Analog

15 July 2017

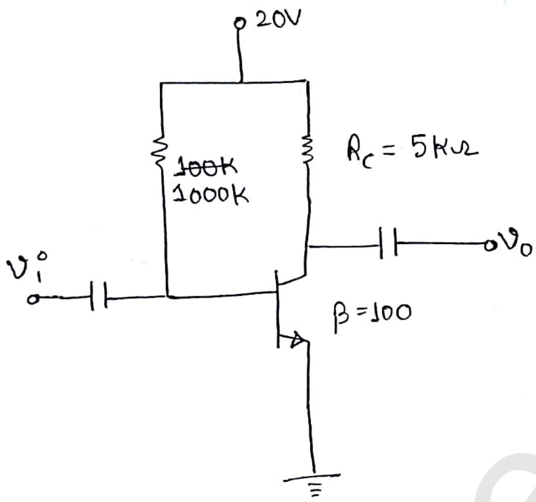
Amplifier

Amplifier = Amplitude + Magnifier

Xmer is not amplifier bcz i/p power = o/p power

Q

Do DC analysis



$-20 + 1000 I_B + V_{BE} = 0$

$I_B = 19.3\ \mu A$

$I_B \simeq 20\mu A$

$I_C = 2mA$

$V_{CE} = 20 - 5\times 2$

$= 10$

$$\boxed{\begin{aligned} V_{BE} &= 0.7 = 700mV \\ I_B &= 20\mu A \\ I_C &= 2mA \\ V_{CE} &= 10V \end{aligned}}$$

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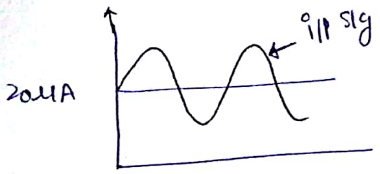
what is small s/g and large s/g.



इ = 1μA Sinωt

if i/p s/g 1μA
2μA
3μA
then called

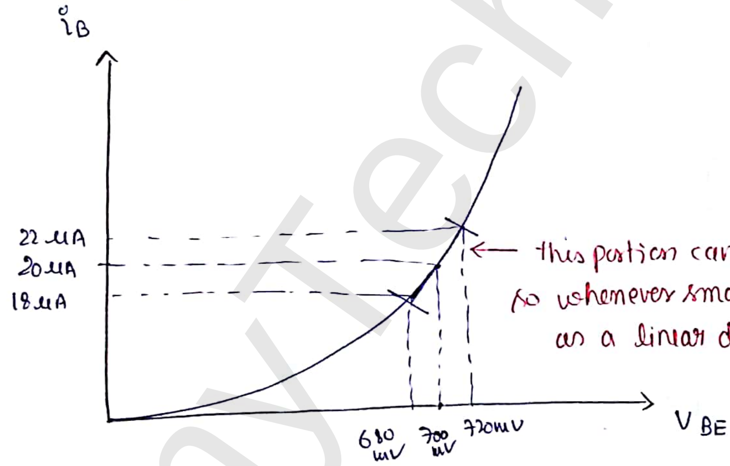
<u>Small s/g.</u>

if i/p s/g is comparable to 20μA
then called <u>large s/g.</u>

Small s/g Analysis के लिए linear char' assume करते हैं (Benefit)

Let $V_i = 20mV \sin\omega t$

give rise to the sinusoidal Base (ac current) of 2 μA



this portion can be used as linear.
so whenever small s/g tx. can be used as a linear device.

Let us assume that ~~change in~~ due to change in V_{BE}, change in i_B is

$\Delta i_B = \pm 2 \mu A$

so change in i_C

$\Delta i_C = \beta \Delta i_B = 100 \times \pm 2 \mu A$

$= \pm 0.2 mA$

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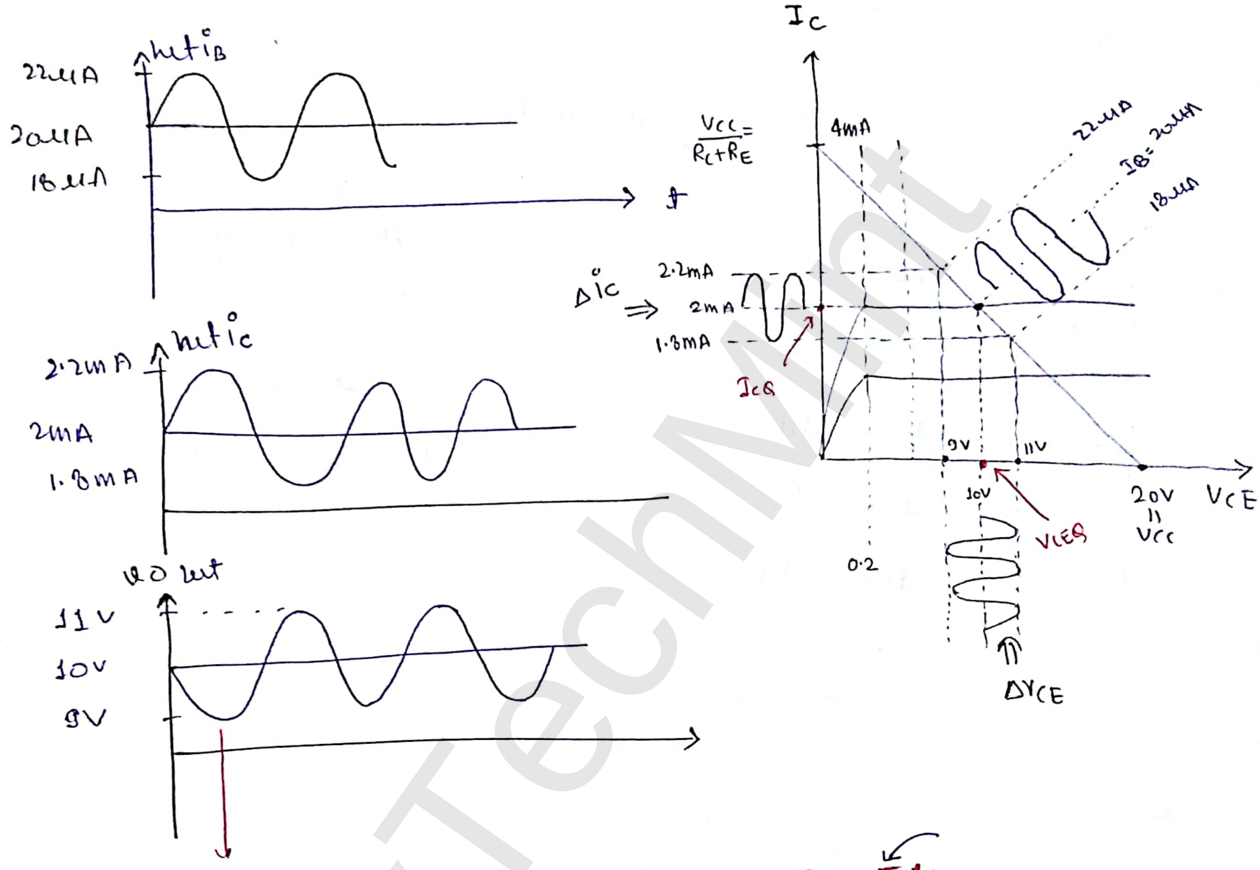
$$v_o = v_{ce} = V_{cc} - i_c R_c$$

$$\Delta v_o = 0 - \Delta i_c R_c$$ greater the R_c, greater the gain so for higher gain, R_c should be high.

$$\Delta v_o = -(\pm 0.2m) \times 5k$$

$$\Delta v_o = \mp 1V$$



CE में 180° का phase shift due to above $\Delta v_o = \mp 1V$

but the o/p will ~~be~~ don't contain dc. it will contain pure a c of ~~one~~ 1 volt variation.

" we applied i/p voltage of 20mV sinωt and o/p we are getting is of 1V sinωt

$$\frac{1000\,mV}{20\,mV} = 50 \text{ times}$$

o/p is of 50 times greater than i/p. "

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Analysis of small signal amplifier

In the analysis of small sig Amplifier transistor behave as a ~~non~~-linear element and it is replaced with an equivalent ckt known as equivalent model ckt.

Small Signal Model

- Low Frequency (LF) and Medium Frequency (MF) models
  - h parameter model
  - π parameter model
  - T- parameter Model
- High Frequency (HF) Models
  - HF- π model
  - HF- T model

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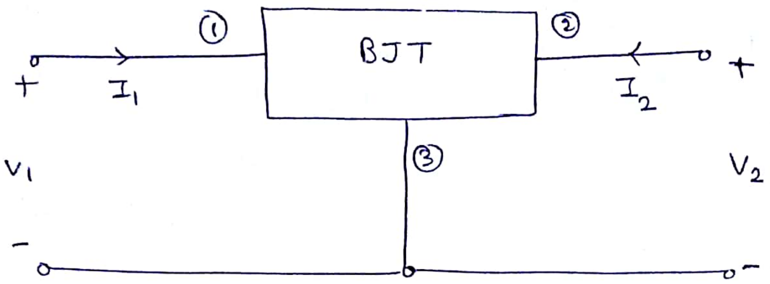
Hybrid - Parameter model



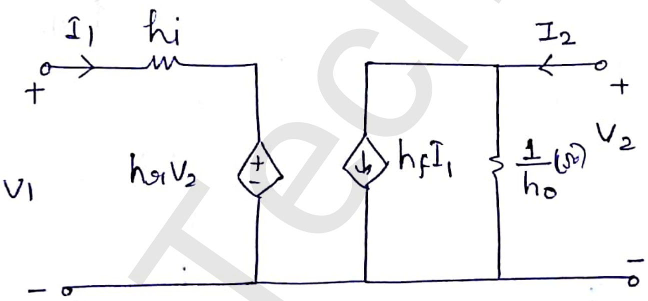
$V_1 = h_{11} I_1 + h_{12} V_2$

$I_2 = h_{21} I_1 + h_{22} V_2$

$V_1 = h_i I_1 + h_r V_2$

$I_2 = h_f I_1 + h_o V_2$

Conversion formulae:



I. Common collector parameter in terms of common Emitter parameter

$h_{fc} = -(1 + h_{fe})$

$h_{ic} = h_{ie}$

$h_{oc} = h_{oe}$

$h_{rc} = 1 - h_{re} \simeq 1$

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II. CB parameter in terms of CE parameter

$$h_{fb} = \frac{-h_{fe}}{1+h_{fe}}$$ (once asked in Object)

$$h_{ob} = \frac{h_{oe}}{1+h_{fe}}$$

$$h_{ib} = \frac{h_{ie}}{1+h_{fe}}$$

$$h_{rb} = \frac{h_{ie}h_{oe}}{1+h_{fe}} - h_{re}$$

this is neglected

h_{ie} h_{re}

$1.1\,k\Omega$ 2.5×10^{-4}

unit less

h_{fe} h_{oe}

50    $24\,\mu S$

this is neglected

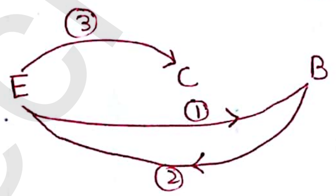
Standard CE parameter.

$h_{fe} = 50$

$h_{ie} = 1.1\,k\Omega$

$h_{oe} = 24\,\mu\mho$

$h_{re} = 2.5 \times 10^{-4}$



CE to CB	CB to CE	CE to CC
$h_{ib} = \frac{h_{ie}}{1+h_{fe}}$	$h_{ie} = \frac{h_{ib}}{1+h_{fb}}$	$h_{ic} = h_{ie}$
$h_{rb} = \frac{h_{ie}h_{oe}}{1+h_{fe}} - h_{re}$	$h_{re} = \frac{h_{ib}h_{ob}}{1+h_{fb}} - h_{rb}$	$h_{rc} \simeq 1$
$h_{fb} = \frac{-h_{fe}}{1+h_{fe}}$	$h_{fe} = \frac{-h_{fb}}{1+h_{fb}}$	$h_{fc} = -(1+h_{fe})$
$h_{ob} = \frac{h_{oe}}{1+h_{fe}}$	$h_{oe} = \frac{h_{ob}}{1+h_{fb}}$	$h_{oc} \approx h_{oe}$

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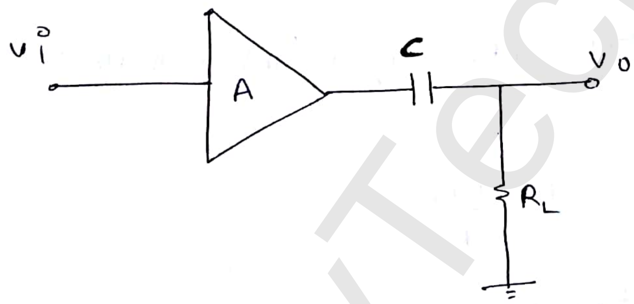
Medium Frequency Ac Analysis

Procedure to Analyse ampr ckt

Step ① Identify the BJT config in the ckt.

② Convert the given ckt into medium freq ac equivalent ckt by replacing large capacitances (C_E C_B C_C) by short ckt and small capacitances (C_{sh}, C_μ, C_π) by open ckt. and de activate all the dc sources. (dc batteries should be grounded and dc current source should be open ckt)

③ Using appropriate model calculate the desired values.



RC coupled amplifier means
- Load is resistive
- capac is used for connecting load to ampr.

We will use a general ckt (Self Bias BJT ckt to bias BJT in active region) to explain all above

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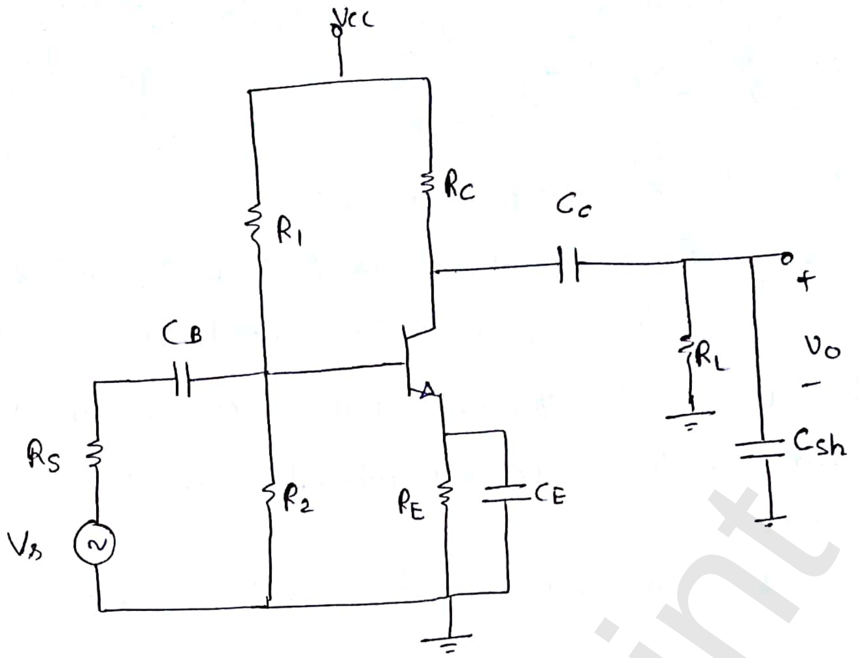

- Self bias ckt is used to operate BJT in active region and to maintain I_C stable

  can't remove R_E bcz $S = 1 + \frac{R_{th}}{R_E}$

  if $R_E = 0$ $S = \infty$ unstable

- Bypass cap^c C_E prevents decrease in voltage gain.

- Blocking cap^c C_B and coupling cap^c C_c provides dc isolation to the biasing ckt, so that no dc current flows out of the ckt and no dc current enters the biasing ckt from outside.

- C_B C_C and C_E are large capacitances {in μF range} bcz they should act as short ckt for ac signal

  $X_C = \frac{1}{\omega C \uparrow} \approx 0$

- C_{sh} (shunt capa^c) is connected to control bandwidth of amp^r. it is a small capacitance of (pF range) and act as open ckt for dc sig.

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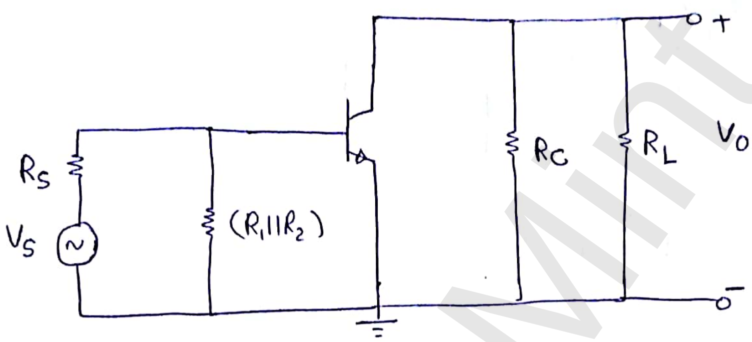
- In ac analysis dc supply (V_{cc}) will be disabled or replaced with short ckt.

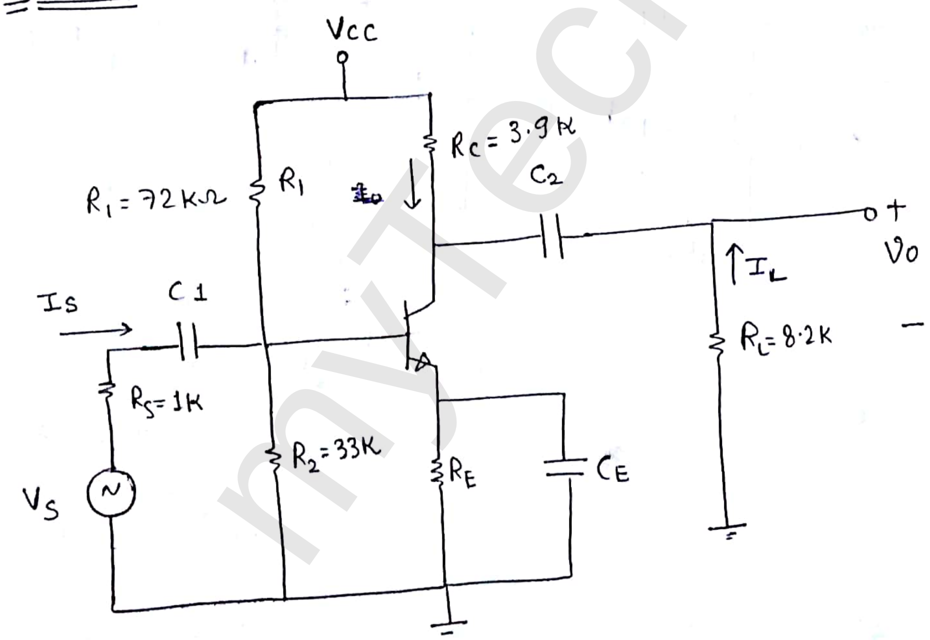
MF Ac equivalent ckt

medium freq^{c}

If we have to do ac analysis by default we do MF ac analysis.



<u>Question</u>



In the amp^{r} ckt shown Tx has $h_{fe} = 75$, $h_{ie} = 2.5k$, $h_{re} = 2\times10^{-4}$, $h_{oe} = 20\mu$℧

Calculate voltage gain $\left\{\frac{V_o}{V_S}\right\}$, current gain $\left(\frac{I_o}{I_S}\right)$, i/p and o/p resistances.

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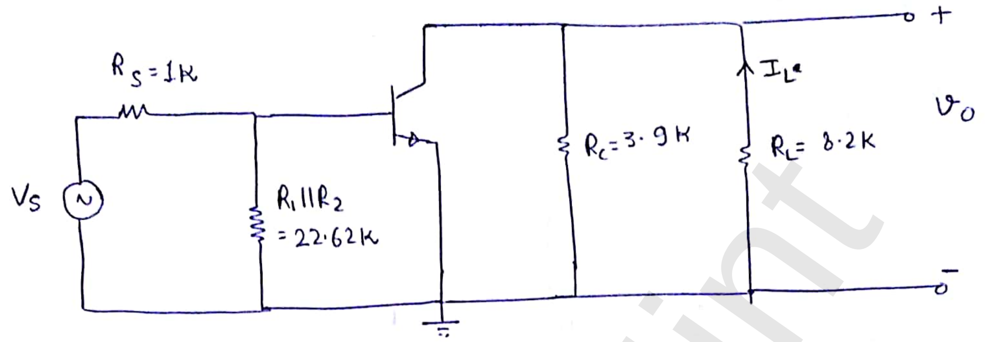
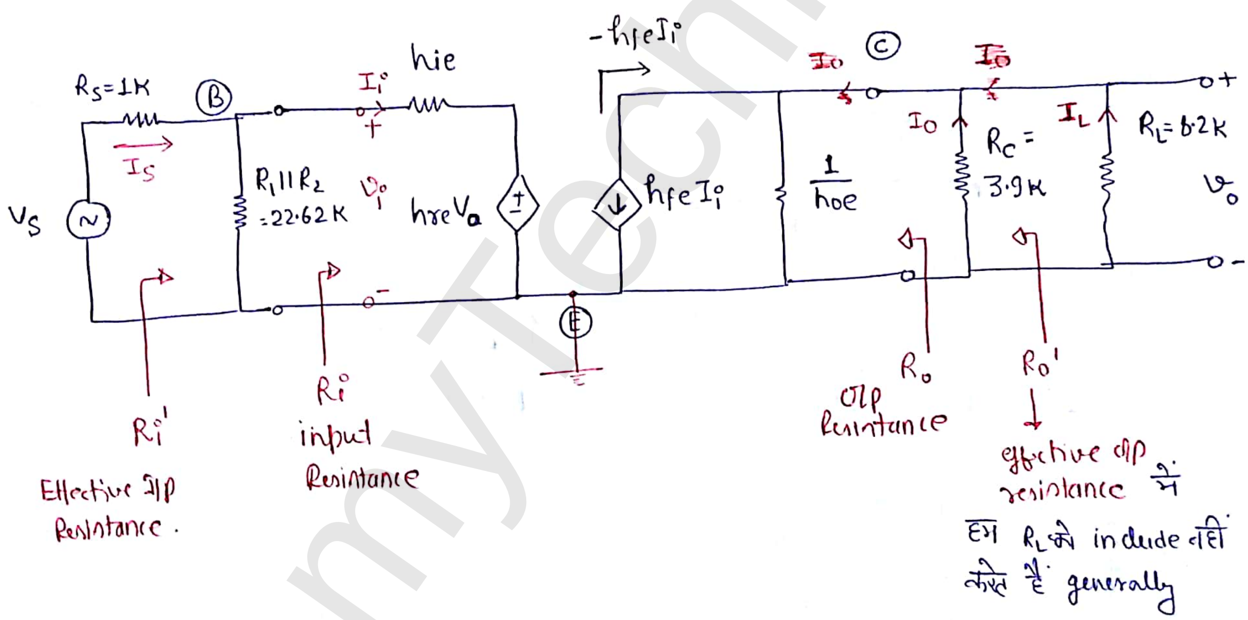
Solution :- First Identify BJT config.

Draw AC equivalent ckt



Replace BJT with its model



Don't remember formula

current gain

$$A_I = \frac{I_L}{I_i}$$

we will use current division rule

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$$I_L = \frac{\left(R_c \parallel \frac{1}{h_{oe}}\right)}{\left(R_c \parallel \frac{1}{h_{oe}}\right) + R_L} (h_{fe} I_i) = \frac{(3.9 \parallel 50)}{(3.9 \parallel 50) + 8.2} \times h_{fe}$$

$$= \frac{3.62}{3.62 + 8.2} \times 75 = 22.92$$

$$\frac{I_L}{I_i} = A_I = \left(\frac{R_c \parallel \frac{1}{h_{oe}}}{R_c \parallel \frac{1}{h_{oe}} + R_L} \right) h_{fe} = \cancel{24.39} =$$

② Input Resistance

$$R_i = \frac{V_i}{I_i}$$

KVL in loop ①

$$V_i = h_{ie} I_i + h_{re} V_o$$

$$V_i = h_{ie} I_i + h_{re}(-I_L R_L)$$

$$V_i = h_{ie} I_i - h_{re} R_L I_L$$

$$\frac{V_i}{I_i} = h_{ie} - h_{re} R_L \cdot \frac{I_L}{I_i}$$

$$\boxed{R_i = h_{ie} - h_{re} R_L \cdot A_I}$$

$$= 2.5K - 2 \times 10^{-4} \times 8.2K \times \cancel{24.39}\ 22.92$$

$$R_i = 2.46K$$

③ voltage gain

$$A_V = \frac{V_o}{V_i} = \frac{-I_L R_L}{V_i} = -\frac{A_I I_i R_L}{V_i} = \frac{-A_I R_L}{R_i}$$

$$A_V = -\frac{\cancel{24.39}\ 22.92 \times 8.2}{2.46} = \cancel{-81.3}\ -76.4$$

-ve sign shows 180° phase shift

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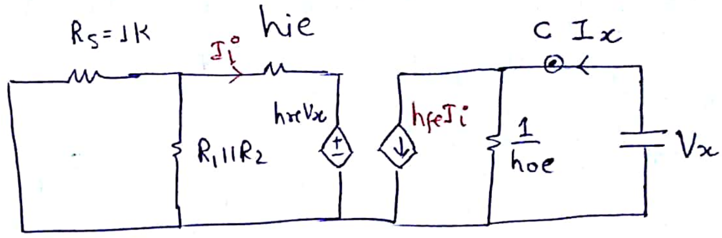
4. o/p resistance (R_o)

KCL :

$$I_x = h_{fe} I_i + \frac{V_x}{1/h_{oe}}$$

$$I_x = h_{fe} I_i + V_x h_{oe} \quad \text{--- (1)}$$



KVL in i/p loop

$$R_s' I_i + h_{ie} I_i + h_{re} V_x = 0$$

$$I_i = \frac{-h_{re} V_x}{R_s' + h_{ie}}$$

$$R_s' = R_s \| R_1 \| R_2$$
$$= 1 \| 22.62$$
$$= 0.96$$

putting above value in eq^n (1)

$$I_x = h_{fe}\left(\frac{-h_{re}V_x}{R_s' + h_{ie}}\right) + h_{oe}V_x$$

$$\boxed{\frac{I_x}{V_x} = \frac{1}{R_o} = Y_o = h_{oe} - \frac{h_{fe}h_{re}}{R_s' + h_{ie}}}$$

$$Y_o = 20\times10^{-6} - \frac{75\times 2\times10^{-4}}{(2.5+0.96)\times10^{3}}$$

$$Y_o = 1.566\times10^{-5}$$

$$R_o = 63.837\ K\Omega$$

5. R_i'

$$R_i' = R_i \| R_2 \| R_1 = 2.22K$$
$$= 2.46 \| 22.62$$

6. R_o'

$$R_o' = R_o \| R_C$$
$$= 63.837 \| 3.9 = 3.675K$$

अगर सिर्फ के i/p and o/p resistance पूछा है तो R_i^* and R_o^* find करना है

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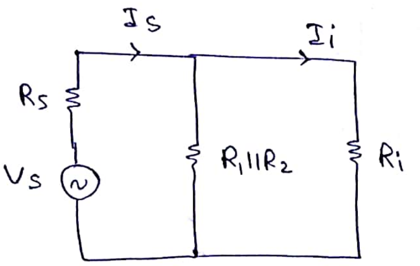
7. Current gain ($A_{IS} = \frac{I_L}{I_S}$)

$$A_{IS} = \frac{I_L}{I_S} = \frac{I_L}{I_i} \cdot \frac{I_i}{I_S}$$

$$\boxed{A_{IS} = A_I \cdot \frac{I_i}{I_S}}$$



$$I_i = \frac{R_1 \| R_2}{R_1 \| R_2 + R_i} I_S$$

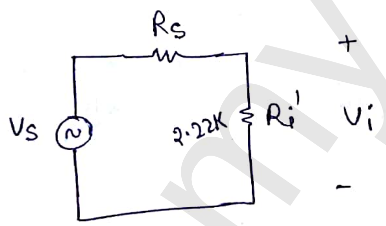
$$\boxed{A_{IS} = A_I \cdot \frac{R_1 \| R_2}{(R_1 \| R_2) + R_i}} = \frac{22.92 \times 22.62}{22.62 + 2.46} = 20.67$$

8. voltage gain

$$A_{VS} = \frac{V_o}{V_S} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_S}$$

$R_i' = 2.22K$

$$A_{VS} = A_V \cdot \frac{V_i}{V_S}$$



$$V_i = \frac{R_i'}{R_i' + R_S} \cdot V_S$$

$$\Rightarrow \frac{V_i}{V_S} = \frac{R_i'}{R_i' + R_S} = \frac{2.229}{2.22 + 1} = 0.689$$

$$\boxed{A_{VS} = A_V \cdot \frac{R_i'}{R_i' + R_S}}$$

$A_{VS} = -76.4 \times 0.689$

$= -52.67$

overall gain is less than only BJT gain.

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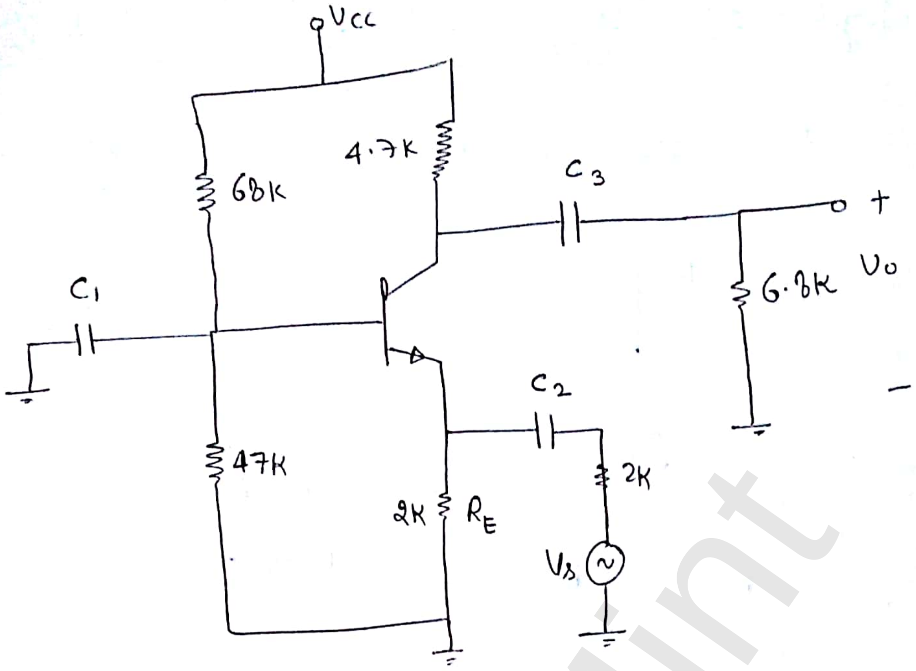
Solution



In the ckt shown above $h_{fe} = 50$ $h_{ie} = 1.2K$, $h_{re} = 2.5 \times 10^{-4}$ $h_{oe} = 24 \mu ℧$

cal^c voltage gain i/p and o/p resistance

Sol^n Common Base

$$h_{fb} = -\frac{h_{fe}}{1+h_{fe}} = \frac{-50}{1+50} = -0.98$$

$$h_{ib} = \frac{h_{ie}}{1+h_{fe}} = \frac{1.2}{51} = 23.52 \ \Omega$$

$$h_{rb} = \frac{1.2 \times 10^{3} \times 24 \times 10^{-6}}{1+50} - 2.5 \times 10^{-4} = 3.24 \times 10^{-4}$$

$$h_{ob} = \frac{24 \times 10^{-6}}{51} = 0.47 \ \mu S$$

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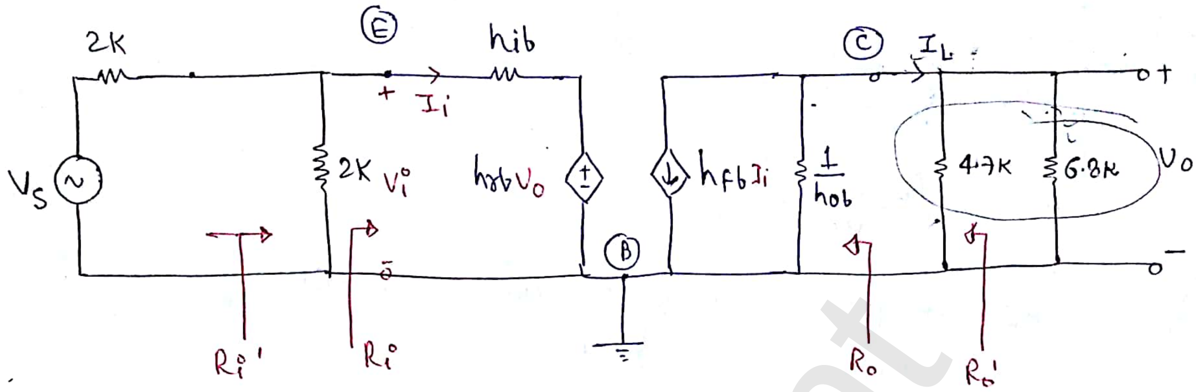
Ac equivalent

Ask? why i am not taking the load current, the current across 6.8 k



$R_L' = 4.7 \parallel 6.8$

$= 2.78\ k$

1. Current gain

$$A_I = \frac{I_L}{I_i}$$

KCL:

$$I_L = \frac{\frac{1}{hob}}{\frac{1}{hob} + R_L'}(-h_{fb}I_i)$$

$V_o = I_L R_L'$

$V_o = I_L R_L$

$$\frac{I_L}{I_i} = \frac{\frac{1}{0.47 \times 10^{-6}}}{\frac{1}{0.47\times10^{-6}} + 2.78}(-(-0.98)) \cong 0.98$$

2. Input resistance

$$R_i = \frac{V_i}{I_i}$$

KVL:

$$V_i = h_{ib}I_i + h_{rb}V_o$$

$$= h_{ib}I_i + h_{rb}(I_L R_L')$$

$$\boxed{R_i' = \frac{V_i}{I_i} = h_{ib} + h_{rb}A_I R_L'} = \cancel{23.4\ \Omega} = 24.4\ \Omega$$

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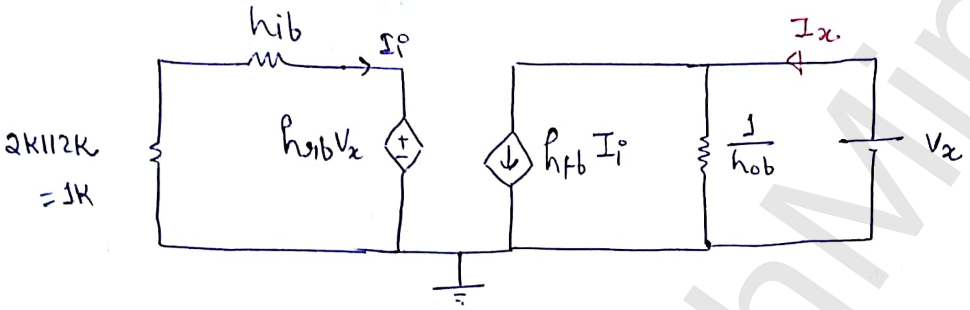
voltage gain $\left(A_V = \frac{V_0}{V_i}\right)$

$$A_V = \frac{V_0}{V_i} = \frac{I_L R_L'}{V_i}$$

$$A_V = \frac{A_I\, I_i\, R_L'}{V_i}$$

$$A_V = \frac{A_I\, R_L'}{R_i} = \frac{0.98 \times 2.78 \times 10^{3}}{24.4\,\Omega} = 111.66$$

output resistance



$$I_x = h_{fb} I_i + V_x h_{ob} \longrightarrow ①$$

KVL in i/p loop

$$1K\, I_i + h_{ib} I_i + h_{rb} V_x = 0$$

$$I_i = \frac{-V_x h_{rb}}{h_{ib} + 1K}$$

$$I_x = h_{fb}\left(\frac{-V_x \cdot h_{rb}}{h_{ib} + 1K}\right) + h_{ob} V_x$$

$$\boxed{\frac{1}{R_0} = \frac{I_x}{V_x} = h_{ob} - \frac{h_{fb} h_{rb}}{h_{ib} + 1K}}$$

$$\overbrace{0.47 \times 10^{-6} - \frac{(-0.98)(3.74 \times 10^{-4})}{23.52 + 1000}}^{78 \times 10^{-6}}$$

$R_0 = 1281.68\ K\Omega$

(very high)

$= 1.28\ M\Omega$

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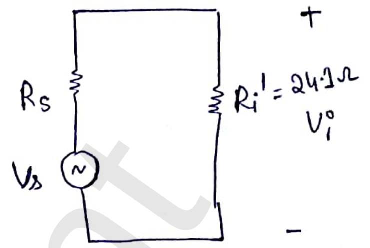
$R_i' = R_i \| 2k = 24.4\Omega \| 2000 = 24.1\Omega$

$R_o' = R_o \| R_C = R_o \| 4.7k\Omega$

$= 1.2M\Omega \| 4.7K \approx 4.7K\Omega$

\# voltage gain

$$A_{VS} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = A_V \cdot \frac{V_i}{V_s}$$



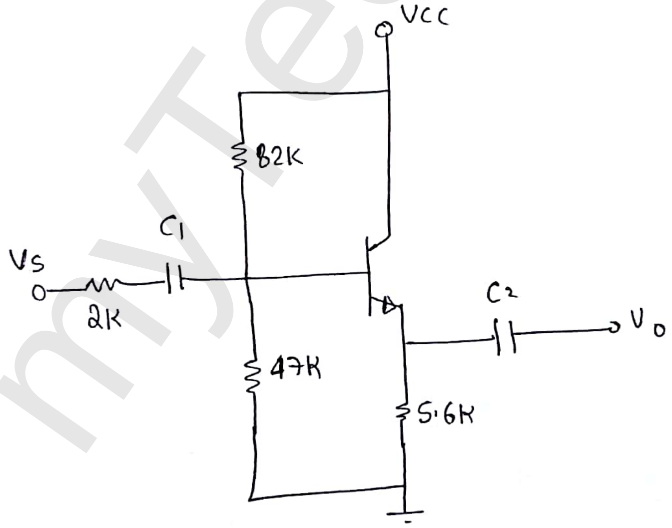
$$\boxed{A_{VS} = A_V \cdot \frac{R_i'}{R_i' + R_s}}$$

$$= 111.6 \times \frac{24.1}{24.1 + 1000}$$

$$\frac{V_i}{V_s} = \frac{R_i'}{R_i' + R_s}$$

$$\boxed{A_{VS} = 1.328}$$

Q In the ckt shown below BJT has $h_{fe} = 50$ $h_{ie} = 1.5K$ $h_{re} = 2 \times 10^{-4}$ $h_{oe} = 22\ \mu S$ cal^c voltage gain i/p and o/p resistance.



