Ideal Char^c of amplifier:

ideal:

Gain $= \infty$

BW $= \infty$

$Z_{in} = \infty$

$Z_{out} = 0$

Slew rate: change of O/P wrt ~~input~~ time $= \infty$

practically

Gain = finite

BW = finite

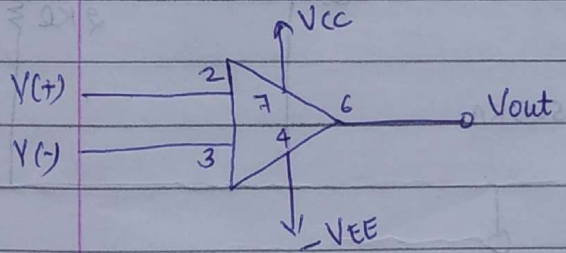
Z_{in} = finite (in MΩ) ~~<100Ω~~

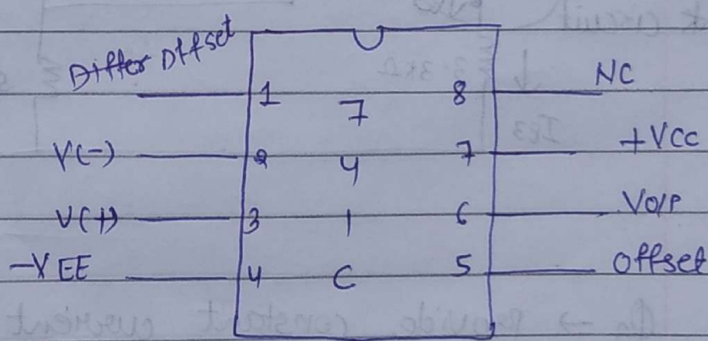
Z_{out} = (< 100Ω)

SR = (0.5 − 100 V/μsec)

- Op-amp can be used for a variety of applications, such as ac & dc amplification, comparator, oscillators, active filters, regulators

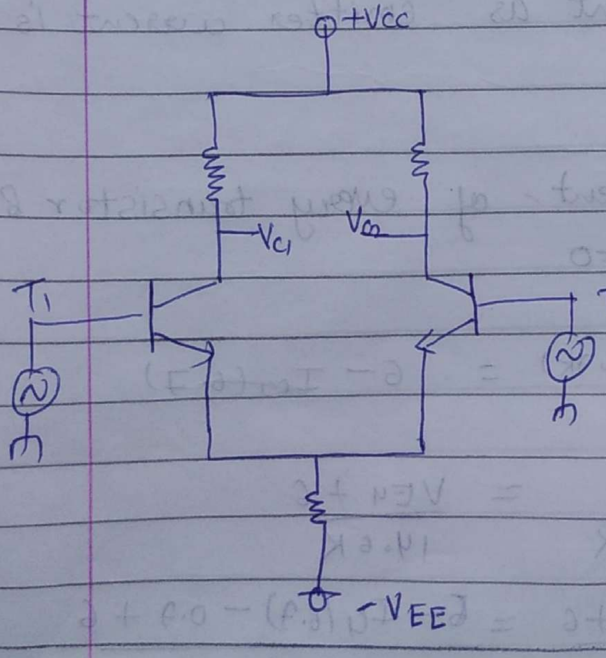
Block Diagram & circuit symbol of Op-amp:





741 C → commercial
↓ ↳ single O/P

7 terminals is used

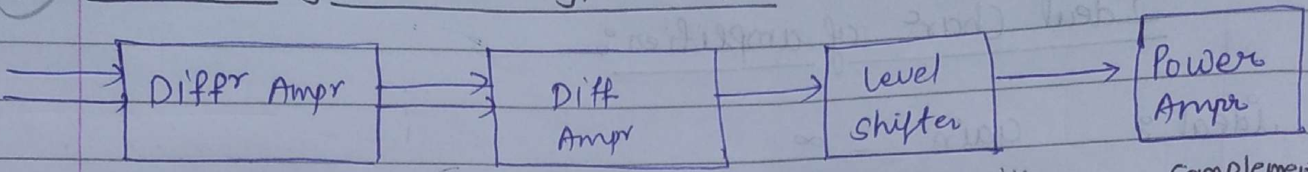


dual i/p ~~dual~~ balanced O/P (O/P V_{c1} & V_{c2} is taken)

" " Unblanced O/P

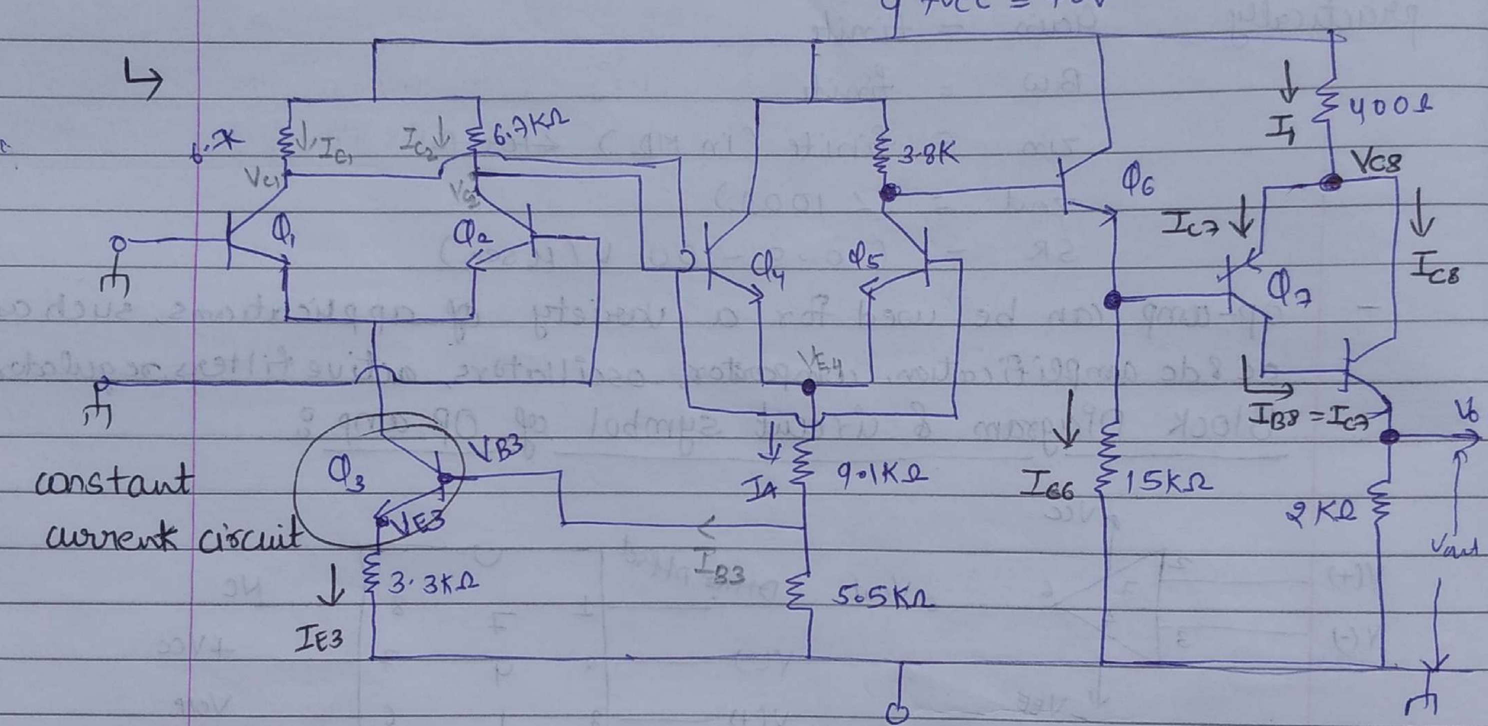
Hybrid or monolithic
Digital and linear

(65) Block Diagram of a typical op-amp:



Diffr Ampr	Diff Ampr	Level shifter	Power Ampr
Dual I/P Balanced O/P D.Ampr	Dual I/P Unblanced O/P D.Ampr	Such as emitter follower using const. current source	Complementary symmetry Push-Pull ampr

* purpose of two differential ampr is high gain & high I/P impedence.



