 1.592 = 79.577K$$

$$A_{V(max)} = \frac{R_1}{R_4} \longrightarrow R_4 = \frac{R_1}{A_{V(max)}} = \frac{79.577K}{100}$$

$$\therefore R_4 = 0.79577K\Omega.$$

$$BW = \frac{f_0}{Q} = 0.2KHZ$$

$$f_L = f_0 - \frac{BW}{2} = 9.9KHZ$$

$$f_H = f_0 + \frac{BW}{2} = 10.1KHZ$$