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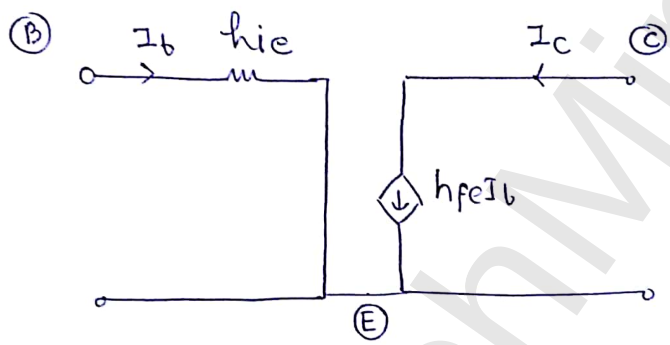
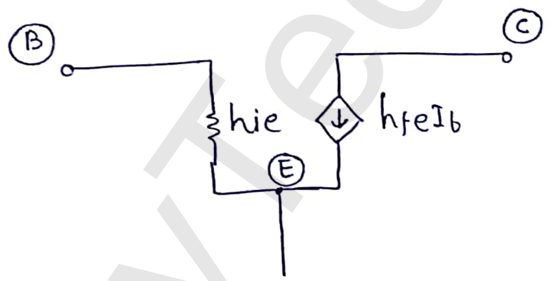
H parameter are configuration based For different config CE, CB, CC we need conversion formulae ~~and different ckt~~. so we use approximate h parameter - Here we have just two parameters.

Approximate H - parameter of BJT Amplifier.

$h_{re} \simeq 0$

$h_{oe} \approx 0$





Now whatever configuration either CE, CC, CB we will just replace BJT by this and don't bother about hfc or hic. values will not be exact i.e answers

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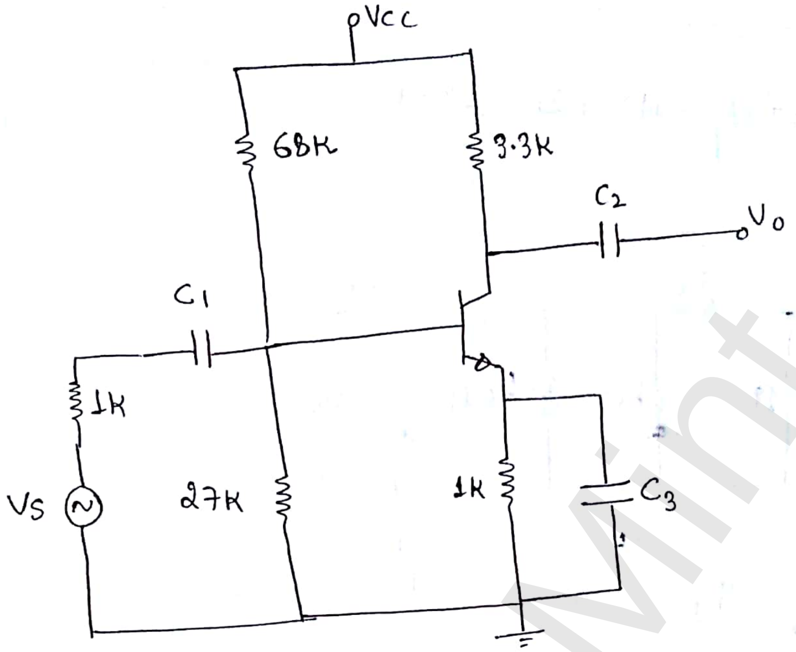
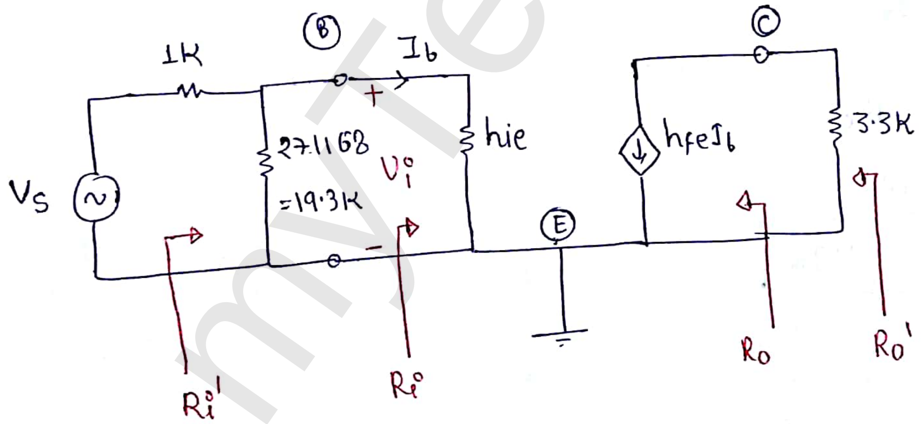
Q In the amp^r ckt shown below Tx. has $h_{fe} = 60$, $h_{ie} =$ ~~20K~~ 2KΩ calc voltage gain $\frac{V_o}{V_s}$, i/p and o/p resistance.



Soln. CE config.

approximation



$V_o = -h_{fe} I_b \times 3.3k$ —— (1)

$V_i = h_{ie} I_b$ —— (2)

$R_i = \frac{V_i}{I_b} \approx h_{ie}$

If we are given hfe and hie means use approximate ckt. if we are given hfe, hie and hoe then also use approximate ckt but add $\frac{1}{h_{oe}}$ Resistance.

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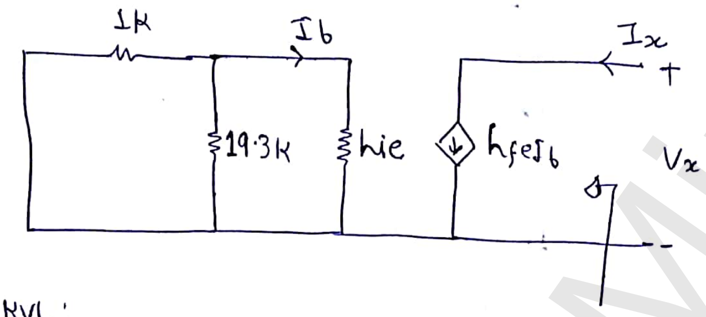
Voltage gain

$$\boxed{A_V = \frac{V_o}{V_i} = \frac{-h_{fe} \times 3.3K}{h_{ie}}}$$

$$\boxed{R_i'' = 19.3K \,||\, h_{ie}} = (19.3 \,||\, 2) = 1.81\,K$$



KVL:

$$R_s' I_b + h_{ie} I_b = 0$$

$$(R_s' + h_{ie}) I_b = 0$$

$$\Rightarrow I_b = 0$$

$$R_o = \frac{V_x}{I_x} = \frac{V_x}{0} = \infty$$

$$R_o' = R_o \,||\, R_c$$

$$= \infty \,||\, R_c$$

$$\boxed{R_o' = R_c = 3.3K}$$

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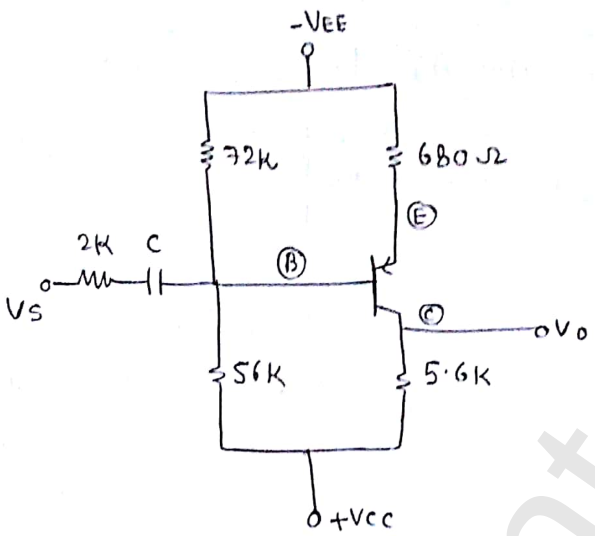
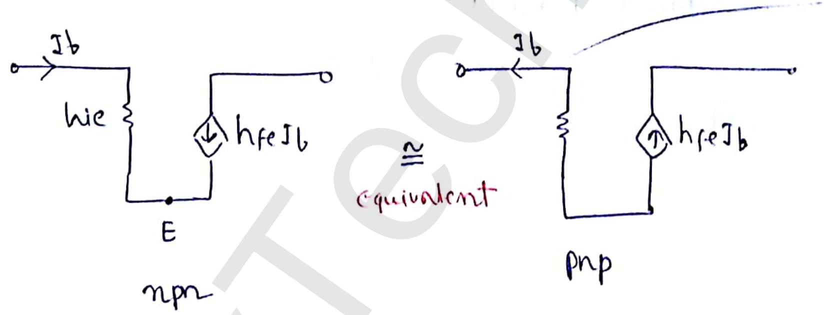
Q

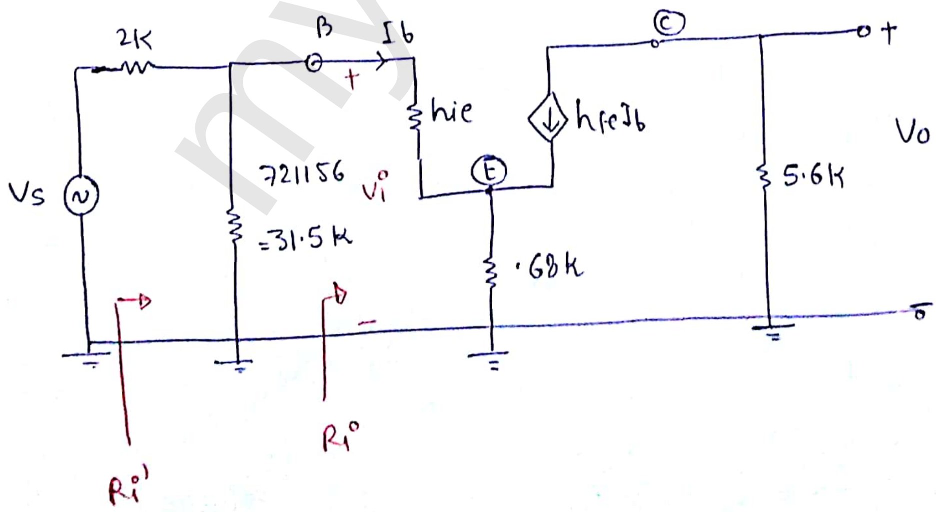


In the ckt shown below transistor has $h_{fe} = 50$ $h_{ie} = 1.5k\Omega$, current gain voltage gain, i/p resistance, o/p resistance.

Sol^n

Either pnp or npn there will be no change in model.





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$V_i = I_b h_{ie} + (1+h_{fe}) I_b \cdot R_E$

$$\Rightarrow \frac{V_i}{I_b} = \boxed{R_i = h_{ie} + (1+h_{fe}) R_E}$$

If C_E is present

$R_i = h_{ie}$

If C_E is absent

$R_i = h_{ie} + (1+h_{fe}) R_E$

$v_o = -h_{fe} I_b \times 5.6K$

$$\therefore \quad A_v = \frac{v_o}{v_i} = \frac{-h_{fe} \times 5.6K}{h_{ie} + \underbrace{(1+h_{fe}) R_E}}$$

If cap^c present this term will be removed.

Gate question -

Q1 what is the effect on i/p Resistance when the cap^c is removed accidently & what is the effect on voltage gain.

Q2. What is the effect on i/p Resistance is cap^c is connected across emitter resistance.

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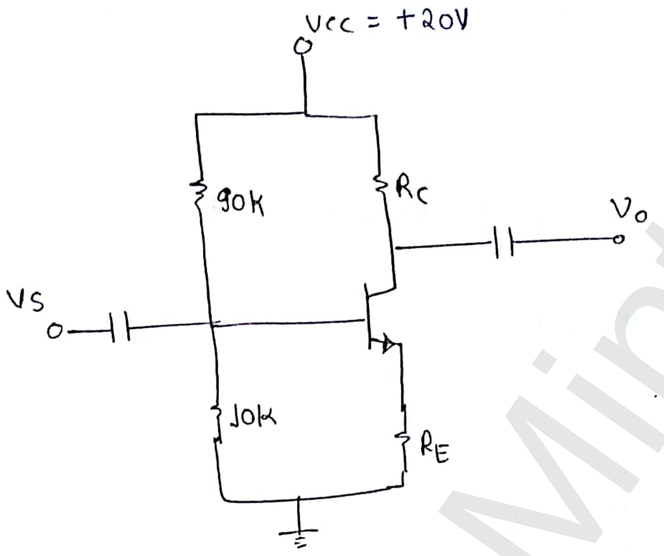
Q

In the ckt shown below transistor has large β $V_{BE} = 0.7$, $V_{CEQ} = \frac{V_{cc}}{2}$

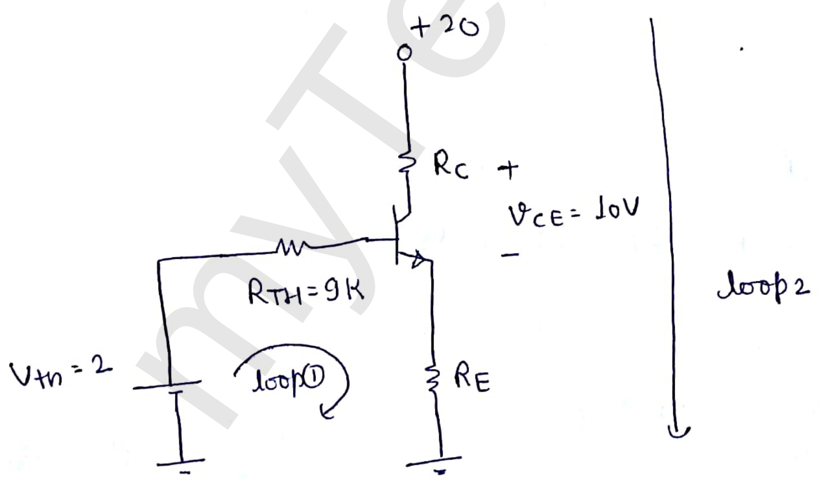
calc voltage gain $\frac{V_o}{V_s}$



Soln

We are given no h parameter and we are also not given Rc & RE

so 1st find Rc and RE



β is very large

$I_B \simeq 0$

$I_C \approx I_E$

KVL in loop ①

$-V_{th} + I_B R_{th} + V_{BE} + I_C R_E = 0$

$\Rightarrow I_C = \frac{V_{th} - V_{BE}}{R_E} = \frac{1.3}{R_E}$

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KVL in loop 2

$$-20 + R_C I_C + 10 + I_C R_E = 0$$

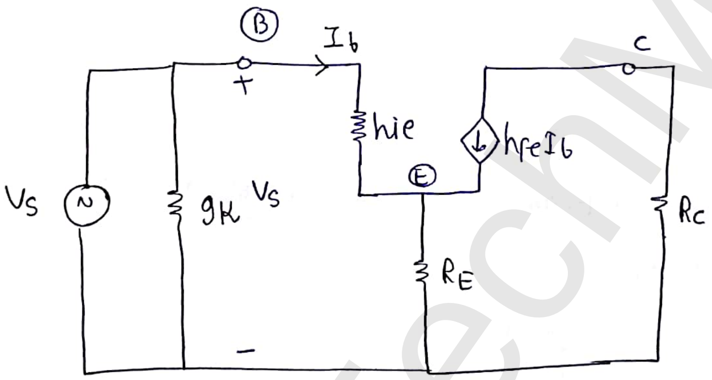
$$(R_C + R_E) I_C = 10$$

$$(R_C + R_E) \times \frac{1.3}{R_E} = 10$$

$$\Rightarrow \quad \frac{R_C}{R_E} = 6.69$$

Voltage gain is found for ac eq^v ckt not for dc

so we will draw ac eq^v ckt



$$v_o = -h_{fe} I_b R_C \quad — (1)$$

$$V_s = h_{ie} I_b + (1 + h_{fe}) I_b R_E \quad — (2)$$

$$A_{vs} = \frac{V_o}{V_s} = \frac{-h_{fe} R_C}{h_{ie} + (1 + h_{fe}) R_E}$$

$$A_{vs} \simeq \frac{-h_{fe} R_C}{(1 + h_{fe}) R_E}$$

bcz we don't know hie
since $(1+h_{fe})R_E$ is >> hie

$$A_{vs} \simeq \frac{-h_{fe} R_C}{h_{fe} R_E} = -\frac{R_C}{R_E}$$

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$$\boxed{A_{vs} = -\frac{R_C}{R_E}}$$

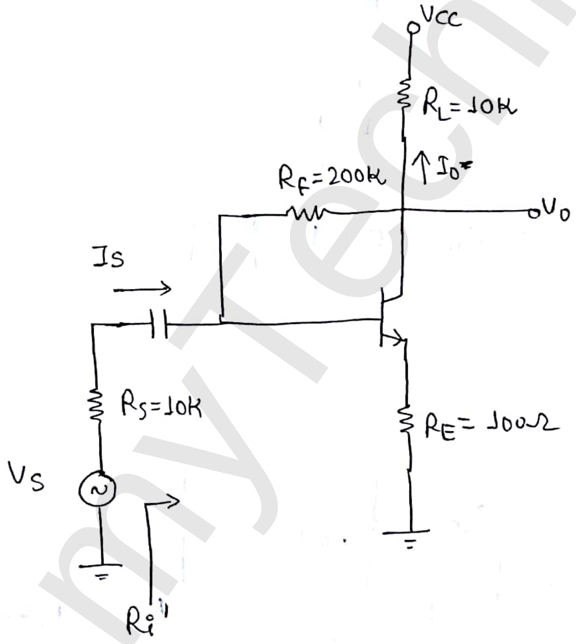
but if V_o के across कोई एक Resistor R_L और लगा है, तो

$$\boxed{A_{vs} = -\frac{(R_C \| R_L)}{R_E}}$$

*** Remb' directly for gate

$$\boxed{A_{vs} = -\frac{R_C}{R_E} = -6.69}$$

Answer



For the ckt shown below BJT has $h_{ie} = 1.1 K\Omega$, $h_{fe} = 50$ cal^c $A_{IS} = \frac{I_o}{I_s}$

$A_{vs} = \frac{V_o}{V_s}$ and R_i'

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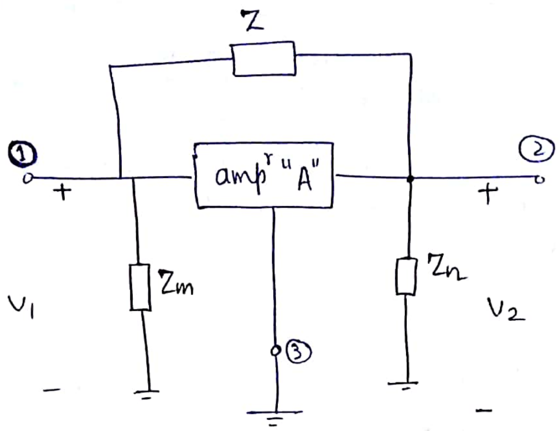
Miller's Theorem :-



$$Z_m = \frac{Z}{1-A} \qquad Z_n = \frac{Z}{1-\frac{1}{A}}$$

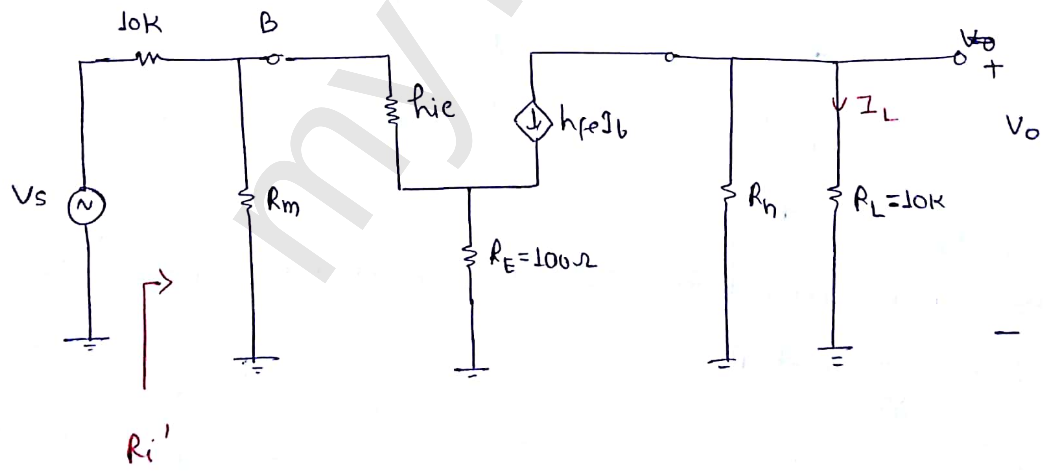
A = open loop gain (i.e without considering the effect of Z)

$$R_m = \frac{R}{1-A} \qquad R_n = \frac{R}{1-\frac{1}{A}}$$

*****

$$\boxed{C_m = (1-A)C \qquad C_n = C\left(1-\frac{1}{A}\right)}$$

Sol^n



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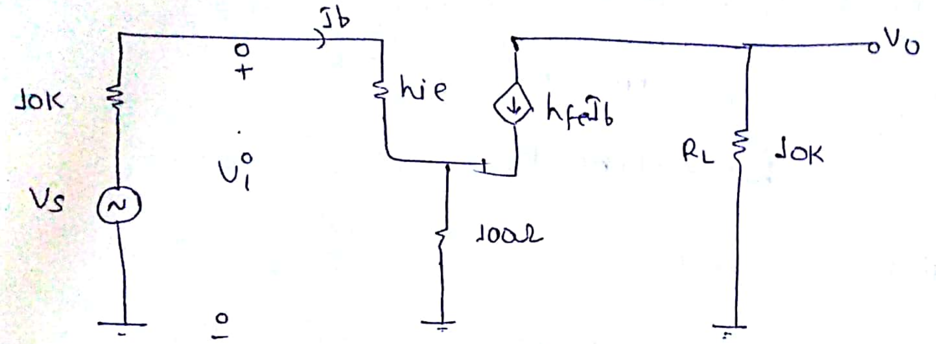
To cal^c open loop gain R_m & R_n are not considered i.e feedback is neglected



$$V_0 = -h_{fe} I_b R_L$$

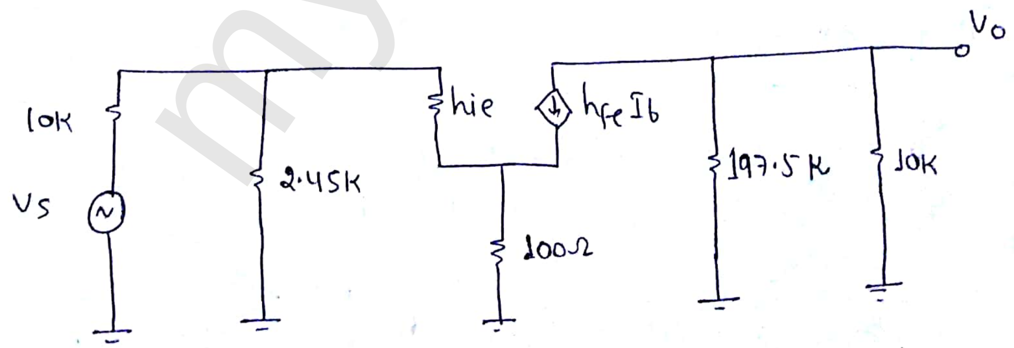
$$V_i = h_{ie} I_b + (1+h_{fe}) I_b R_E$$

voltage gain without feedback → $A = \dfrac{V_o}{V_i} = \dfrac{-h_{fe} R_L}{h_{ie} + (1+h_{fe}) R_L} = -80.6$

Now cal^c R_m & R_n

$$R_m = \frac{200K}{1-A} = \frac{200K}{81.6} = 2.45\,k$$

$$R_n = \frac{200K}{1-\frac{1}{A}} \approx 197.5\,k$$



Now finding $A_{vs} = \dfrac{V_o}{V_s}$

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$$V_o = -h_{fe} I_b (R_n \parallel 10K)$$

$$V_i = h_{ie} I_b + (1+h_{fe}) R_E I_b$$

$$\frac{V_o}{V_i} = A_{vf} = \frac{-h_{fe}(R_n \parallel 10K)}{h_{ie} + (1+h_{fe})R_E}$$

$$A_{vf} = -76.7$$

$$R_i = \frac{V_i}{I_b} = h_{ie} + (1+h_{fe})R_E = 6.2K\Omega$$

$$\boxed{R_i' = R_m \parallel 6.2K = 1.75K}$$ Ans

From o/p ckt

$$I_L = \frac{R_n}{R_L + R_L}(-h_{fe} I_b)$$

$$\frac{I_L}{I_b} = -47.6$$

Current gain

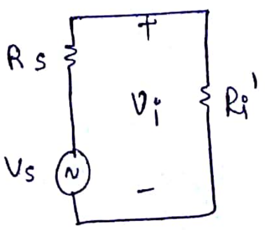
$$A_{IS} = \frac{I_L}{I_s} = \frac{I_L}{I_b} \cdot \frac{I_b}{I_s} = (-47.6) \times \frac{R_m}{R_m + R_i}$$

$$\boxed{A_{IS} = -13.48}$$

$$A_{vs} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = -76.7 \times \frac{R_i'}{R_i' + R_s}$$

$$\boxed{A_{vs} = -11.4}$$

-ve f/b is reducing gain.



$$\frac{V_i}{V_s} = \frac{R_i'}{R_i' + R_s}$$

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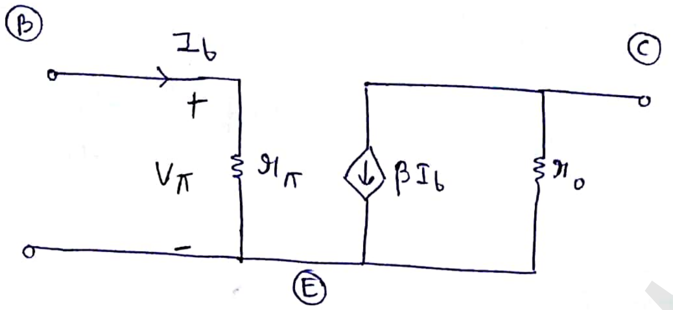
π Model generally used for CE
(CE- Model)



comparing with approximate h- parameter model:

$$r_\pi = h_{ie}$$
$$\beta = h_{fe}$$
$$r_o = \frac{1}{h_{oe}}$$

objective que^n can be

BJT

g_m Vs I_C	linear
g_m Vs V_{BE}	exponential curve

π parameter

$\beta \quad r_\pi \quad g_m \quad r_o$

Calculation of π parameter

(I) g_m (Transconductance of BJT)

It is the rate of change of

$$g_m = \frac{\partial I_C}{\partial V_{BE}}$$

we have

$$I_C = I_{Co}\, e^{V_{BE}/V_T}$$

$$\frac{\partial I_C}{\partial V_{BE}} = \frac{I_{Co}}{V_T} e^{V_{BE}/V_T} = \frac{I_C}{V_T}$$

$$g_m = \frac{I_C}{V_T}$$

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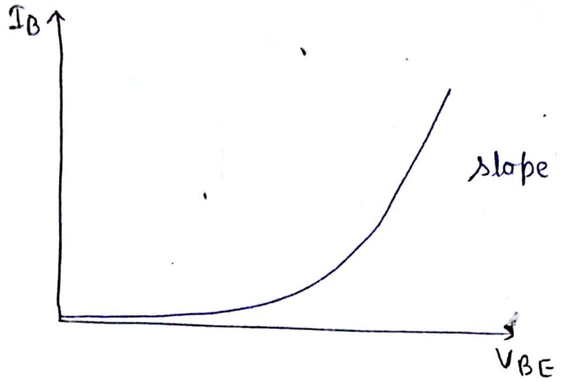
r_π :

It is reciprocal of slope of i/p char^c of CE config.



slope $= \dfrac{\partial I_B}{\partial V_{BE}}$

$$r_\pi = \frac{1}{\text{slope}} = \frac{\partial V_{BE}}{\partial I_B}$$

$$r_\pi = \frac{\partial V_{BE}}{\partial I_B}$$

$$r_\pi = \frac{\partial V_{BE}}{\partial I_C} \cdot \frac{\partial I_C}{\partial I_B}$$

$$r_\pi = \frac{1}{g_m} \times \beta \quad ***$$

$$\boxed{r_\pi = \beta / g_m}$$

$$r_\pi = \beta \times \frac{V_T}{I_C}$$

$$r_\pi = \beta \times \frac{V_T}{\beta I_B}$$

$$\boxed{r_\pi = \frac{V_T}{I_B}}$$

I_B – DC – Q point base current

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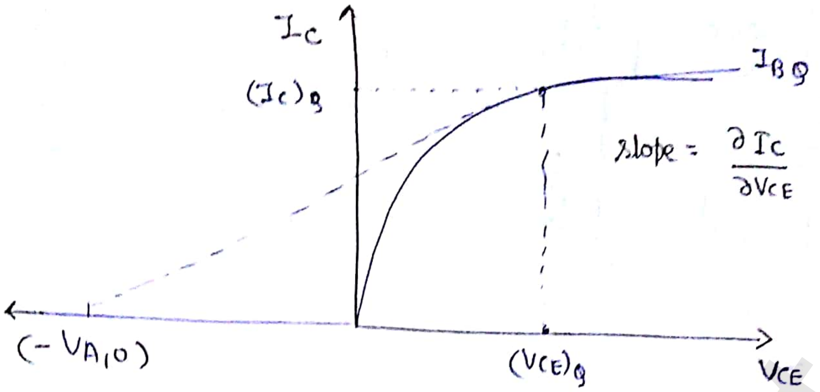
r_o :- It is reciprocal of the slope of o/p char^c of CE configuration.

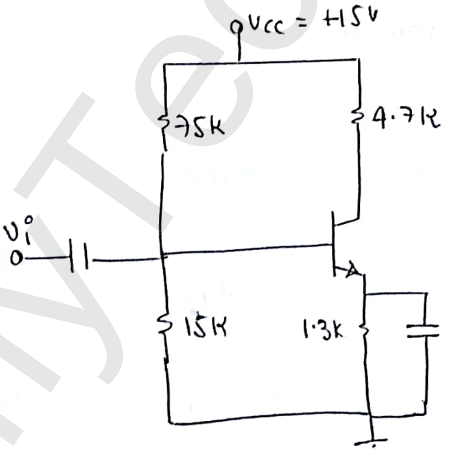


$$r_o = \frac{1}{slope} = \frac{\partial V_{CE}}{\partial I_C}$$

$$\Rightarrow \boxed{r_o = \frac{V_{CEQ} + V_A}{I_{CQ}}} \qquad V_A = \text{Early voltage}$$

If early voltage is not given $\boxed{r_o = \infty}$.

Q



In the ckt shown. Tx. has $\beta = 200$, $V_{BE} = 0.7V$ cal^c.

① operating point of BJT

② π parameter

③ voltage gain

④ i/p and o/p resistance, given early voltage = 80 volt.

⑤

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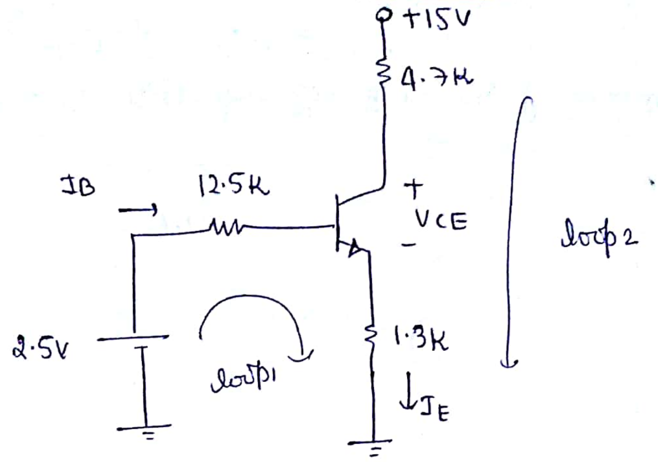
Sol^n



KVL in loop 1

$$-2.5 + 12.5K I_B + 0.7 + 1.3K I_E = 0$$

$$12.5K I_B + 201 \times 1.3K\, I_B = 2.5 - 0.7$$

$$I_B = \frac{1.8}{12.5K + 201 \times 1.3K} = 6.57\ \mu A$$

$$I_C = 1.314\ mA$$

$$V_{CE} = 7.1\ V$$

(i) operating point (7.1V, 1.314 mA)

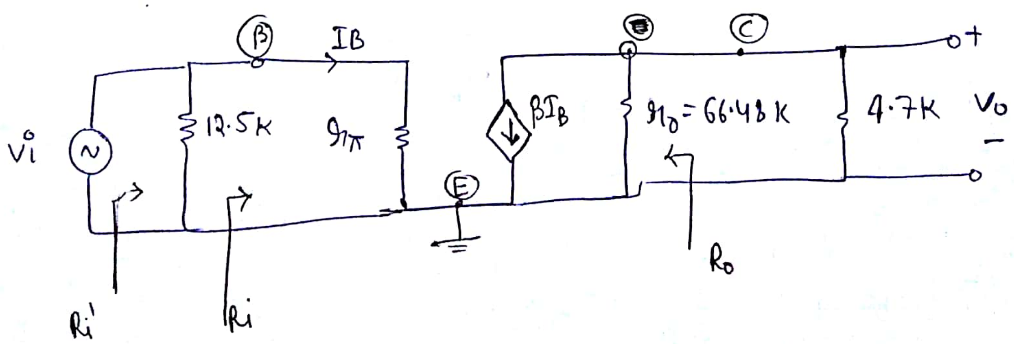
(ii) π parameter

$$g_m = \frac{I_c}{V_T} = \frac{1.314\,mA}{26\,mV} = 50\,ms$$

$$r_\pi = \frac{\beta}{g_m} = \frac{200}{50 \times 10^{-3}} = 4\ k\Omega$$

$$r_o = \frac{V_{CE} + V_A}{I_c} = \frac{7.1 + 80}{1.314\,m} = 66.48\ k\Omega$$

(3)



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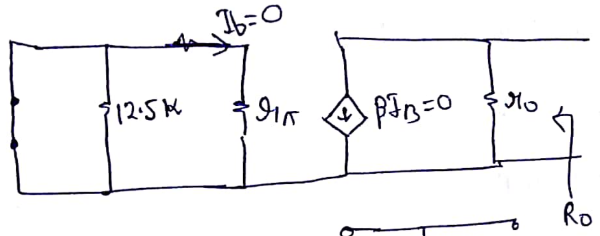
(4) Input Resistance

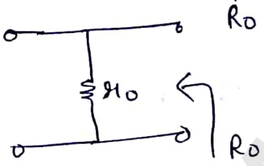
$R_i' = \beta(12.5 \| r_\pi)$

$= (12.5 \| 14) = 3.03 K\Omega$

(5) o/p Resistance.