$Q_3 \rightarrow$ provide constant current as emitter current is constant.

Q.1 Determine collector current of every transistor & dc O/P voltage; when I/P = 0

$$V_{C1} = V_{CC} - I_{C1}(6.7K) = 6 - I_{C1}(6.7)$$

$$V_{E4} = V_{C1} - V_{BE5}$$

$$I_4 = \frac{V_{E4} - (-V_{EE})}{(9.1 + 5.5)K} = \frac{V_{E4} + 6}{14.6K}$$

$$= \frac{V_{C1} - V_{BE5} + 6}{14.6K} = \frac{6 - I_{C1}(6.7) - 0.7 + 6}{14.6K}$$

Date ______
Page ______

$I_4 = \dfrac{11.3 - (6.7K) I_{C1}}{14.6K}$

$V_{B3} = (5.5K) I_4 - V_{EE} = \dfrac{5.5}{14.6}\left[11.3 - 6.7K I_{C1}\right] - 6$

$V_{E3} = V_{B3} - V_{BE3}$

$\quad\quad = V_{B3} - 0.7 = 9.55 - 2.52K\, I_{C1}$

$= 10.25 - 2.52K\, I_{C1}$

$V_{E3} = (5.5K) I_4 + (-6) - 0.7$

$I_{E3} = \dfrac{V_{E3} - (-V_{EE})}{3.3K\Omega} = \dfrac{3.55 - 2.52K I_{C1}}{3.3K}$

$I_{E3} = 1.07 \times 10^{-3} - 0.75\, I_{C1}$

$I_{E3} = 2 I_{C1}$

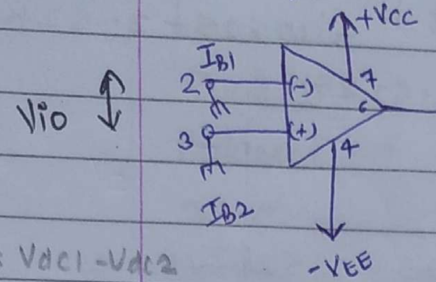
$2.75\, I_C = 1.07 \times 10^{-3}$

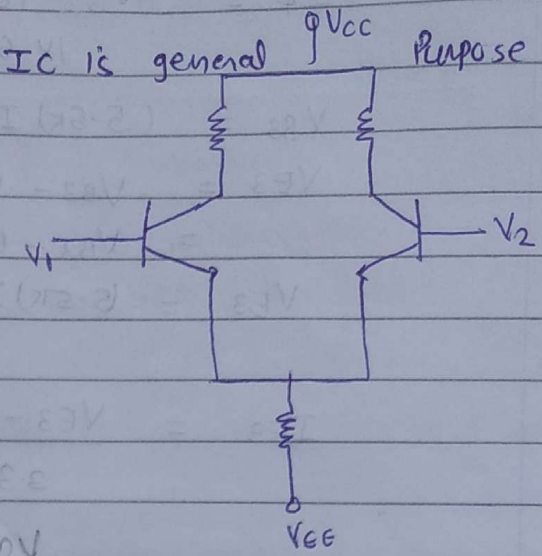
$I_C = 388.02\ \mu A$

(10) OP-amp IC-741 parameters :

OP-amp is linear IC's and 741 IC is general Purpose IC

Input offset voltage :





$V_{io} = V_{dc1} - V_{dc2}$

- i/p offset is dc voltage

for IC 741 $V_{io} = 5mV$ / 6mV

i/p offset current :

I_{B1} & I_{B2} are in nA.

i/p offset current $I_{io} = |I_{B1} - I_{B2}| = 200nA$

Bias current $I_B = \frac{I_{B1} + I_{B2}}{2} = 500nA$

i/p capacitance : $C = 1.4pF$ (741C)

$R_{i/p} = 10^9\Omega$

$R_{o/p} = < 100\Omega$

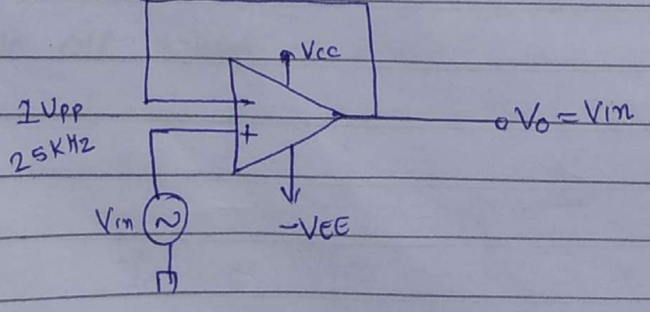
Open loop voltage gain $= \frac{\text{o/p Voltage}}{\text{diff}^r \text{ i/p voltage}}$

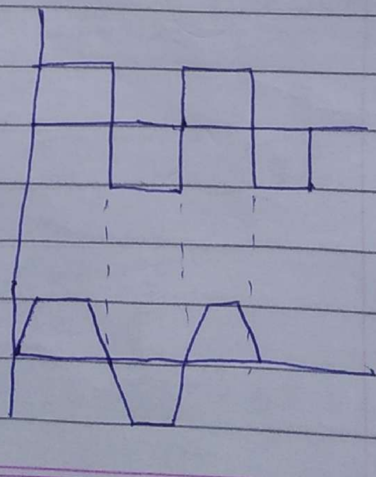
$= \frac{V_o}{V_{id}}$

$= 2\times10^5$

Slew rate → is defined in data sheet at Unity gain.

$SR = \frac{dV_{out}}{dt}$ V/μs $= 0.5$ V/μs



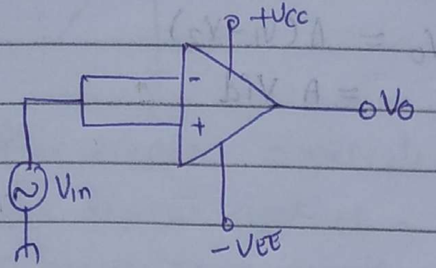


741C — $V_{CM} = \pm 13V$ | $I_{sc} = 25mA$ | Power consumption = 85mW
$CMRR = 90dB$ | $V_{io} = 6mV$ | Slew rate = $0.5V/\mu s$
$SVRR = 150 \mu V/V$ | $I_{io} = 200nA$
large signal V gain = 2×10^5 | $I_s = 2.8mA$

Output Voltage $|V_o| < |V_{cc}|$

$V_{out} = \pm 13V$

CMRR:



$V_o = A_d (V_1 - V_2) + A_c V_c$

practicaly $A_d = \infty$ & $A_c = 0$

$$CMRR = \frac{A_d}{A_c} = 90dB$$

$$V_c = \frac{V_1 + V_2}{2}$$

SVRR & PSRR:

SVRR → Supply voltage rejection ratio
PSRR → Power supply rejection ratio

$[SVRR = PSRR] = \frac{\Delta V_{io}}{\Delta V}$ μVolt/Volt

ΔV → supply voltage

$$SVRR)_{dB} = \left(\frac{1}{\Delta V_i / \Delta V}\right)$$

Short circuit Protection:

$I_{sc} = 25mA$

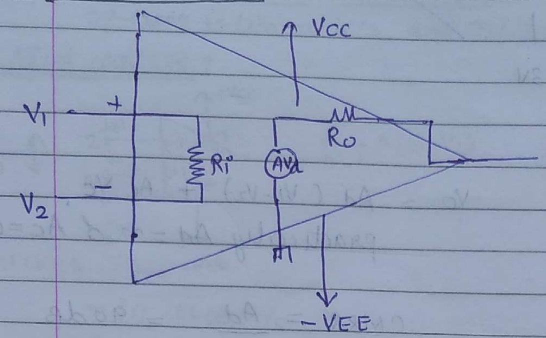
power dissiaption $I_{source} = 2.8mA$ (supply current)

- its analogus ic's → we supply only 5-15V.
- i/p + noise → [Ampr] → amplify the noise also
- i/p + noise → [OP-Amp Ampr] → only amplify the signal. when CMRR is high
- CMRR gives the Knowldge about the how efficient the op-amp for rejection of noise

Scanned by CamScanner

Date: 25-July

Equivalent circuit : (110)



$V_o = A(V_1 - V_2)$

$= A\,V_{id}$

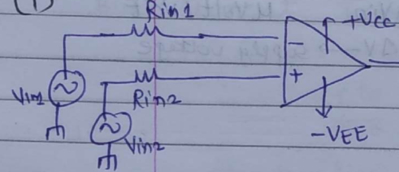
Open loop Cofiguration : (111)

(i) Differential Amp.

(ii) inverting

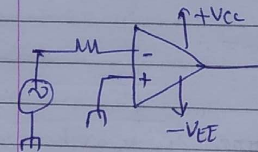
(iii) non-inverting

(i)



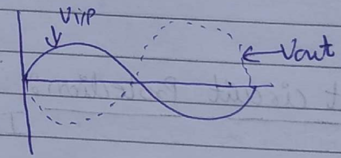
$V_o = A(V_{in1} - V_{in2})$

(ii)

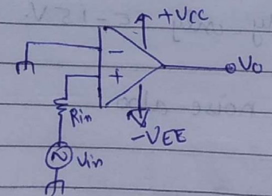


$V_o = A(V_1 - V_2)$

$= -A\,V_{in}$

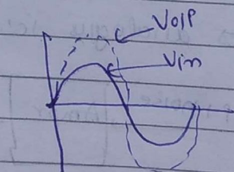


(iii)



$V_o = A(V_1 - V_2)$

$= A\,V_{in}$



$\Rightarrow$ $V_o = A(V_1 - V_2) = A V_d$

$|V_o| < |V_{cc}|$

$|V_{id}| < \dfrac{|V_{cc}|}{A} = 75\,\mu V$

$V_{cc} = 15V$

$A = 2 \times 10^5$

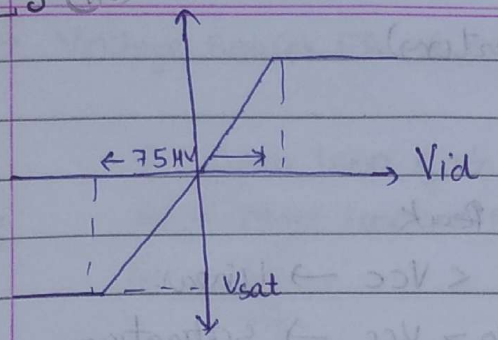
Open loop: — used in non linear application as comparator

Closed loop: " " linear " as adder, subtractor

Date ______

Page ______

charc : (I/O) V_o



— for linear application, $V_{id} \leq 75\mu V$

$V_{id} > 75\ \mu V$, then op-amp will ~~wo~~ goes on saturation region.

- for linear application, open loop conf. is not used becuz for linear application $V_{id} < 75\mu V$, which is difficult to achieve (Very small range).

Exs — (i) $V_{in1} = 5\mu V$, $V_{in2} = -7\mu V$ } dC

741C
$A = 2\times10^5$

(ii) $V_{in1} = 10mV$, $V_{in2} = 20mV$ } sine wave (rms value)

Sol: $V_{out} = A[V_{in1} - V_{in2}]$

$= 2\times10^5[5+7]\mu$

$= 24\times10^5\times10^{-6}$

$= 2.4\ V\ dc$

linear

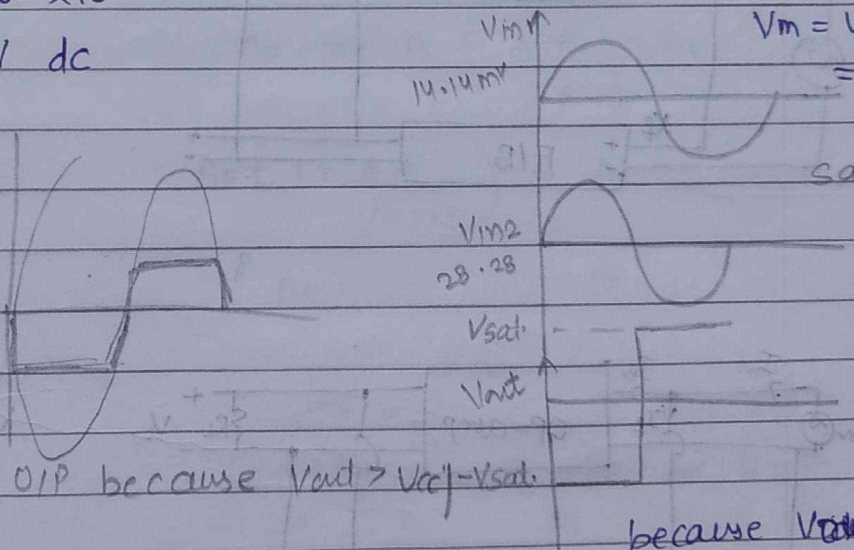
$V_{out} = 2\times10^5[-10]m$

$= -2\times10^5\times10^{-2}$

$= -2KV$ (rms)

$V_m = V_{rms}\times\sqrt{2}$

=



clip the O/P because $V_{out} > V_{cc}$ - V_{sat}

because $V_{out} > V_{CC}$

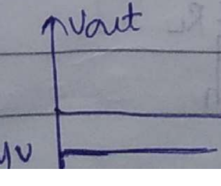
(iii) $V_{in1} = 20mV\ dc$ (inverting ampr)

$V_{out} = A(V_{in1} - V_{in2})$

$= -AV_{in2}$

$= -2\times10^5\times20\times10^{-3}$

$= -40\times10^2 = -4000V$ dc



saturation

(?) single Power ↓ dual power supply

Date 28-july
Page

(iv) $V_{in} = -50\ \mu V$ Peak (inverting)

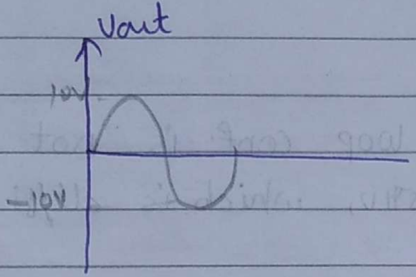
$V_o = -A V_{in}$

$= 2 \times 50 \times 10^{-6} \times 10^5$

$= 100 \times 10^{-1} = 10V$ Peak

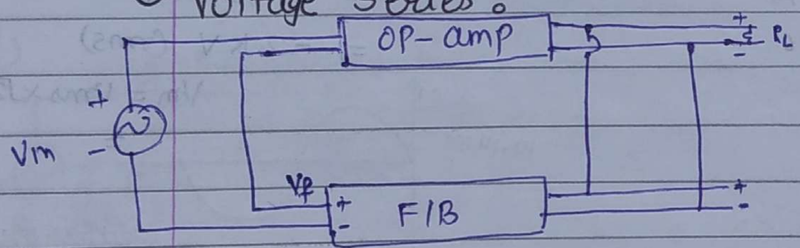
$V_o < V_{cc} \rightarrow$ linear

$V_o > V_{cc} \rightarrow$ saturation

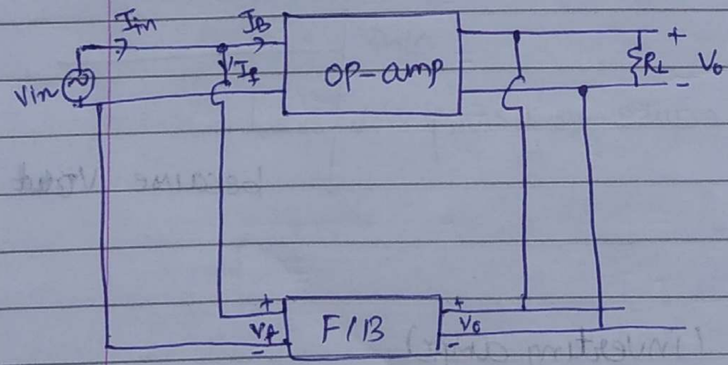


feed back configuration: (118)

