Unit 2

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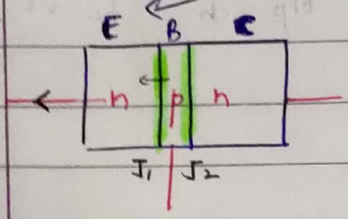
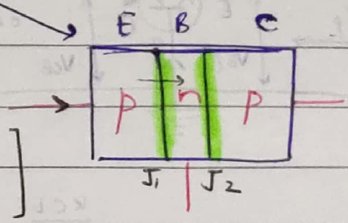
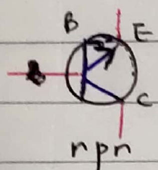
* Bipolar Junction Transistor



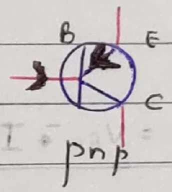


[width : C > E > B
doping : E > C > B]



$B \rightarrow E$

npn

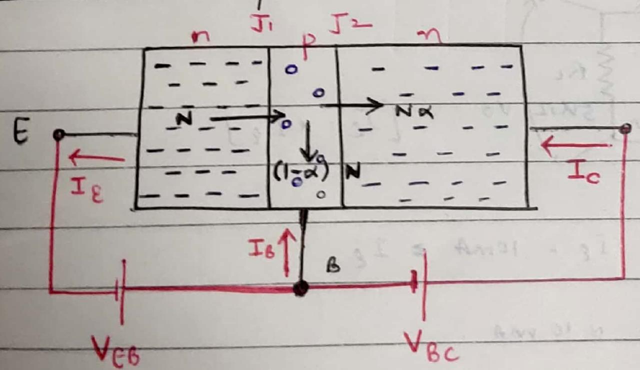


$E \rightarrow B$

pnp

J_1 (E-B)	J_2 (B-C)	Region of op.	
f.b.	r.b.	Active	Amplifier
f.b	f.b.	Sat^n.	ON
r.b.	r.b.	cut off	OFF
r.b.	f.b.	Inverted	$E \leftrightarrow C$

* Transistor oper^n (Active mode)

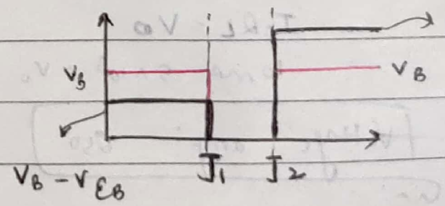


{ $\alpha \simeq 0.98 - 0.95$ }

N : no of e^- flowing

I_c : Sat^n current

as Base region is v. lightly doped & thin.



KCL

$$I_C + I_B = I_E$$

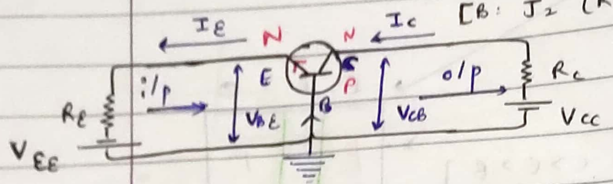
$$I_C = \alpha I_E + I_{C_0}$$ reverse sat^n

CB

Common Base config^n

EB : J_1 (fb)
CB : J_2 (Rb)

i/p ch : I_E vs V_{BE}
o/p ch : I_C vs V_{CB}



KCL : $I_E = I_C + I_B$

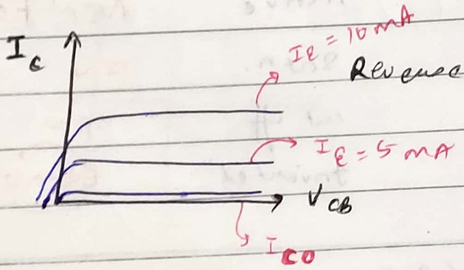
$I_C = \alpha I_E + I_{CO}$

$\boxed{V_{BE} = V_{EE} - I_E R_E}$

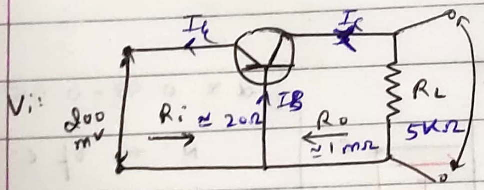
also $I_C \simeq \alpha I_E$
as $I_{CO} \simeq 0$

$\boxed{\alpha = \frac{I_C}{I_E}}$ → out / → input

$\boxed{V_{CB} = V_{CC} - I_C R_C}$



eg:



$[I_C = \alpha I_E]$

$\frac{200\,mV}{20\Omega} = i_{input} = I_E = 10\,mA = I_E$

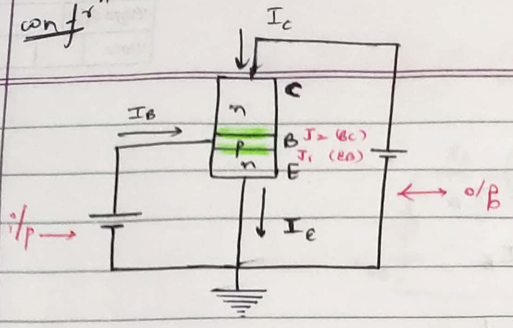
$I_E \simeq I_C \simeq 10\,mA$

$I_C R_L = V_o$

$10\,mA \cdot 5 \times 10^3 = V_o = 50\,V$

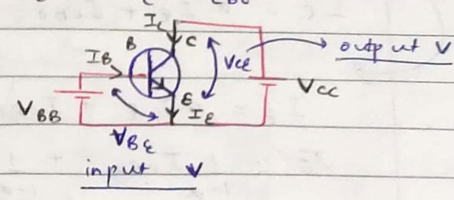
$\boxed{\text{Voltage amp : } 250}$

CE confrⁿ



$I_E = I_C + I_B$

$I_C = \alpha I_E + I_{CBO}$



$\beta = \frac{I_C}{I_B}$ $\quad \alpha = \frac{I_C}{I_E}$

also

$\boxed{I_C = \beta I_B + (\beta+1) I_{CBO}}$

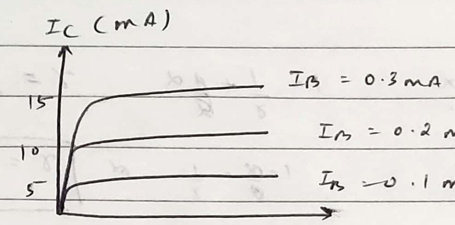
$\frac{I_C}{\beta} + I_C = \frac{I_C}{\alpha}$ $\quad \frac{1}{\beta} + 1 = \frac{1}{\alpha}$

$\boxed{\beta = \frac{\alpha}{1-\alpha}}$

or

$\boxed{\frac{\beta}{\beta+1} = \alpha}$

also



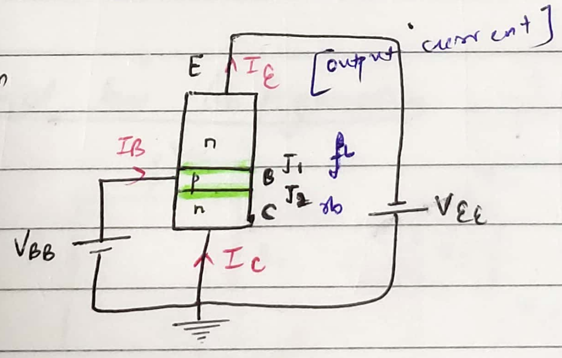
$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{5}{0.1} = 50$