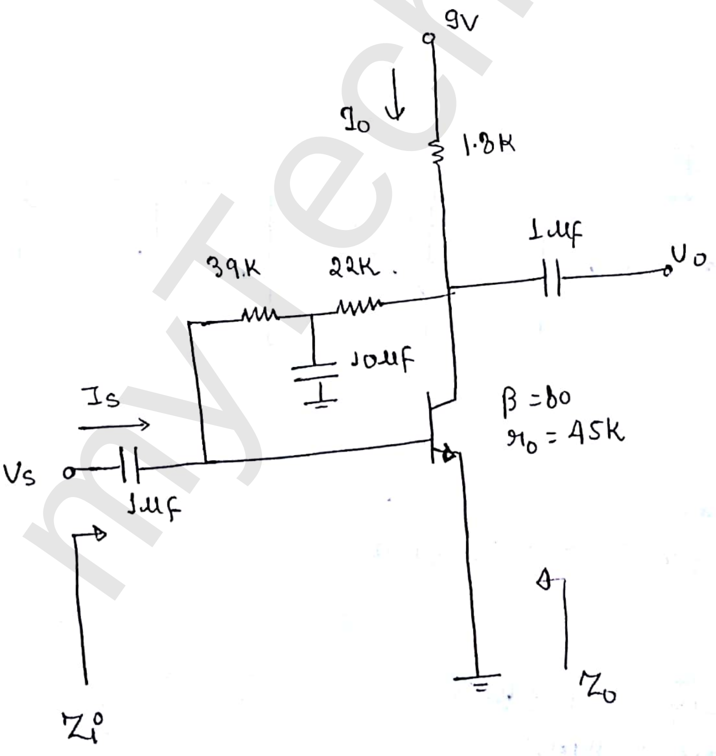
R_o





$R_o = 66.48 K\Omega$. Ans

Q



By -ve f/b the close loop gain dec but now due to 10uf cap^c the effect of -ve f/b is removed bcz for ac cap^c act as short ckt so now 39K is i/p and 22K is o/p resistance so for ac 39, 22K are not the f/b

Find $Z_i, Z_o, \frac{V_o}{V_s}, \frac{I_o}{I_s}$

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Sol^n First dc analysis.

KVL

$$-9 + 1.8K(I_B+I_C) + 61k\, I_B + V_{BE} = 0$$

$$1.8K I_B + 80\times1.8K I_B + 61K I_B = 8.3$$

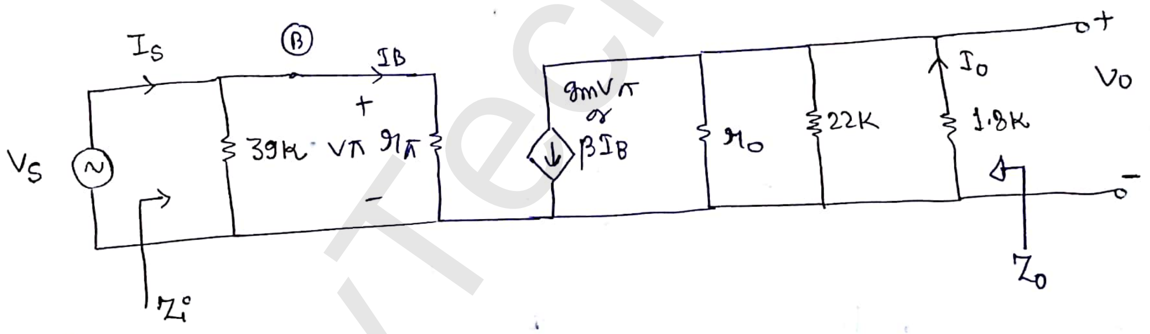
$$I_B = 40.13\ \mu A$$

$$I_C = 3.21\ mA$$

$$g_m = \frac{I_C}{V_T} = \frac{3.21mA}{26mV} = 123.4\ ms$$

$$r_\pi = \frac{\beta}{g_m} = \frac{80}{123.4\times10^{-3}} = 0.648\ k\Omega \approx 0.65\ k\Omega$$

ac analysis



a) input resistance.

$$Z_i = (39 \| r_\pi)$$

$$Z_i = (39\|0.65) = 0.64\ k\Omega$$

b) o/p resistance

$$Z_o = (r_o \| 22k \| 1.8k)$$

$$= (45\|22\|1.8)$$

$$Z_o = 1.6k\Omega$$

c) $$V_o = -g_mV_\pi\,(r_o\|22\|1.8)$$

$$\frac{V_o}{V_\pi} = \frac{V_o}{V_S} = -0.123\times1.6\ k$$

$$\boxed{\frac{V_o}{V_\pi} = -196.8}$$

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$$A_I = \frac{I_o}{I_s} = \left(\frac{-V_o}{1.8K}\right) \times \frac{.640K}{V_s}$$

$$A_I = -\left(\frac{V_o}{V_s} \times \frac{.640}{1.8}\right)$$

$$= \frac{196.8 \times .64}{1.8} = 69.97$$

$$\boxed{A_I \simeq 70}$$

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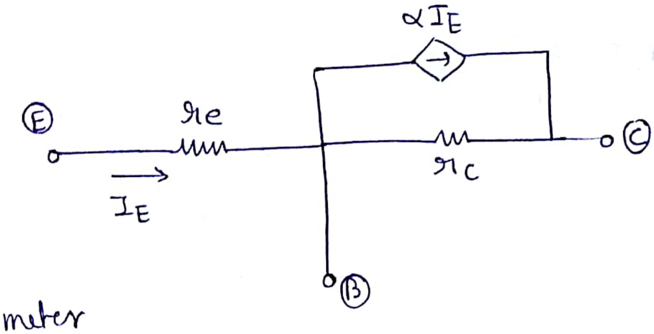
T model of BJT (generally designed according to CB model)



T model parameter

α, r_e, r_c

r_e is the ac resistance of emitter junction J_E or it is reciprocal of the slope of i/p characteristics of CB

(resistance of diode) $r_d = \frac{\eta V_T}{I_D}$

here $I_D = I_E$ $\quad$ $\eta = 1$ for BJT

$$\boxed{r_e = \frac{V_T}{I_E}}$$

I_E = Q point emitter current

$$r_e = \frac{V_T}{I_E} = \frac{V_T}{I_C} \cdot \frac{I_C}{I_E}$$

$$\boxed{r_e = \frac{1}{g_m} \cdot \alpha}$$

<u>objective</u>

$\alpha = g_m r_e$

$\beta = g_m r_\pi$

$$\boxed{\frac{\alpha}{\beta} = \frac{r_e}{r_\pi}}$$

$$r_e = \frac{\alpha}{g_m}$$

$$= \frac{\alpha}{\beta / r_\pi} = r_\pi \times \frac{\alpha}{\beta}$$

$$r_e = r_\pi \times \frac{\beta / \beta + 1}{\beta}$$

$$\boxed{r_e = \frac{r_\pi}{1 + \beta}}$$

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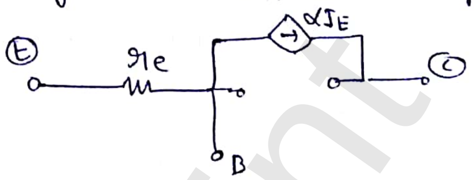
r_c :

It is ac resistance of collector to base junction J_c or it is reciprocal of slope of o/p characteristics of CB configuration

$$\boxed{r_c = (1+\beta) r_o} \leftarrow \text{directly written}$$

r_c will go in MΩ range so in differential ampr analysis so can remove r_c and ckt becomes



Q

$\beta = 100$

$V_{BE} = 0.7V$

Early voltage $= 100V$ and it is operating at $(10V, 2mA)$ calc

① π parameter

② T parameter

Soln

$$g_m = \frac{I_C}{V_T} = \frac{2}{26} = 0.0769$$

$r_e = 12.8\Omega$

$r_c = 5.5\,M\Omega$

$$\beta = r_\pi g_m$$

$$r_\pi = \frac{100}{0.0769} = 1300.4\,\Omega$$

$$r_e = \frac{r_\pi}{(1+\beta)} = \frac{1300.4}{(101)} = 12.875\,\Omega$$

$$r_o = \frac{(V_{CE})_Q + V_A}{(I_C)_Q} = \frac{10+100}{2} = 55\,k$$

$$r_c = r_o(1+\beta) = 101 \times 55 = 5.5\,M\Omega$$

π parameter	T parameter
$r_\pi = 1.3\,k\Omega$	$r_e = 12.875\,\Omega$
$r_o = 55\,k$	$r_c = 5.5\,M\Omega$
$g_m = 0.0769$	$g_m = 0.0769$
$\beta = 100$	$\alpha = g_m r_e = 0.99$

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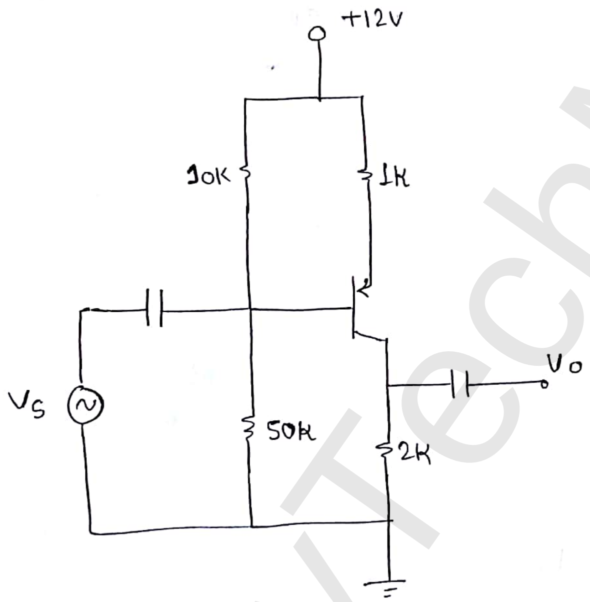
Q In the ckt shown below $\beta = 100$ $V_A = \infty$

① The small s/g voltage gain $A_V = \frac{V_o}{V_s}$ is

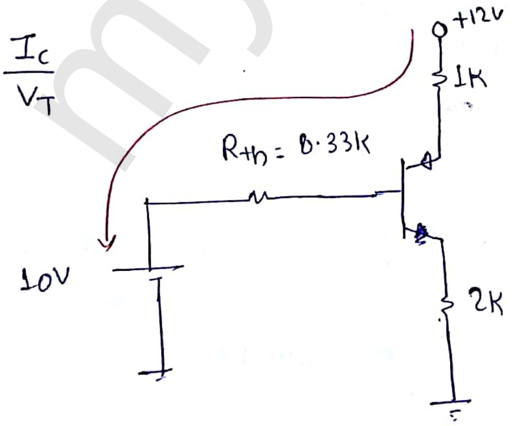
ⓐ -1.6
ⓑ -3.18
ⓒ -4.73
ⓓ -10.43

Sol ② If the total instantaneous emitter to collector voltage is to remain in the range $1V \leq V_{EC} \leq 11V$. the max^m undistorted swing in the o/p voltage is a) 2.58 V(p-p) b) 5.16V (p to p) c) 1.48V (p-p) d) 2.96 V (p-p)



Soln $g_m = \frac{I_c}{V_T}$

Find I_c



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$-12 + I_E \times 1K + V_{EB} + 8.34K\, I_B + 10 = 0$

$101\, I_B\, 1K + 8.34K\, I_B = 2 - 0.7$

$109.34\, I_B = \cancel{13}\ 1.3$

$I_B = \dfrac{1.3}{109.34} = 11.8\ \mu A$

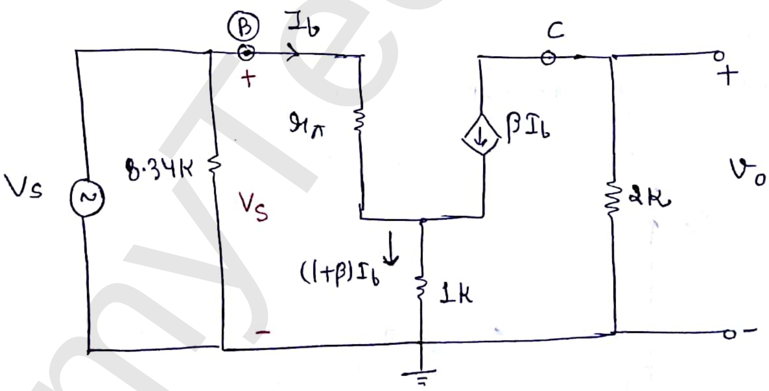
$I_C = 1.18\ mA$

$I_E = 1.2\ mA$

$V_{EC} = 8.42V$

$g_m = \dfrac{I_C}{V_T} = \dfrac{1.18\ mA}{26\ mV} = 45\ ms$

$r_\pi = \dfrac{\beta}{g_m} = 2.18\ k\Omega$



$v_o = -\beta I_b \times 2K$

$v_s = r_\pi I_b + (1+\beta) I_b \times 1K$

$\therefore \dfrac{v_o}{v_s} = \dfrac{-\beta \times 2K}{r_\pi + (1+\beta)1K}$

option (a) is correct.

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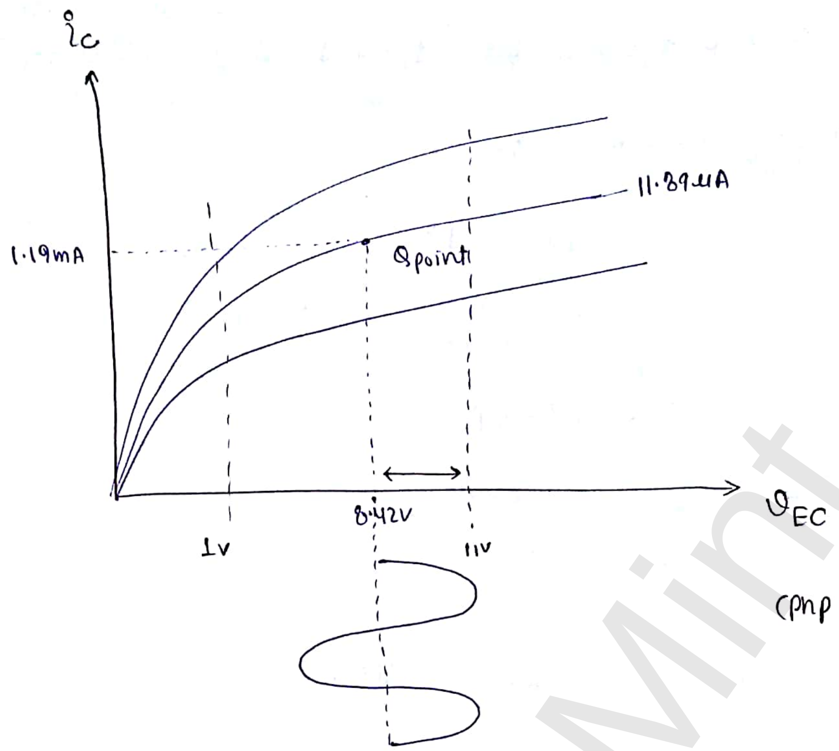
(2)

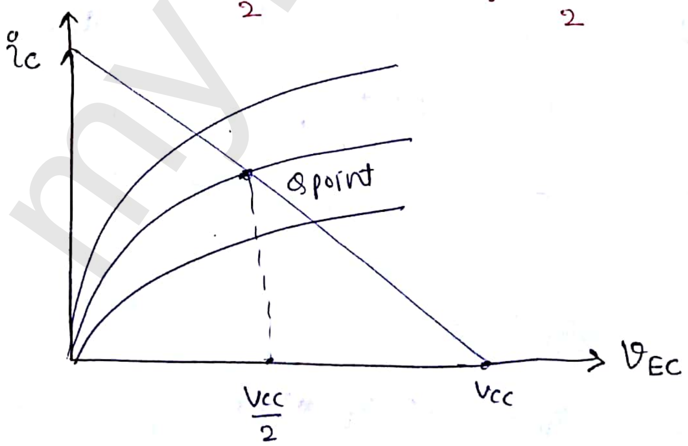


(pnp) type

O/p peak voltage = 11 − 8.42 = 2.58 V

so peak to peak swing in o/p voltage = 2 x 2.58 = 5.16 V

Sometime question - For maximum symmetrical swing the Q point should be at $\frac{V_{CC}}{2}$ i.e $V_{CEQ} = \frac{V_{CC}}{2}$



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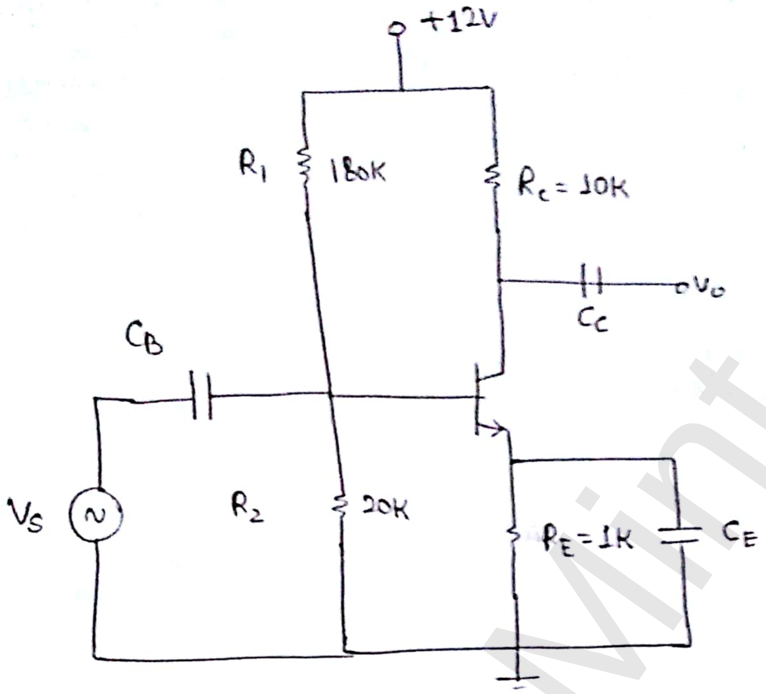
Low freq^c analysis of

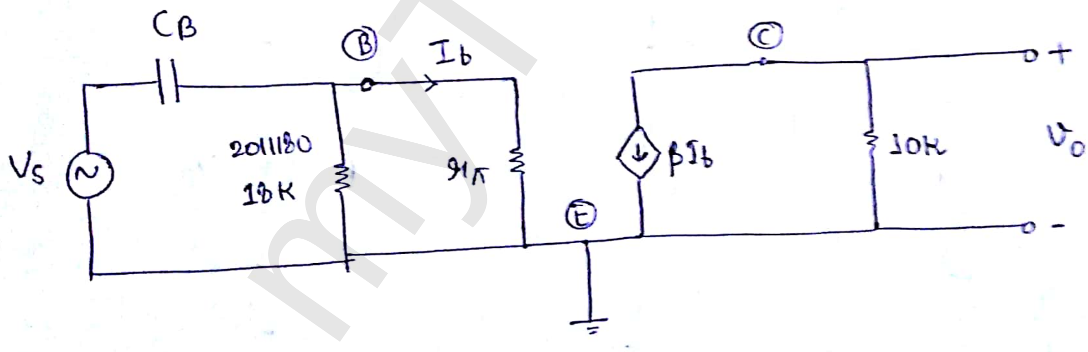
Q



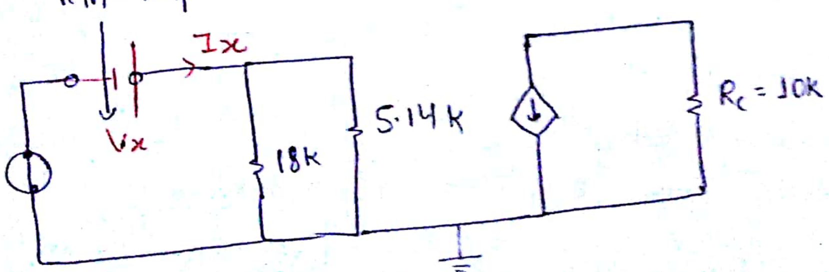
If the lower cut off freq^c due to C_B is $20Hz$ then calc^c the value of C_B
$\beta = 80$ $r_o = \infty$

Sol^n

$r_\pi = 5.14 K\Omega$



$R_{th} = R_{eq}$



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18 11 5.14

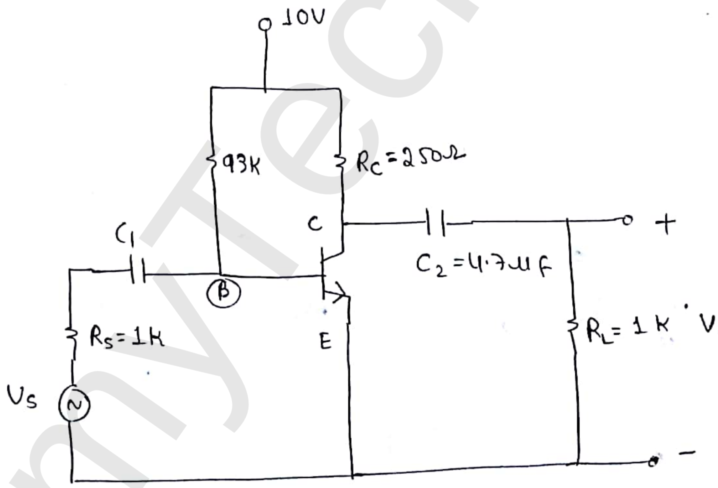
$R_{eq} = 3.99\,k\Omega$

$$f = \frac{1}{2\pi R_{eq} \cdot C}$$

$$f = \frac{1}{2\pi \times 3.99 \times 10^3 \times C}$$

$$20 = \frac{1}{2\pi \times 3.99 \times 10^3 \times C}$$

Q



consider CE ckt shown below

$\beta = 100$, $g_m = 0.3861 \frac{Amp}{V}$ $r_o \simeq \infty$ $r_\pi = 259\,\Omega$

Cal^c lower cut off freq^c due to C_2.

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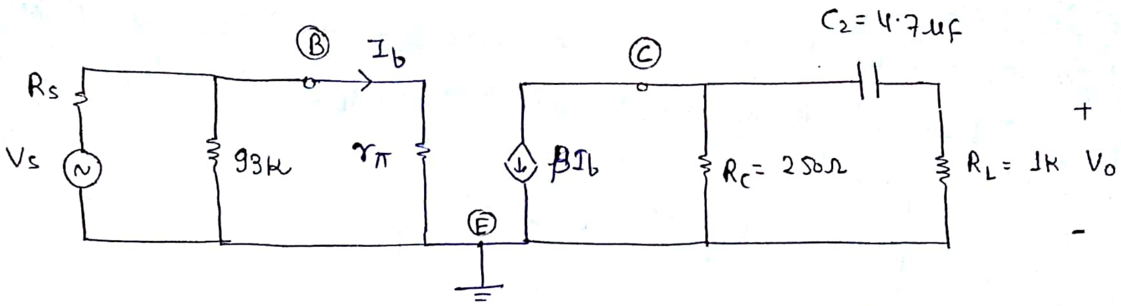
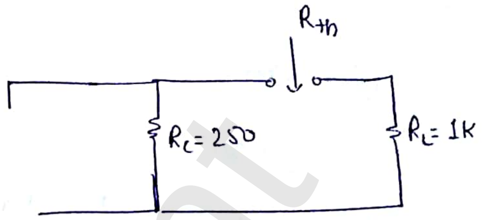


$$f_L = \frac{1}{2\pi R_{eq} C_2}$$



$$R_{eq} = R_{th} = R_C + R_L$$

$$= 250 + 1000 = 1250 = 1.25K$$

$$f_L = \frac{1}{2\pi\, 1250 \times 4.7}$$

$$= 27\ Hz \quad \text{Ans.}$$

Note* If the values of all the capacitors C_B C_C and C_E are given then net lower cut off freq^c can be calculated as

Step(I) Calculate the individual lower cut off freq^cies by considering one cap^c and S.C other two.

let $f_1 \longrightarrow C_B$

$f_2 \longrightarrow C_C$

$f_3 \longrightarrow C_E$

Step(II) The overall lower cutoff freq^c will be the highest of 3 frequencies if it is higher by 4 times in comparision to other two frequencies

$f_1 \longrightarrow 2Hz$

$f_2 \longrightarrow 9Hz$

$f_3 \longrightarrow 40Hz$

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If no freq^c is found to be greater 4 times than the other two than the overall lower cutoff freq^c can be calculated as f_L

$$\boxed{f_L = 1.1\sqrt{f_1^2 + f_2^2 + f_3^2}}$$

$f_1 \longrightarrow 2Hz$

$f_2 \longrightarrow 9Hz$

$f_3 \longrightarrow 15Hz$ } greater than 4 times of f_1 but not 4 times of f_2

Comparision of CE CC and CB amplifiers

S.NO.	Parameter	CE amp^r	CC amp^r	CB amp^r
1.	A_V	Large	≈ 1	Large
2.	A_I	Large	Large	≈ 1
3.	R_i	Medium	large	≈ 1
4.	R_o	Medium	Small	Large
5.	Phase-shift in o/p & i/p voltage	180°	0°	0°
6.	Applications	As an audio amp^r or LF amp^r	Buffer ***	HF amp^r

Buffer amp^r (i.e voltage amp^r) i.e CC amp^r.

Buffer is used for impedance matching. impedance matching is done for maximum power transfer.

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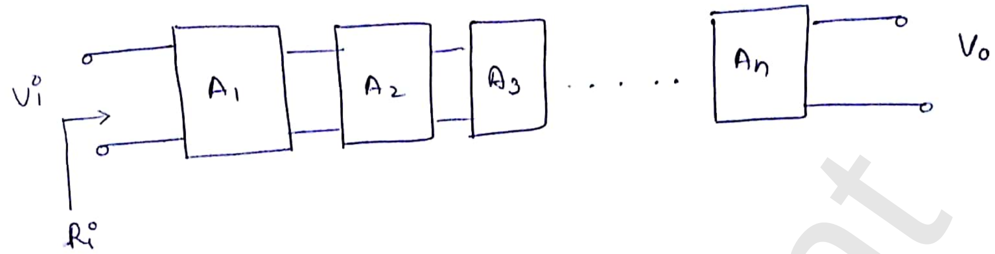
Multistage Amplifiers

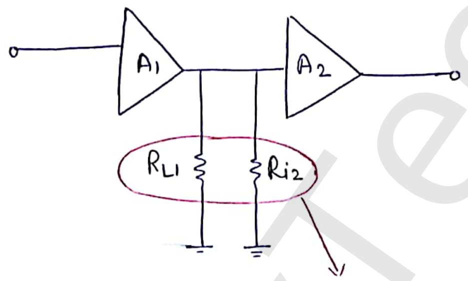


$A_V = A_{V1} A_{V2} A_{V3} \cdots A_{Vn}$

$A_I = A_{I1} A_{I2} A_{I3} \cdots A_{I3}$

$A_p =$

Two ampr in cascade



$R_L' = R_{L1} \parallel R_{i2}$

Case 1: If R_{i2} is very large

$R_L' = R_{L1} \parallel R_{i2} \approx R_{L1}$

$A_V = A_1 A_2$

ये दो connected तो है लेकिन एक दूसरे पे कोई प्रभाव नहीं डालते

$\Rightarrow$ Non-interactive cascading.

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case 2: If R_{i2} is small

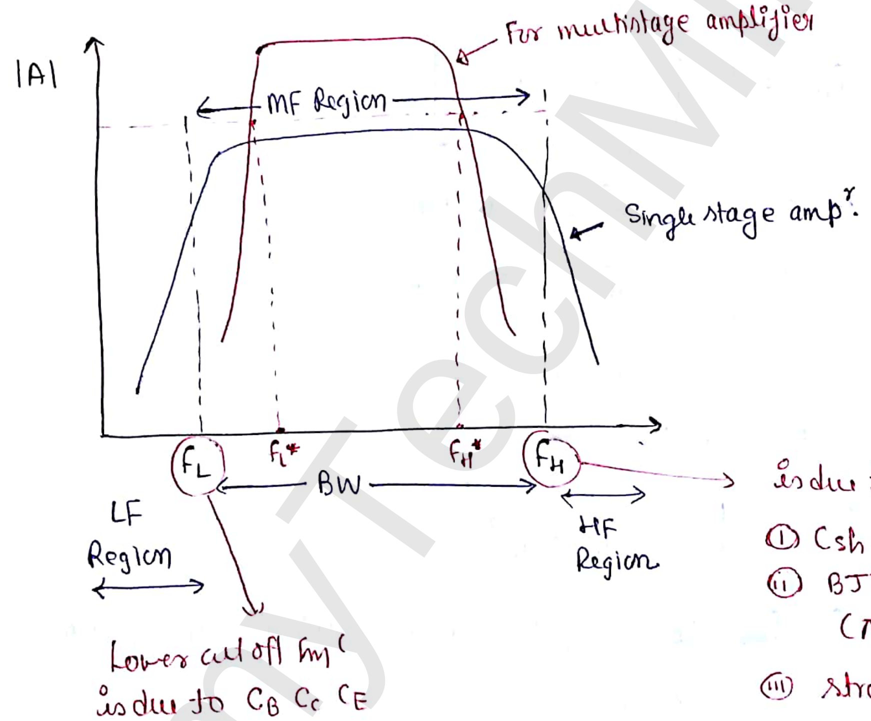
$$R_L' = R_{L1} \parallel R_{i2} \quad (\downarrow)$$

Loading effect

Gain of 1st stage decreases. bcz the gain of 1st stage depends on the load of 1st stage which is fed by the R_{i2}

⇒ Interactive cascading

Gain Vs frq^c For RC coupled amp^r



is due to

① Csh

(ii) BJT capacitances (C_π & C_μ)

(iii) stray capacitances

(iv) parasitic capacitance

Note* gain Bandwidth product of amp^r remain constant

* In multistage amp^r gain is ↑ed, hence BW is reduced.

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case① For non interactive cascading

let us assume that f_L is the lower cut off freq and f_H is the higher cut off freq of individual stage.

so overall lower cut off freq

$$\boxed{f_L^* = \frac{f_L}{\sqrt{2^{1/n} - 1}}}$$

stage ↑

Remb'r

$$\boxed{\begin{array}{ll} n=2 & f_L^* = 1.55 f_L \\ n=3 & f_L^* = 1.96 f_L \end{array}}$$

overall higher cutoff freq

$$\boxed{f_H^* = f_H \sqrt{2^{1/n} - 1}}$$

$n = 2$; $f_H^* = 0.64 f_H$

$n = 3$; $f_H^* = 0.51 f_H$

Case 2: For interactive cascading

$$f_L^* = 1.1 \sqrt{f_{L1}^2 + f_{L2}^2 + f_{L3}^2 + \cdots}$$

where f_{L1} f_{L2} f_{L3} ..... are lower cut off freq of each stage

$$\frac{1}{f_H^*} = 1.1 \sqrt{\frac{1}{f_{H1}^2} + \frac{1}{f_{H2}^2} + \frac{1}{f_{H3}^2} + \cdots}$$

where f_{H1}, f_{H2}, f_{H3} are higher cut off frequency of individual stage.

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Q 3 Identical cascaded stages have an overall upper 3 dB frq^c of 20 kHz and Lower 3 dB frq^c of 20 Hz what are f_L and f_H of each stage assume non-interactive stages.

Sol^n

$n = 3$

$f_L^* = 20\,Hz$

$f_H^* = 20\,kHz$

$$f_L^* = \frac{f_L}{\sqrt{2^{1/n} - 1}}$$

$$f_L = f_L^* \sqrt{2^{1/n} - 1}$$

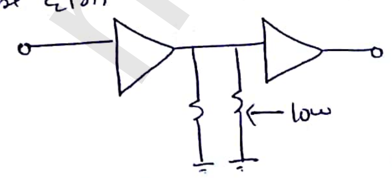
$$\boxed{f_L = 20 \times \sqrt{2^{1/3} - 1}}$$

$$f_H^* = f_H \sqrt{2^{1/3} - 1}$$

$$\boxed{f_H = \frac{f_H^*}{\sqrt{2^{1/3} - 1}}} = \frac{20\,kHz}{\sqrt{2^{1/3} - 1}}$$

Q The First and II^nd stage of a 2 stage RC coupled amp^r have the lower cut off frequencies to be 100 Hz and 200 Hz respectively. Their upper cut off frequencies are 140 kHz and 100 kHz respectively find the overall 3 dB bw required.

Sol^n RC Coupled amp^r का i/p resistance low होता है so interactive cascading. दोनों stages की lower cut off frq^c अलग-अलग है so interactive cascading का formula ही use होगा।



$n = 1$

$f_{L1} = 100\,Hz \qquad f_{L2} = 200\,Hz$

$$f_L^* = 1.1 \sqrt{(100)^2 + (200)^2} = \boxed{246\,Hz} = f_L^*$$

$f_{H1} = 140 \qquad f_{H2} = 100$

$$1/f_H^* = 1.1 \sqrt{\frac{1}{(100)^2} + \frac{1}{(140)^2}} = \boxed{73.975\,kHz = f_H^*}$$

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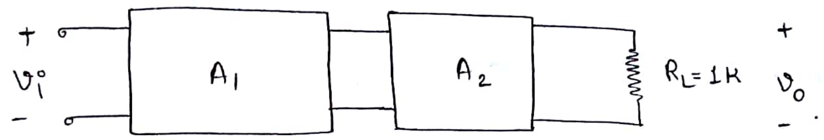
$BW^* = f_H^* - f_L^*$

$BW^* \simeq f_H^*$

Q

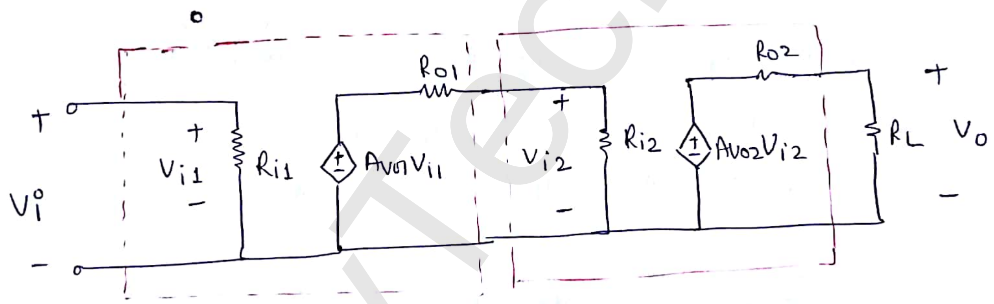


A_1 : $A_{vo} = 10$ $R_i = 10k\Omega$ $R_o = 1k\Omega$

A_2 : $A_{vo} = 5$ $R_i = 5k$ $R_o = 200\Omega$

A cascade connection of two voltage ampr A_1 and A_2 is shown below the open loop voltage gain A_{vo}, i/p resistance R_i and o/p resistance are given. Calc the approximate overall voltage gain

soln.



$$V_o = \frac{R_L}{R_{o2}+R_L} A_{vo2} V_{i2} \qquad V_{i2} = \frac{R_{i2}}{R_{o1}+R_{i2}} A_{vo1} V_{i1}$$

$$V_o = \frac{R_L}{R_{o2}+R_L} A_{vo2} \times \frac{R_{i2}}{R_{o1}+R_{i2}} A_{vo1} \cdot V_{i1}$$

$$\Rightarrow \frac{V_o}{V_{i1}} = \frac{V_o}{V_i} = A_v = \frac{R_L}{R_{o2}+R_L} \cdot A_{vo2} \times \frac{R_{i2}}{R_{o1}+R_{i2}} \times A_{vo1} = 34.72$$

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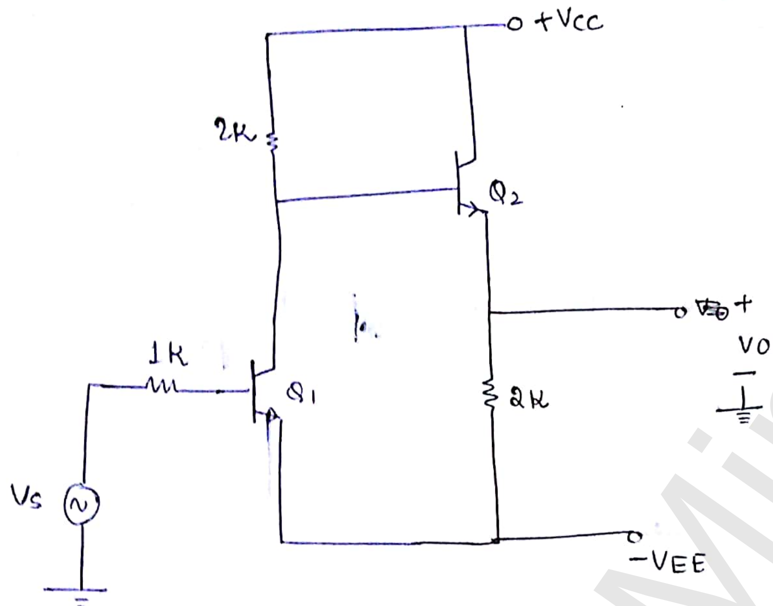
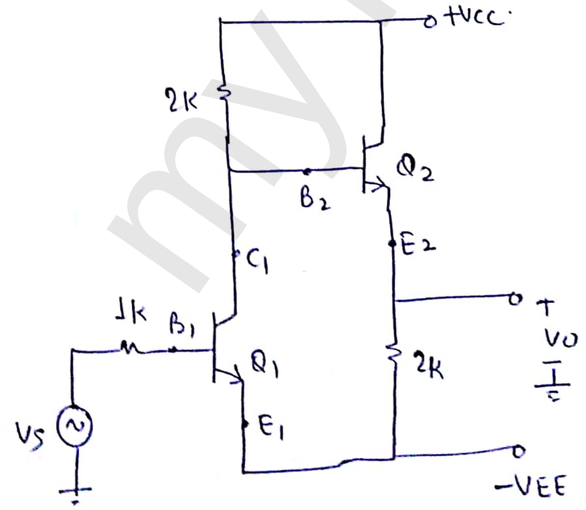
Q Draw the ckt of Darlington ampr and explain its advantages.