① Voltage Series:

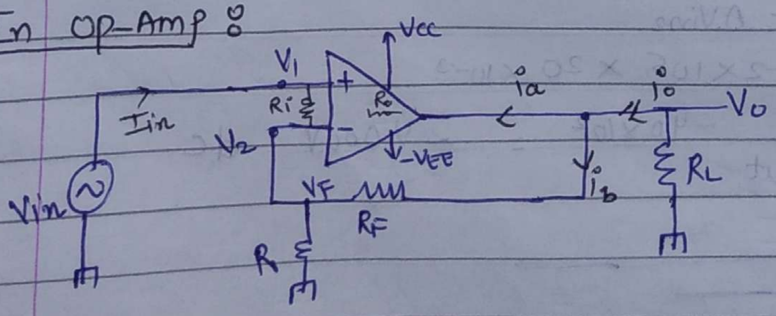


② Voltage Shunt:



In op-Amp:

①



By doi

Date ______
Page ______

↳ Voltage Series FB OP-amp / Non-inverting ampr

gain :

A – open loop gain

A_F – close loop or Feedback gain

$$A_F = \frac{V_o}{V_{in}}$$

$V_1 = V_{in}$

$$V_2 = V_f = \frac{R_1}{R_1 + R_F} \cdot V_o$$

$$V_o = A(V_1 - V_2)$$

$$\text{so; } A_F = A\left(\frac{V_1 - V_2}{V_1}\right) = A\left(1 - \frac{V_2}{V_{in}}\right)$$

$$A_F = A\left[1 - \frac{R_1 V_o}{V_{in}(R_1 + R_F)}\right]$$

$$A_F = A - \frac{A R_1}{R_1 + R_F} \cdot A_F$$

$$A_F\left[1 + \frac{A R_1}{R_1 + R_F}\right) = A$$

$$A_F = \frac{A(R_1 + R_F)}{R_1 + R_F + AR_1}$$

$\because AR_1 >> R_1 + R_F$

$$\text{So; } A_F = \frac{R_1 + R_F}{R_1} = \boxed{1 + \frac{R_F}{R_1} = A_F}$$

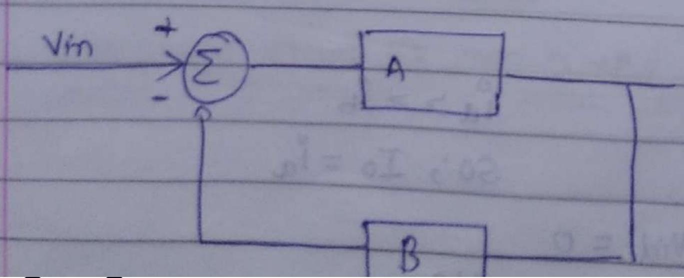
if $A_F = 11$

then $R_F = 10 R_1$

(i) $R_1 = 1K$; $R_F = 10K$

(ii) $R_1 = 5K$; $R_F = 50K$

(iii) $R_1 = 100\Omega$; $R_F = 1K$



Scanned by CamScanner

$$\boxed{B = \frac{V_f}{V_o} = \frac{R_1}{R_1+R_F}}$$ → gain of feedback circuit

$$A_F = \frac{A}{1 + A\frac{R_1}{R_1+R_F}} = \boxed{\frac{A}{1+AB}} = \frac{V_{out}}{V_{in}}$$

in ideal condition :

$$V_o = AV_{id}$$

ideally A is infinite

$$V_{id} = \frac{V_o}{A} \cong 0$$

$$V_1 - V_2 = 0$$

$$V_{in} = V_F = \frac{R_1}{R_1+R_F} V_o$$

$$A_f = \frac{V_o}{V_{in}} = 1 + \frac{R_F}{R_1}$$

I/P impedence :

$$R_{if} = \frac{V_{in}}{I_{in}}$$

$$I_{in} = V_{id} / R_i$$

$$V_o = AV_{id}$$

$$A(V_1 - V_2) = V_{out} = \frac{A}{1+AB} V_{in}$$

$$\cancel{\frac{1 - V_{id}}{V_{in}}} \qquad \frac{1}{AB+1} \frac{V_{in}}{I_{in}} = \frac{V_{id}}{I_{in}}$$

$$\boxed{R_{if} = (1+AB) R_i}$$

O/P impedence :

By doing short to V_{in} for finding the R_{of}

$$R_{of} = \frac{V_o}{I_o}$$

$$i_o = i_a + i_b \qquad i_a >> i_b$$

so; $I_o = i_a$

$$V_o - i_o R_o - A V_{id} = 0$$

$$V_{id} = V_1 - V_2 = 0 - V_f$$

- when gain = 1 ⇒ $(1+A\beta) \cong A$, follower ⇒ non inverting ampr

$A_F = 1$; $f_F = f_0 A$

$R_{iF} = R_i A$; $V_{OOT} = \pm V_{sat}/A$

$R_{OF} = R_o/A$

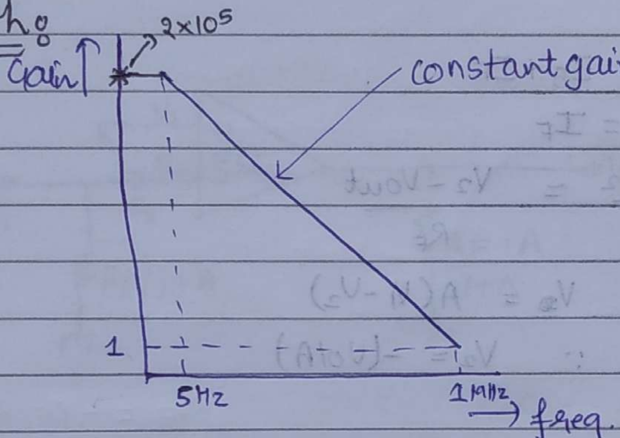
Date 1- Augo
Page

$\Rightarrow V_{id} = -V_f$

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

$$\boxed{R_{OF} = \frac{R_o}{1+A\beta}}$$

Bandwidth:



↳ only single break freq. that is 3dB ~~for~~ that only BW x gain = constant

for open loop op-amp : $A = 2\times10^5$; $f_0 \rightarrow$ single break ~~away~~ freq.