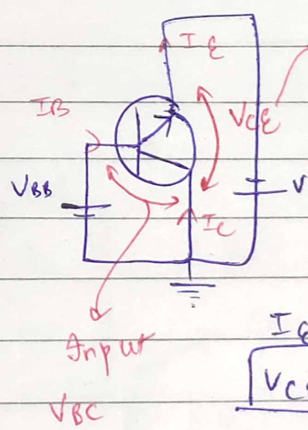
I_C is output current

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

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

CC confgrⁿ



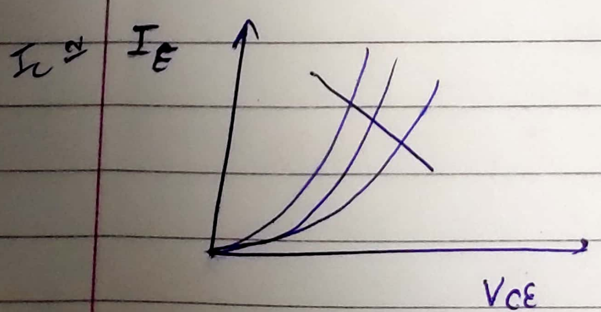


$\boxed{V_{CE} = V_{BE} + V_{BC}}$

$I_E = I_B + I_C$

$\boxed{V_{CE} = V_{BE} + V_{BC}}$

now $I_C = \alpha I_E$



o/p ch of CE ≅ o/p of CC

$\boxed{\gamma = \frac{I_E}{I_B} \simeq \frac{\Delta I_E}{\Delta I_B}}$

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$I_E = I_C + I_B$

$I_C = \alpha I_E + I_{CBO}$

$I_E = \alpha I_E + I_{CBO} + I_B$

$I_E = \frac{1}{1-\alpha} I_{CBO} + \frac{1}{1-\alpha} \cdot I_B$

$\boxed{I_E = \gamma [I_{CBO} + I_B]}$

$\gamma = \frac{I_E}{I_B}$ $\beta = \frac{I_C}{I_B}$ $\alpha = \frac{I_C}{I_E}$

$I_E = I_B + I_C$

$I_E = \frac{I_E}{\gamma} + \frac{I_E}{\beta}\alpha$ $1 = \frac{1}{\gamma} + \alpha$ $\gamma = \alpha$

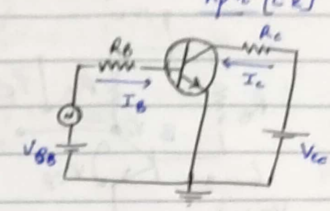
$\cancel{I_B} \cdot \gamma = \cancel{I_B} + \cancel{I_B} \cdot \beta$ $1 - \alpha = \frac{1}{\gamma}$ or $\boxed{\gamma = \frac{1}{1-\alpha}}$

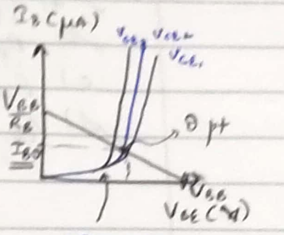
$\boxed{\gamma = \beta + 1}$

$\boxed{\beta = \frac{\alpha}{1-\alpha}}$

DC Biasing of Transistors

npn [CE]





[Diode] chr

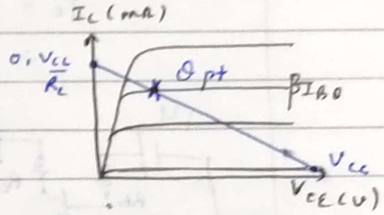
input

also DC:

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

$$\left[\frac{V_{BB}}{R_B} - \frac{V_{BE}}{R_B} = I_B\right]$$

if $V_{CE_1} > V_{CE_2} > V_{CE_3}$



output

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

$$\left[\frac{V_{CC}}{R_C} - \frac{V_{CE}}{R_C} = I_C\right]$$

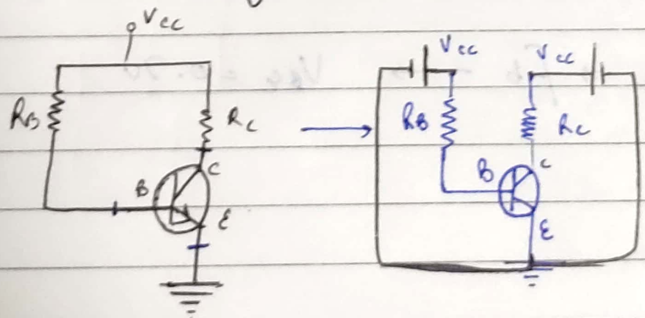
* Operating pt must be selected in centre of active region [for no distortion]

also

$$I_C = \beta I_B + (\beta + 1) I_{CBO}$$

$$T\uparrow \longrightarrow I_{CBO} \uparrow\uparrow \quad I_C \uparrow$$

Fixed Bias Configuration



$$V_{CC} - I_B R_B = V_{BE}$$

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

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

$$I_C = \beta \left(\frac{V_{CC} - V_{BE}}{R_B}\right)$$

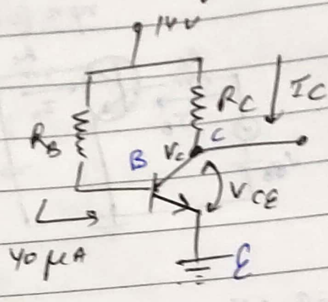
Q: for fixed-bias config^n find

a) I_C

b) R_C

c) R_B

d) V_{CE}

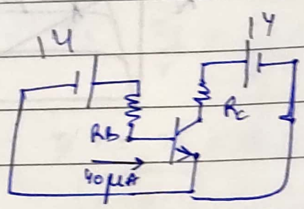


$\beta = 80$

$I_B = 40\ \mu A$

$I_C = 80 \times 4 \times 10^{-5}$ A

$= 3.2 \times 10^{-3} = 3.2$ mA



$$\boxed{\frac{13.3}{40} \times 10^{6} = R_B}$$

$14 - (40\ \mu A) R_B = V_{BE}$

$14 - (3.2\, mA) R_C = 6V = V_C = V_{CE} = V_C - V_E$

$V_C = 6V$, $V_E = 0$

$\overset{4}{\cancel{8}} = \underset{10}{(\cancel{3.2}\ mA)} R_C$

$$\boxed{2.5\ k\Omega = R_C}$$

also $V_{BE} \Rightarrow$ Fb $\longrightarrow$ $V_{BE} = 0.7V$

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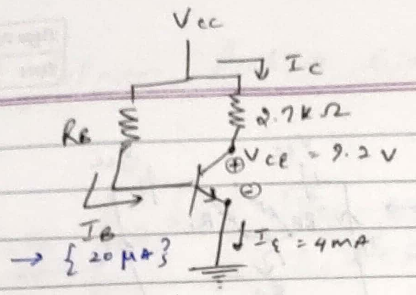
Q:



β

Find:

a) I_c

b) V_{cc}

c) β

d) R_B

Sol: $I_E \simeq I_C \simeq 4\,mA$ — (a)

$V_{cc} - (2.7\times10^{3})(4\times10^{-3}) = 7.2V$

$V_{cc} - 10.8 = 7.2\,V$

$\boxed{V_{cc} = 18V}$ — (b)

$18 - I_B R_B = 0.7V$

$\boxed{17.3 = I_B R_B}$ — (c)