Q



For the cascaded ampr shown find the i/p impedance, current gain and voltage gain make any reasonable assumption if required that h parameter are $h_{ie} = 1.1k\Omega$, $h_{fe} = 50$

Soln



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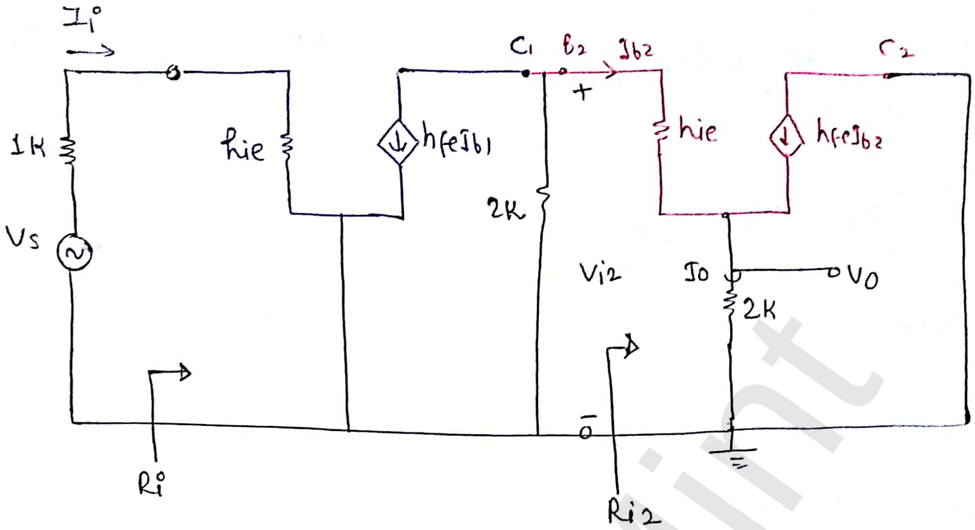


$I_o = (1+h_{fe})I_{b2}$

$V_{i2} = h_{ie}I_{b2} + (1+h_{fe})I_{b2} \times 2K$

$\frac{V_{i2}}{I_{b2}} = R_{i2} = h_{ie} + (1+h_{fe})2K$

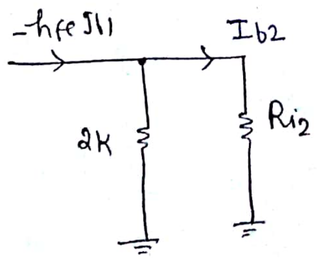
$= 1.1K + 51 \times 2K$

$R_{i2} = 103.1K$

$I_{b2} = \frac{2K}{2K + R_{i2}}(-h_{fe}I_{b1})$

$= \frac{2K \times (-50)}{2K + 103.1K} I_{b1}$

$\boxed{I_{b2} = -0.95 I_{b1}}$



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1. Current gain

$$A_I = \frac{I_o}{I_i} = \frac{(1+h_{fe}) I_{b2}}{I_{b1}} = \frac{(1+50) \cdot (-0.95) \cancel{I_{b1}}}{\cancel{I_{b1}}}$$

$$\boxed{A_I = -48.45}$$ Ans

2. I/p resistance.

$$R_i = \frac{V_i}{I_i}$$

$$V_i = I_i \times h_{ie}$$

$$R_i = h_{ie}$$

$$\boxed{R_i = 1.1 K\Omega}$$

3. Voltage gain

$$A_V = \frac{V_o}{V_s} = \frac{I_o \times 2K}{V_s}$$

$$= \frac{(1+h_{fe}) I_{b2} \times 2K}{V_s}$$

$$= \frac{51 \times (-0.95 \cancel{I_{b1}}) \times 2K}{\cancel{I_{b1}} (1K + h_{ie})} = 46.2144$$

$$-V_s + 1K I_{b1} + h_{ie} I_{b1} = 0$$

$$V_s = (1K + h_{ie}) I_{b1}$$

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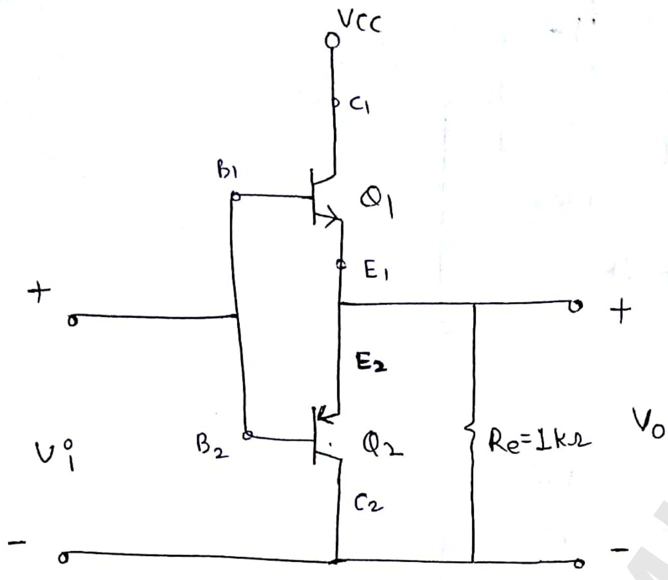
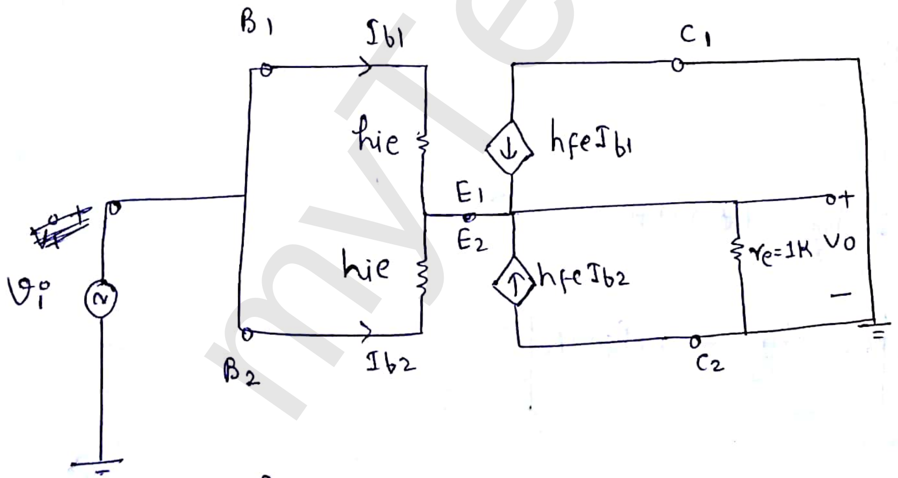
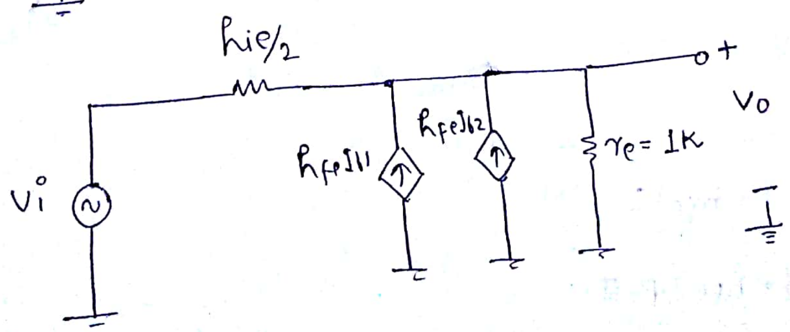
Q



Derive the expression for voltage gain A_v and i/p resistance R_i

Find the values of A_v and R_i if $h_{ie} = 1k\Omega$ $h_{fe} = 100$ $R_E = 1k\Omega$





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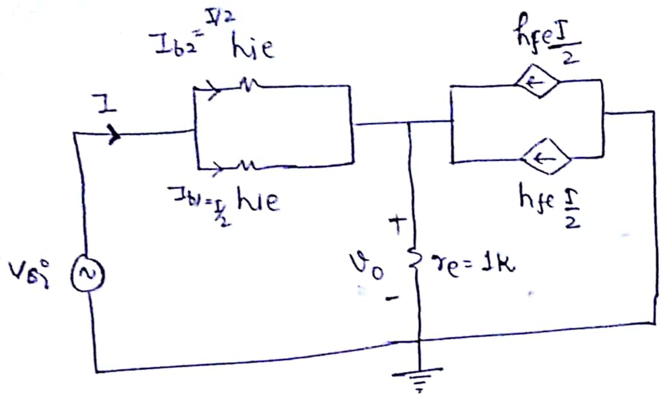

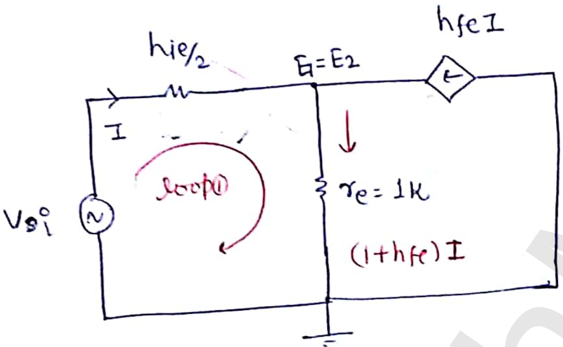

① Input resistance

$$R_i = \frac{v_i}{I}$$

KVL in loop ①

$$-v_i + I \times \frac{hie}{2} + R_e(1+h_{fe})I = 0$$

$$\frac{V_i}{I} = \boxed{R_i = \frac{hie}{2} + (1+h_{fe})R_e}$$

② Voltage gain

$$A_v = \frac{v_o}{v_i}$$

$$v_o = R_e \times (1+h_{fe}) I$$

$$\therefore \frac{v_o}{v_i} = \frac{(1+h_{fe}) R_e I}{\left[\frac{hie}{2} + (1+h_{fe}) R_e\right] I}$$

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$$\boxed{A_v = \frac{(1+h_{fe})R_e}{\frac{h_{ie}}{2} + (1+h_{fe})R_e}}$$

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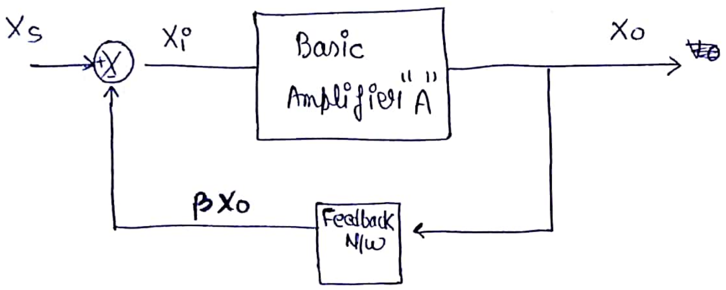
Feedback amplifier



generally in case of −ve f/b, f/b N/w is Resistive
" " " " +ve f/b f/d N/w is Combination of RLC

$$X_0 = AX_i \quad \text{—— (1)}$$

$$X_i = X_s - \beta X_0 \quad \text{—— (2)}$$

$$\Rightarrow X_i = X_s - \beta(AX_i)$$

$$\Rightarrow X_s = X_i + A\beta X_i$$

$$\Rightarrow X_s = (1 + A\beta)X_i$$

Open loop gain $= A = \dfrac{X_0}{X_i}$

Closed loop gain or Gain with feedback $= A_f$ or $A_{CL} = \dfrac{X_0}{X_s}$

$$\Rightarrow A_f = \frac{X_0}{X_s} = \frac{AX_i}{(1 + A\beta)X_i}$$

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

Stability of gain

if $\frac{\Delta A_f}{A_f} > \frac{\Delta A}{A}$ means close loop is more stable.

$\frac{\Delta A}{A} > \frac{\Delta A_f}{A_f}$ means ~~do~~ open loop is more stable.

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

Diff wrt 'A'

$$\frac{dA_f}{dA} = \frac{(1+A\beta)\cdot 1 - (0+\beta)A}{(1+A\beta)^2}$$

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

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

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

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

$$\boxed{\frac{dA_f}{A_f} = \frac{1}{(1+A\beta)} \frac{dA}{A}}$$ ★★★★ Remb^r this eq^n

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$$\Rightarrow \frac{dA_f}{A_f} < \frac{dA}{A} \quad [\because 1+A\beta > 1$$

For Objective type question

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

but $A\beta \gg 1$

$\beta \longrightarrow$ feedback factor or retransmission factor

$$A_f \approx \frac{A}{A\beta}$$

$$\Rightarrow \boxed{A_f \approx \frac{1}{\beta}}$$

Q An ampr with openloop voltage gain $A = 1000 \pm 100$ it is required to have an ampr whose gain varies no more than $\pm 0.2\%$ find

(1) Reverse transmission factor of the f/d N/w.

(2) gain with f/b

Soln $\frac{dA_f}{A_f} = 0.002$

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

$$0.002 = \frac{1}{(1+1000\beta)} \cdot \frac{\cancel{100}}{\cancel{1000}}$$

$$(1+1000\beta) = \frac{1}{10 \times 0.002} = \frac{100\cancel{0}}{2\cancel{0}} = 50$$

$$1000\beta = 49$$

$$\beta = \frac{49}{1000} = .049$$

$$\boxed{\beta = 0.049}$$

$$A_f = \frac{A}{1+A\beta} = \frac{1000}{1000 * 0.049 + 1} = 20 \text{ Ans}$$

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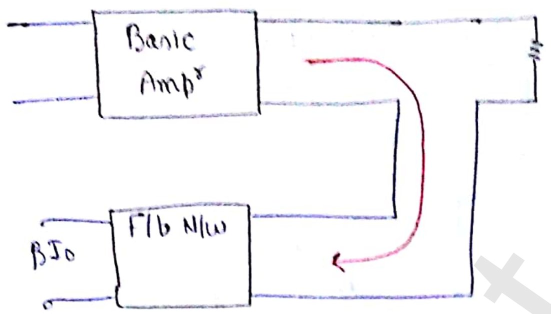
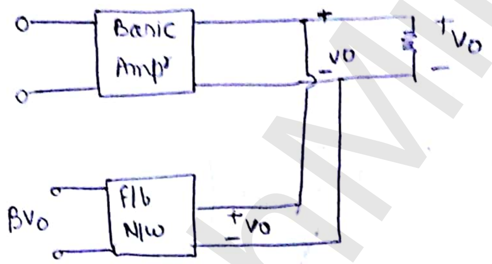
Sampling –





Sampling

(Current) Sampling — Series N/w → Current S/g → R_{of} (↑)

Shunt N/w (Voltage Sampling) → Voltage S/g → R_{of} (↓)

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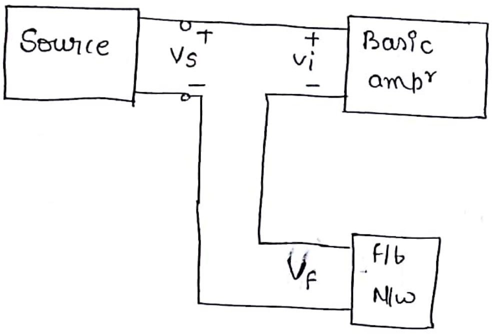
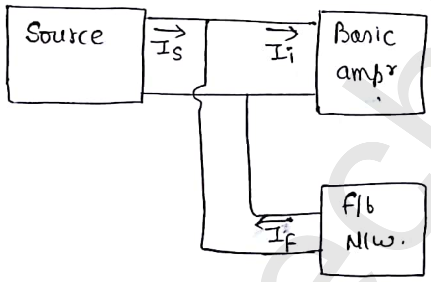
Mixing :-





Mixing

- Series → Voltage Signal → Rif (↑)
- Shunt → Current Signal → Rif (↓)

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Voltage → Sampling
Shunt → Mixing

Voltage → Sampling
Series → Mixing

Series → Mixing
Shunt → Sampling

Shunt → Mixing
Shunt → Sampling

S.No.	Type of f/b ampr	R_{if}	R_{of}
1.	Voltage Series or Series Shunt	$R_i(1+A\beta)$	$\frac{R_o}{(1+A\beta)}$
2.	Voltage Shunt or Shunt Shunt	$\frac{R_i}{(1+A\beta)}$	$\frac{R_o}{(1+A\beta)}$
3.	Current Series or Series Series	$R_i(1+A\beta)$	$R_o(1+A\beta)$
4.	Current Shunt or Shunt Series.	$\frac{R_i}{(1+A\beta)}$	$R_o(1+A\beta)$

R_i → open loop i/p resistance

R_o → open loop o/p resistance

$D = 1 + A\beta$

A → open loop gain.

β → Feedback factor.

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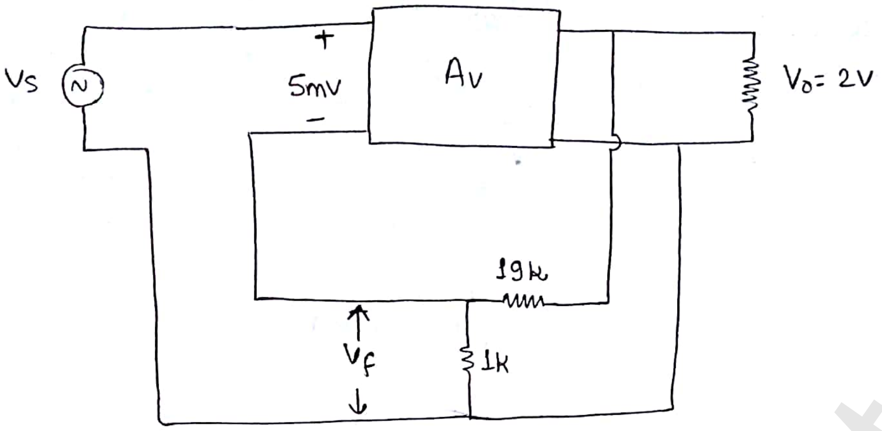
Q



For the voltage series f/b ampr shown below calc V_f f/b ratio β, A_v (voltage gain without f/b), and A_{vf} (with f/b)

Soln

$$V_f = \frac{V_o \times 1k}{20k} =$$

$$\boxed{V_f = \frac{V_o}{20}}$$

$$\boxed{V_f = \beta V_o}$$

$$\boxed{\beta = \frac{1}{20}}$$

$$A_v = \frac{V_o}{5mV} = \frac{2000}{5} = 400$$

$$A_v = 400$$

$$A_{vf} = \frac{A_v}{1 + A_v \beta} = \frac{400}{1 + \frac{400}{20}} = \frac{400}{1 + 20} = \frac{400}{21} = 19.04$$

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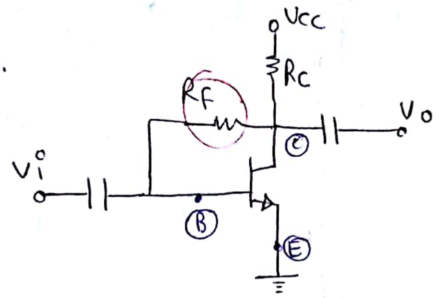
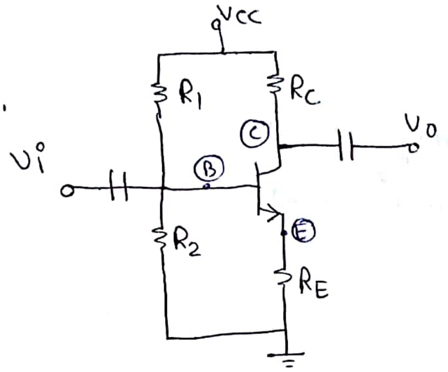
Q Identify the type of f/b in the ckt shown below

1.



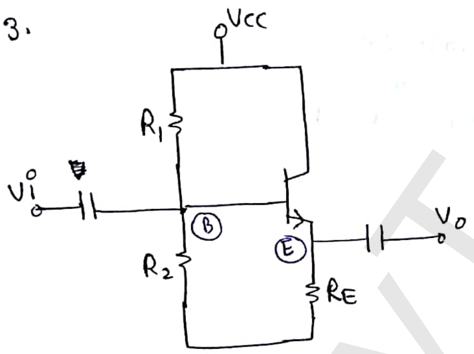
Voltage shunt
or
Shunt Shunt

2.



Current series.
or
Series Series.

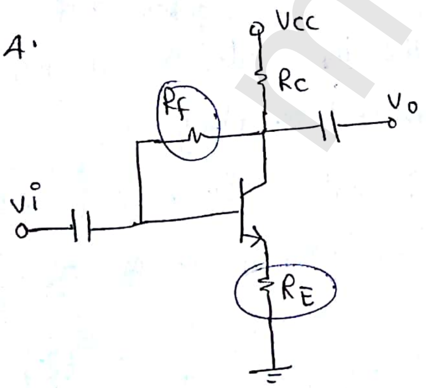
3.



Voltage ~~Series~~ Series.
or
Series Shunt

Qu.
{ In Buffer ampr which type of f/b
{Voltage ser}.

4.



→ A ckt can have multiple f/b

→ R_F creates voltage shunt f/b while R_E creates current series f/b.

Qu. If capr is connected across R_E then voltage shunt f/b bcz effect of R_E is removed.

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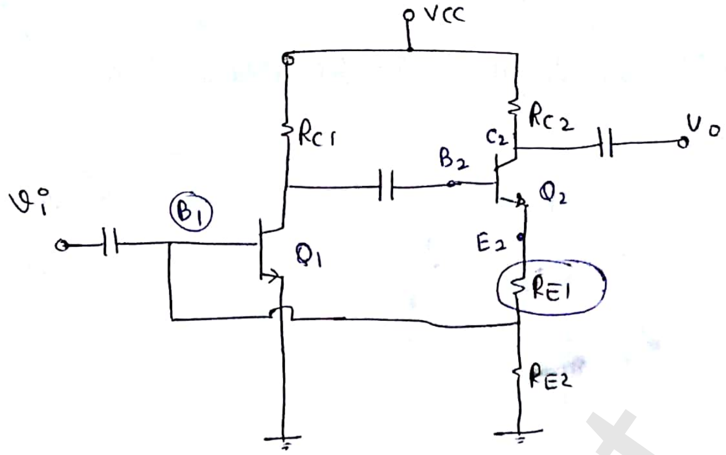
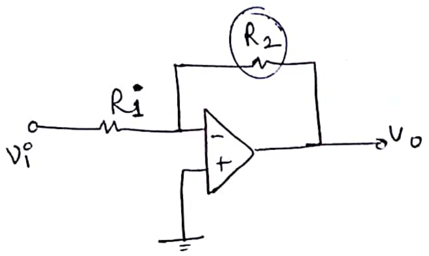
(5)

Current shunt
or
shunt series

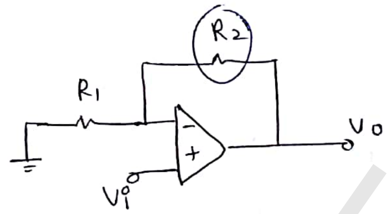


(6)



Voltage shunt
or
Shunt shunt

(7)



Voltage series
or
Series shunt.

Procedure to identify the type of f/b

step(1) Identify the element responsible for feedback

step(2) If f/b element is directly connected to the o/p node of basic ampr. then it indicates voltage sampling otherwise it indicates current sampling

step(3) If f/b element is directly connected to the i/p node of Basic ampr then it indicates shunt mixing otherwise it indicates series mixing.

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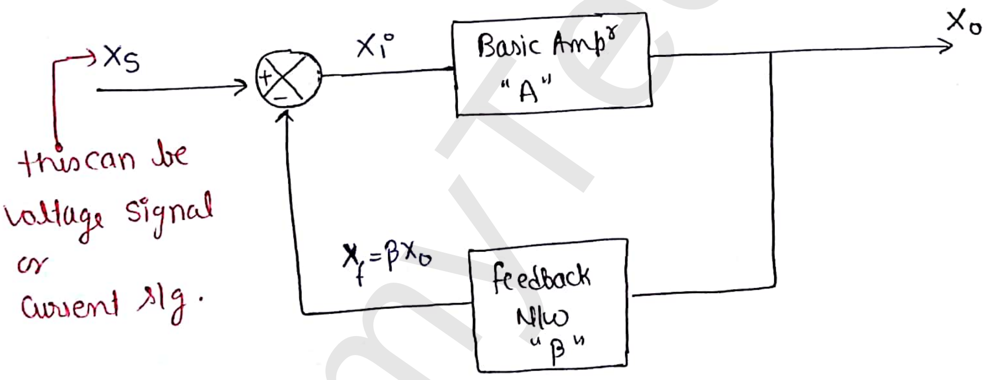
Oscillators :- ckts in which no ac i/p given but we get ac o/p.
but we give dc i/p in osc.

diff^{ce} b/w multivibrator and Oscillator

- multivibrator ↓ we can get
  - Squarewave
  - triangularwave
- Oscillator ↓ gives single freq^{c} o/p

multi + vibrator
↓ many ↓ freq^{c}
multiple frequencies

Q Show that a f/b amp^{r} can be made to work as an oscillator



$$X_o = A X_i$$

$$X_f = \beta X_o = A\beta X_i$$

$$X_i = X_s - X_f$$

$$X_i = X_s - A\beta X_i$$

$$X_s = X_i(1 + A\beta)$$

$$A_f = \frac{X_o}{X_s} = \frac{A X_i}{X_i(1+A\beta)} =$$

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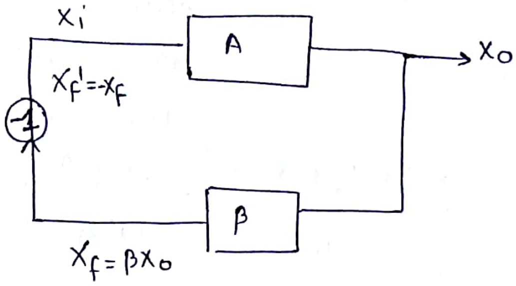
$$\Rightarrow A_f = \frac{A}{1 + A\beta} \longrightarrow (1)$$



why loop gain is like this

$$\text{Loop gain} = \frac{X_f'}{X_i} = \frac{-X_f}{X_i} = \frac{-A\beta X_i}{X_i} = -A\beta$$

but $X_f' = X_i$

so loop gain $[-A\beta] = 1$

so from eqⁿ (1)

$$A_f = \frac{A}{1 + (-1)}$$

$$A_f = \frac{A}{0} \longrightarrow \infty$$

gain is ∞ means.

There is just ~~in~~ an o/p slg even in the absence of an externally applied i/p slg. the condⁿ $[-\beta A] = 1$

why only these condⁿ for oscillation

$$\Rightarrow |[-\beta A]| = 1$$

$$\Rightarrow \angle[-\beta A] = 0^\circ \text{ or } 2n\pi$$

$\Rightarrow$ condⁿ for oscillation

This is called Barkhausen Criterion

for oscillator ideally loop gain should 1 and phase shift ~~will~~ should be 0°.

It is not that only +ve f/b gives oscillation.

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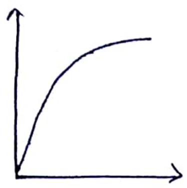
Non linear devices की वजह से amplitude घटता है

this is the o/p of oscillator which can be ↑ing in nature due to non linearity of device. but after a fix value it will stop ↑ing. i.e called ONSET OF NON-LINEARITY



$$i_c = \frac{k_1 + k_2 i_b + k_3 i_b^3}{k_4 i_b^4}$$

due to ONSET of Non-linearity. the o/p of oscillator can't increase beyond a fix value.

Oscillator
- Audio frq^c osc
  - RC phase shift osc
  - Wien Bridge osc
- Radio frq^c osc (RF)
  - LC oscillator
    - Hartley osc
    - Colpitt osc
    - Clapp's osc
  - Quartz crystal osc

Q colpit is used at which frq^c Range

Sol^n - Radio frq^c Range

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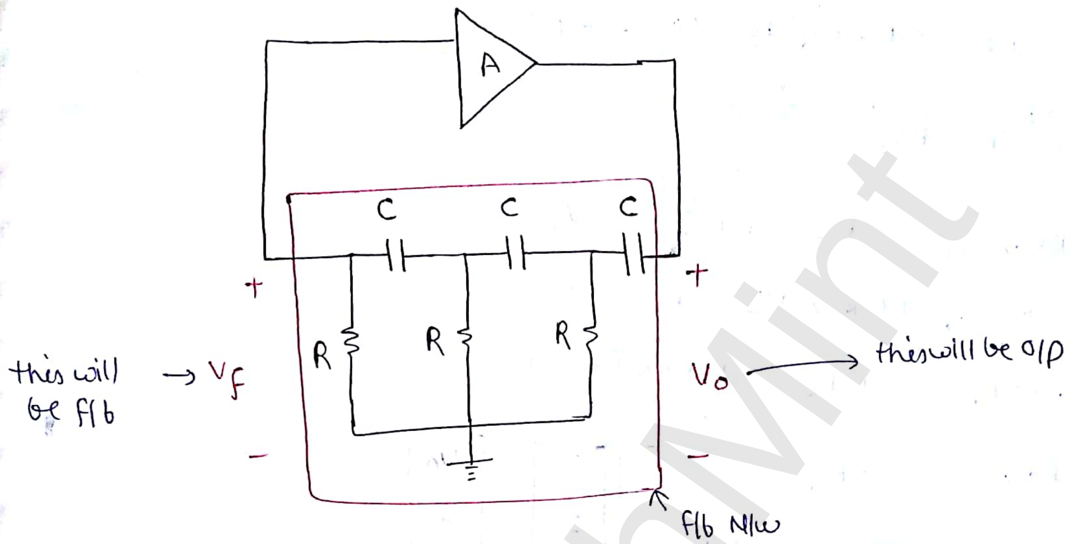
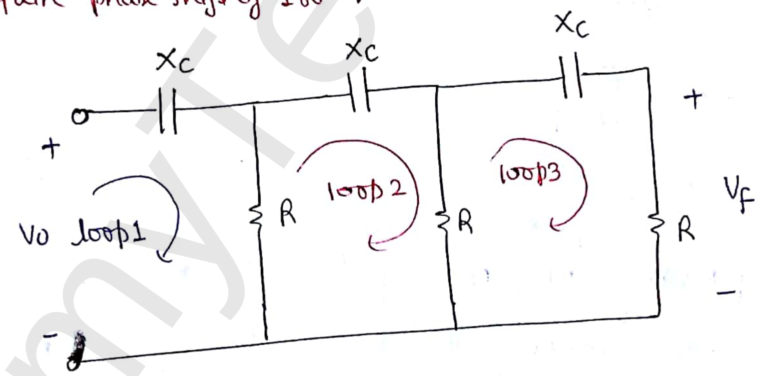
Q Derive the condⁿ of oscillation and the expression for freq of oscillation for the ckt shown below.



One alone capc can provide 90° but with R i.e RC provide phase shift less than 90° so 3 RC ckts are required.

Q why we require phase shift of 180°?



KVL: loop1

$$-V_o + X_C I_1 + R(I_1 - I_2) = 0$$

$$(R + X_C)I_1 - RI_2 = V_o \longrightarrow ①$$

KVL in loop 2

$$X_C I_2 + R(I_2 - I_3) + R(I_2 - I_1) = 0$$

$$X_C I_2 + R(2I_2 - I_3 - I_1) = 0$$

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$$-RI_1 + (2R+X_c)I_2 - RI_3 = 0 \quad \text{--- (2)}$$

KVL in loop (3)

$$X_cI_3 + RI_3 + R(I_3 - I_2) = 0$$

$$-RI_2 + (2R+X_c)I_3 = 0 \quad \text{--- (3)}$$

we know $V_f = RI_3$

$$(R+X_c)I_1 - RI_2 + 0 \cdot I_3 = V_0$$

$$-R I_1 + (2R+X_c)I_2 - RI_3 = 0$$

$$+0I_1 - RI_2 + (2R+X_c)I_3 = 0$$

$$\begin{bmatrix} (R+X_c) & -R & 0 \\ -R & 2R+X_c & -R \\ 0 & -R & (2R+X_c) \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_0 \\ 0 \\ 0 \end{bmatrix}$$

using crammers rule

$$\boxed{I_3 = \frac{\Delta_3}{\Delta}}$$

where

$$\Delta = \begin{vmatrix} R+X_c & -R & 0 \\ -R & 2R+X_c & -R \\ 0 & -R & 2R+X_c \end{vmatrix}$$

$$= (R+X_c)\left[(2R+X_c)^2 - R^2\right] + R\left[-2R^2 - RX_c\right]$$

$$\Delta = (R+X_c)\left[4R^2 + X_c^2 + 4RX_c - R^2\right] - 2R^3 - R^2X_c$$

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$$= (R+X_c)(3R^2+X_c^2+4RX_c) - 2R^3 - R^2X_c$$

$$= 3R^3 + RX_c^2 + 4R^2X_c + 3R^2X_c + X_c^3 + 4RX_c^2 - 2R^3 - R^2X_c$$

$$\boxed{\Delta = R^3 + X_c^3 + 6R^2X_c + 5RX_c^2}$$

How we → find this?

$$\Delta^3 = \begin{vmatrix} R+X_c & -R & V_0 \\ -R & 2R+X_c & 0 \\ 0 & -R & 0 \end{vmatrix} = V_0R^2$$

$$V_f = I_3 \cdot R$$

$$V_f = \frac{\Delta_3}{\Delta} \cdot R$$

$$V_f = \frac{V_0 R^2}{R^3 + X_c^3 + 6R^2X_c + 5RX_c^2} \cdot R$$

$$\Rightarrow \frac{V_f}{V_0} = \beta = \frac{R^3}{R^3 + X_c^3 + 6R^2X_c + 5RX_c^2}$$

$$\Rightarrow \beta = \frac{1}{1 + \left(\frac{X_c}{R}\right)^3 + 6\left(\frac{X_c}{R}\right) + 5\left(\frac{X_c}{R}\right)^2}$$

put $X_c = \frac{1}{j\omega C}$

$$\beta = \frac{1}{1 + \frac{1}{(j\omega RC)^3} + \frac{6}{j\omega RC} + 5 \cdot \frac{1}{(j\omega RC)^2}}$$

Let us assume $\alpha = \frac{1}{\omega RC}$

so

$$\beta = \frac{1}{1 + j\alpha^3 - j6\alpha - 5\alpha^2}$$

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

Loop gain $= A\beta$

$$= \frac{A}{(1-5\alpha^2) + j(\alpha^3 - 6\alpha)}$$

To satisfy Barkhausen criterion

$$\angle A\beta = 0^\circ \text{ or } 2n\pi$$

$$\text{so } \mathrm{Img}[A\beta] = 0^\circ \quad \text{at} \quad \omega = \omega_0$$

$$\alpha^3 - 6\alpha = 0$$

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

α cant be 0 so $\alpha^2 - 6 = 0$

$$\alpha^2 = 6$$

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

At $\omega = \omega_0$

$$\alpha = \frac{1}{\omega_0 RC} = \sqrt{6}$$

$$\boxed{\begin{array}{l} \omega_0 = \dfrac{1}{\sqrt{6}\,RC} \text{ rad/sec} \\[2ex] f = \dfrac{1}{2\pi RC\sqrt{6}} \text{ Hz} \end{array}}$$

$\Rightarrow$ frequency of oscillation

क्या मैं RC की ऐसी value choose नहीं कर सकता हूँ तो phase shift 70% दे तो 3 RC ckt का phase shift 210° हो जाएगा पर उस RC के corresponding की तो हैं उन freq मिलेगी

or

या मुझे R and C की ऐसी ही value choose करनी है जिससे phase shift 60° मिले

क्या R and C के different different combination के लिए phase shift 60° हो सकता है?