$BW = 5\,Hz$

Bandwidth is ↑ses in non-inverting feedback ampr

$2\times10^5 \times 5 = 1\,MHz$ = for open loop

Unity gain BW = $1 \times 1\,MHz$

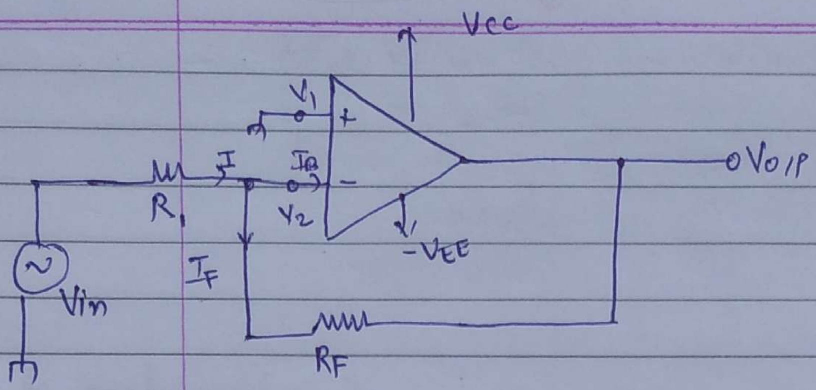
* $\boxed{\text{UGB (Unity gain Bandwidth)} = A f_0 = A_F f_F}$

$$f_F = \frac{A f_0}{A_F} = f_0(1+\beta A)$$

- $V_{too} = \dfrac{\pm V_{sat}}{1+A\beta}$ (O/P offset voltage)

$V_{sat} \rightarrow$ total o/p voltage swing

(2) Voltage shunt FB op-amp / inverting ampr :



$$I = I_B + I_F$$

$$I = I_F$$

$$\frac{V_{in} - V_2}{R_1} = \frac{V_2 - V_{out}}{R_F}$$

$$V_1 = 0 \; ; \quad V_o = A(V_1 - V_2)$$

$$\therefore \quad V_2 = -(V_o/A)$$

$$\frac{V_{in}}{R_1} - \frac{V_2}{R_1} - \frac{V_2}{R_F} = \frac{-V_{out}}{R_F}$$

$$\frac{V_{in}}{R_1} + \frac{V_{out}}{R_F} + \frac{V_o}{A}\left(\frac{1}{R_1} + \frac{1}{R_F}\right) = 0$$

$$\frac{V_{in}}{R_1} = -V_{out}\left[\frac{1}{R_F} + \frac{1}{AR_1} + \frac{1}{AR_F}\right] = 0$$

$$\frac{AR_1 + R_F + R_1}{(AR_1R_F)/R_1} = \frac{-V_{out}}{V_{in}} = A_F$$

$$\cancel{R_1(1+A) + R_F = A_F}$$

$$A_F = \frac{V_{out}}{V_{in}} = \frac{-R_F A}{R_1 + R_F + AR_1}$$

$$\because \quad AR_1 >> R_1 + R_F$$

$$\text{so} \quad \boxed{A_F = -R_F/R_1}$$

IIo $\quad AV_{id} = V_o$

ideally very high gain $A = \infty$

$V_{id} = 0$

$V_1 = V_2$ (virtually ground)

so $I = I_F$

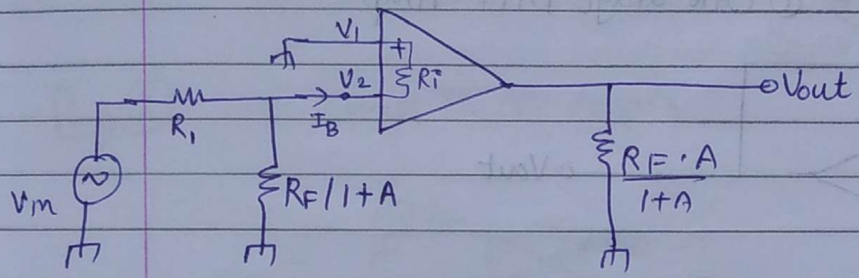
O/P impedence : – Vin is shorted

– same as non-inverting

$$R_{of} = \frac{R_o}{1+\beta A}$$

I/P impedence :

$K = \frac{R_F}{R_1+R_F} \rightarrow$ Voltage attenuation factor



$$R_{iF} = R_1 + \left(\frac{R_F}{1+A} \parallel R_i \right) \qquad \because A \cong \infty$$

(with $\frac{R_F}{1+A} \rightarrow 0$)

$$R_{iF} \cong R_1$$

Gain:

$$A_F = \frac{V_{out}}{V_{in}} = \frac{-R_F A / R_1 + R_F}{\frac{R_1 + R_F + A R_1}{R_1 + R_F}}$$

$$\boxed{A_F = -\frac{AK}{1+A\beta}} \qquad \left(K \rightarrow \frac{R_F}{R_1 + R_F} \right)$$

frequency :

$$f_F = (A\beta + 1) f_o$$

$$UGB = A f_o \Rightarrow f_o = \frac{UGB}{A}$$

$$\text{so; } f_F = \frac{UGB}{AK} (1 + A\beta) K$$

$$\boxed{f_F = \frac{UGB \cdot K}{A_F}} \longrightarrow \text{inverting}$$

$$f_{F_{NON}} = \frac{UGB}{A_F} \longrightarrow \text{non-inverting}$$

Date 4-Augo

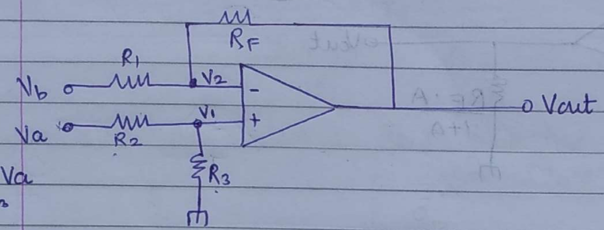
- BW is higher for non-inverting ampr. because $0<K<1$

so $f_{F\,non} = UGB$

$f_{f\,inv.} = \frac{UGB}{2}$; if $R_F = R_1$

By eqn ① & ②

Differential Ampr : (142) ① One stage Diffr Ampr



$V_1 = \frac{R_3}{R_2+R_3} V_a$

$A_D = -R_F/R_1 = V_o/V_{xy}$

$R_{iFx} = R_1$

$R_{iFy} = R_2 + R_3$

By Superposition theorem :

→ V_b active (inverting) ; V_a grounded

V_{ob} ~~Vout~~ $= \frac{-R_F}{R_1} V_b$

→ V_a active (non inverting) ; V_b grounded

~~Vout~~ $V_{oa} = \left(1+\frac{R_F}{R_1}\right) V_1$

$V_{oa} = \left(1+\frac{R_F}{R_1}\right)\left(\frac{R_3}{R_2+R_3}\right) V_a$

Let assume $R_3 = R_F$ & $R_2 = R_1$

$V_{oa} = \left(1+\frac{R_F}{R_1}\right)\left(\frac{R_F}{R_1+R_F}\right) V_a$

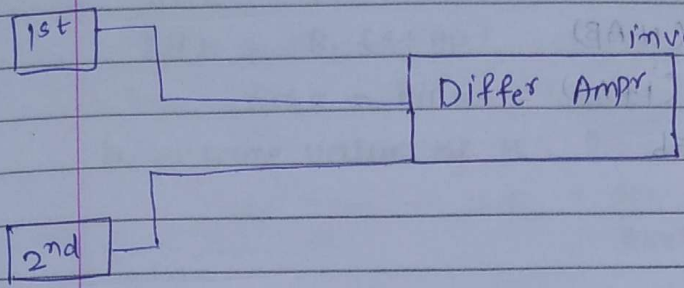
$V_{oa} = \frac{R_F}{R_1} V_a$

Hence we get diff. i/p impedence when connected to different terminals.

Hence while we connect $V(+)$ & $V(-)$ together impedence won't match. So avoid this problem some modification is done.