$\boxed{I_B = \frac{4mA}{\beta}}$

$5\ \cancel{20}\times10^{\cancel{-6}\,-3} = \frac{\cancel{4}\times10^{-3}}{\beta}$

$\boxed{\beta = 200}$

$\boxed{\frac{17.3}{4} = \frac{R_B}{\beta}}$

$R_B = 17.3\times50$

$R_B = 173\times5 = 865\,\Omega$

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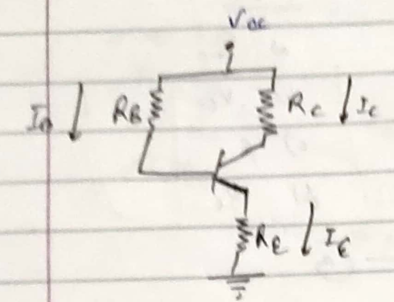
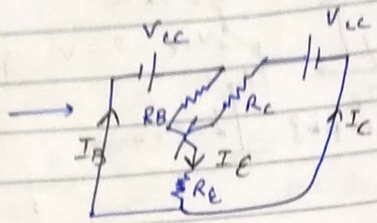
Emitter-Bias config^n





~~$V_{cc} - I_B R_B = V_{CE}$~~

~~$V_{cc} - I_C R_C = V_{CE}$~~

$V_{CC} - I_B R_B - I_E R_E = V_{BE}$

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

$I_E = \gamma I_B$

$I_E = (\beta+1) I_B$

$V_{CC} - \{\beta R_B + (\beta+1) R_E\} I_B = V_{BE}$

$$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1) R_E}}$$

$R_B << (\beta+1) R_E$

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

V_{CE} ✓

$I_C = \beta I_B$

$I_C \simeq \frac{[V_{CC} - V_{BE}]\beta}{R_E(\beta)}$

Q. for Emitter-bias det:

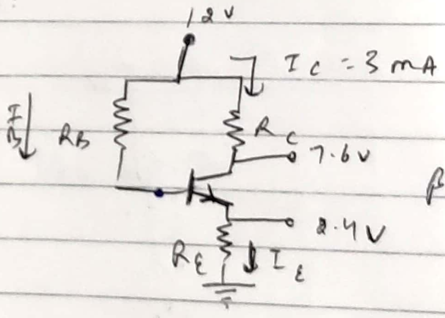
a) R_C ✓

b) R_E ✓

c) R_B ✓

d) V_{CE} ✓

e) V_B



$\beta = 80$

$V_{CE} = 5.2$ V

Sol.

$8.4 = \frac{3}{80} \times 10^{-3} R_B$

$R_B = \frac{8.4}{1} \times \frac{80}{3} \times 10^3$

$\boxed{R_B = 2.4 \times 10^5 \Omega}$

$12 - I_B R_B - I_E R_E = 0.7$ V

$\boxed{12 - I_B R_B = 3.1 \text{ V}} = V_B$

$12 - (3 \times 10^{-3}) R_C = 7.6$ V $\longrightarrow$ $R_C = \frac{4.4}{3} \times k\Omega = R_C$

$2.4 - I_E R_E = 0$

$\frac{80}{81} = \frac{\beta}{1+\beta} = \alpha$

$I_C \simeq I_E$

$R_E = \frac{2.4}{243} \times 80 \times 10^3$ $1.366\ k\Omega = R_C$

$\boxed{R_E = 800\ \Omega}$

$I_B = \frac{3}{80}$ mA

$\frac{81}{80} \times 3\text{mA} = I_E = \frac{243}{80}$ mA

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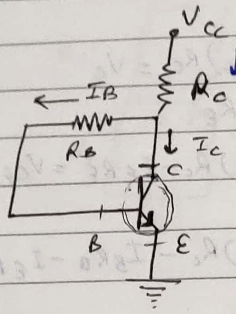
Q. Collector Feedback Biasing



$\boxed{V_{CC} - IR_C = V_C} = V_{CE}$ as $\boxed{V_E = 0}$

$V_{CC} - IR_C - I_BR_B = V_B = V_{BE}$ as $\boxed{V_E = 0}$

$V_{CC} - (I_B + I_C) R_C = V_{CE}$ —— (i)

$V_{CC} - (I_B + I_C) R_C - I_BR_B = V_{BE}$ —— (ii)

$I_C = \beta I_B$

$\dfrac{V_{CC} - V_{CE}}{(\beta+1)R_C} = I_B \longleftarrow V_{CC} - (\beta+1) I_B R_C = V_{CE}$ — (i)

$V_{CC} - (\beta+1) I_B R_C - I_BR_B = V_{BE}$ — (ii)

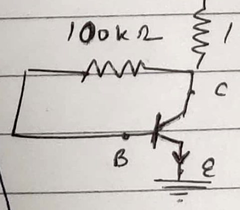
or

$$\left[\frac{V_{CC} - V_{BE}}{(\beta+1) R_C + R_B} = I_B\right] \quad \left[I_C = \beta \left\{\frac{V_{CC} - V_{BE}}{(\beta+1) R_C + R_B}\right\}\right]$$

<u>Advantage Q point</u>:
1. Against varn to T.
2. " " " V_{CC}
3. " " " β.

<u>Disadvantage</u>:
1. $R_C \uparrow\uparrow$ $V_{CC} \uparrow\uparrow$ cos $\uparrow$
$R_B \downarrow\downarrow$ R.b. of C-B $\downarrow$

Q:



$\beta = 100$ find Q pt.

$V_{BE} = 0.7V$
$I_B = 96.01 \mu A$
$V_{CE} = 10.30 V$
$I_C = 9.601 kA$

$20 - (I_C + I_B) 10^3 = V_{CE}$

$20 - (I_C + I_B) 10^3 - I_B (10^5) = V_{BE}$

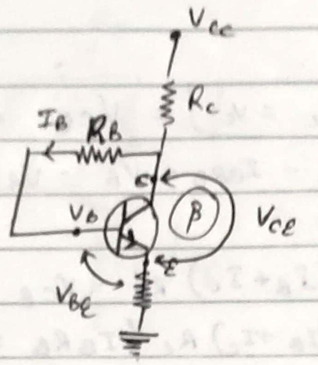
$I_C = 100 I_B$

$20 - (101) 10^3 I_B = V_{CE}$

$\boxed{96.01 \mu A = I_B}$

$\dfrac{19.3}{201}$ mA $= I_B \longleftarrow 20 - [(101)10^3 + 10^5] I_B = V_{BE} = 0.7V$

Collector feedback Biasing with Emitter Resistance



$$V_{cc} - (I_B + I_C) R_C = V_C$$

$$V_E = I_E R_E$$

$$V_{cc} - (I_B + I_C) R_C - I_E R_E = V_{CE} \quad \text{—(i)}$$

$$V_{cc} - (I_B + I_C) R_C - I_B R_B - I_E R_E = V_{BE} \quad \text{—(ii)}$$

$(I_E \simeq I_C)$ $\quad \boxed{I_B \beta = I_C}$

$\boxed{\text{Values}}$ $\leftarrow$ $V_{cc} - V_{CE} = [(\beta+1) R_C + \beta R_E] I_B$

$$\frac{V_{cc} - V_{BE}}{(\beta+1) R_C + \beta R_E + R_B} = I_B$$

$$\beta I_B = I_C \approx I_E = \frac{\beta [V_{cc} - V_{BE}]}{(\beta+1) R_C + \beta R_E + R_B}$$