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condition of oscillation

$|A\beta| = 1$ at $\omega = \omega_0$

For sustained oscillation

$$\left|\frac{A}{(1-5\alpha^2)+j0}\right| \geq 1$$

For practical oscillation the gain $|A\beta|$ should be slightly > than 1 so that if due to some improperness if gain dec. then it must not fall below 1.

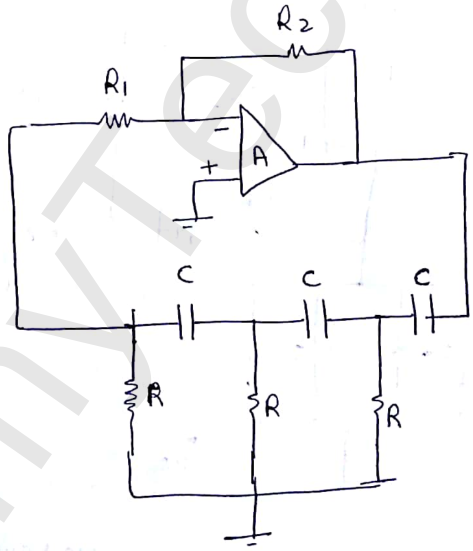
oscillations are occuring that means imaginary part is 0. or imag. part is 0 that's why oscillations are there.

$$\Rightarrow \left|\frac{A}{1-5\times 6}\right| \geq 1$$

$|A| \geq 29$

$$\boxed{|A| \geq 29}$$

actual ckt of RC phase shift oscillator



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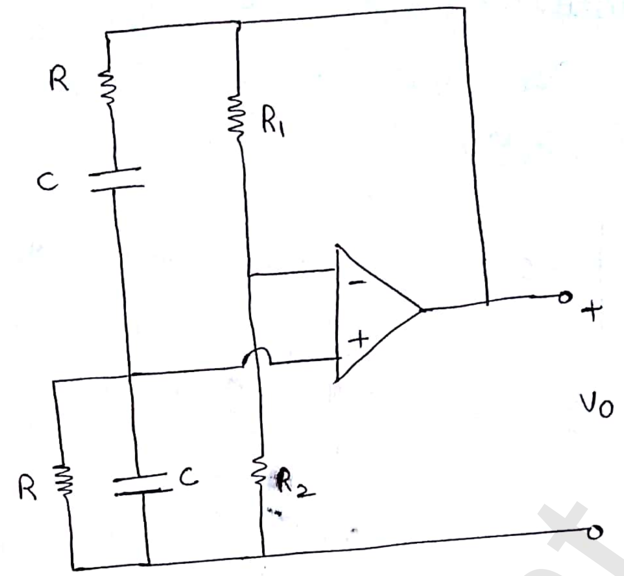
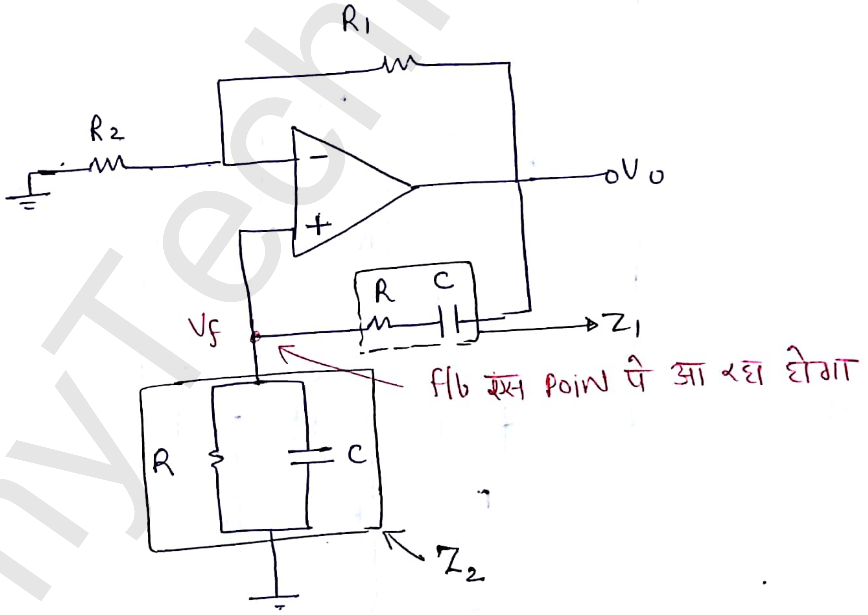
Q



obtain the condn under which the ckt below produce oscillation what is the frqc of oscillation.

Soln

wein Oscillator



$$V_f = \frac{Z_2}{Z_1+Z_2} \cdot V_0$$

$$= \frac{V_f}{V_0} = \beta = \frac{Z_2}{Z_1+Z_2}$$

We have two f/b
(1) R_1
(2) RC
2nd f/b will be dominating and providing phase shift
-ve f/b in opamp work as ampr. but we want to operate it as an oscillator.

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Now

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

$$Z_2 = \frac{R \times \frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} = \frac{R/j\omega C}{\frac{1 + j\omega RC}{j\omega C}}$$

$$Z_2 = \frac{R}{1 + j\omega RC}$$

$$\beta = \frac{\frac{R}{1+j\omega RC}}{\frac{1+j\omega RC}{j\omega R} + \frac{R}{1+j\omega RC}}$$

$$A\beta = \frac{A}{3 + j\left(\omega RC - \frac{1}{\omega RC}\right)}$$

at $\omega = \omega_0$, phase shift of loop gain should be zero

$$\therefore \omega_0 RC - \frac{1}{\omega_0 RC} = 0$$

$$\Rightarrow \boxed{\begin{aligned} \omega_0 &= \frac{1}{RC} \text{ rad/sec} \\ f_0 &= \frac{1}{2\pi RC} \text{ Hz} \end{aligned}}$$

For sustained oscillation

$$|A\beta| \geq 1$$

$$\frac{|A|}{3} \geq 1$$

$$\boxed{|A| \geq 3}$$

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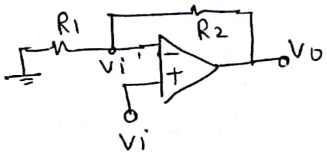
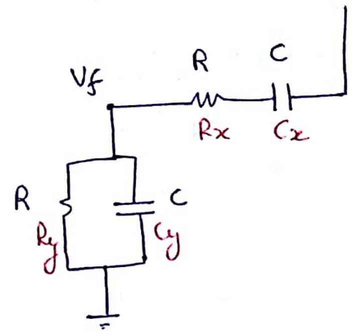
open loop gain of op amp. Without f/b

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



$$\therefore\ 1 + \frac{R_1}{R_2} \geq 3$$

$$\Rightarrow \boxed{R_1 \geq 2R_2}$$



Note*

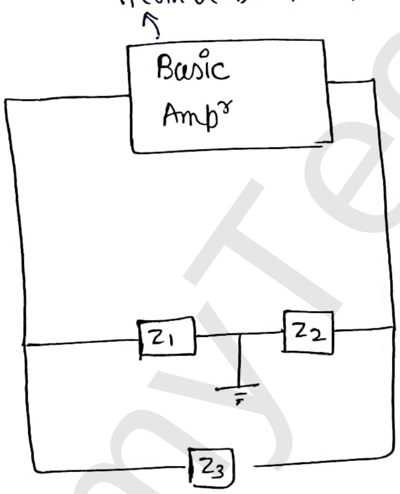
$$f_0 = \frac{1}{2\pi\sqrt{R_x R_y C_x \cdot C_y}}$$

$$|A| \geq 1 + \frac{R_x}{R_y} + \frac{C_y}{C_x}$$

$1 + \frac{R_x}{R_y} + \frac{C_y}{C_x} \Rightarrow$ should not be less than 3.

so $R_x > R_y$ and $C_y > C_x$

LC oscillators



S.NO.	Type of LC OSC	Z_1	Z_2	Z_3
1.	Hartley	—mmm—	—mmm—	—||—
2.	Colpitts c cap^c are dominating.	—||—	—||—	—mmm—
3.	clapp's	—||—	—||—	—mmm—||—

Clap is modification of Colpitt.

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To calculate resonant freq^c

$\boxed{X_1+X_2+X_3=0}$ at $\omega=\omega_0$

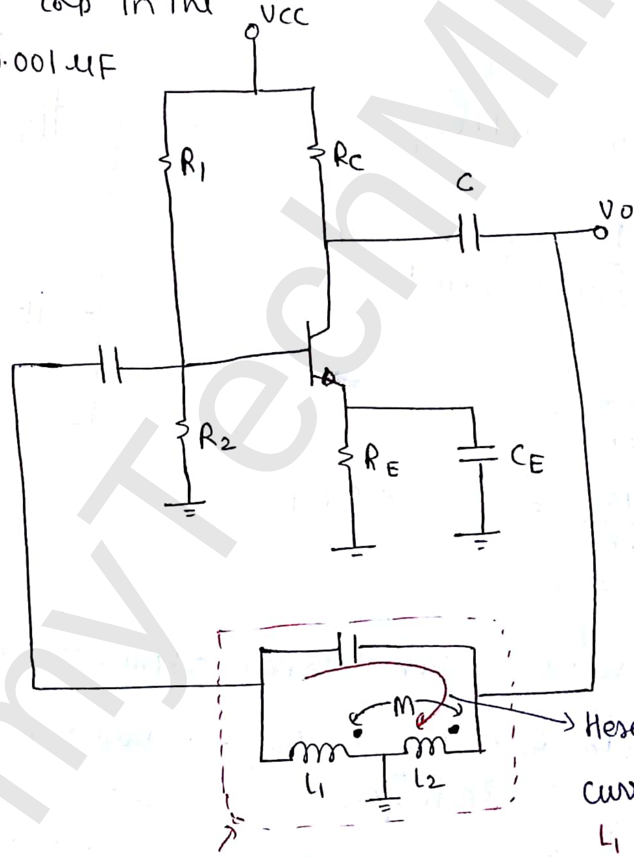
where X's are reactances without j term.

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

$X_C = \frac{-j}{\omega C}$ — j removed.

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

Q consider the Hartley oscillator ckt shown below given $L_1 = 100\,\mu H$, $L_2 = 100\,\mu H$ the mutual inductance b/w L_1 and L_2 is $20\,\mu H$ what is the freq^c of oscillation for given ckt if cap^c in the F/b N/w is of $0.001\,\mu F$



Here we will flow a current current in C, L_1 and L_2 will be same i.e $L_1 L_2$ and C are in series for both L_1 and L_2 current entering from •(dot) so additive polarity.

this is F/b N/w.

Sol^n

$$f_0 = \frac{1}{2\pi\sqrt{L_{eq}C_{eq}}} = \frac{1}{2\pi\sqrt{L_{eq}C}}$$

$$L_{eq} = L_1 + L_2 + 2M$$
$$= 100 + 100 + 2 \times 20$$
$$= 240\,\mu H$$

$$f_0 = \frac{1}{2\pi\sqrt{240\times10^{-6} \times 0.001\times10^{-6}}}\ Hz.$$

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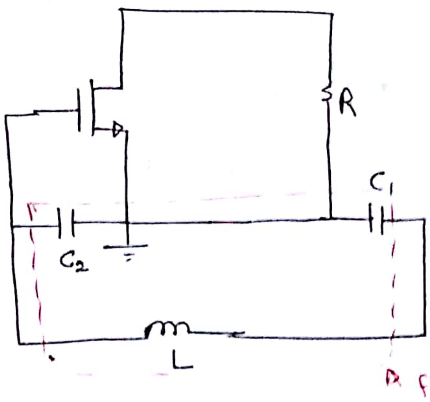
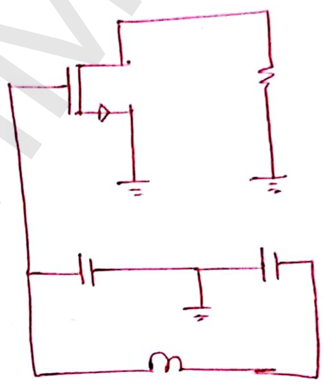
Q



Consider colpitt osc. ckt shown above with $L = 1\mu H$ $C_1 = 1nF$ $C_2 = 1nF$ $R = 4K\Omega$ what is the frq of osc for the ckt.

$$f_0 = \frac{1}{2\pi\sqrt{L_{eq}C_{eq}}} = \frac{1}{2\pi\sqrt{LC_{eq}}}$$



$$f_0 = \frac{1}{2\pi\sqrt{10^{-6}\times 0.5\times 10^{-9}}} \text{ Hz}$$

$$C_{eq} = \frac{C_1C_2}{C_1+C_2}$$

$$= \frac{1\times 1}{1+1} = \frac{1}{2} = 0.5\, nF$$

if R is across C_1 then it is not colpitt osc. so we can't calculate from the Formula $f_0 = \frac{1}{2\pi\sqrt{L_{eq}C_{eq}}}$ so we need to calc ~~seperately~~ fo from complete process.

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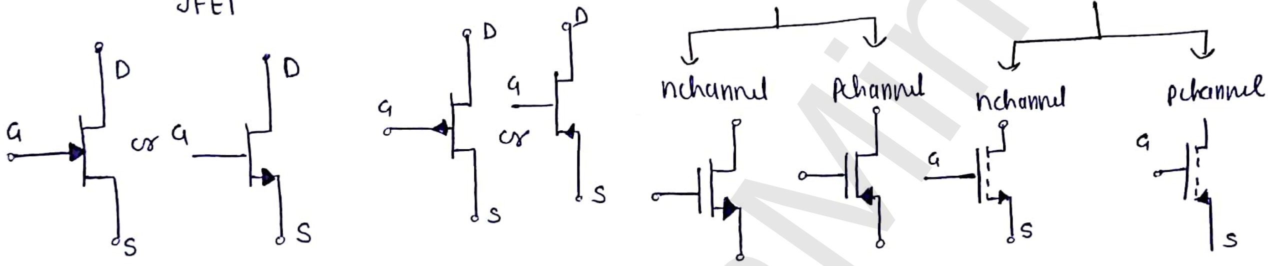
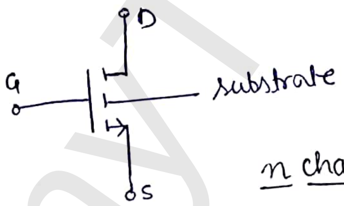
Field Effect Transistor

- FET
  - JFET
    - n-channel JFET
    - p-channel JFET
  - MOSFET
    - Depletion type MOSFET
      - nchannel
      - Pchannel
    - Enhancement type MOSFET
      - nchannel
      - pchannel



Depletion mosfet and JFET show same char^r. ~~Show~~ follow same mathematical equations $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

one more MOSFET



n channel

Biggest advantage of JFET is its i/p resistance is very high. whereas in BJT it is very low.

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For JFET and Depletion type MOSFET

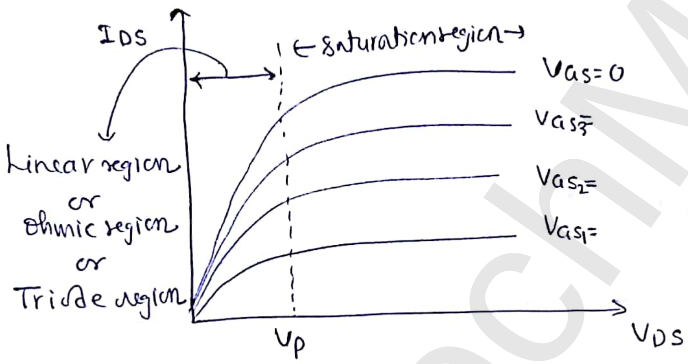
Drain Current

$$I_{DS} = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

where $I_{DSS} \rightarrow$ Drain to source saturation current (when $V_{GS} = 0$)

$V_P \rightarrow$ pinch off voltage

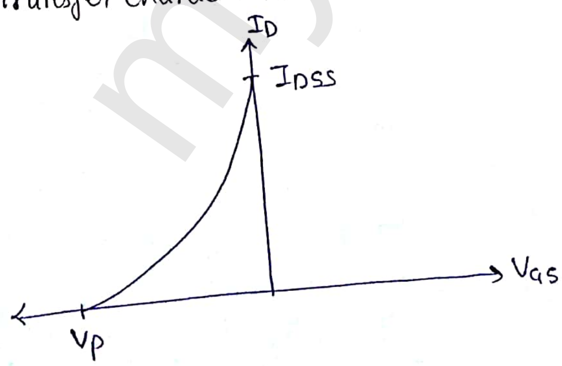
O/P Characteristics



⇒ Used as an ampr in saturation region. For sat. region

$$V_{DS} \geq |V_{GS}| - |V_P|$$

Transfer characteristics.



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For Enhancement type MOSFET

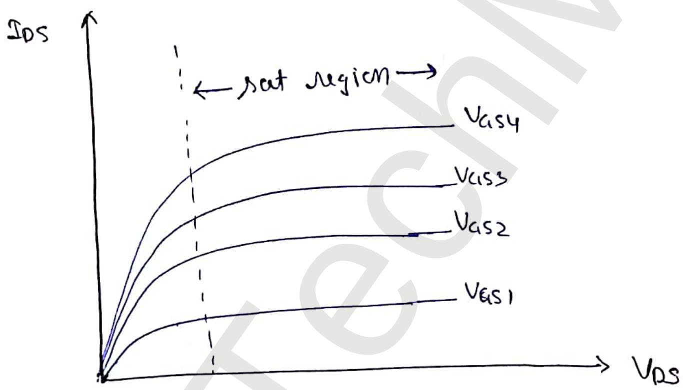
Drain to Source current

$$I_{DS} = K_n (V_{GS} - V_T)^2$$

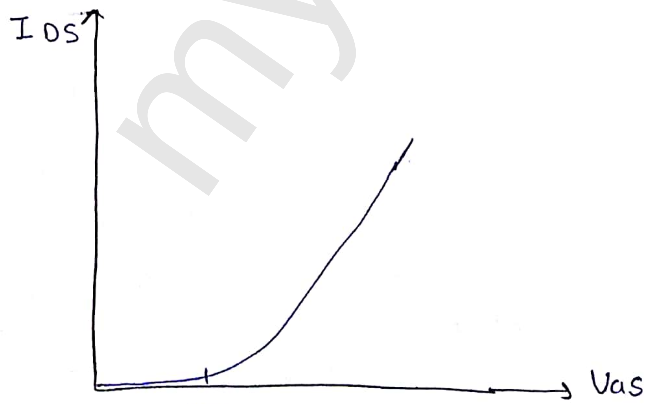
where $K_n = \frac{1}{2} \mu_n C_{ox} \frac{W}{L}$ $\qquad K_n = \frac{1}{2} K_n' \frac{W}{L}$

$$\boxed{I_{DS} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2}$$

O/p Characteristics



<u>Transfer characteristics</u>



↓

threshold Voltage

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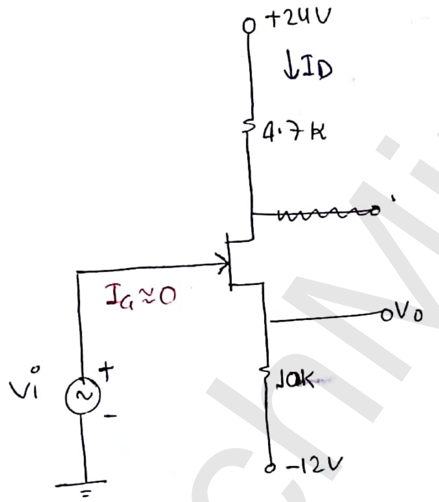
Q The FET shown below has following parameter $I_{DSS} = 5.6mA$ and $V_p = -4V$

a) If $V_i = 0$ find V_o

b) if $V_i = 10V$ find V_o

c) if $V_o = 0V$ find V_i

d)



$I_G \approx 0$ is assumption that we take while solving FET questions.

Soln.

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$I_D = 5.6mA\left(1 - \frac{V_{GS}}{(-4)}\right)^2$$

$$-V_i + \cancel{0} \overset{V_{GS}}{} + 10K I_D - 12$$

$$V_{GS} = 12 - 10K I_D$$

$$V_{GS} = 12 - 10 I_D$$

$$I_D = 5.6\left(1 + \frac{12 - 10 I_D}{4}\right)^2$$

$$\frac{16}{5.6} I_D = (4 + 12 - 10 I_D)^2$$

$$2.86 I_D = 196 + 100 I_D^2 - 320 I_D$$

$$100 I_D^2 - 322.86 I_D + 196 = 0$$

$$I_D = \frac{322.86 \pm \sqrt{(322.86)^2 - 4 \times 100 \times 196}}{200}$$

$$I_D = \frac{322.86 \pm 160.74}{200} = 2.418mA, \quad 0.8106mA$$

-12.16 $\qquad$ 3.894

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By Sir

$V_i = 0$

$V_{GS} + 10K\, I_{DS} - 12 = 0$

$$I_{DS} = \frac{12 - V_{GS}}{10}\ mA$$

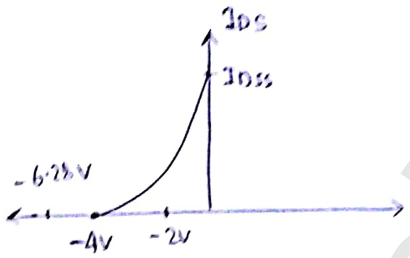
but

$$I_{DS} = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$\frac{12 - V_{GS}}{10}\ mA = 5.6mA\left(1 + \frac{V_{GS}}{4}\right)^2$$

$V_{GS} = -2V$ ✓

$= -6.28V$ (✗)



$V_{GS} = -2$

$$I_{DS} = \frac{12 + 2}{10} = 1.4mA$$

(ii) $V_i = 10V$

$-10 + V_{GS} + 10K\, I_{DS} - 12 = 0$

$$I_{DS} = \frac{22 - V_{GS}}{10}\ mA$$

$$\frac{22 - V_{GS}}{10}\ mA = 5.6mA\left(1 + \frac{V_{GS}}{4}\right)^2$$

$V_{GS} = -1.413\ V$ (✓)

$= -6.87\ V$ (✗)

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$\therefore \; I_{DS} = \dfrac{22 + \cancel{1.142}^{\,1.413}}{10} = \cancel{2.214}^{\,2.341}\ mA$

$V_o = 10 \times 2.214 - 12$

$= 10.14$

(iii) $V_o = 0$

$\cancel{V_o = 10k\, I_{DS} - (-12)}$

$V_o = 10k\, I_{DS} - 12$

$\boxed{I_{DS} = 1.2mA}$

$$1.2mA = 5.6mA\left[1 + \frac{V_{GS}}{4}\right]^2$$

$V_{GS} = -2.148\,V$ ✓

$= -5.85\,V$ ✗

$\boxed{V_{GS} = -2.148\,V}$

$V_{GS} = V_G - V_S$

$V_{GS} = V_i - 0$

$\boxed{V_i = V_{GS} = -2.418\,V}$ Ans

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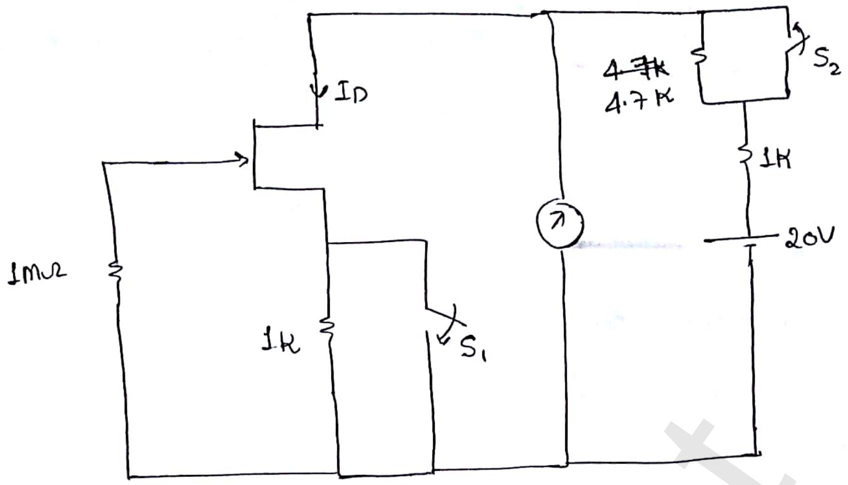
$\underline{Q}$



In the ckt of JFET shown below

① Find I_{DSS} when Both switches S_1 and S_2 are closed take the reading of the dc voltmeter as 10 V

② Find the operating point and dc voltmeter reading when both switches are open given $V_p = -5V$

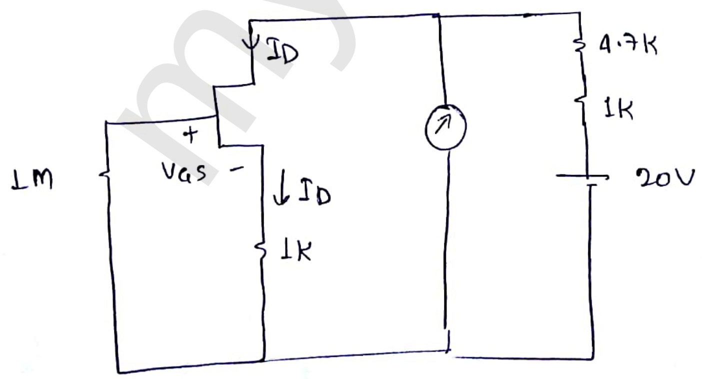
Soln ① S_1 an S_2 are short ckt

$V_{GS} = 0$

$I_D = I_{DSS}$

$$I_D = I_{DSS} = \frac{20-10}{1K} = 10\,mA$$

②



$V_{GS} + I_D\,1K = 0$

$\boxed{I_D = -V_{GS}\ mA}$

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$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$-V_{GS}\,mA = 10\,mA\left(1 + \frac{V_{GS}}{5}\right)^2$$

$$V_{GS} = -2.5\,V$$
$$= -10\,V$$

$$\boxed{V_{GS} = -2.5\,V}$$

$$\boxed{I_D = 2.5\,mA}$$

$$-20 + 6.7k\,I_D + V_{DS} = 0$$

$$V_{DS} = 20 - 6.7 \times 2.5$$

$$\boxed{V_{DS} = 3.25\,V}$$

Operating point
= (3.25 V, 2.5mA)

Reading of voltmeter = $V_{DS} + I_D \times 1k$

$$= 3.25 + 2.5$$

$$= \cancel{3.45}\ 5.75 \text{ volt}$$

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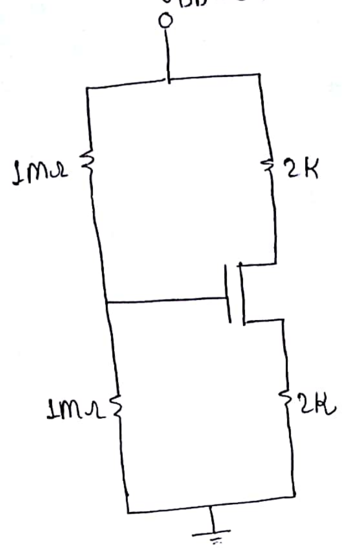
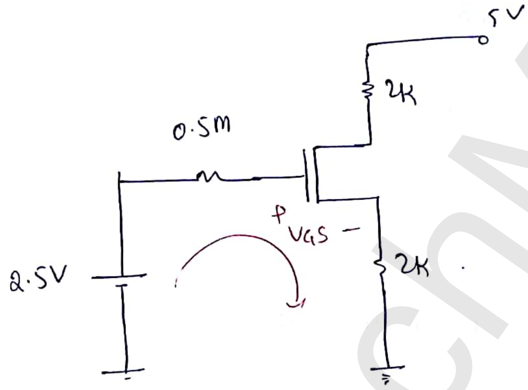
Q



Calculate I_{DS} and V_{DS} for the ckt shown below assume $V_T = 1$ volt and $k_n'\left(\frac{W}{L}\right) = 1\,mA/V^2$

$\mu_n C_{ox} \frac{W}{L} = 1\,mA/V^2$

Sol^n



$2.5 = V_{GS} + I_{DS}\,2K$

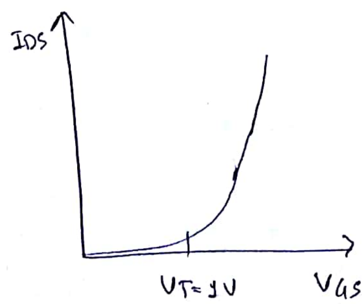
$I_{DS} = \frac{2.5 - V_{GS}}{2}\,mA$

but $I_{DS} = \frac{1}{2}\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2$

$\left(\frac{2.5 - V_{GS}}{2}\right) mA = \frac{1}{2}\, 1\, (V_{GS} - 1)^2$

$V_{GS} = 1.82\,V$ ✓

$V_{GS} = -0.32\,V$ ✗



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$V_{GS} = 1.82\,V$

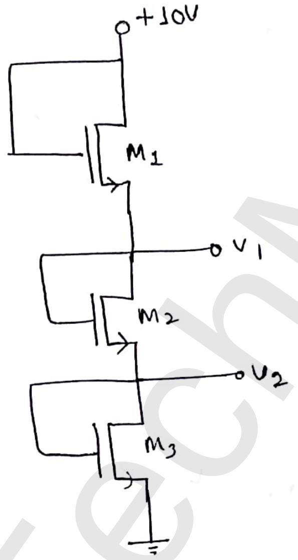
$I_{DS} = \frac{2.5 - 1.82}{2}\,mA$

$V_{DS} = 5 - 4k \times \left(\frac{2.5 - 1.82}{2}\right) m$

$= \cancel{5 - 4}\times$

$V_{DS} = 3.64$ Volt

Question



In the ckt shown below the transistor parameters are $V_T = 1V$ and $k_n' = 36\,\mu A/V^2$ if $I_{DS} = 0.5\,mA$ $V_1 = 5V$, $V_2 = 2V$ then calc the $\frac{W}{L}$ ratio required in each transistor

Solution : "If Drain and gate are shorted then MOSFET is in saturation"

$V_D = V_G$

$V_D - V_S = V_G - V_S$

$V_{DS} = V_{GS}$

$V_{DS} > V_{GS} - V_T$

$\Rightarrow$ If $\boxed{V_{DS} \geq V_{GS} - V_T}$ $\Rightarrow$ MOSFET in saturation

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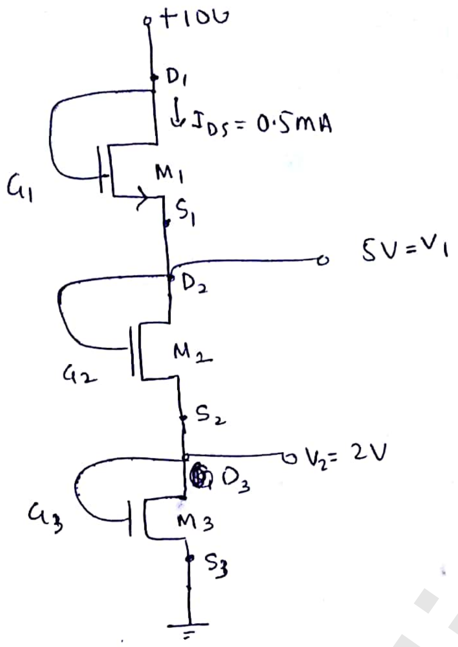

For M1

$$V_{G1S1} = V_{G1} - V_{S1}$$

$$= 10 - 5 = 5V$$

$$\text{So } I_{DS} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS1} - V_T)^2$$

$$0.5mA = \frac{1}{2} \times 36\mu \times \left(\frac{W}{L}\right)_1 (5-1)^2$$

$$\boxed{\left(\frac{W}{L}\right)_1 = 1.736}$$

For M2

$$V_{G2} = V_1 = 5V$$

$$V_{S2} = V_2 = 2V$$

$$\therefore V_{G2S2} = 5 - 2 = 3V$$

$$0.5m = \frac{1}{2} \times 36\mu \times \left(\frac{W}{L}\right)_2 (3-1)^2$$

$$\left(\frac{W}{L}\right)_2 = 6.94$$ Ans

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For M_3

$V_{G3} = V_2 = 2V$

$V_{S3} = 0$

$V_{G3S3} = 2V$

$0.5\,m = \frac{1}{2}\,36\mu \left(\frac{W}{L}\right)_3 \times (2-1)^2$

$\boxed{\left(\frac{W}{L}\right)_3 = 27.7}$ Am

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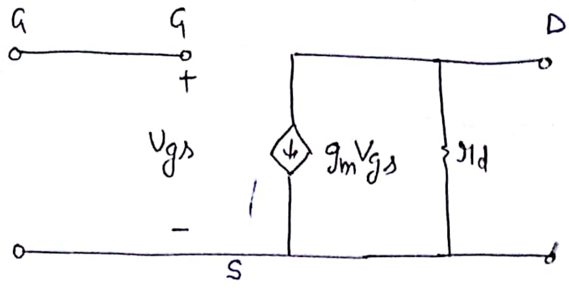
FET AC Analysis or AC Eq^v model



r_d - drain to source ac resistance

$$r_d = \frac{1}{\text{slope of o/p characteristics}}$$

$$\boxed{r_d = \frac{1}{\lambda I_{DS}}}$$

I_{DS} – Drain to source Q point current DC bias current

$\lambda \rightarrow$ channel length modulation parameter.

$V_A = \frac{1}{\lambda} \rightarrow$ Early voltage of FET

If channel length modulation is negligible or λ is not given then

$r_d \longrightarrow \infty$

Q unit of $\lambda = \frac{1}{V_A} = \text{volt}^{-1}$

~~λ is calculated by slope of transfer characteri~~stic

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g_m

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}}$$

For JFET and depletion type mosfet:

$$I_{DS} = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$\frac{\partial I_{DS}}{\partial V_{GS}} = \frac{\partial I_{DS}}{\partial V_{GS}} = I_{DSS} \times 2\left(\frac{-1}{V_P}\right)\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$g_m = \frac{-2I_{DSS}}{V_P}\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$\boxed{g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right)} \quad \text{--- (I)}$$

or

$$\boxed{g_m = g_{mo}\left(1 - \frac{V_{GS}}{V_P}\right)} \quad \text{--- (II)} \quad \text{where } g_{mo} = \frac{2I_{DSS}}{|V_P|}$$

Q. objective

g_m vs I_{DS} — parabola curve

g_m vs V_{GS} — straight line

in BJT is g_m is exponential func of i/p voltage. so g_m ↑es rapidly bcz exponential curve ↑es faster.

* Transconductance of FET is less than BJT due to which gain of FET ↓es. (disadvantage)

$A_v \propto g_m$

$A_v = -g_m R_L$

* gain is less

we have

$$\left(1 - \frac{V_{GS}}{V_P}\right) = \sqrt{\frac{I_{DS}}{I_{DSS}}}$$

so

$$g_m = \frac{2I_{DSS}}{|V_P|} \times \sqrt{\frac{I_{DS}}{I_{DSS}}}$$

$$\Rightarrow \boxed{g_m = \frac{2}{|V_P|}\sqrt{I_{DS} \cdot I_{DSS}}}$$

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g_m for Enhancement type MOSFET

$$I_{DS} = K_n (V_{GS} - V_T)^2 \quad -①$$

$$\frac{\partial I_{DS}}{\partial V_{GS}} = 2K_n (V_{GS} - V_T)$$

$$\boxed{g_m = 2K_n (V_{GS} - V_T)} \quad -②$$

but $K_n = \frac{1}{2} \mu_n C_{ox} \frac{W}{L}$

$$g_m = 2 \times \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)$$

$$\boxed{g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)} \quad -③$$

From eqn

$$V_{GS} - V_T = \sqrt{\frac{I_{DS}}{K_n}}$$

∴ From eqn ②

$$g_m = 2K_n \sqrt{\frac{I_{DS}}{K_n}}$$

$$\Rightarrow g_m = \sqrt{4 K_n I_{DS}}$$

$$g_m = \sqrt{4 \times \frac{1}{2} \mu_n C_{ox} \frac{W}{L} I_{DS}}$$

$$\boxed{g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_{DS}}}$$

I_{DS} = DC bias current Drain to Source.