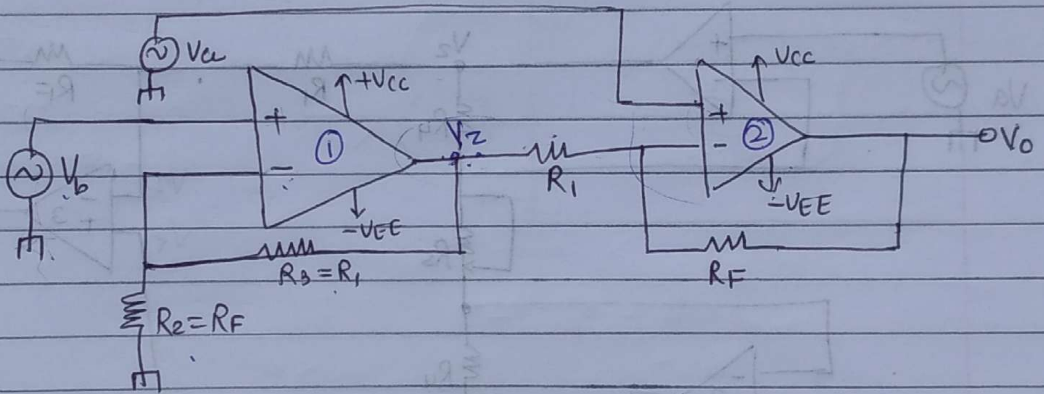
Date ______
Page ______

non·invert $V(+)$: $R_{IF1} = R_1(1 + A\beta)$
inverting $V(-)$: $R_{IF2} = R_1$



– Loading impedence matching is not done for Differen Ampr

② Two stage Differ Amprs



OP-amp ① is non-inverting ampr
OP-amp ② is differential ampr

$$V_Z = \left(1 + \frac{R_F}{R_1}\right) V_b$$

$$V_{out} = \frac{-R_F}{R_1} V_Z + V_a\left(1 + \frac{R_F}{R_1}\right)$$

(when $V_a = 0$) (when $V_Z = 0$)

superposition theorem

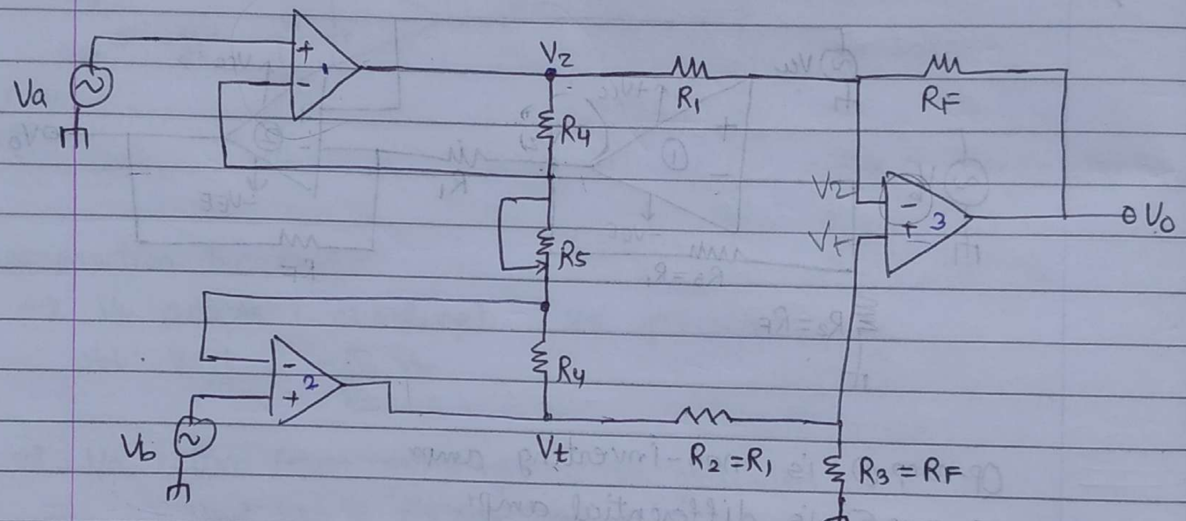
$$V_{out} = \frac{-R_F}{R_1}\left[1 + \frac{R_1}{R_F}\right] V_b + V_a\left(1 + \frac{R_F}{R_1}\right)$$

$$= \frac{-R_F}{R_1} \cdot V_b - V_b + V_a + V_a \frac{R_F}{R_1}$$

$$= \left(1 + \frac{R_F}{R_1}\right)(V_a - V_b)$$

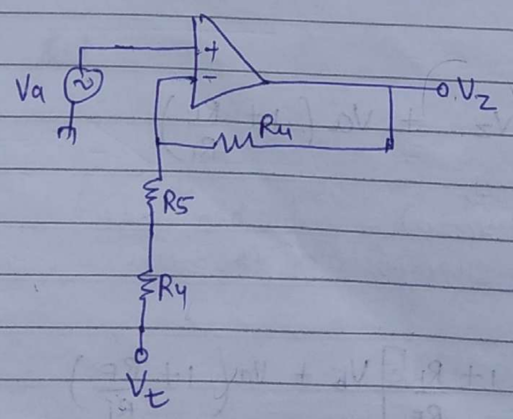
$$R_{iFa} = R_i(1+A\beta)$$
$$R_{iFb} = R_i(1+A\beta)$$
$$R_{iFa} \neq R_{iFb}$$

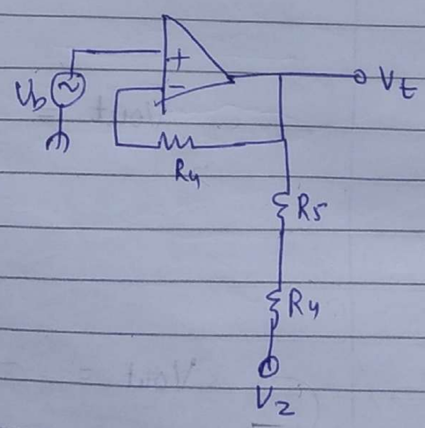
⇒ ③ Three stage Diff^r Ampr:



① When $V_b = 0$

② When $V_a = 0$





$-\frac{R_f}{R_1}$

(1) $V_z = V_a\left[1 + \frac{R_4}{R_4+R_5}\right] + V_t\left[\frac{-R_4}{R_4+R_5}\right]$

(2) $V_t = V_b\left[1 + \frac{R_4}{R_4+R_5}\right] + V_z\left[\frac{-R_4}{R_4+R_5}\right]$

$R_{ifa} = R_1(1 + A\beta)$

$R_{ifb} = R_1(1 + A\beta)$

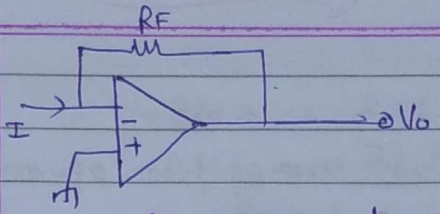
$R_{ifa} = R_{ifb}$ (both one coming from op-amp)

becuz same value of β, $R_{ifa} = R_{ifb}$

$\beta \rightarrow \frac{R_4}{R_4 + R_5}$ $\beta \rightarrow \frac{R_4}{R_4 + R_5}$

(3) $V_{out} = V_z\left(-\frac{R_F}{R_1}\right) + V_t\left(1 + \frac{R_F}{R_1}\right)$

Date 11-Aug
Page



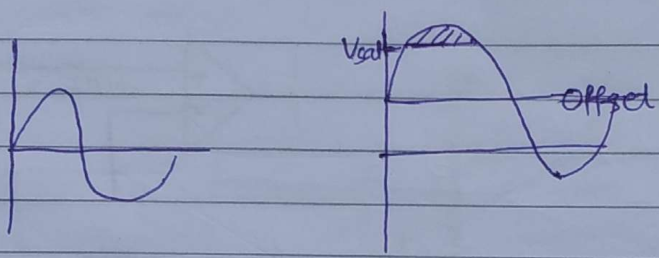
P/P → current
O/P → voltage

Application :
– Solar Panel
– fiber optic commⁿ
– DAC

$V_o = -\frac{R_F}{R_1} V_{in}$

$= -R_F \cdot I_{in}$

OFFSET VOLTAGE – Compensating n/w Design :



By offset our signal is clip because of Vsat.