V_{CE} — (i)

$I_E R_E = V_{BE}$ (ii)

I_B

R_B

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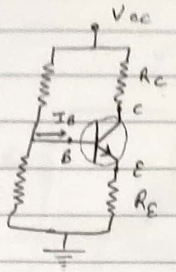
Voltage-Divider Bias Configuration



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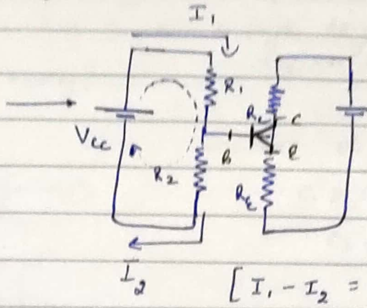


$[I_1 - I_2 = I_B]$

$V_{CC} - I_1R_1 - I_2R_2 = 0$

or

$\boxed{V_B = I_2R_2 = V_{CC} - I_1R_1}$ — (i)

$V_{BE} = I_2R_2 - I_ER_E$

(ii) — $\boxed{V_{BE} = V_{CC} - I_1R_1 - I_ER_E}$ $\quad \boxed{V_E = I_ER_E}$

$V_{CC} - I_CR_C = V_C$

(iii) — $\boxed{V_{CC} - I_CR_C - I_ER_E = V_{CE}}$

Find:

a) I_C

b) V_E

c) V_{CC}

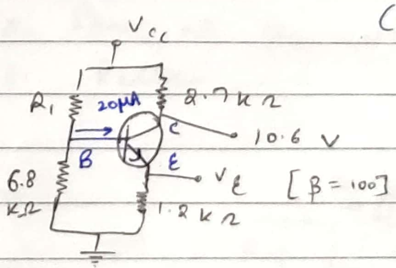
d) V_{CE}

e) V_B

f) R_1

$(V_{BE} = 0.7V)$

S.



$V_{BE} = 0.7V$

$V_E = 1.2V$

$V_B = 1.9V$

Sol: $V_{CC} - (2.7 \times 10^3)\, I_C = 10.6$

$I_B = 20\,\mu A \quad I_C = 2\,mA$

$V_{CC} = 10.6 + 5.4$

$100 I_B = I_C \simeq I_E$

$V_E = 2 \times 10^{-3} \times 1.2 \times 10^3$

* $\boxed{V_{CC} = 16\ V}$

$\boxed{V_E = 2.4V}$

$\boxed{V_{CE} = 16 - V_E}$

$16 - R_1I_1 = V_B$

$I_2 \cdot 6.8k\Omega = V_B$

$R_1I_1 + 6.8 \times 10^3 I_2 = 16$

$\boxed{V_{CE} = 13.6V}$

$16 = R_1I_1 + (6.8)10^3 I_2$

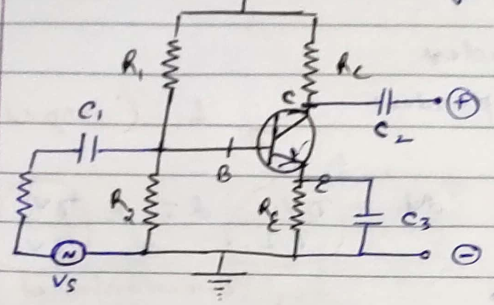
$I_1 + I_2 = 20\,\mu A \rightarrow (6.8 \times 10^3) I_1 + 6.8 \times 10^3 I_2 = 136 \times 10^{-3}$

$(R_1 - 6.8 \times 10^3) I_1 = 15.864$

AC response or Small Signal Analysis of BJT

↳ small enough to get Q pt in active region only

V_{cc} (DC biasing?)



in case of DC

C_1 & C_2 → Coupling cap.

C_3 → By pass cap.

$X_C = \frac{1}{\omega C}$ or $\frac{1}{2\pi f C}$

for DC → $f = 0$ $X_C = \infty$

AC ⇒ $f \neq 0$ $X_C \neq \infty$

(gen) X_C → small as f high

so $\boxed{X_C \approx 0}$

for C_3 $X_{C_3} \approx 0$

thus I_e goes via C_3 not R_E (short ckt)

to find AC resp:

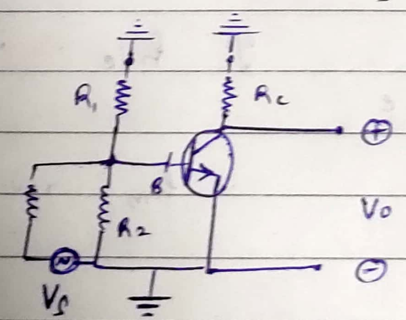
i) ac eqv ckt find

ii) replace the transistor with eq model of eqv. ckt.

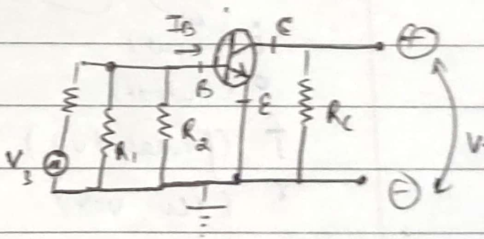
~~AC response~~

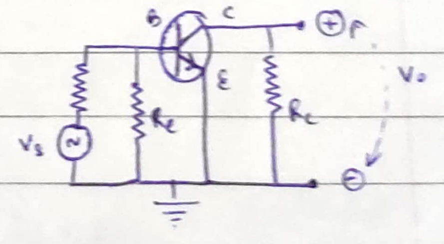
[AC eqv ckt]

1. Short ckt all DC source $V = 0$
2. Short all the caps.
3. Redraw.



⇒





Eq model of Transistor →

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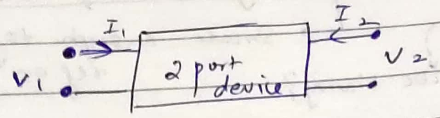
Date

Hybrid Model (h-model)



v_1 & $I_2 \longrightarrow$ dependent
V_2 & $I_1 \longrightarrow$ Independent

h_{11} (impedence)

$V_1 = f_1(I_1, V_2) \longrightarrow dV_1 = \frac{\partial V_1}{\partial I_1} dI_1 + \frac{\partial V_1}{\partial V_2} dv_2$

dimesionless

$I_2 = f_2(I_1, V_2) \longrightarrow dI_2 = \frac{\partial I_2}{\partial I_1} dI_1 + \frac{\partial I_2}{\partial V_2} dv_2$

admittance (h_{22})

$v_1 = h_{11} i_1 + h_{12} v_2$

$i_2 = h_{21} i_1 + h_{22} v_2$

$\left.\frac{v_1}{i_1}\right|_{V_2=0} = h_{11}$ & $h_{12} = \left.\frac{v_1}{v_2}\right|_{i_1=0}$

$\left.\frac{i_2}{i_1}\right|_{V_2=0} = h_{21}$ & $h_{22} = \left.\frac{i_2}{v_2}\right|_{i_1=0}$

Nomenclature :

$h_{e_1 e_2}$

i (input)
o (output)
f (forward vol.)
r (rev. volt.)