Note* For any FET

$\boxed{\mu = g_m r_d}$ where μ = amplification factor

μ = unit less

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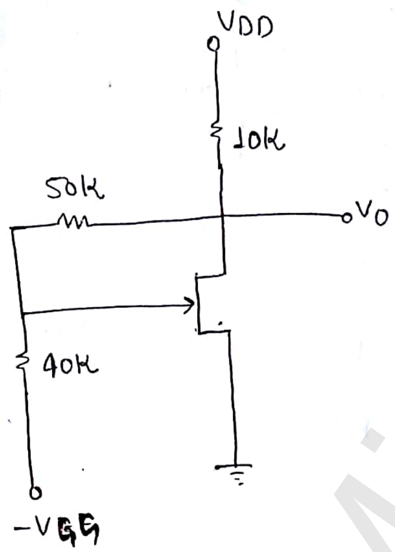
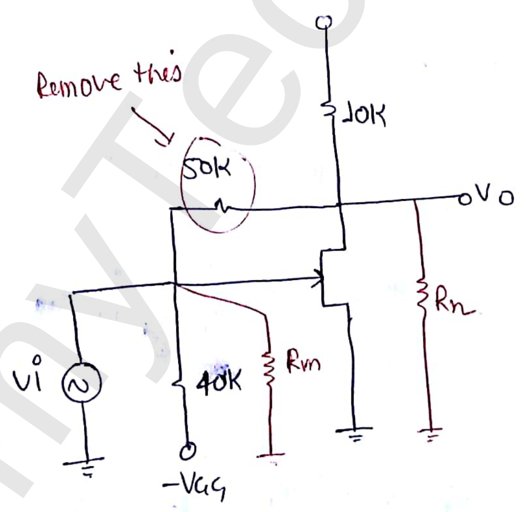
Question



If an i/p sig Vi is impressed b/w gate and ground find the amplification $A = \frac{V_o}{V_i}$

apply millers theorem to the 50KΩ resistor the FET parameters are $\mu = 30$ and $r_d = 5K\Omega$ neglect capacitances.

Solution



$\mu = 30$

$r_d = 5K$

$\mu = g_m r_d$

$\Rightarrow g_m = \frac{\mu}{r_d} = 30/5K = 6 mA/V$

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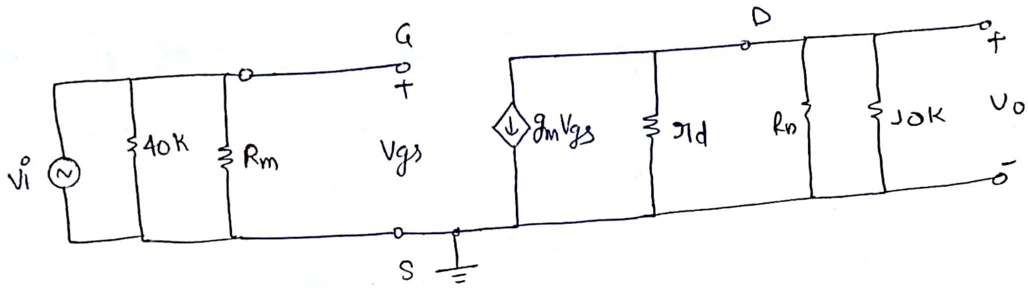


First we need to find open loop voltage gain i.e by removing Rm and Rn

voltage gain without Rm and RN

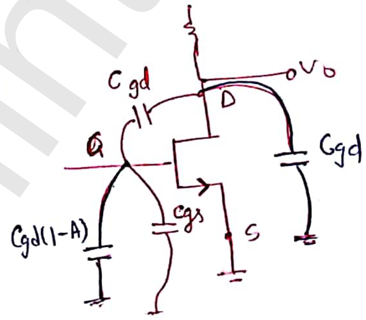
$V_{gs} = v_i$

$v_o = -g_m V_{gs} (r_d \parallel 10K)$

$\frac{V_o}{V_{gs}} = \frac{V_o}{V_i} = A = -g_m (r_d \parallel 10K)$

$= -6m \left(\frac{5K \times 10K}{15K}\right)$

$= -20$



Now

$R_m = \frac{50K}{1-(-20)} = \frac{50K}{21} = 2.38K$

In gate.

Note*

$C_i = C_{gs} + (1-A) C_{gd}$

i/p capacitance.

$R_n = \frac{50K}{1-\frac{1}{A}} = \frac{50K}{1+\frac{1}{20}} = 47.62$

Voltage gain of ckt (consisting Rm and Rn)

$V_{gs} = v_i$

$v_o = -g_m V_{gs} (r_d \parallel R_n \parallel 10K)$

$\frac{V_o}{V_{gs}} = \frac{V_o}{V_i} = A_f = -g_m (r_d \parallel R_n \parallel 10K)$ Ans

$= -6 \frac{mA}{V} (5 \parallel 47.62 \parallel 10)K$

$= -6 (3.33 \parallel 47.62) = -6 \times 3.11$

$\boxed{\frac{V_o}{V_{gs}} = -18.67}$ Ans

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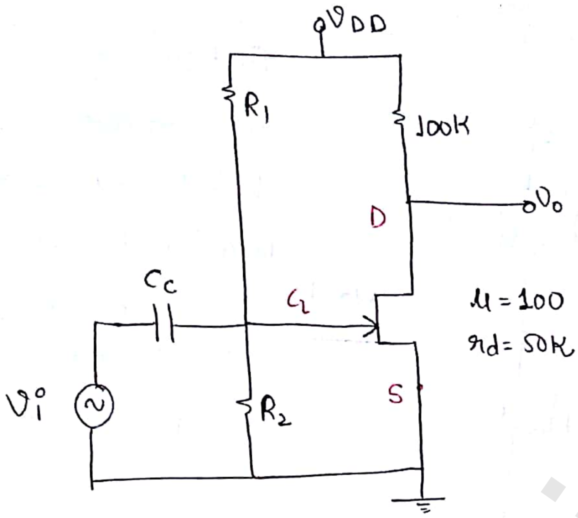
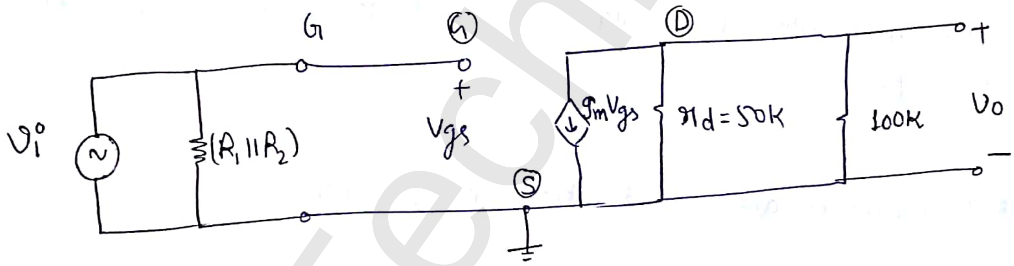
Q

For the ckt shown below draw the ac eq^v ckt and find voltage gain of the amplifier



Soln



$\mu = 100 = g_m r_d$

$g_m = \frac{100}{50K} = 2\ mA/V$

$V_{gs} = V_i$

$V_o = -g_m V_{gs} (r_d \parallel 100K)$

$\frac{V_o}{V_{gs}} = -g_m (r_d \parallel 100K)$

$$\boxed{\frac{V_o}{V_i} = A_V = -2\times10^{-3} (33.33\times10^{3}) = -66.66}$$

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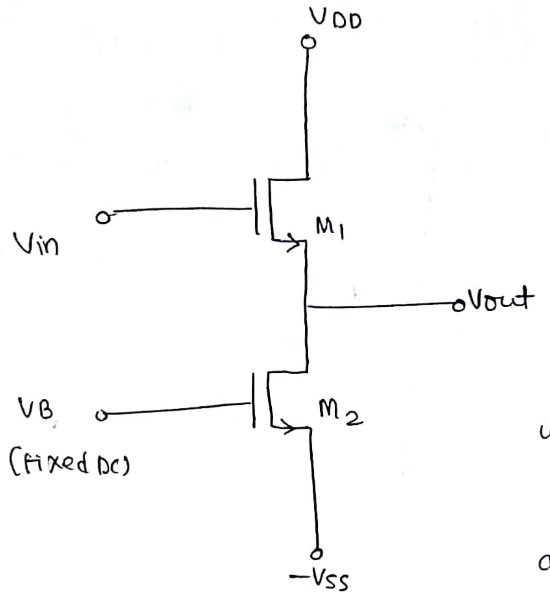
Q)

The figure below is is Source follower using n channel Mosfet. assume that M_1 and M_2 both are in saturation and have different transconductance parameter K_1 and K_2 where $K_i = \mu_n C_{ox}\left(\frac{W}{L}\right)_i$, $i = 1, 2$ and symbols have there usual meaning.



derive an expression for Vout in terms of $V_{in}, V_{DD}, V_{SS}, V_B, V_T$ and K_1, K_2. Find ~~the~~ o/p small s/g voltage gain and dc offset voltage appearing at the o/p.

Sol^n

Both M_1 and M_2 are in saturation so $I_{D1} = I_{D2}$

$$I_{D1} = I_{D2}$$

$$K_1(V_{GS1} - V_T)^2 = K_2(V_{GS2} - V_T)^2$$

$$K_1\left[V_{in} - V_{out} - V_T\right)^2 = K_2(V_B - (-V_{SS}) - V_T)^2$$

$$K_1\left[V_{in} - V_{out} - V_T\right]^2 = K_2(V_B + V_{SS} - V_T)^2$$

$$V_{in} - V_{out} - V_T = \sqrt{\frac{K_2}{K_1}}\left[V_B + V_{SS} - V_T\right]$$

$$V_{out} = V_{in} - V_T - \sqrt{\frac{K_2}{K_1}}\left[V_B + V_{SS} - V_T\right]$$

$$\boxed{V_{out} = V_{in} + V_T\left[\sqrt{\frac{K_2}{K_1}} - 1\right] - \sqrt{\frac{K_2}{K_1}}(V_B + V_{SS})}$$

o/p offset voltage is $V_{out} = V_{oo}$ if $V_{in} = 0$

$$\boxed{V_{oo} = \left(\sqrt{\frac{K_2}{K_1}} - 1\right)V_T - \sqrt{\frac{K_2}{K_1}}(V_B + V_{SS})}$$

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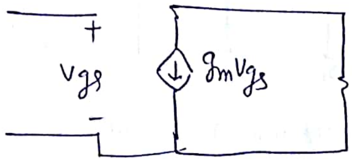
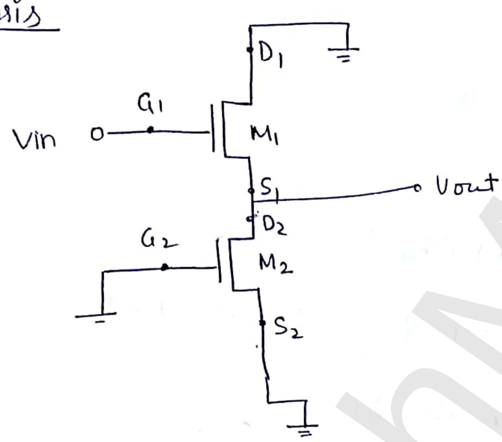
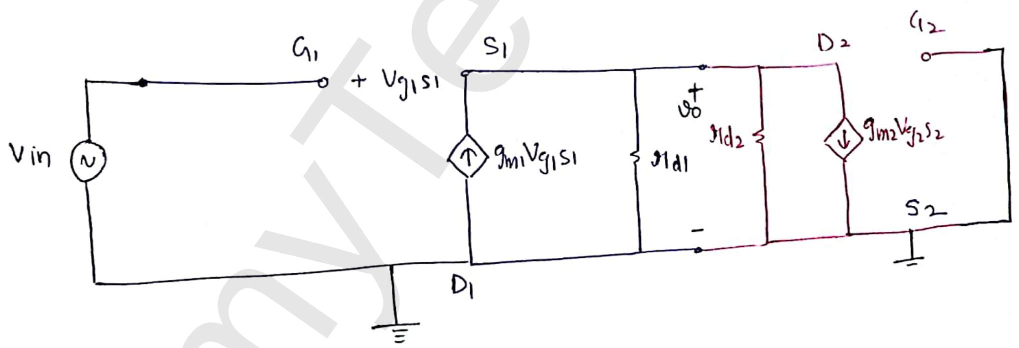
ac analysis.



Ac analysis



g_{m1} and g_{m2} are different i.e given in question.



$G_2 S_2$ short means $V_{g_2 s_2} = 0$

means $g_{m2} V_{g_2 s_2} = 0$ i.e make current source open

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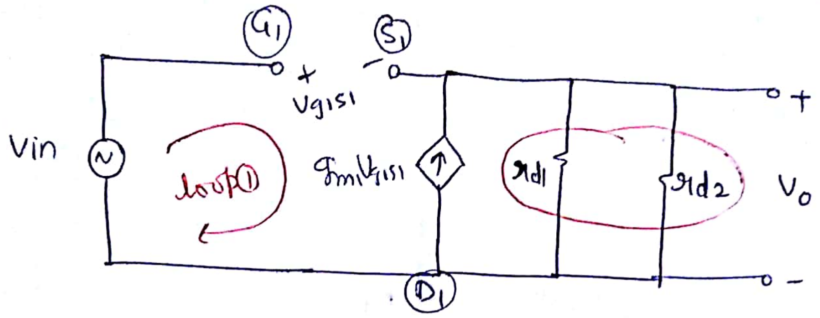

$$v_o = g_{m1} v_{g1s1} (r_{d1} \| r_{d2}) \longrightarrow ①$$

KVL in loop ①

$$-v_{in} + v_{g1s1} + v_o = 0$$

$$v_{g1s1} = v_{in} - v_o$$

$$v_o = g_{m1} (r_{d1} \| r_{d2}) (v_{in} - v_o)$$

$$\Rightarrow v_o = g_{m1} (r_{d1} \| r_{d2}) v_{in} - g_{m1} (r_{d1} \| r_{d2}) v_o$$

$$\frac{v_o}{v_{in}} = A_v = \frac{g_{m1} (r_{d1} \| r_{d2})}{1 + g_{m1} (r_{d1} \| r_{d2})} \simeq 1$$

u-gnd.

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Most Important

Op- Amp

⇒ Available as IC-741 in 8 pin package

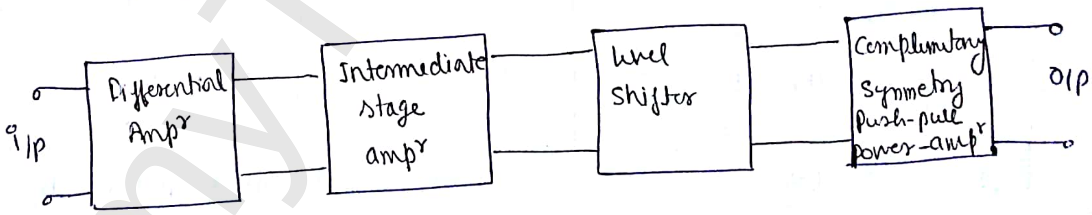
7 : 7 pins are used

4 : 4 pins as i/p pin (inverting i/p ~~and~~, non inverting i/p, +Vcc, $-V_{EE}$)

1 : 1 pin as o/p.

Note :- Remaining 2 pins are used ~~as~~ for off set null balancing.

⇒ It is a direct coupled multistage amplifier with very high voltage gain



Q why op-amp called op-amp.?

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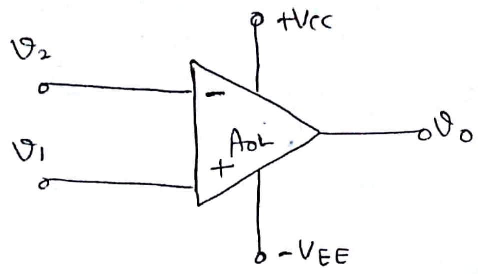

$v_o = A_{OL} v_d$

$\boxed{v_o = A_{OL}(V_1 - V_2)}$ Governing equation

$V_d = V_1 - V_2$

obj
V.Imp.

properties of op-amp

S.No.	Parameter	Ideal op amp.	Practical op-amp
1.	A_{OL}	∞	Practical op-amp
2.	R_i	∞	1 to 2 MΩ
3.	R_o	0	50 to 100Ω
4.	BW	∞	open loop BW = 5Hz
5.	offset voltage	If $V_1=0$, $V_2=0$ then $V_0=0$	If $V_1=0$, $V_2=0$ then $V_0 \neq 0$
6.	CMRR	∞	10^6 or 120dB
7.	Slew rate	∞	0.5 to 1V/μsec

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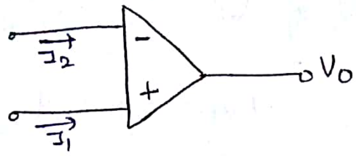
Some impr defn For Practical op-amp



① Input Bias Current

It is the avg of two currents I_1 and I_2 which flow into the i/p node

For IC 741 : 100's of nA

② Input offset current

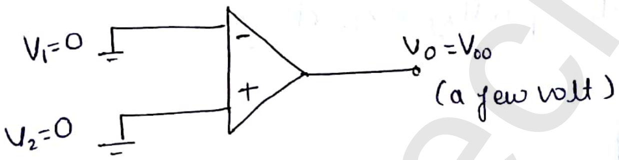
It is the difference of I_1 and I_2

$I_{io} = I_1 \sim I_2$: For IC 741 a few nA

this sign indicates that substract smaller one from larger one.

③ O/P offset voltage

V_{oo} = O/P offset voltage



④ I/P offset voltage It is the voltage which must be applied as difference i/p to make the o/p voltage 0.

If $V_d = V_{io}$ then $V_o = 0$

$\boxed{10\text{'s of } \mu V}$

⑤ Power supply rejection ratio (PSRR or SPRR)

It is a measure of change in i/p offset voltage due to changes in supply voltages and is given by

$$PSRR \text{ in dB} = 20 \log \frac{\Delta V_s}{\Delta V_{io}}$$

ΔV_s → change in i/p supply vltg

ΔV_{io} → " " " offset vltge.

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⑥ CMRR

It is the ratio of differential mode gain to the common mode gain

$$CMRR = \frac{A_{dm}}{A_{cm}}$$

A_{dm} - diff^r mode gain

A_{cm} - common mode gain

$$CMRR \text{ in dB} = 20 \log \left(\frac{A_{dm}}{A_{cm}} \right)$$

$$= A_{dm} (\text{in dB}) - A_{cm} (\text{in dB})$$

CMRR is a measure of sensitivity of a differential amp^r to common mode i/p such as noise.

High CMRR indicates that op-amp is efficiently rejecting the noise sig.

⑦ Slew rate Max^m rate at which o/p voltage can change

$$SR = \left. \frac{dV_o}{dt} \right|_{max}$$

consider an op-amp with closed loop gain A_{CL}

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

$$\text{If } v_i = V_m \sin \omega t$$

$$\text{then } V_o = A_{CL} V_m \sin \omega t$$

$$\text{so } \left. \frac{dV_o}{dt} \right|_{max} = \left. (A_{CL} V_m \omega \cos \omega t) \right|_{max}$$

$$SR = A_{CL} V_m \cdot \omega$$

$$\boxed{SR = 2\pi A_{CL} V_m f \ \frac{volt}{sec}}$$

$$\boxed{SR = \frac{2\pi A_{CL} V_m f}{10^6} \ volt/\mu sec}$$

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SR provided by manufacturer.

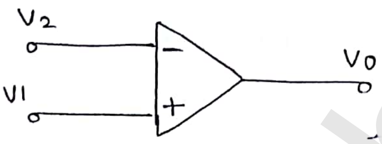
To obtain distortionless output

$$\boxed{SR \leq \frac{2\pi A_{CL} f V_m}{10^6}} \quad V/\mu sec$$

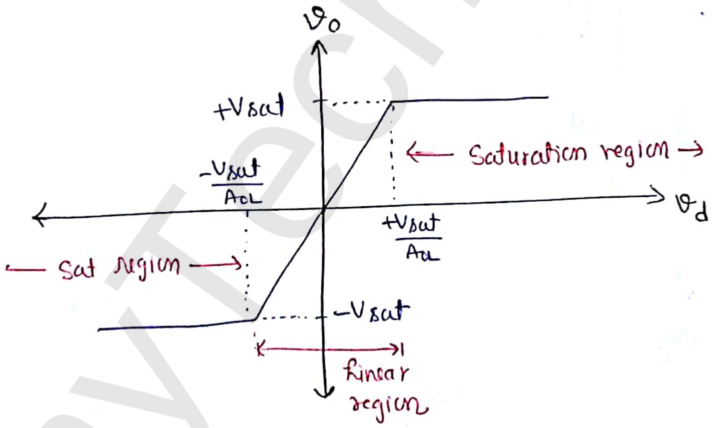
Note* In question if A_{CL} is not given then

$$\boxed{A_{CL} = 1}$$

Transfer characteristics



$V_d = V_1 - V_2$



⇒ op-amp can be used as an ampr only in linear region.

⇒ with +ve f/b configuration or with open loop configuration op-amp always operates in saturation region

i.e $\boxed{V_0 = \pm V_{sat}}$. for open loop or +ve feedback.

⇒ For negative feedback configuration op-amp can be operated in linear region

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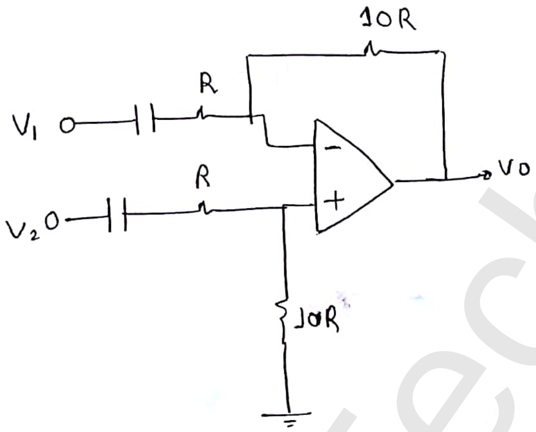
In this case $V_o = A_{OL}(V_1 - V_2)$ but $A_{OL} \longrightarrow \infty$, so $V_1 - V_2 = 0$

$V_1 - V_2 = \frac{V_o}{A_{OL}}$ $\Rightarrow$ $\boxed{V_1 \simeq V_2}$ $\Rightarrow$ Inverting and non-inverting terminals are virtually short-ckted to each other.

Note* Virtual Short ckt concept ($V_1 = V_2$) is valid for negative feedback op amp and this concept is not applicable for open loop or +ve feedback op amp.

Q =



In fig i/p offset voltage of the opamp is 2mV calc the o/p dc error voltage or dc offset voltage.

o/p offset voltage =

$$\boxed{V_{oo} = \left(1 + \frac{R_F}{R}\right) V_{io}}$$

For inverting opamp and non-inverting opamp both

$$V_{oo} = \left(1 + \frac{10R}{R}\right) V_{io}$$

$$V_{oo} = 11 \times 2mV = 22\ mV$$

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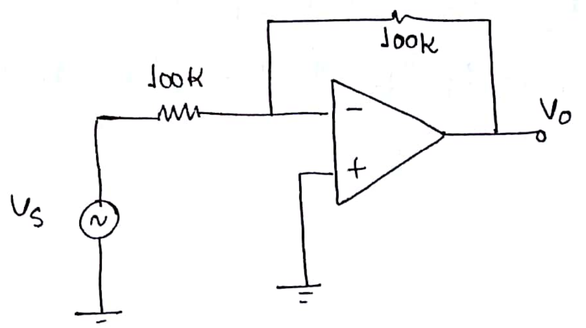
o In the ckt shown below the op-amp has i/p bias current $I_b < 10nA$ and i/p offset voltage $V_{io} < 1mV$ calc the max^m dc error voltage in the o/p



DC error voltage in the o/p. of op-amp

① Due to bias current

$$V_{oo1} = |I_B R_F|$$

$$= |10 \times 10^{-9} \times 100 \times 10^{3}|$$

$$= 1\,mV$$

② Due to i/p offset voltage

$$V_{oo2} = \left(1 + \frac{R_F}{R}\right) V_{io}$$

$$= \left(1 + \frac{100K}{100K}\right) \times 1$$

$$= 2\,mV$$

so total error in o/p voltage

$$V_{oo} = V_{oo1} + V_{oo2}$$

$$= 1mV + 2mV$$

$$V_{oo} = 3mV$$

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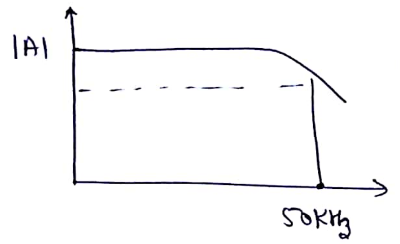
Q. Define and use the expression for slew rate of op-amp. opamp has ~~slew rate~~ has slew rate of 0.5V/μsec. It is used as a non-inverting ampr with gain of 25. the voltage gain against frqc curve is flat up to 50 KHz. Calc the maxm (p-p) i/p Slg that can be applied to get undistorted o/p.

$A_{CL} = 25$



$$SR \leq \frac{2\pi f A_{CL} V_m}{10^6}$$

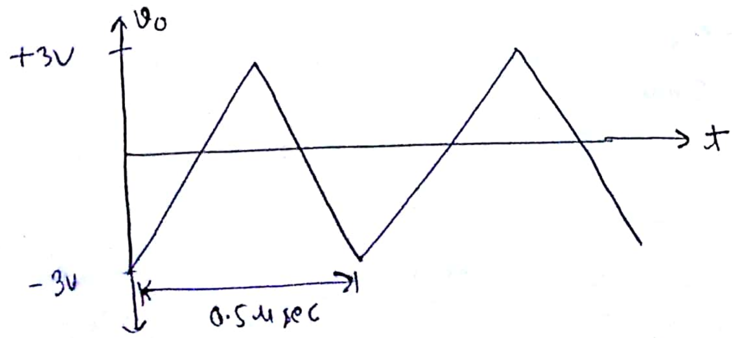
$$\Rightarrow 0.5 \leq \frac{2\pi\, 50 \times 10^3 \times 25 \times V_m}{10^6}$$

$V_m = 63.7\ mV$

peak to peak I/p = $2 \times 63.7\,mV$

$= 127.4\ mV$

Q. The o/p of an op amp voltage follower is a triangular wave. assume for a square wave i/p of frqc of 2 MHz and 8 volt (p-p) voltage what is the slew rate of op-amp.



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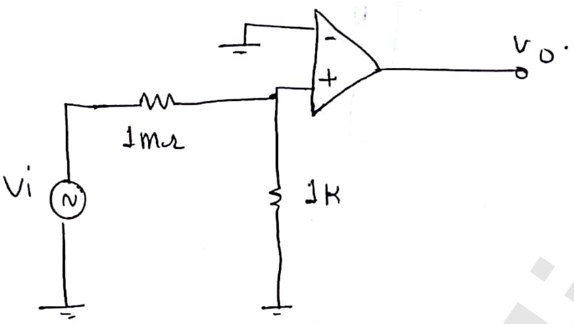
$$SR = \left.\frac{dV_0}{dt}\right|_{max} = \frac{3-(-3)}{0.5/2} \ V/\mu sec$$

$$SR = 24 \ V/\mu sec$$

Q.

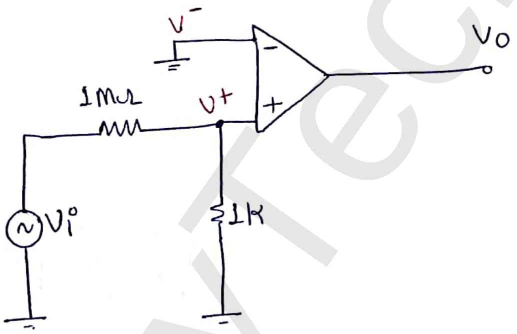


The fig shown uses an op amp that is ideal except for having finite gain A measurement indicate that $V_0 = 4$ volt when $V_i = 4$ volt what is the opamp gain A. (open loop gain)

Soln

$V_0 = 4V$

$V_i = 4V$



$$V^+ = \frac{V_i \times 1K + 0 \times 1M}{1M + 1K}$$

$$= \frac{V_i \times 1K}{1001 K}$$

$$\boxed{V_0 = A(V^+ - V^-)}$$ ← this always valid either +ve loop, -ve loop or open loop.

$$V_0 = A\left(\frac{V_i}{1001} - 0\right)$$

$$A = 1001 \frac{V_0}{V_i}$$

$$A = 1001 \times \frac{4}{4} = 1001$$

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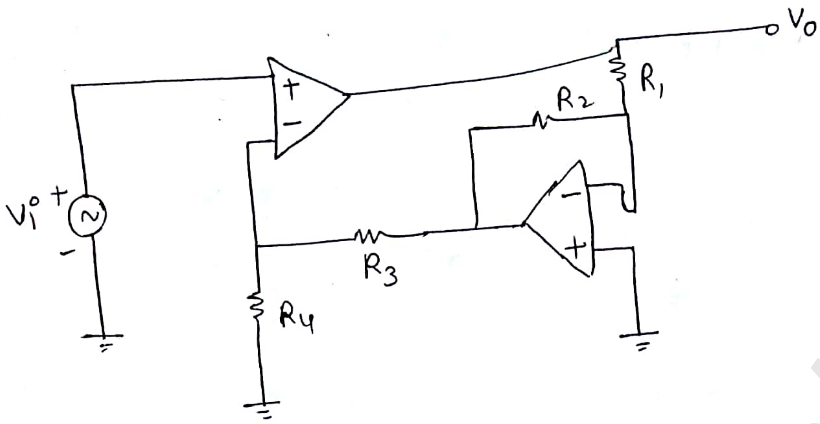
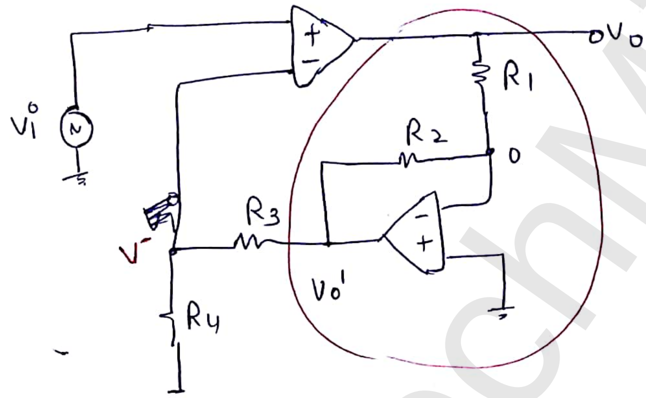
Q For the ckt shown below cal^c $\frac{V_o}{V_i}$



Soln



$$V_o' = -\frac{R_2}{R_1} V_o$$

$$V^- = \frac{R_4}{R_3+R_4} \times V_o'$$

$\boxed{v^- = v_i}$ virtual gnd.

$$v^- = \frac{R_4}{R_3+R_4}\left(\frac{-R_1}{R_1}\right) V_0 = v_i$$

$$\Rightarrow \quad \frac{v_o}{v_i} = \frac{1}{\left(\frac{R_4}{R_3+R_4}\right)\left(-\frac{R_2}{R_1}\right)}$$

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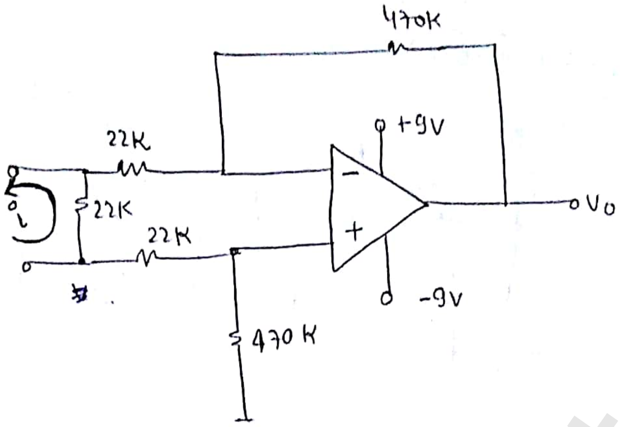
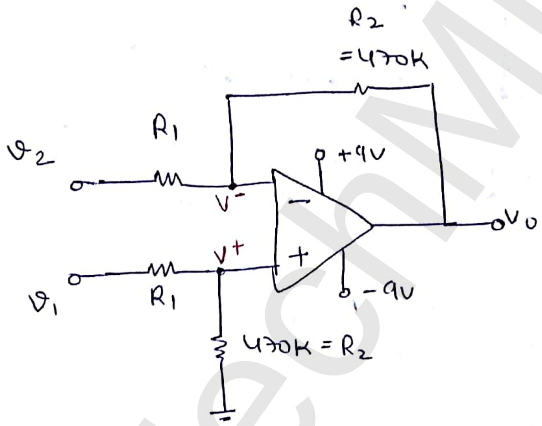
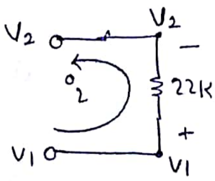
Q



calc the o/p voltage of the ckt if i/p sig current i is 5.5 uA

Soln





$$V^+ = \frac{R_2}{R_1+R_2} \cdot V_1$$

$$V^- = \frac{V_2 \times R_2 + V_0 \times R_1}{R_1+R_2}$$

$$V^+ = V^-$$

$$\frac{R_2}{R_1+R_2} \cdot V_1 = \frac{V_2 R_2 + V_0 R_1}{R_1+R_2}$$

$$V_0 R_1 = R_2(V_1 - V_2)$$

$$\boxed{V_0 = \frac{R_2}{R_1}(V_1 - V_2)}$$

So $V_1 - V_2 = i \times 22K = 5.5 \times 10^{-3} \times 22$

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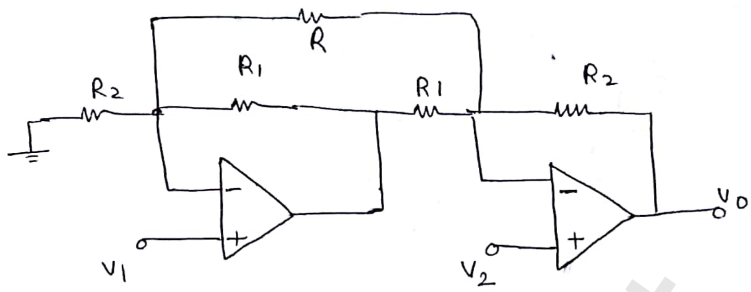
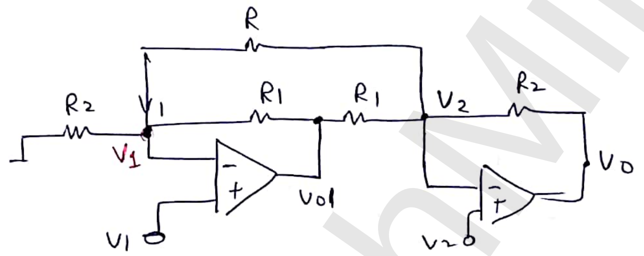
$$v_o = \frac{470}{22}\left(5.5\times 10^{-3}\times 22\right)$$

Q



Calculate V_o in terms of V_1 and V_2 and resistances.