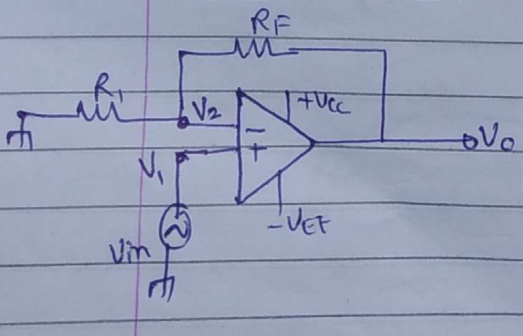
$V_{io} = V_1 - V_2$

$V_{io} > 0$ $V_{io} < 0$

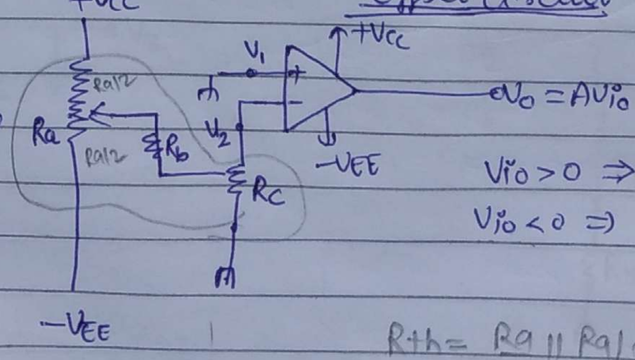
$V_1 > V_2$ $V_1 < V_2$

– if non-inverting ampʳ, then offset voltage comp. n/w connected to inverting terminal. if inverting then, non-inverting terminal comp. n/w

(i) Non inverting :



Offset circuit

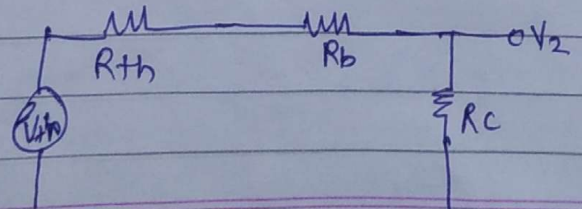


$V_{io} > 0 \Rightarrow V_1 > V_2$

$V_{io} < 0 \Rightarrow V_1 < V_2$

$R_{th} = \frac{R_a}{2} \parallel R_a/2$

Thevnin ckt:



$R_{th} = R_a/4$

Date
Page

$$V_2 = \frac{R_c V_{th}}{R_c + R_b + R_{th}}$$

$$V_{th} = |+V_{cc}| = |-V_{EE}|$$

So; $$V_{io} = \frac{R_c V}{R_c + R_b + R_{th}}$$

R_c is very small (because current is less & voltage is low)

$R_b > R_a > R_c$ (assumption)

So; $R_c + R_b + R_{th} \cong R_b$

then

design equation: $\boxed{V_{io} = \frac{R_c V}{R_b}}$

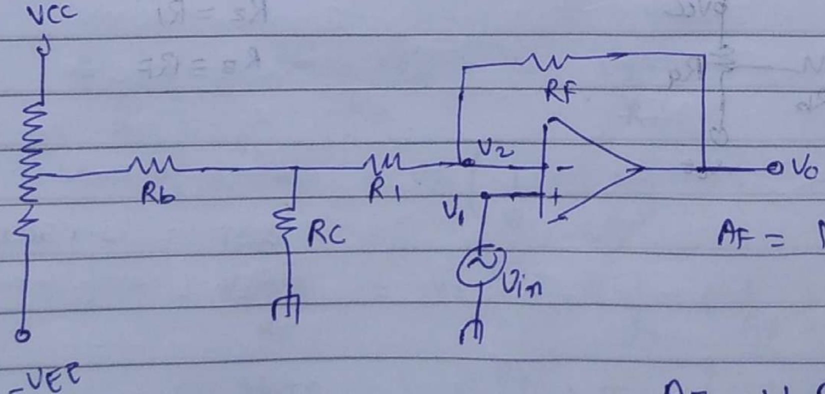
for IC LM 307: $V_{io} = 10mV$

$V = 10V$

$\frac{R_c}{R_b} = 1m \Rightarrow R_b = 1000 R_c$

Let assume $R_c = 10\Omega$	$R_c = 100\Omega$
$R_b = 10K\Omega$	$R_b = 100K\Omega$
~~$R_a = 1k\Omega$~~	$R_a = 10K$; $R_b = 10 R_a$
$R_b > R_{th}$	$\because R_b > R_{th}$
$R_b = 10 R_a/4$	$R_b = 10 R_{th}$
So $R_a = 4K$	$= 10 R_a/4$

Non inverting:



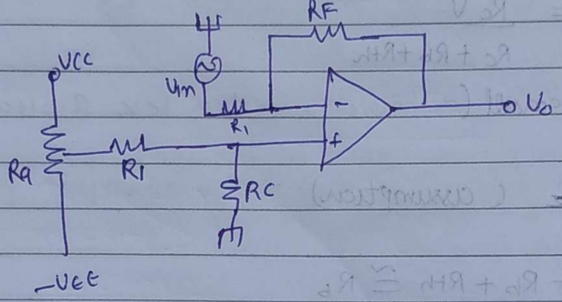
$A_F = 1 + \frac{R_F}{R_1}$ (without compensating n/w)

$A_F = 1 + \frac{R_F}{R_1 + R_c}$ (with comp. n/w)

So R_c should be very less, because its does not affecting the gain of feedback n/w.

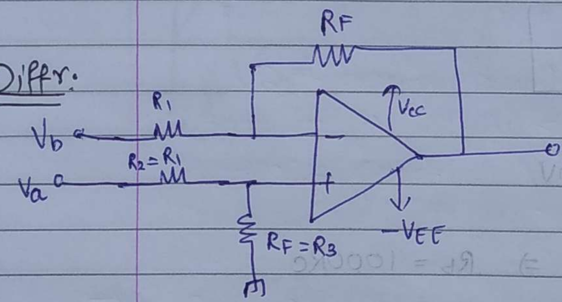
- gain of the ampr, will not charge by using the value of R_c is very less.

inverting



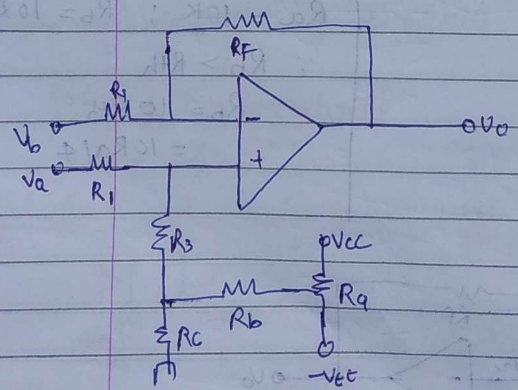
its not affected the gain.

Differ:



$V_o = \frac{R_F}{R_1}(V_a - V_b)$

- when we connected compensating n/w to non-inverting terminal than its effect the CMRR less.