CE for e
CB → b
CC → c

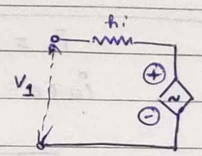
eg: h_{ie} : input impedance of CE.

h_{rb} : rev. voltage of CB

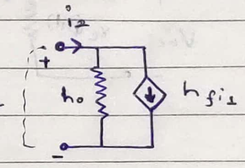
$v_1 = h_i i_1 + h_r v_2 \longrightarrow$ (i)

$i_2 = h_f i_1 + h_o v_2 \longrightarrow$ (ii)

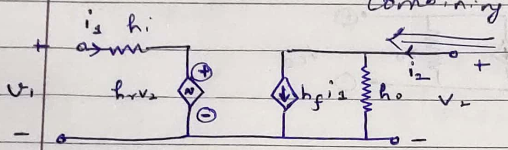
Reverse KVL



Rev. KCL



Combining



$\underline{\underline{CE}}$:

$h_i \longrightarrow h_{ie}$ $\quad i_1 \longrightarrow i_b$

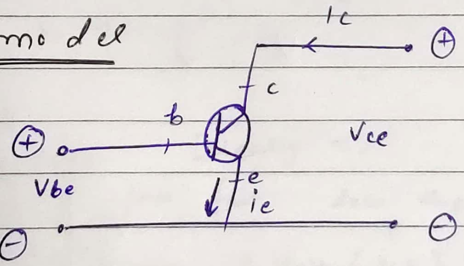
$h_f \longrightarrow h_{fe}$ $\quad v_1 \longrightarrow v_{be}$

$h_o \longrightarrow h_{oe}$ $\quad i_2 \longrightarrow i_c$

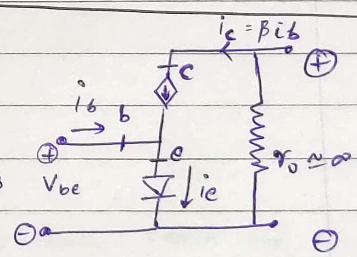
$h_r \longrightarrow h_{re}$ $\quad v_2 \longrightarrow v_{ce}$

---

r_e - model



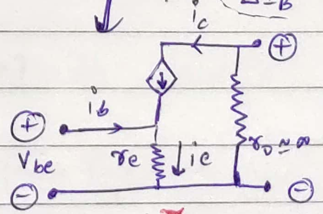
$\Longrightarrow$



$r_d = \dfrac{\Delta V_{BE}}{\Delta I_B}$

$[r_d \rightarrow r_e]$

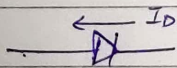
emmiter



r_e - Model

what is r_e?

$r_d = \dfrac{\Delta V_{BE}}{\Delta I_B}$



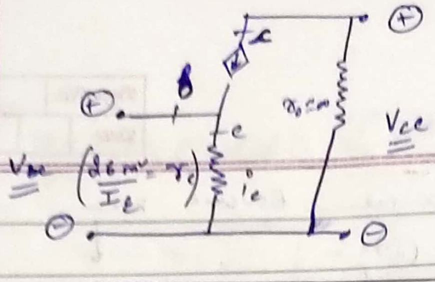
$I_D = I_s\left(e^{\frac{V_D}{\eta V_T}} - 1\right)$

$T = 300K \quad \eta = 1$

$1/r_d = \dfrac{dI_d}{dV_d} = I_s \cdot \dfrac{d}{dV_d}\left(e^{\frac{V_d}{300} \cdot 11600} - 1\right)$

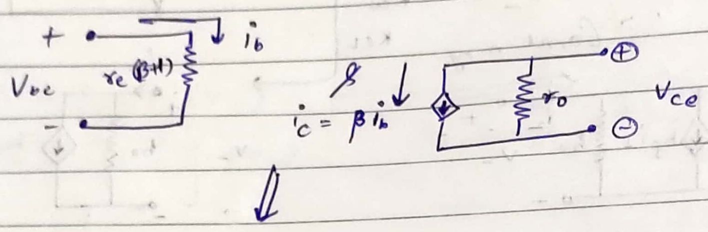
$1/r_d = \dfrac{I_s \cdot e^{\frac{V_d}{V_T}}}{V_T} = \dfrac{I_s + I_D}{V_T}$ $\quad I_s << I_d$ $\quad \dfrac{1}{r_d} \simeq \dfrac{I_D}{V_T}$

$\boxed{r_d = \dfrac{26\,mV}{I_E}}$ or $\boxed{r_d = \dfrac{26\,mV}{I_D}}$

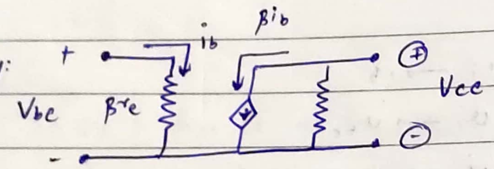


$$i_e = (\beta+1)\, i_B$$

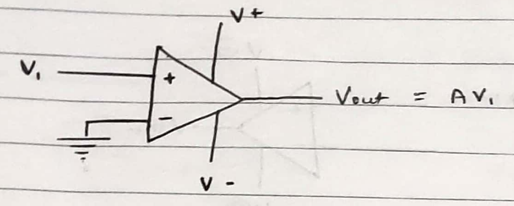
$$i_e r_e = (\beta+1)\, r_e \cdot i_B = \underline{\left[(\beta+1) r_e\right]} \cdot i_b$$

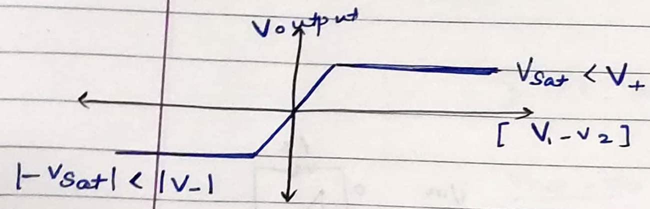


Finally:

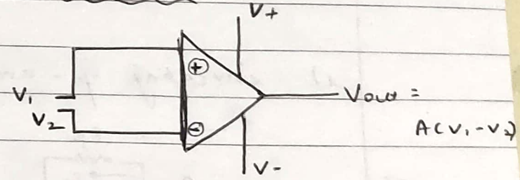


Operational Amplifier





In general:

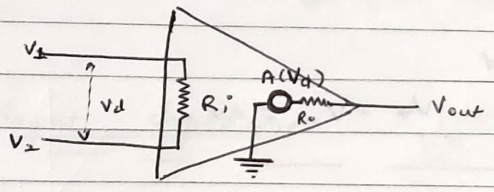


Equivalent ckt: (Ideal op-amp ⟶ $R_i = \infty$)

($R_o = 0$)

(Bandwidth $= \infty$)

($A = \infty$)



* Slew rate: [Ideally: ∞]

How fast does the op-amp reach the max voltage given: [Volt / μs]

* CMRR : $\frac{A_d}{A_c}$ [Ideally: ∞]

⟶ Practical

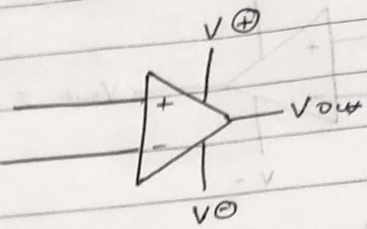
R_i	MΩ
R_o	Ω
A	$10^5 - 10^6$
when $V_{in} = 0$	mV ⟶ Vout
Slew rate	0·5 V/μs
CMRR	70 - 90 dB