Sol^n



KCL at V_1

$$\frac{V_1}{R_2} + \frac{V_1 - V_2}{R} + \frac{V_1 - V_{o1}}{R_1} = 0$$

$$\frac{V_1}{R_2} + \frac{V_1}{R_1} - \frac{V_o'}{R_1} + \frac{v_1}{R} - \frac{v_2}{R} = 0$$

$$\frac{V_o'}{R_1} = v_1\left(\frac{1}{R} + \frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{v_2}{R}$$

$$\Rightarrow v_o' = v_1\left(1 + \frac{R_1}{R} + \frac{R_1}{R_2}\right) - \frac{R_1}{R}V_2 \quad \text{—(1)}$$

KCL at V_2

$$\frac{v_2 - v_o'}{R_1} + \frac{v_2 - v_1}{R} + \frac{v_2 - v_o}{R_2} = 0$$

$$\frac{v_o}{R_2} = \frac{v_2}{R_1} - \frac{v_o'}{R_1} + \frac{v_2}{R} - \frac{v_1}{R} + \frac{v_2}{R_2}$$

$$\Rightarrow v_o = \left(\frac{R_2}{R_1} + \frac{R_2}{R} + 1\right)v_2 - \frac{R_2}{R}v_1 - \frac{R_2}{R_1}v_o'$$

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$$v_o = \left(1 + \frac{R_2}{R} + \frac{R_2}{R_1}\right) v_2 - \frac{R_2}{R} v_1$$

$$= -\frac{R_2}{R_1}\left[v_1 + \frac{R_1}{R} v_1 + \frac{R_1}{R_2} v_1 - \frac{R_1}{R} v_2 \right]$$

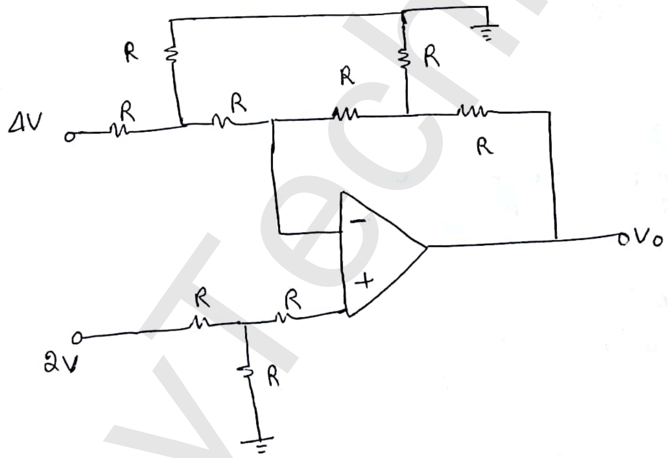
$$\Rightarrow v_o = v_2 + \frac{R_2}{R} v_2 + \frac{R_2}{R_1} v_2 - \frac{R_2}{R} v_1 - \frac{R_2}{R_1} v_1 - \frac{R_2}{R} v_1 - v_1 + \frac{R_2}{R} v_2$$

$$= v_2\left[1 + \frac{R_2}{R} + \frac{R_2}{R_1} + \frac{R_2}{R}\right] + v_1\left[-\frac{R_2}{R} - \frac{R_2}{R_1} - \frac{R_2}{R} - 1\right]$$

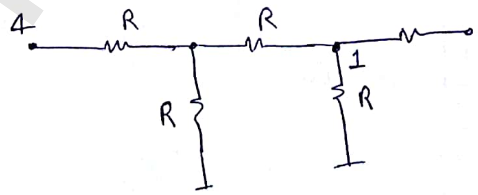
$$= v_2\left[1 + \frac{R_2}{R_1} + \frac{2R_2}{R}\right] - v_1\left[1 + \frac{R_2}{R_1} + \frac{2R_2}{R}\right]$$

$$\boxed{v_o = \left[1 + \frac{R_2}{R_1} + \frac{2R_2}{R}\right](v_2 - v_1)}$$

Q



Soln



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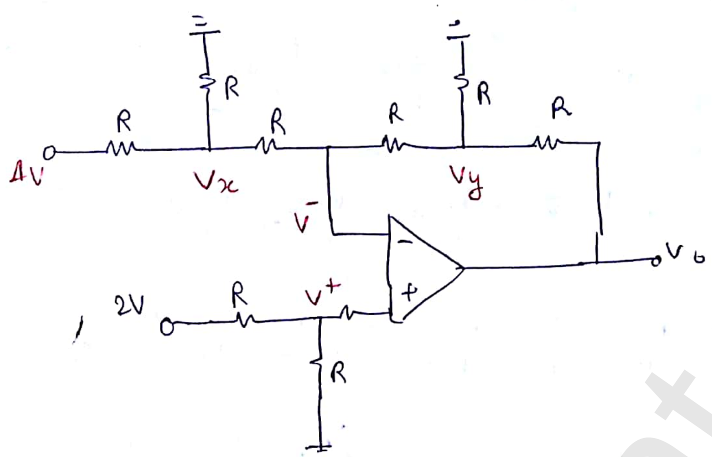

$$V^+ = \frac{R}{R+R} \cdot 2 = 1V$$

By virtual ground

$$V^+ = V^- = 1V$$

KCL at V_x

$$\frac{V_x}{R} + \frac{V_x - 4}{R} + \frac{V_x - 1}{R} = 0$$

$$3V_x - 5$$

$$V_x = 5/3$$

KCL at V_y

$$\frac{V_y}{R} + \frac{V_y - 1}{R} + \frac{V_y - V_0}{R} = 0$$

$$3V_y = 1 + V_0$$

$$\boxed{V_0 = 3V_y - 1} \longrightarrow (1)$$

KCL at V^-

$$\frac{1 - V_x}{R} + \frac{1 - V_y}{R} = 0$$

$$2 \times 1 = \frac{5}{3} + V_y$$

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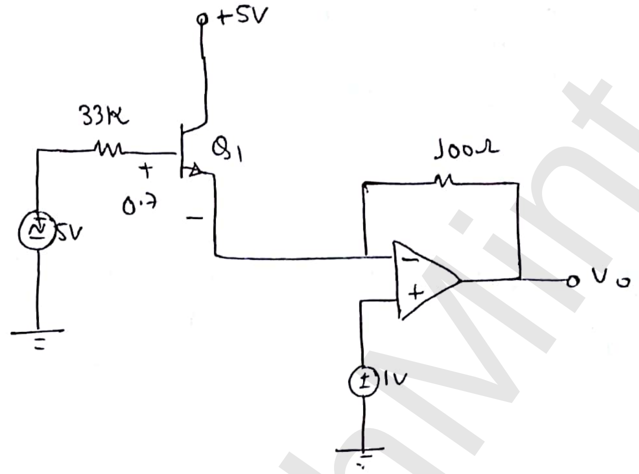
$V_y = 2 - \frac{5}{3} = \frac{1}{3}$

So $V_0 = 3 \times \frac{1}{3} - 1$

$= 0$ volt.

Question



Assume base emitter voltage of 0.7 volt and $\beta = 99$ of Q_1(Tr) calc the o/p voltage V_0 in the ckt shown.

$-5 + I_B 33k + 0.7 + 1 = 0$

$I_B = \frac{3.3}{33} = 0.1\,mA$

$I_E = I_C + I_B = \cancel{100\times}$

$= (\beta+1) I_B = 100 \times 0.1\,mA = \cancel{20A}\ \cancel{10A}$

$= 100 \times 0.1 \times 10^{-3} = \frac{100 \times 1}{1000 \times 10} = 0.01$

$1 - V_0 = \cancel{100 \times 10}\ 100 \times 0.01$

$1 - V_0 = 1$

$\boxed{V_0 = 0 \text{ volt}}$

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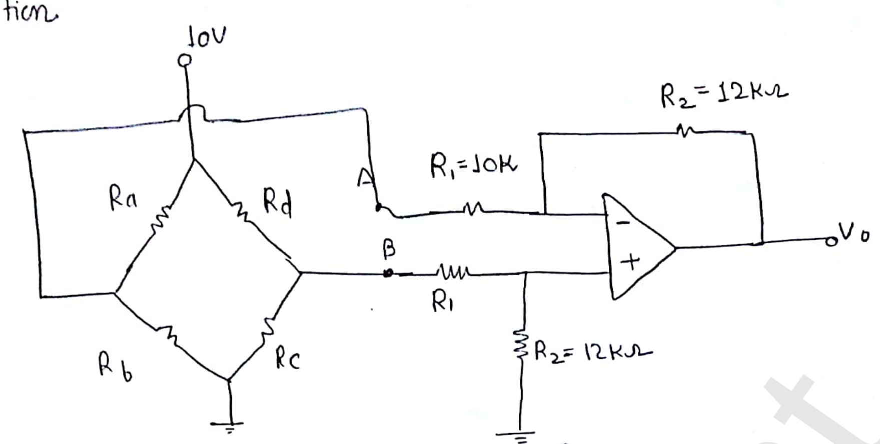
Question



The ckt shown uses an ideal opamp. assume the impedances at nodes A and B don't load the preceeding bridge ckt calculate the o/p voltage V_0

① $R_a = R_b = R_c = R_d = 100\Omega$

② $R_a = R_b = R_c = 100\Omega$ $R_d = 120\Omega$

Soln

$$v_B = \frac{R_c}{R_c + R_d} \cdot 10 \qquad v_o = \frac{R_2}{R_1}(v_B - v_A)$$

$$v_A = \frac{R_b}{R_a + R_b} \cdot 10 \qquad v_o = \frac{12K}{10K}(v_B - v_A)$$

Case①

$$v_B = \frac{1}{2} \times 10 = 5$$

$$v_A = \frac{1}{2} \times 10 = 5$$

$$\therefore v_o = \frac{12k}{10k}(5-5) = 0$$

Case②

$$v_B = \frac{100}{100+120} \times 10$$

$$v_A = \frac{100}{100+100} \times 10$$

$$v_o = \frac{12k}{10k}\left[\frac{100 \times 10}{220} - \frac{100 \times 10}{200}\right]$$

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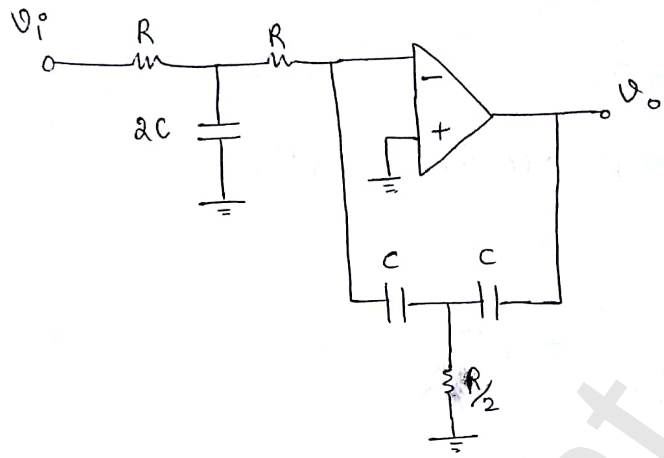
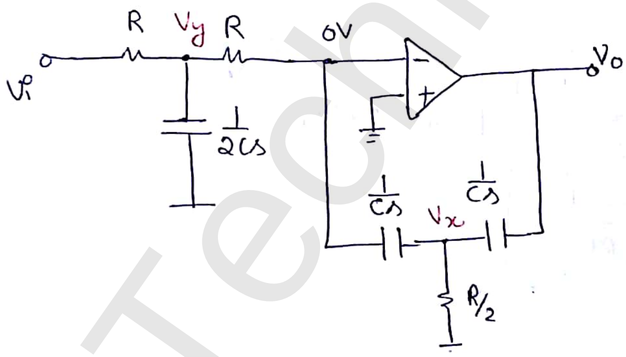
Q



Show that the ckt shown below act as a double integrator i.e

$$\frac{V_o(s)}{V_i(s)} = \frac{-1}{(RC)^2 s^2}$$

Sol^n



KCL at $V^- = 0$

$$\frac{0 - V_y}{R} + \frac{0 - V_x}{1/Cs} = 0$$

$$\Rightarrow \frac{-V_y}{R} - V_x Cs = 0$$

$$V_x = -\frac{V_y}{RCs} \quad \text{—(1)}$$

KCL at V_y

$$\frac{V_y}{1/2Cs} + \frac{V_y - 0}{R} + \frac{V_y - V_i}{R} = 0$$

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$$\Rightarrow \quad 2sC\,V_y + \frac{1}{R}V_y + \frac{1}{R}V_y = \frac{V_i}{R}$$

$$(2sRC+2)\,V_y = V_i$$

$$\Rightarrow V_i = (2+2sRC)\,(-sRC)\,V_x \quad \text{—— (11)}$$

KCL at V_x :

$$\frac{V_x}{R/2} + \frac{V_x - 0}{1/Cs} + \frac{V_x - V_o}{1/Cs} = 0$$

$$\frac{2}{R}V_x + sCV_x + sCV_x - sCV_o = 0$$

$$\frac{2}{sRC}V_x + V_x + V_x - V_o = 0$$

$$\Rightarrow V_o = \left(2 + \frac{2}{sRC}\right)V_x = \left(\frac{2+2sRC}{sRC}\right)V_x$$

$$V_o = \left(\frac{2+2sRC}{sRC}\right) \times \left[\frac{-1}{(sRC)(2+2sRC)}\right] V_i$$

$$\boxed{\frac{V_o}{V_i} = \frac{-1}{(RC)^2 s^2}}$$

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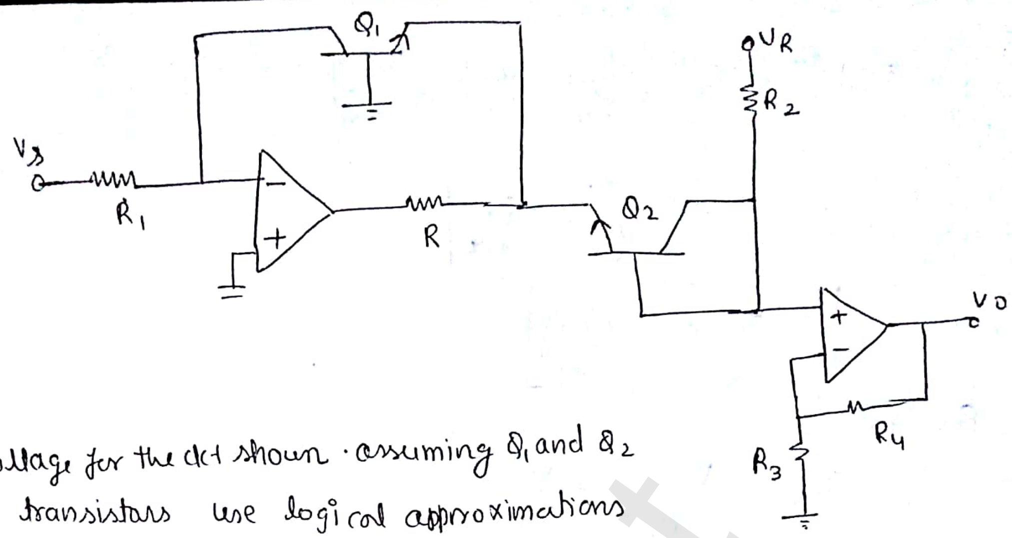
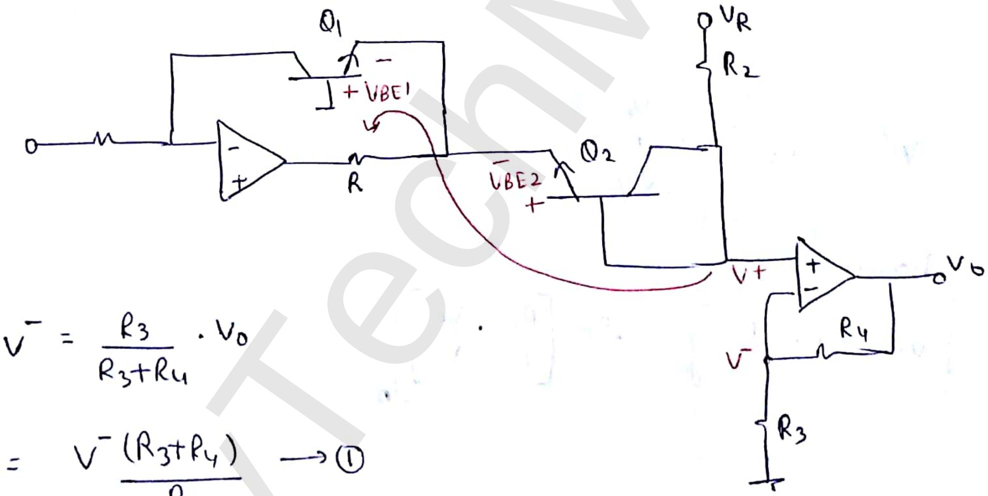
Q



Calc the o/p voltage for the ckt shown. assuming Q_1 and Q_2 are matched transistors use logical approximations if any required.

Soln



$$V^+ = V^- = \frac{R_3}{R_3+R_4} \cdot V_o$$

$$V_o = \frac{V^-(R_3+R_4)}{R_3} \longrightarrow (I)$$

$$V^+ = V_{BE2} - V_{BE1} \longrightarrow (II)$$

$$I_c = I_{co}\, e^{V_{BE}/V_T}$$

$$V_{BE} = V_T \ln\left(\frac{I_c}{I_{co}}\right)$$

$$V_{BE1} = V_T \ln\left(\frac{I_{c1}}{I_{co}}\right)$$

$$V_{BE2} = V_T \ln\left(\frac{I_{c2}}{I_{co}}\right)$$

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So $V^+ = V_T \ln\left(\frac{I_{C2}}{I_{C0}}\right) - V_T \ln\left(\frac{I_{C1}}{I_{C0}}\right)$

$$= V_T \ln\left[\frac{I_{C2}}{I_{C0}} \times \frac{I_{C0}}{I_{C1}}\right]$$

$$\boxed{V^+ = V_T \ln\left(\frac{I_{C2}}{I_{C1}}\right)}$$

From ckt

$$I_{C1} = \frac{V_S - 0}{R_1} = \frac{V_S}{R_1}$$

$$I_{C2} = \frac{V_R - V^+}{R_2}$$

bcz $V^+ = V_{BE2} - V_{BE1}$ so very very small

$$I_{C2} \simeq \frac{V_R}{R_2}$$

$$V^+ = V_T \ln\left(\frac{V_R/R_2}{V_S/R_1}\right)$$

Hence

$$\boxed{V_O = \left[1 + \frac{R_4}{R_3}\right] V_T \ln\left[\frac{R_1}{R_2} \cdot \frac{V_R}{V_S}\right]}$$

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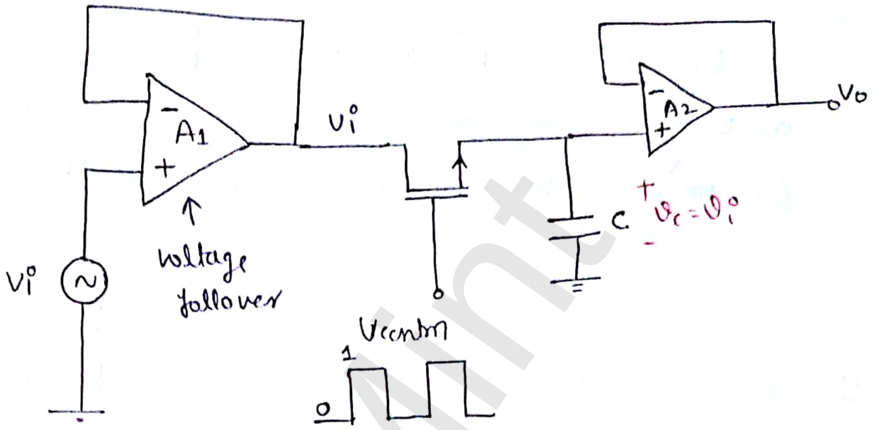
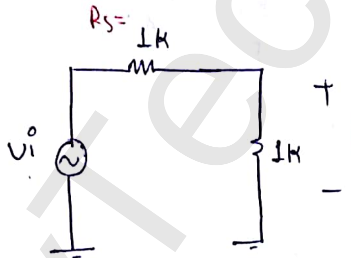
Q. Draw the ckt dgm for Sample and Hold ckt using op-amp & explain its operation

Sample and Hold ckt



above mosfet is working as a switch when i/p 1 switch-0.

we can't directly use V_i across MOSFET



$\frac{1}{2}V_i$ ← voltage across mos switch bcz of $R_s = 1K\Omega$

हमें mos के across V_i voltage चाहिए थी पर source (V_s) के Resistance के कारण हमें $\frac{1}{2}V_i$ ही मिल पा रही है इसलिए हम source Resistance के across कोई drop नहीं चाहते हैं।

- It is used in A to D converter
- It consist of two voltage follower, a MOSFET Switch and a capacitor having negligible charge leakage property.
- when Vcontrol = 1 mos switch turns ON and V_c follows V_i this is called sampling operation
- when Vcontrol = 0 mos switch turns off then cap^c voltage remains const at V_c bcz it doesn't have any discharging path Voltage follower A_2 prevents discharge of cap^c this is called Hold operation this is resemble Sample and Hold sig

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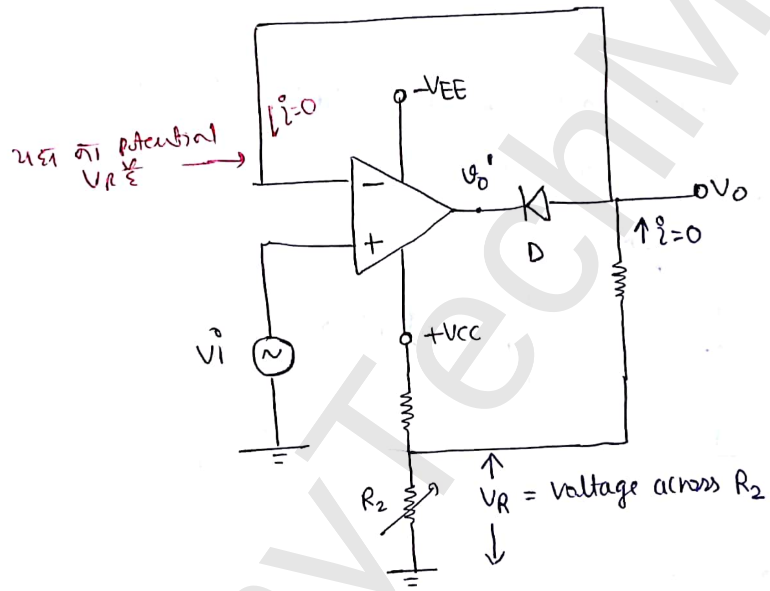
- Vol follow A_1 is used to eliminate the effect of sig source resistance R_s (if A_1 is not used then R_s appears in conduction path during sampling operation thereby V_c can't follow V_i perfectly

- For better hold operation –
  1. low leakage cap^c should be used.
  2. MOSFET switch should have negligible leakage current.
  3. opamp A_2 should have negligible bias current.

Q Draw the ckt dgm for clipper using op-amp & diode Explain its operation



- if diode off. (is assumed to be) $i=0$. then reference voltage V_R appears at the inverting terminal of the opamp and hence v_i is compared with V_R.

Case 1

if $v_i < V_R \Rightarrow v_0' = -ve \rightarrow$ D is FB $\rightarrow$ Replace with short ckt $\rightarrow$ opamp act as voltage follower

$\rightarrow V_0 = V_i$

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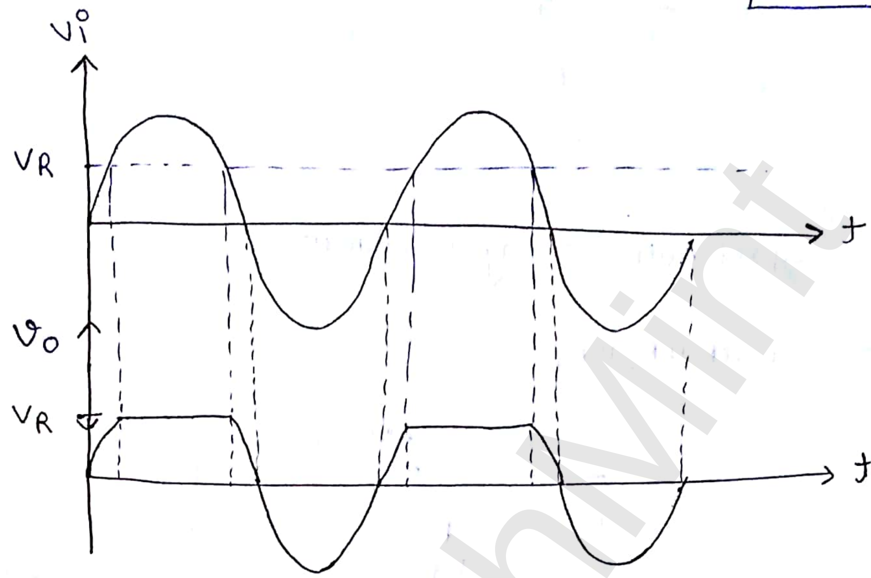
Case 2

If $V_i > V_R \Rightarrow V_o' = +ve \longrightarrow$ D is RB $\rightarrow$ Replace with open ckt

$\boxed{V_0 = V_R}$



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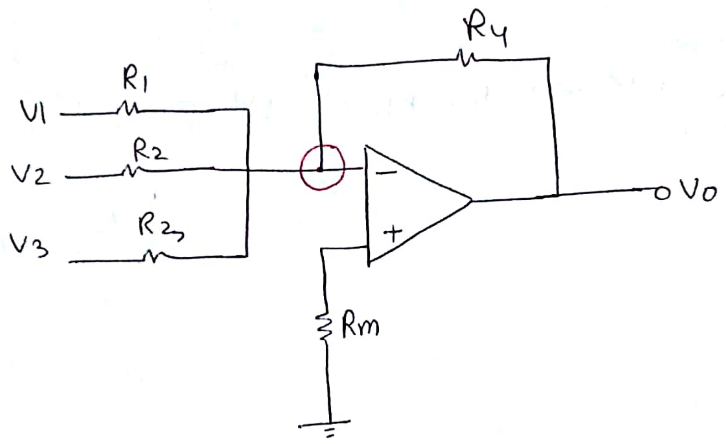
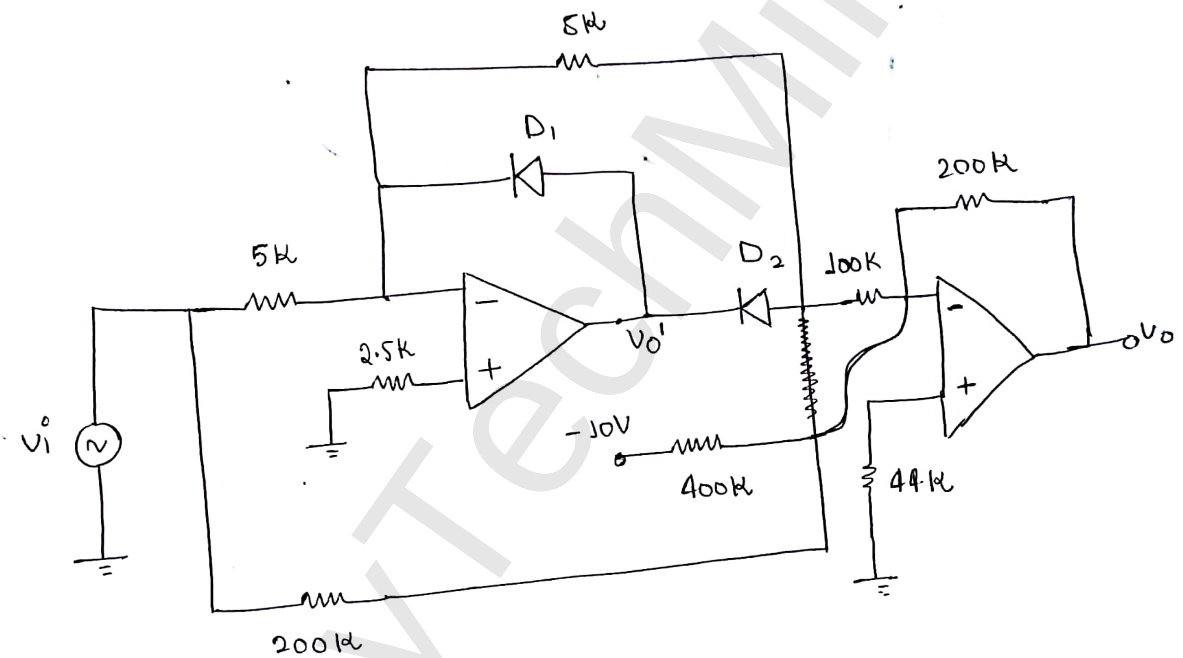
Q Note*



R_m = offset null balancing resistance

$R_m = R_1 \| R_2 \| R_3 \| R_4$

Q



Draw the transfer char' of op amp ckt shown below assuming diodes ideal (by default considered ideal)

Soln For the half cycle of the i/p

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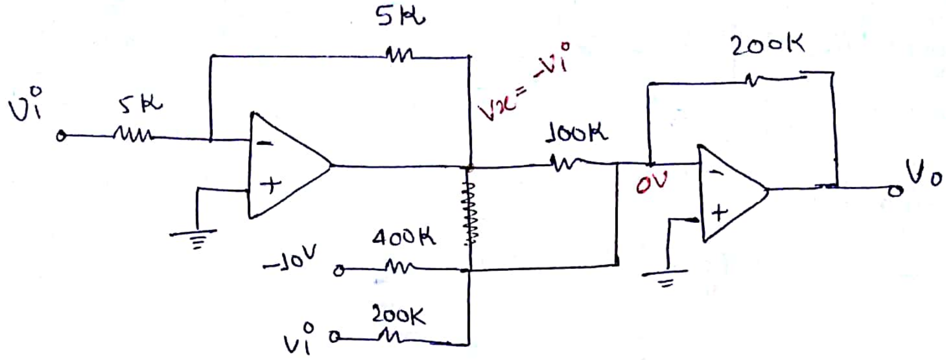


very important thing to understand here is when $V_i > 0$ $V_o' < 0$, actually our 1st opamp is not in -ve feedback (it looks like but its not). bcz the feedback is always taken from o/p. and feedback is not given through diode.

For $V_i > 0 \Rightarrow V_o' < 0$ $\Rightarrow$ D_1 is off and D_2 is on

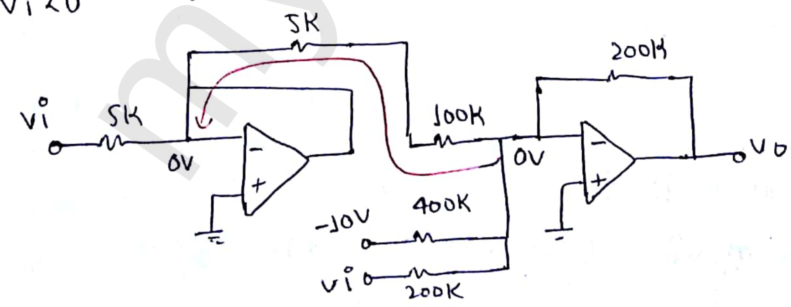
$$\frac{0+V_i}{100K} + \frac{0+10}{400K} + \frac{0-V_i}{200K} + \frac{0-V_o}{200K} = 0$$

$$\frac{4V_i + 10 - 2V_i - 2V_o}{400K} = 0$$

$$2V_o = 2V_i + 10$$

$$\boxed{V_o = V_i + 5}$$

For $V_i < 0$ $V_o' > 0$ $\Rightarrow$ D_1 is ON & D_2 is off



0V to 0V no current flow.

$$\frac{0-(-10)}{400K} + \frac{0-V_i}{200K} + \frac{0-V_o}{200K} = 0$$

$$\frac{10 - 2V_i - 2V_o}{400K} = 0$$

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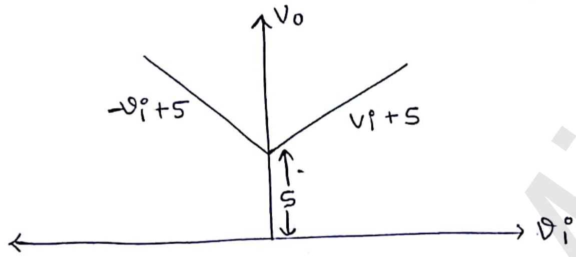
$2v_o = -2v_i + 10$

$$\boxed{v_o = -v_i + 5}$$

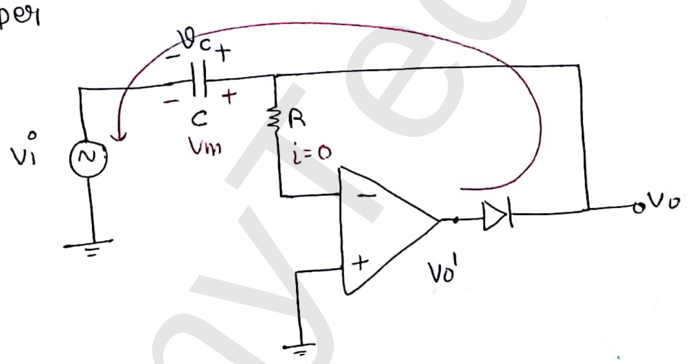
$$v_o = \begin{cases} v_i + 5 & \text{if } v_i > 0 \\ -v_i + 5 & \text{if } v_i < 0 \end{cases}$$



-: Transfer char^c :-

Q Draw the ckt dgm for clamper ckt using opamp and diode ~~using~~.

clamper



$V_o = V_i + V_m$

in clamper we charge C first.

at first -ve cycle of v_i Diode ON and cap^c charge

- during -ve cycle cycle of the i/p v_i opamp o/p V_o' becomes +ve and diode begins conduction hence cap^c charges through diode up to peak value of i/p voltage i.e $V_c = V_m$

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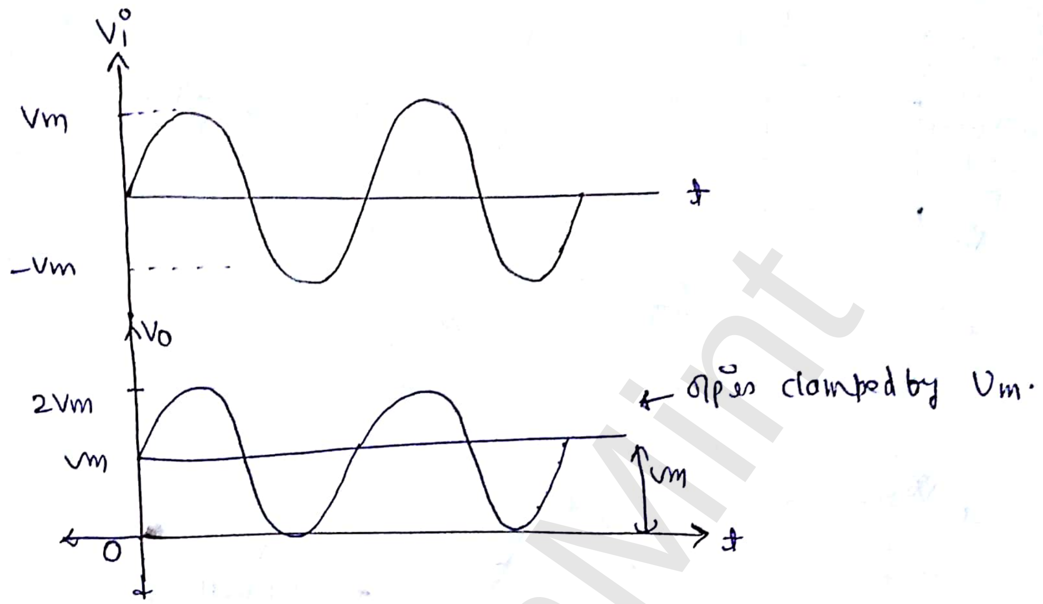
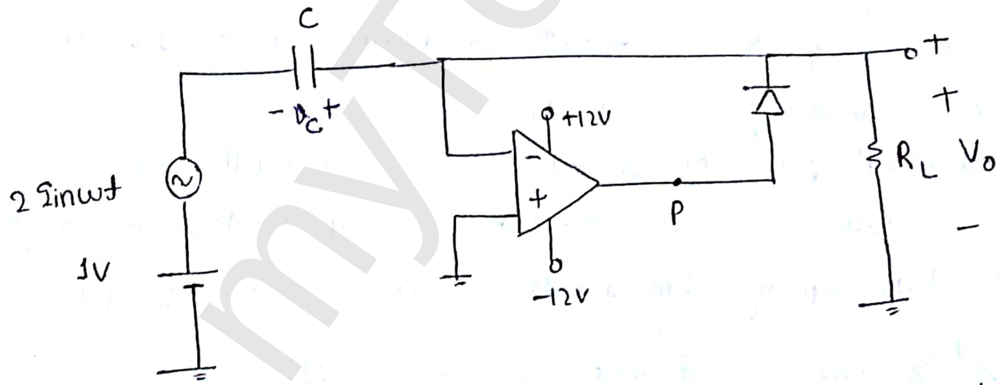
during the cycle of i/p V_0' becomes −ve and diode remains off so cap^c can't discharge therefore if cap^c is fully charged up to peak value of i/p then V_c remains at V_m and $V_0 = V_i + V_m$



Note* if diode connection is reversed then ckt becomes −ve clamper

Q)



a voltage $v_i = 1 + 2\sin\omega t$ is applied to the ckt shown below draw the o/p voltage and cap^c voltage waveform find the avg o/p voltage assuming $\omega = 1$ rad/sec.

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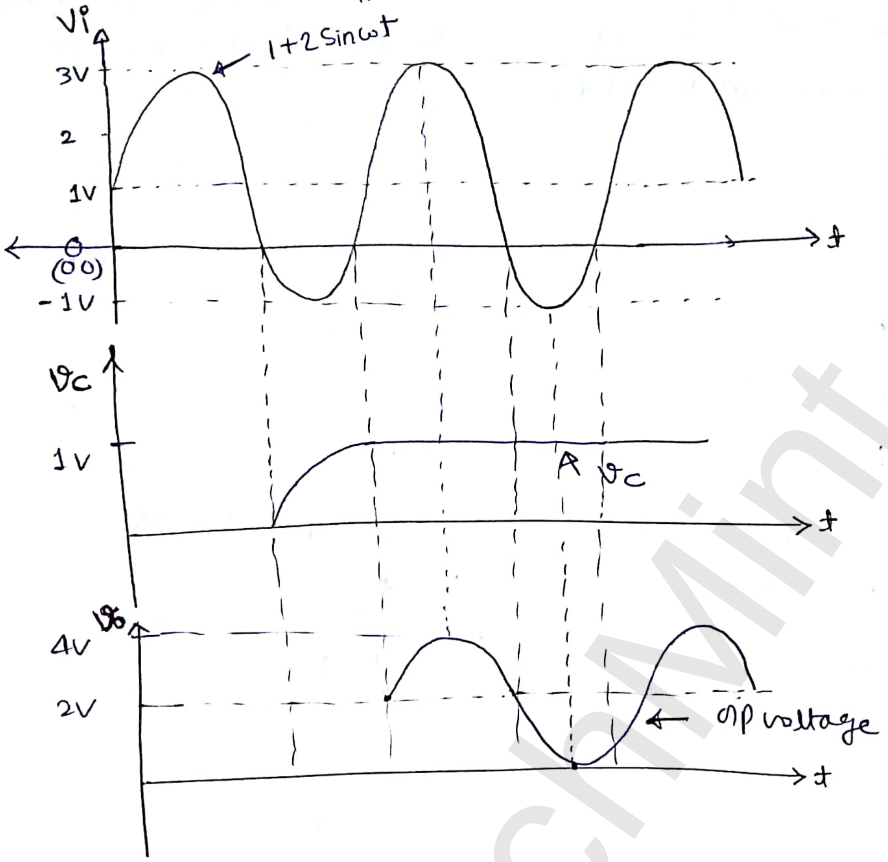
Solⁿ

1 volt dc is available in i/p



when Vi will be -ve the o/p of di opamp will be the D → ON

so capᶜ will charge by the maxᵐ -ve value i.e by 1V . bcz here maxᵐ -ve value of Vi is 1 volt.