Date

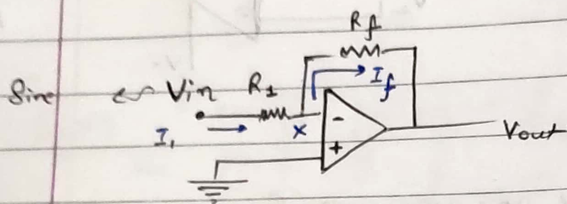
* *feedback op-amp*

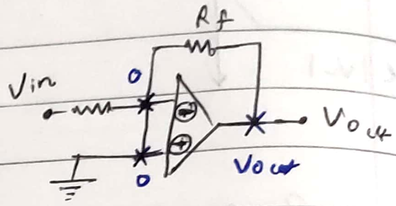
Non-Inverting Input

Inverting input



i) inverting op-amp





eg: $A_{OL} = 10^6$

$V_{out} = A \cdot V_d$

$10\,\mu V = V_d = V_+ - V_- \simeq 0V$

$I_1 = \frac{V_{in}}{R_1}$

$I_f = \frac{V_{out}}{R_f}$

& we know the resistance of diode is v high thus no current goes in there

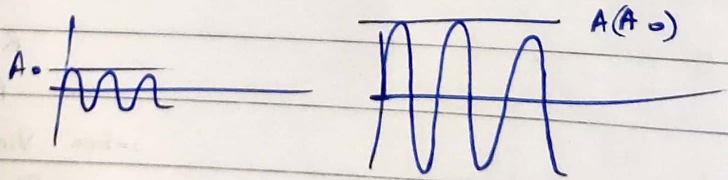
$$\frac{V_{in}}{R_1} = I_1 = I_f = \frac{V_{out}}{R_f}$$

$V_d = -V_{in}$

$$\boxed{\frac{V_{out}}{V_{in}} = \frac{R_f}{R_1} = A}$$

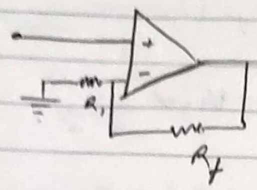
Inverted

Vin

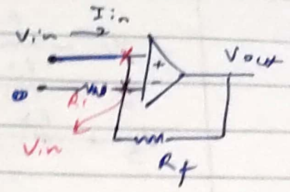


$Z_{in} = \frac{V_{in}}{V_{in}} \cdot R_1 = R_1$

ii) Non-inverting op-amp / Buffer ckt



Virtual short in Linear region $\longrightarrow$



$$I_f = \frac{V_{out} - V_{in}}{R_f} \ (\longrightarrow)$$

$I_f = I_1$ as I (op-amp $\simeq 0$) $\quad I_1 = \frac{V_{in}}{R_1} \ (\longrightarrow)$

$$\left[\frac{V_{out} - V_{in}}{V_{in}} = \frac{R_f}{R_1} = \frac{V_{out}}{V_{in}} - 1 \right]$$

$$\boxed{\frac{R_f + R_1}{R_1} = \frac{V_{out}}{V_{in}} = \frac{R_f}{R_1} + 1} = A$$

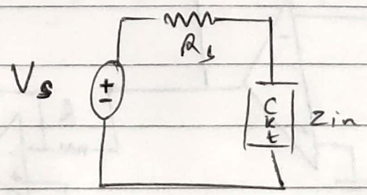
[No-Inversion] Same phase

Input Impedence: $\frac{V_{in}}{I_{in}} = Z_{in}$

$I_{in} \simeq 0$

$$\left[\frac{V_{in}}{I_{in}} \simeq \infty = Z_{in} \right]$$

If



$$\left[\frac{V_s}{R_s + Z_{in}} \cdot Z_{in} = V_{in} \right]$$

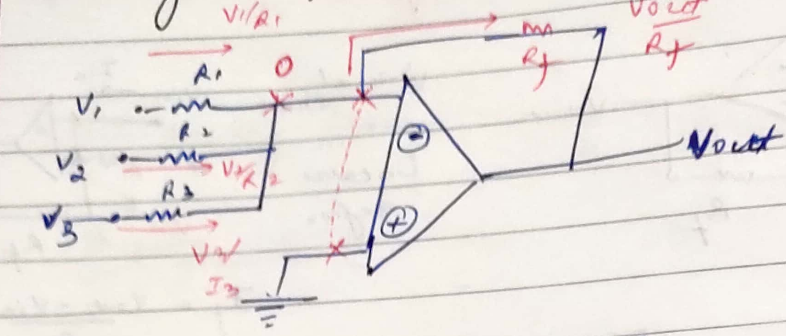
Non-Inverting: thus if $Z_{in} \simeq \infty$ then $V_{in} \simeq V_s \rightarrow$ Better

Inverting: but if $Z_{in} = R_s \longrightarrow \frac{V_{in}}{2} \simeq \frac{V_s}{2} \rightarrow$ Nope

(a)

? Inverting ?

* Summing Amplifier



$$\left[\frac{\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}} = V_n\right]$$

$$\left[\frac{V_{out}}{R_f} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right]$$

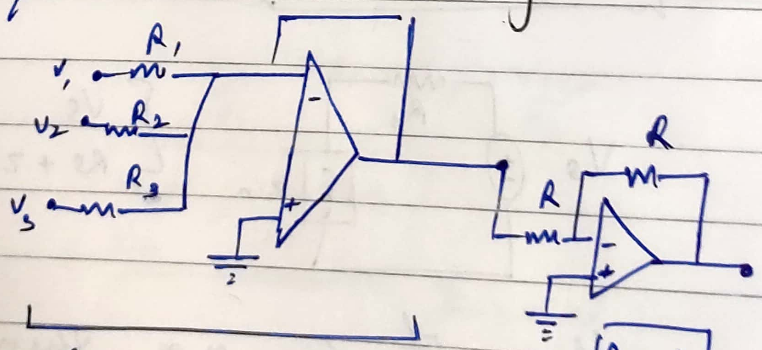
[Inverted]

$$\boxed{V_{out} = \sum \frac{R_f}{R_i}(V_i)}$$

Application of Summing Amp.

> Providing DC offset
> Digital to Analog converter
> Audio Mixer

→ Also you can do: (for inverting problem)

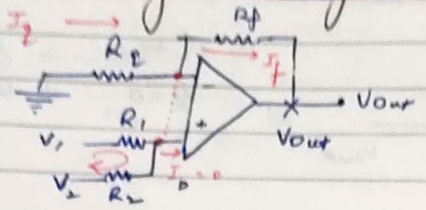


(+ → −

A = 1

− → +)

* Non-inverting summing amp.



$$V_1 - I_1R_1 - I_2R_2 = V_2$$

$$V_1 - V_2 = I_1R_1 + I_2R_2$$

$$[I_1 = I_2] \text{ as } I_0 \approx 0$$

$$\left[\frac{V_1 - V_2}{R_1 + R_2} = I_1\right] = I_2$$

$$V_x - V_{out} = I_fR_f$$

$$V_1 - I_1R_1 = V_x = I_qR_q = V_{out} + I_fR_f$$

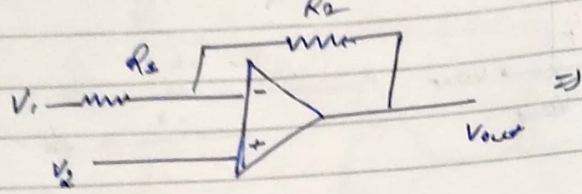
$$V_1 - \left(\frac{V_1 - V_2}{R_1 + R_2}\right)R_1 = I_qR_q = V_{out} + I_fR_f$$

$$I_f = I_q$$

$$V_1 - \frac{(V_1 - V_2)}{R_1 + R_2}R_1 = V_{out} + I_qR_f = I_qR_q$$

$$\left\{\frac{V_1}{R_f} - \frac{V_{out}}{R_f} - \frac{(V_1 - V_2)}{R_1 + R_2}\frac{R_1}{R_f} = I_q = \frac{V_1}{R_q} - \frac{(V_1 - V_2)}{R_1 + R_2}\frac{R_1}{R_q}\right\}$$