Now this capᶜ for always remains at +1V, actually this capᶜ don't discharge through R_L also. and now our i/p voltage $V_i = 1 + 2\sin\omega t$ again shift up by ~~1m~~ 1 volt (bcz capᶜ is charged by 1V)

so For V_o our dc reference is now 2 volt.

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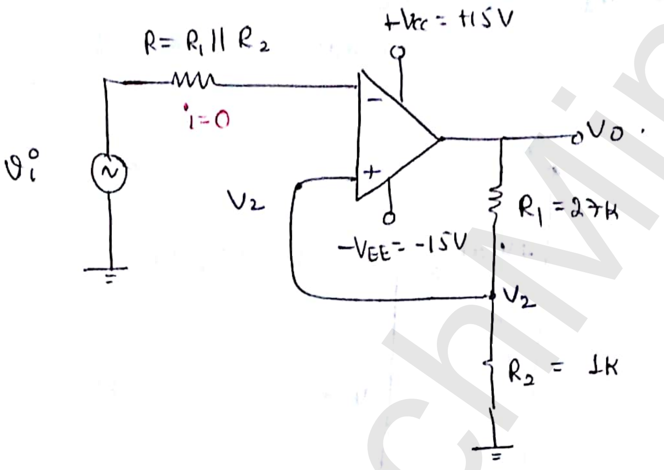
Q. A regenerative comparator ckt is shown below

① derive expression for upper threshold and lower threshold voltages and hence the value of hysteresis voltage. also calculate values of these parameters for given values of R_1 and R_2

② A sinwave with 2V (p-p) amplitude and 1KHz freq. is applied at the i/p of the ckt plot the i/p and o/p wavyforms.

Schmitt trigger



Schmitt trigger also called Regenerative comparator

$$V_d = v^+ - v^-$$

$$v_d = V_2 - v_i$$

If $V_d > 0 \Rightarrow V_o = +V_{sat}$

If $V_d < 0 \Rightarrow V_o = -V_{sat}$

$$V_2 = \frac{R_2}{R_1+R_2} \cdot V_o$$

If $V_o = +V_{sat}$

then $V_2 = \boxed{\frac{R_2}{R_1+R_2} \cdot V_{sat} = V_{UT}}$

If $V_o = -V_{sat}$

$V_2 = \boxed{\frac{R_2}{R_1+R_2}(-V_{sat}) = V_{LT}}$

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Case 1 : Assume $v_o = +v_{sat}$

then $V_2 = V_{UT} = \frac{R_2}{R_1 + R_2} \cdot V_{sat} = \frac{15 \times 1}{28} = 0.54\ V$

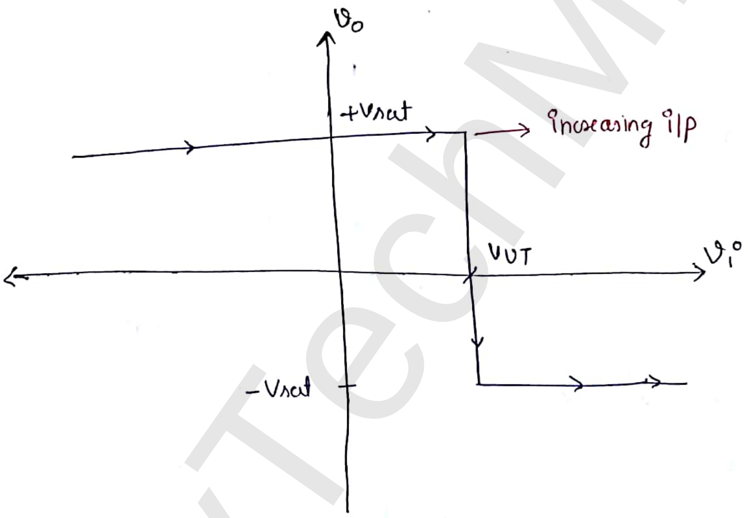
$v_d = V_{UT} - v_i$

If $v_i < V_{UT} \Rightarrow v_o = +ve \Rightarrow v_o = +V_{sat}$

→ means o/p remains at $+V_{sat}$

If $v_i > V_{UT} \Rightarrow v_d = -ve \Rightarrow v_o = -V_{sat}$

→ means o/p changes from $+V_{sat}$ to $-V_{sat}$



Note* For an increasing i/p s/g o/p voltage changes from $+V_{sat}$ to $-V_{sat}$ only at V_{UT}

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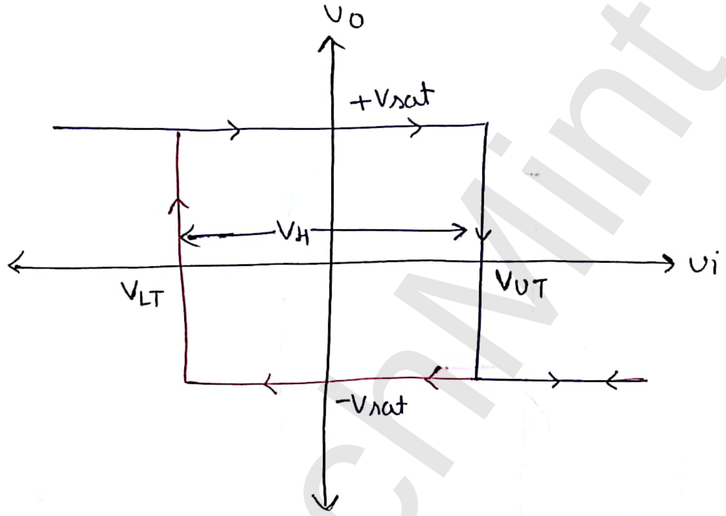
Case 2 $v_o = -V_{sat}$

then
$$v_2 = V_{LT} = \frac{-R_2}{R_1+R_2} \cdot V_{sat}$$

$$v_d = V_{LT} - v_i$$

If $v_i > V_{LT} \Rightarrow v_d = -ve \Rightarrow v_o = -V_{sat}$ .... o/p remains at $-V_{sat}$

If $v_i < V_{LT} \Rightarrow v_d = +ve \Rightarrow v_o = +V_{sat}$ .... op changes from $-V_{sat}$ to $+V_{sat}$



Note* For a ~~rising~~ i/p voltage, o/p changes from $-V_{sat}$ to $+V_{sat}$ only at $V_i = V_{LT}$

$V_H \Rightarrow$ Hysteresis voltage

$$V_H = V_{UT} - V_{LT}$$

$$\frac{R_2}{R_1+R_2} \cdot V_{sat} - \frac{R_2}{R_1+R_2} \cdot V_{sat}$$

$$\boxed{V_H = \frac{2 R_2 V_{sat}}{R_1 + R_2}}$$

V_{sat} if not given, taken as V_{CC}

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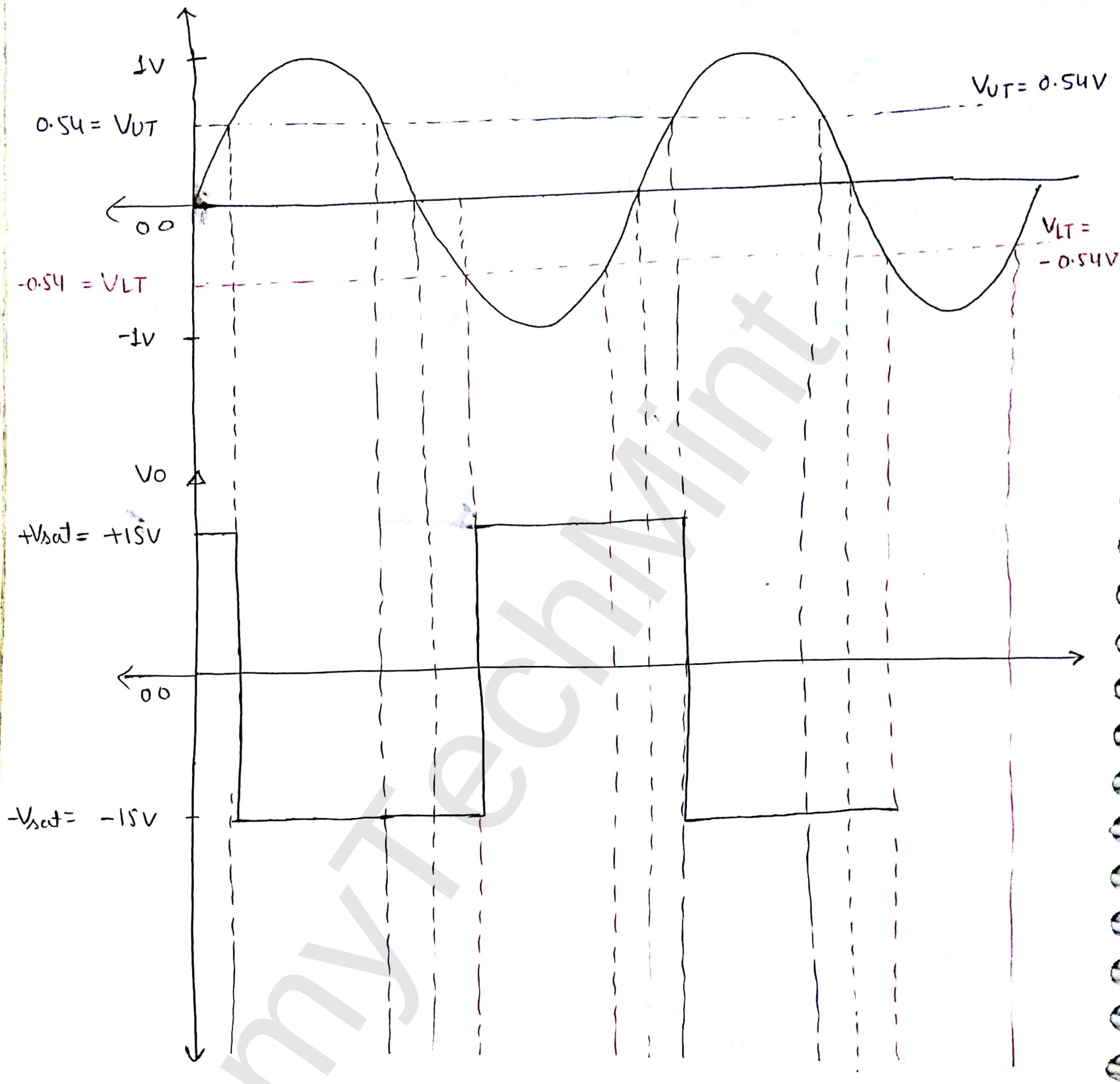

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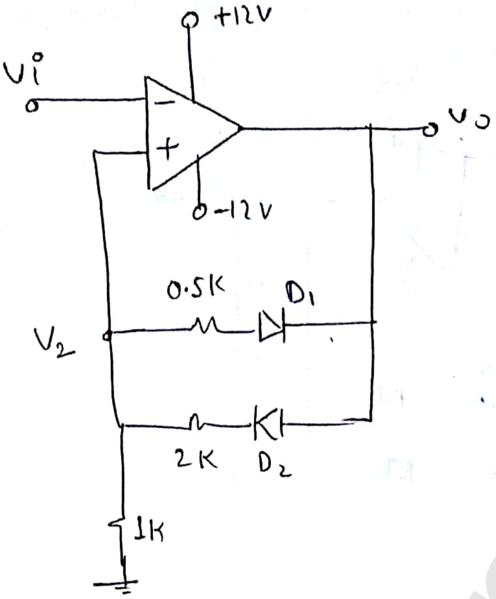


Q. Diodes are ideal plot transfer characteristic

Soln

If $V_0 = +V_{sat} = +12V$

then $V_2 = V_{UT}$

In this case D_1 is RB and D_2 is FB

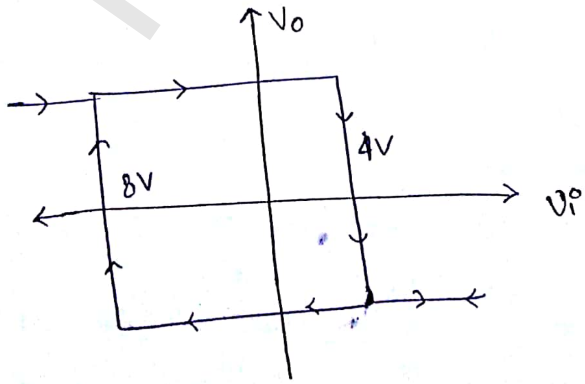
$$V_2 = V_{UT} = \frac{1K}{1K + 2K} \times 12 = 4V$$

If $V_0 = -V_{sat} = -12V$

In this case D_1 is FB and D_2 is RB.

$$V_2 = V_{LT} = \frac{1K}{1K + 0.5K} \times (-12)$$

$$= -8V$$



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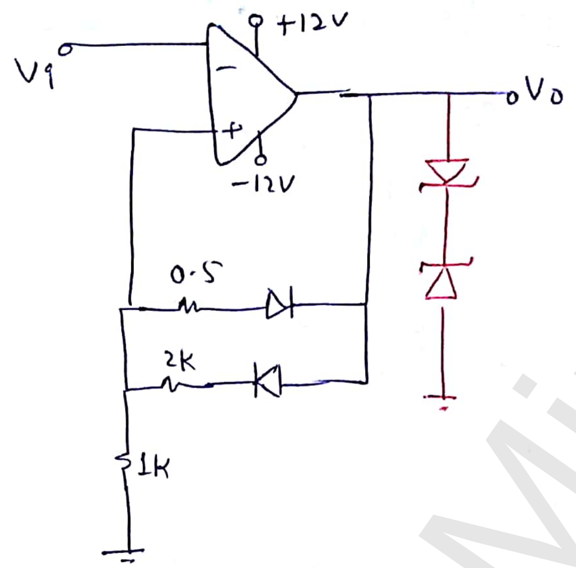
Note:* if we want to take less than Vsat

then we add.



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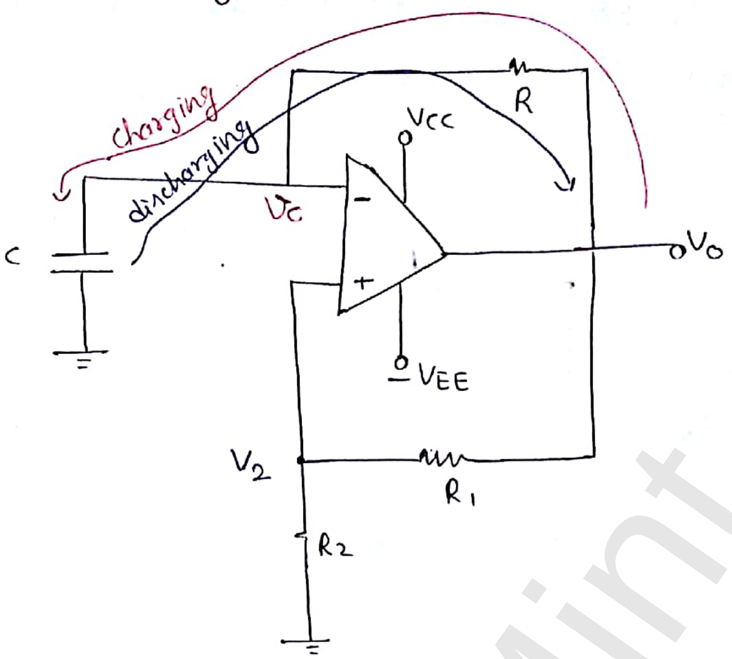
Q Explain the working of Astable multivibrator



$$V_2 = \underbrace{\frac{R_2}{R_1+R_2}}_{\beta} \cdot V_o$$

If $V_o = +V_{sat}$ then $V_2 = +\beta V_{sat}$

If $V_o = -V_{sat}$ then $V_2 = -\beta V_{sat}$

Case 1:

Assume $V_o = +V_{sat}$ than $V_d = \beta V_{sat} - V_c$

In this case cap^c charge through resistance R and V_c continues to increase till βV_{sat}

If V_c becomes slightly > than βV_{sat} then V_d becomes -ve and V_o changes to $-V_{sat}$

Case 2 If $V_o = -V_{sat}$ than $V_2 = -\beta V_{sat}$

and $V_d = (-\beta V_{sat}) - V_c$

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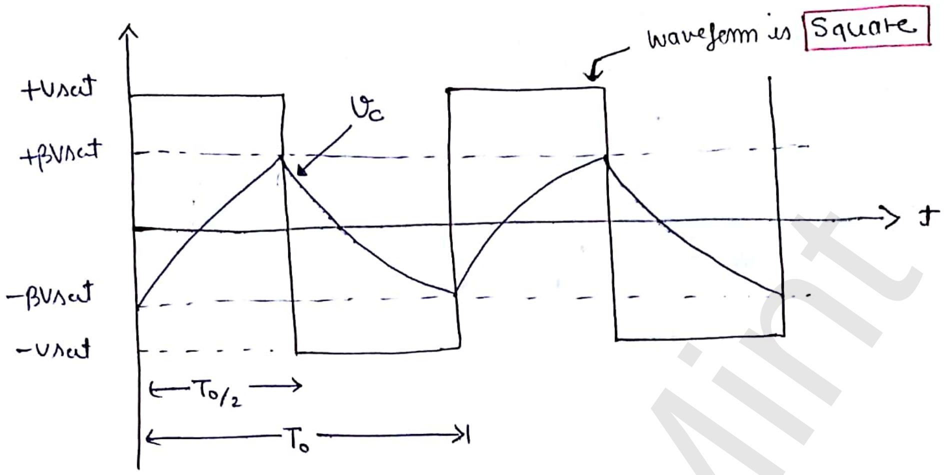
In this case cap^c discharges through resistance R and V_c continiously ~~dec~~ till $-\beta V_{sat}$. if V_c becomes sligutly less than $-\beta V_{sat}$ then V_d becomes +ve and V_o changes to $+V_{sat}$



cal^c of T_o or f_o

For capacitor

$$v_{initial} = -\beta V_{sat}$$

$$v_{final} = +V_{sat}$$

$$\tau = RC$$

$$v_c(t) = v_{final} + \left[v_{initial} - v_{final}\right] e^{-t/\tau}$$

$$v_c(t) = V_{sat} + \left[-\beta V_{sat} - V_{sat}\right] e^{-t/RC}$$

$$v_c(t) = V_{sat} - V_{sat}(1+\beta) e^{-t/RC}$$

but at $t = \frac{T_o}{2}$; $v_c\left(\frac{T_o}{2}\right) = +\beta V_{sat}$

$$\text{so } +\beta V_{sat} = V_{sat}\left[1 - (1+\beta) e^{-T_o/2RC}\right]$$

$$(1+\beta) e^{-T_o/2RC} = 1-\beta$$

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$$e^{T_0/2RC} = \frac{1+\beta}{1-\beta}$$

$$\Rightarrow \boxed{T_0 = 2RC \ln\left(\frac{1+\beta}{1-\beta}\right)}$$

and $\boxed{f_0 = \frac{1}{T_0}}$ $\boxed{\beta = \frac{R_2}{R_1+R_2}}$

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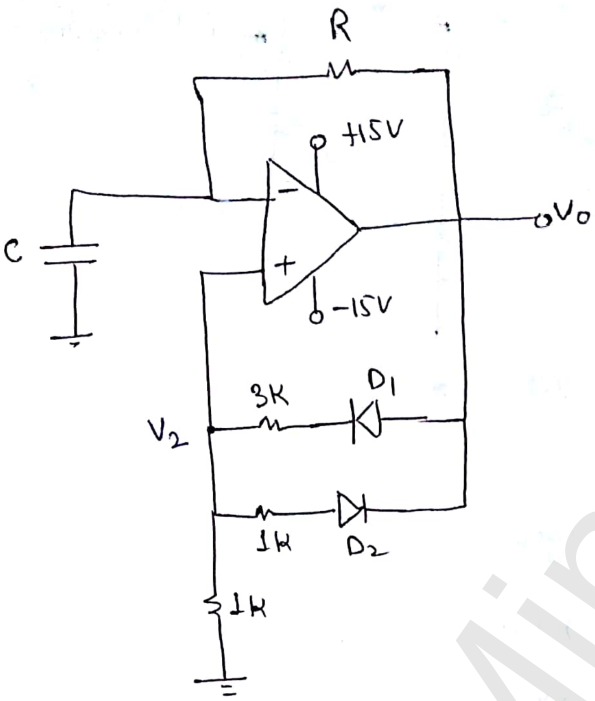
Q



An oscillator ckt using ideal op-amp and diode is shown below. the time duration for the part of the cycle is Δt_1 and for -ve part is Δt_2 then calc the value of $e^{(\Delta t_1 - \Delta t_2)/RC}$

Soln here Δt_1 and Δt_2 are not equal bcz $+\beta V_{sat}$ and $-\beta V_{sat}$ magnitude are different.

If $V_0 = +V_{sat} = +15$

$$V_2 = V_{UT} = \frac{1K}{1K+3K} \times 15$$

$$V_{UT} = 3.75\ V$$

If $V_0 = -V_{sat} = -15$

$$V_2 = V_{LT} = \frac{1K}{1K+1K}(-15) = -7.5\ V$$

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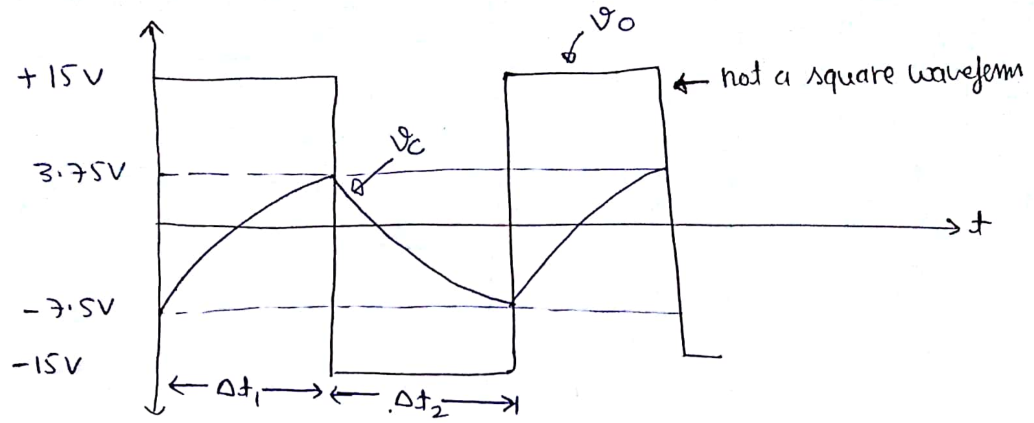

case 1 During +ve cycle

$v_{initial} = -7.5V$

$V_{final} = 15V$

$$v_c(t) = 15 + [-7.5 - 15] e^{-t/RC}$$

$$= 15 - 22.5 e^{-t/RC}$$

at $t = \Delta t_1$

$$3.75 = 15 - 22.5 e^{-\Delta t_1/RC}$$

$$e^{-\Delta t_1/RC} = \frac{15 - 3.75}{22.5}$$

$$e^{-\Delta t_1/RC} = 0.5$$

$$\boxed{e^{\Delta t_1/RC} = 2}$$

case 2 During -ve cycle

$v_{initial} = 3.75$

$v_{final} = -15V$

$$v_c(t) = -15 + [3.75 + 15] e^{-\Delta t_2/RC}$$

$$= -15 + 18.75 e^{-t/RC}$$

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at $t = \Delta t_2$

$$-7.5 = -15 + 18.75\, e^{-\Delta t_2/RC}$$

$$\boxed{e^{-\Delta t_2/RC} = 0.4}$$

$$e^{(\Delta t_1 - \Delta t_2)/RC} = e^{\Delta t_1/RC} \times e^{-\Delta t_2/RC}$$

$$= 2 \times 0.4$$

$$= 0.8 \text{ Ans.}$$

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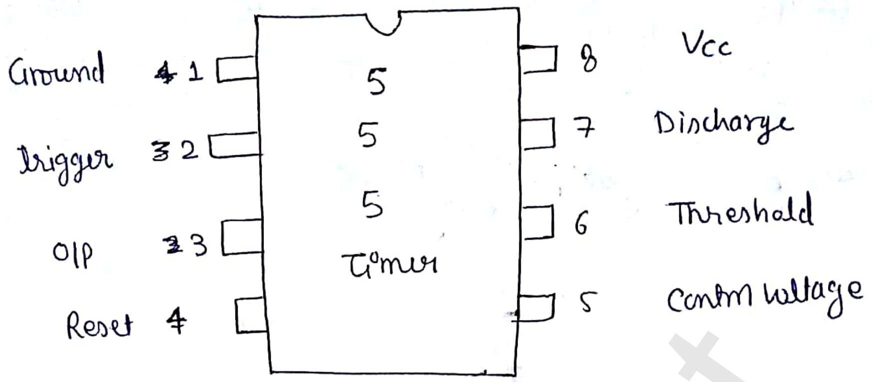

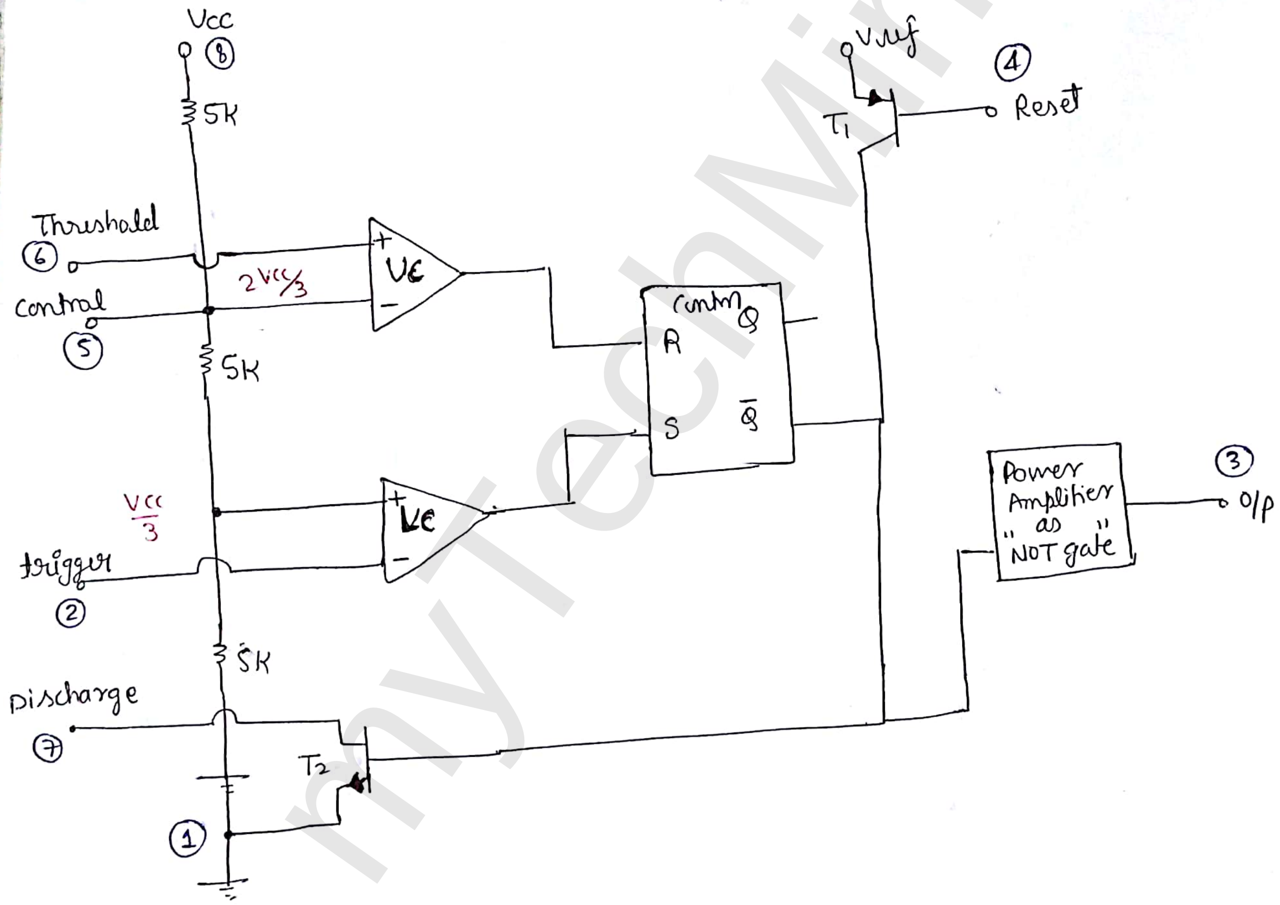

Two opamps in open loop so work as comparator

RS F/F

Power ampr are CE type if we give $\bar{Q}$ so that o/p we get is in phase (amplified). bcz CE gives 180° phase shift and $\bar{Q}$ also will give 180° phase shift so net phase shift will be 0°.

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if threshold > $\frac{2V_{cc}}{3}$

Two comparator ckts are used internally used as upper comparator & Lower comparator

V_{ocomp} → o/p of comparator

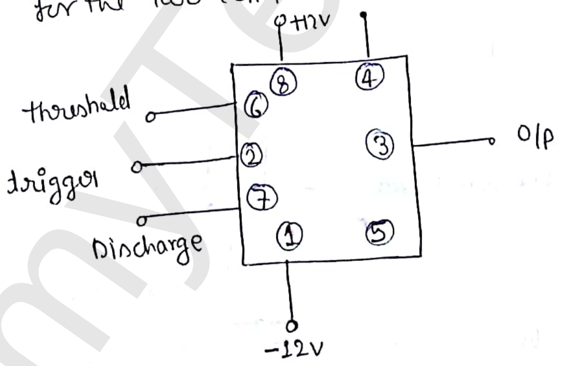
if $V^+ > V^-$ $V_{ocomp} = 1$

if $V^+ < V^-$ $V_{ocomp} = 0$

comparator o/p compares the i/p For SR

(S) V_{OLC}	(R) V_{OUC}	Q_{n+1}
0	0	Q_n
0	1	0
1	0	1
1	1	X (Not allowed)

Question The IC timer 555 is shown below. determine the reference level for the two comparators inside the chip justify your



Answer by drawing a block dgm of internal ckt of IC timer 555

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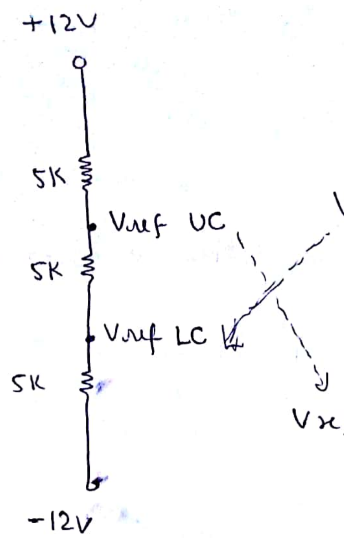
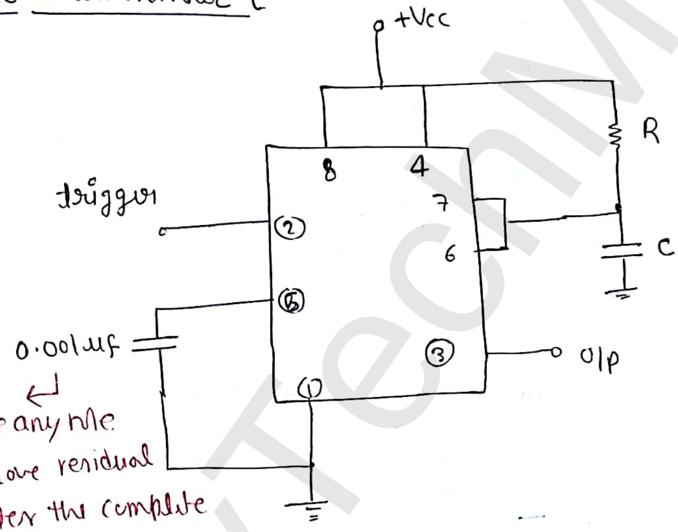


$$V_{ref\,LC} = \frac{12 \times 5K + (-12) \times 10K}{15K}$$

$$= -4V$$

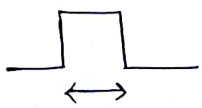
$$V_{ref\,UC} = \frac{12 \times 10 - 12 \times 5}{15} = 4 \text{ volt}$$

Monostable multivibrator [we can make monostable multivibrator from 555 IC]



don't have any role just to remove residual charges after the complete operation.

it generates a pulse waveform



Tp
↳ width of pulse

$$T_p = RC \ln 3$$

$$\boxed{T_p = 1.1\, RC}$$

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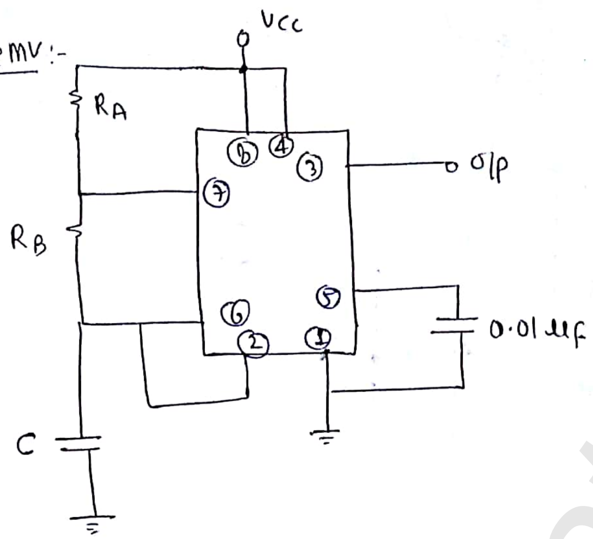
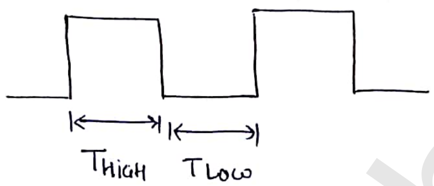
① Astable MV :-





$$T_{high} = 0.69(R_A + R_B)C$$

$$T_{low} = 0.69 R_B C$$

$$\boxed{T_0 = 0.69(R_A + 2R_B)C}$$

$$\boxed{f_0 = \frac{1}{T_0}}$$

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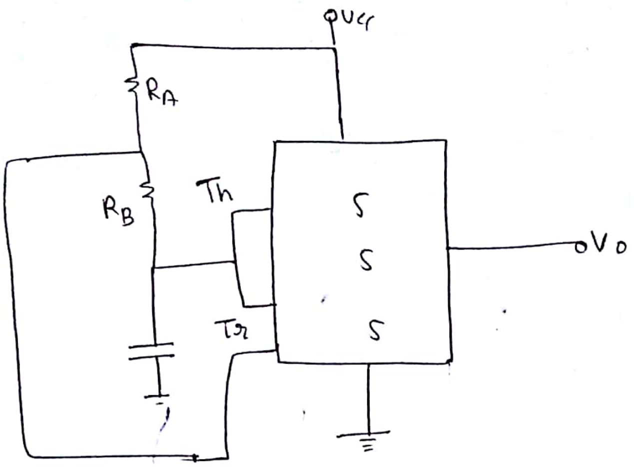
Q



555 Timer IC is connected an Astable MV IC the value of capᶜ C = 10nF the values of resistor R_A and R_B for fm^c of 10 kHz and duty cycle of 0.75 for the o/p waveform are

Solⁿ

$C = 10nF$

$D_T = 0.75$

$f_0 = 10KHz$

$T_0 = \frac{1}{f_0} = \frac{1}{10} = 0.1 \, msec$

$D_T = \frac{T_{ON}}{T_0} = \frac{T_{HIGH}}{T_0} =$

$T_0 \; 0.75 = T_{high} =$

$T_{High} = 0.1 \times 0.75 \times 10^{-3}$

$T_{high} = 0.69(R_A + R_B)C = 0.75 \times 0.1 \times 10^{-3}$ —— (I)

$\frac{T_{Low}}{T_0} = 0.25$

$T_{low} = 0.25 \times 0.1 \times 10^{-3} = 0.69 R_B C$ —— (II)

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