* Differential op-Amp or Subtractor op-amp

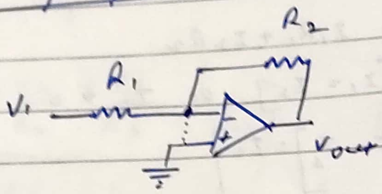


$\Rightarrow$

Case 1: $V_2 = 0$ + Case 2: $V_1 = 0$

Superposition theorem

C_1: $V_2 = 0$

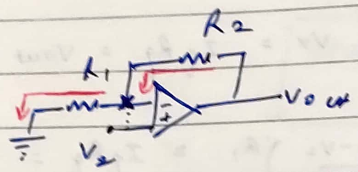


$$\frac{V_1}{R_1} = \frac{V_{out}}{R_2}$$

or

$$V_{out_1} = \frac{V_1 R_2}{R_1}$$

C_2: $V_1 = 0$



$$\frac{V_2}{R_1} = \frac{V_{out} - V_2}{R_2}$$

$$\frac{V_{out}}{V_2} = \frac{R_1 + R_2}{R_2}$$

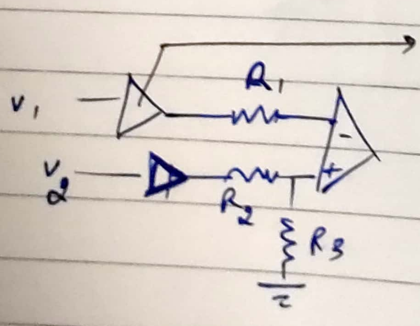
$$V_{out_2} = \frac{V_2 R_2}{R_1 + R_2}$$

$$V_{out} = V_{o1} + V_{o2}$$

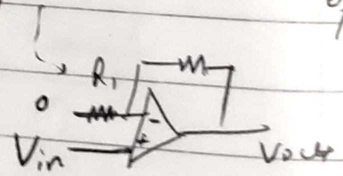
$$V_{out} = \frac{V_1 R_2}{R_1} + \frac{V_2 R_2}{R_1 + R_2} = \frac{(V_2 + V_1) R_1 R_2 + V_1 R_2^2}{(R_1 + R_2) R_1}$$

Impedence is low here.

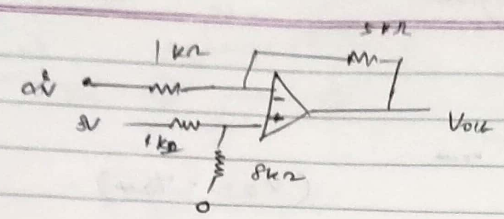
for higher:



▷ Buffer {Non-inverting op-amp}

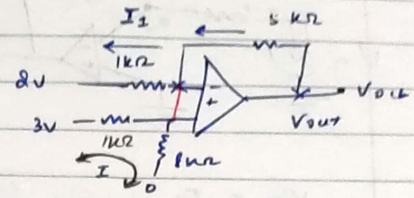


Ex



~~Superposition~~

Method : (mine)



$\frac{3\,k\Omega}{9} = I$ $\qquad V_x = \frac{3\cdot 8}{9\cdot 3} = \frac{8}{3}V$

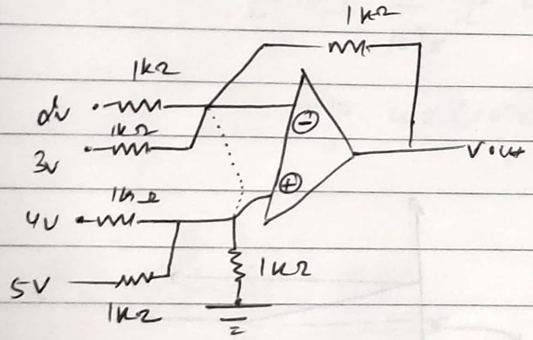
$\frac{8}{3} = 2 + (I_1)(10^3\,\Omega)$

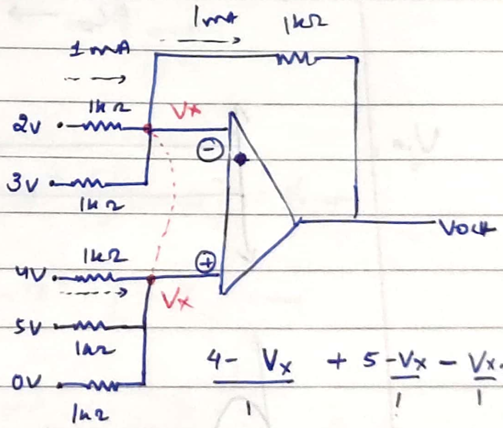
$\boxed{I_1 = \frac{2}{3}\,mA}$

$\frac{V_{out} - \frac{8}{3}}{5}\,mA = I = \frac{2}{3}\,mA$

$\boxed{\frac{18}{3} = V_{out} = 6V}$

Ex





$\frac{4 - V_x}{1} + \frac{5 - V_x}{1} - \frac{V_x}{1} = 0$

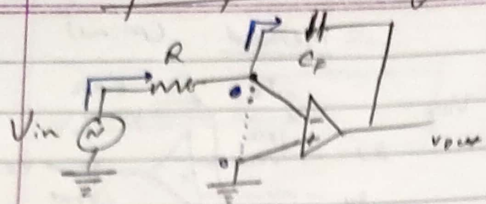
$9 = 3V_x$

$\boxed{V_x = 3\ V}$

$\frac{V_x - V_{out}}{1} = 1$

$\boxed{V_{out} = 2V}$

Op amp as Integrator.



$(V_c = -V_{out})$

$\frac{V_{in}}{R} = I_R$ $\qquad i = \frac{dq}{dt} = C\frac{dv}{dt}$

$\frac{V_{in}}{R} = I_{CF} = \cancel{V_{out}} - C\frac{dV_{out}}{dt}$

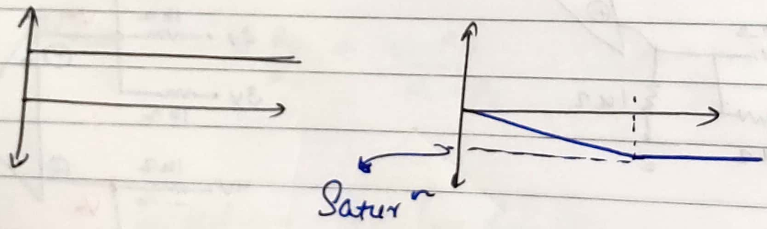
$-\int \frac{V_{in}}{RC}\, dt = \int dV_{out} = V_{out}$

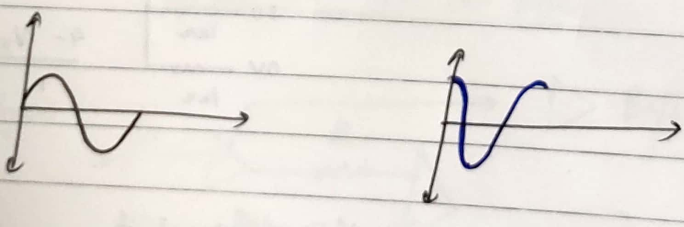
$-\frac{1}{RC}\int V_{in}\, dt = V_{out}(t)$

area under[V_{in}-t curve]/RC

also: $+\frac{1}{RC_F} \rightarrow$ time

V_{in}:





$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$

$\left[V_{out} = -\frac{X_C}{R} \cdot V_{in} \right]$

$A_v = -\frac{X_C}{R} = \frac{1}{2\pi \cdot RC \cdot f}$

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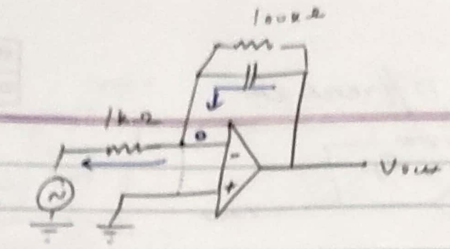
Q.



(a) $\sin(10000\pi t)$ = Vin

$\left(-\frac{V_{in}}{1}\right)$ mA = I_i

$\frac{V_{out} - 0}{} = V_C = V_R = i_R \cdot 100\,k\Omega$

$\left[i_R = \frac{V_{out}}{100}\ mA \right]$

$I_i - I_R = I_C = C \cdot \frac{dV_C}{dt} = \left[-V_{in} - \frac{V_{out}}{100} \right] mA = 10^{-8} \cdot \frac{dV_{out}}{dt}$

$A \int f(t) + B g(t) = C g'(t)$

$-V_{in} \cdot 10^5 - V_{out} \cdot 10^3$

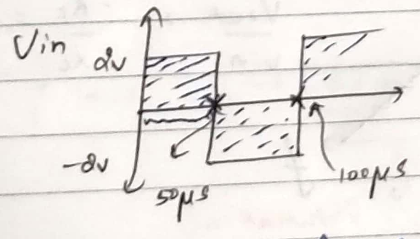
$\int -V_{in} \cdot 10^5 \cdot dt - \int V_{out} \cdot 10^3\, dt = \int dV_{out} = \frac{dV_{out}}{dt}$

$\Rightarrow (-10^5) \int V_{in}\, dt + (-10^3) \int V_{out}\, dt = \int dV_{out}$

$[-10^5] \cdot \frac{1}{10^4 \pi} \left\{ -\cos[10^4 \pi t] \right\} \Big|_0^t \simeq V_{out}$

$+\frac{10}{\pi} \cos(10^4 \pi t) \Big|_0^t \simeq V_{out}$

(b)

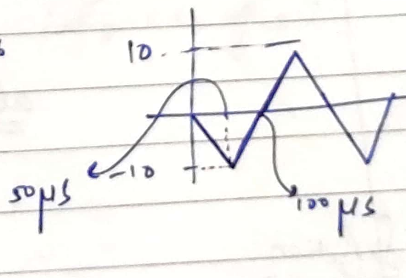


$-10^5 \left[\int V_{in}\, dt \right] = V_{out}$

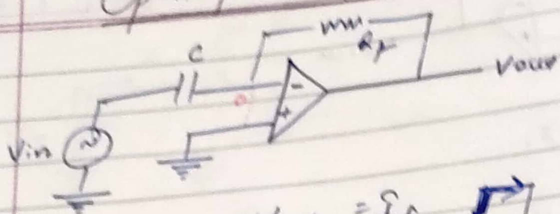
$-10^5 \cdot [10^{-4}] \longrightarrow$

Area B_1: $2 \times 50 \times 10^{-6}$

$= 10^{-4}$



Op-Amp as Differentiator



$-\frac{V_{out}}{R_f} = I_f$

$C \frac{d(+V_{in})}{dt} = I_c$

$$C \frac{d(V_{in})}{dt} = -\frac{V_{out}}{R_f}$$

$$\boxed{-CR_f \frac{dV_{in}}{dt} = V_{out}}$$

If $V_{in} = A\sin(\omega t)$

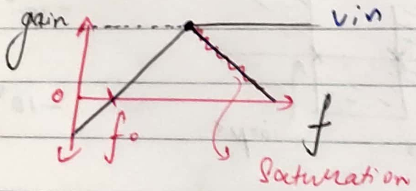
$V_{out} : [\omega C R_f A \cos \omega t = V_{out}]$

$X_c = \frac{1}{2\pi f C}$

$V_{out} = -\frac{R_F}{X_c} \cdot V_{in}$

$\frac{V_{out}}{V_{in}} = -\frac{R_F}{X_c} = A = -R_F \cdot 2\pi f C$

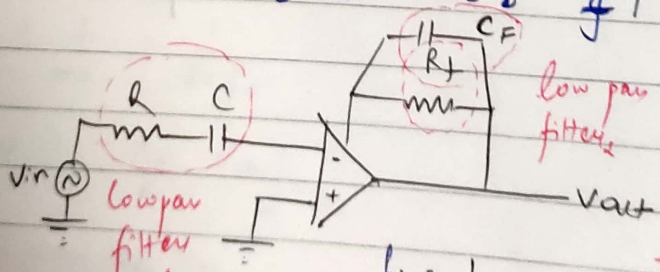
$[f_0 = \frac{1}{2\pi R_f C}]$



also $Z_{in} = X_c \uparrow \; f \downarrow$

$\downarrow Z_{in} \quad X_c \downarrow \quad f \uparrow$ (Problem)

Solution to Z →

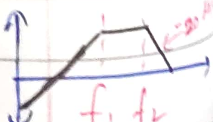


$\boxed{Z_{in} = \sqrt{R^2 + X_C^2}}$

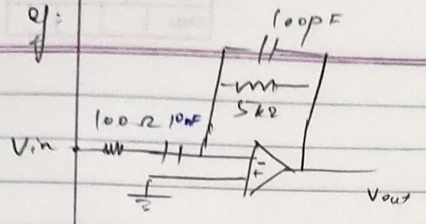
$\boxed{Z_{in} = R}$ better

$f_1 = \frac{1}{2\pi R_1 C}$ if $f_2 > f_1$

$f_2 = \frac{1}{2\pi R C_f}$



eg:



$f_1 = \frac{1}{2\pi (10^{-8})(100)} = \frac{1}{2\pi CR} = \frac{10^6}{2\pi}$

$f_2 = \frac{1}{2\pi \cdot 10^{-10} \cdot 5\times 10^3} = \frac{10^6}{\pi}$

$f_s < [f_1 < f_2]$

for accurate diffⁿ: $\frac{f_1}{10} \rightarrow [\frac{10^5}{2\pi} = f_s]$

eg: if $V_{in} = 2\sin(2\pi \cdot 3000t)$

$3\times 10^3 << f_1 \approx \frac{10^6}{2\pi}$ ✓

thus

$(RC)\ 4\pi\cdot(3000)\ \cos(6000\pi t) = V_{out}$

$10^{-6}\ (12\times 10^3)\pi\ \cos(6000\pi t)$

{ This $-RC\frac{dV_{in}}{dt} = V_{out}$ is app. ∃ only

~~$[V_s << V_{f_1}]$~~

$[f_s << f_1]$

$\left[\text{Slew rate} : \frac{V_{max} - V_{min}}{\text{time taken (min)}} \right]$

now $f \in [0, f_1]$ generally $[f_s = \frac{f_1}{10}]$