$V_o = \frac{R_F}{R_1}(V_a - V_b)$

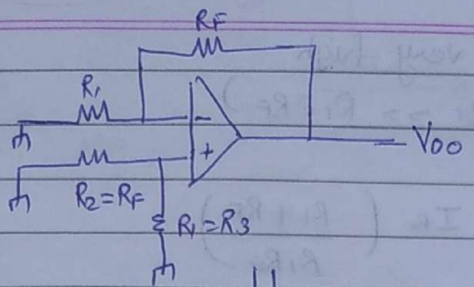
$R_3 >> R_c$

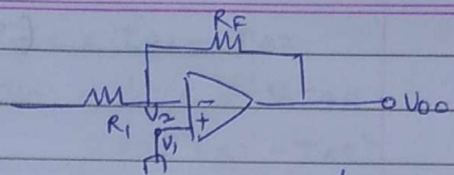
$R_2 = R_1$

$R_3 = R_F$

$$V_{OOT} = f(V_{io}, I_B, I_{io})$$

Date 22- Aug

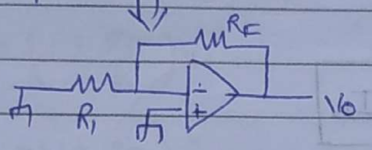




(inverting)

$V_1 = 0$

$$V_2 = \frac{R_1}{R_1 + R_F} V_O$$



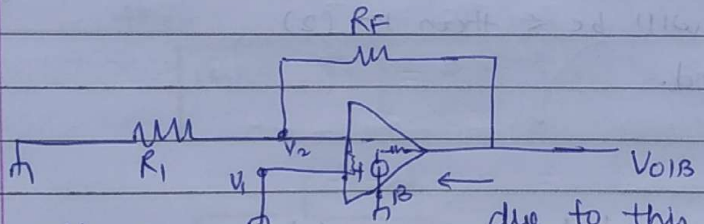
$$V_{io} = |V_1 - V_2| = |V_2|$$

(non-inverting)

$$V_{OO} = \frac{R_1 + R_F}{R} V_{io}$$

$$V_{OO} = \underbrace{\left(1 + \frac{R_F}{R}\right)}_{A_{OO}} V_{io} \longrightarrow \text{for inverting ampr / non inverting ampr}$$

$\Rightarrow$



$V_{io} = 0$

due to this ground, we can say R_F & R_1 are in parallel.

$$\therefore V_2 = \left(\frac{R_1 R_F}{R_1 + R_F}\right) I_B$$

$A_V V_i' = 0$

R_o = very small

$\therefore$ AB whole terminal is grounded $\Rightarrow R_F \parallel R_1$

$$\frac{0 - V_2}{R_1} + \frac{V_{OIB} - V_2}{R_F} = \frac{V_2 - 0}{R_i}$$

$$\frac{V_{OIB} - V_2}{R_F} = V_2\left(\frac{1}{R_i} + \frac{1}{R_1}\right)$$

$$\frac{V_{OIB}}{R_F} = V_2\left(\frac{1}{R_F} + \frac{1}{R_1} + \frac{1}{R_F}\right)$$

$$\frac{V_{OIB}}{R_F} = \left(\frac{R_1 R_F}{R_1 + R_F}\right) I_B \left(\frac{1}{R_1} + \frac{1}{R_F}\right)$$

Scanned by CamScanner

(∵ R_i is very high
$R_i >> R_1 \& R_F$)

$$\therefore \frac{V_{OIB}}{R_F} = \left(\frac{R_1 R_F}{R_1 + R_F}\right) I_B \left(\frac{R_1 + R_F}{R_1 R_F}\right)$$

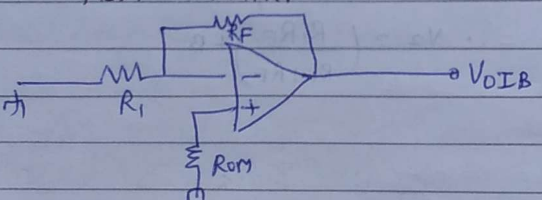
$$\therefore \boxed{V_{OIB} = (R_F) I_B}$$

Design -(1)
$R_1 = 470\Omega$
$R_2 = 47K\Omega$
$1 + \frac{R_1}{R_F} = 101$

Design -(2)
$R_1 = 1K$
$R_F = 100K$
$1 + \frac{R_F}{R_1} = 101$

Both designs provide same gain but the offset voltage in (1) will be < than in (2)
∴ (1) is good.

⇒ R_{OM} → offset minimizing resistors
$R_{OM} = R_1 \| R_F$

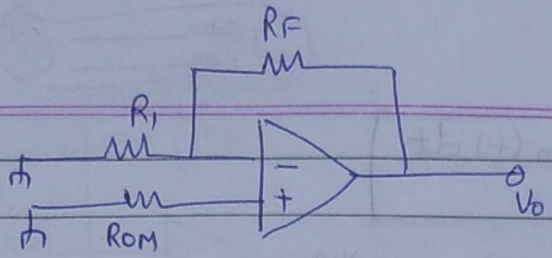


$$V_{OUT} = \left(1 + \frac{R_F}{R_1}\right) V_{io} + R_F I_B$$

(1)
$V_{io} = 6mV$
$I_B = 500nA$
$R_1 = 470\Omega$
$R_F = 47k\Omega$
$V_{OUT} = 0.6295V$
$R_{OM} = 465.346\Omega$

(2)
$V_{io} = 6mV$
$I_B = 500nA$
$R_1 = 1K$
$R_F = 100K$
$V_{OUT} = 0.656V$
$R_{OM} = 990.099\Omega$

$\Rightarrow$



$I_B = I_{B1} = I_{B2}$

$V_O = V_{OIB1} + V_{OIB2}$

$= R_F(I_{B1} - I_{B2})$

$\boxed{V_{OI_{io}} = R_F I_{io}}$

$V_{OIB1} = \left(1 + \frac{R_F}{R_1}\right) V_1$

$= \left(1 + \frac{R_F}{R_1}\right) R_{OM} I_{B1}$

$V_{OIB2} = -R_F I_{B2}$

$V_{OOT} = \left(1 + \frac{R_F}{R_1}\right) V_{io} + R_F I_{io}$

$I_{io} = |I_{B1} - I_{B2}|$

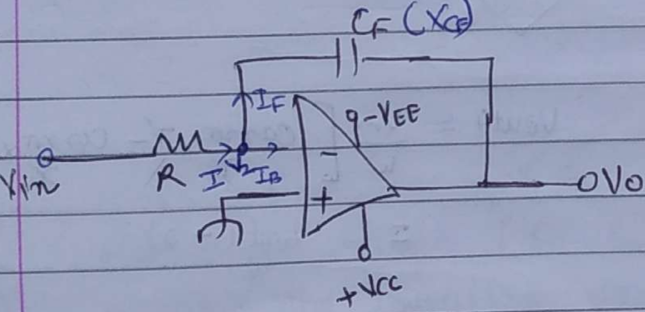
if $I_{B1} \neq I_{B2}$

$I_B > I_{io}$

then

$$\boxed{V_{OOT} = \left(1 + \frac{R_F}{R_1}\right) V_{io} + R_F I_B}$$

Ex:



(integrator circuit)

Sol:

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

$q = CV$

① (if inverting then, node analysis)

$I = I_B + I_F$

$I = I_F$

$$\frac{V_{in} - V_2}{R} = C_F \frac{d}{dt}(V_2 - V_0) \quad \text{—①}$$

② (virtual ground concept in inverting)

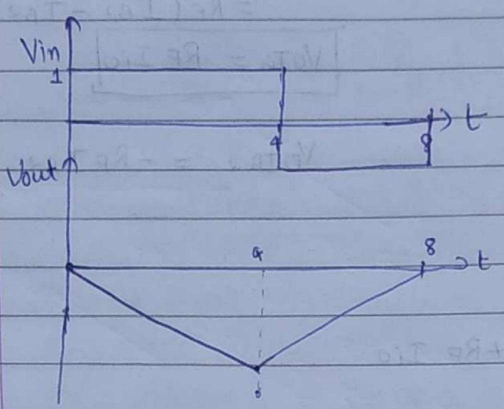
$V_1 = 0$ (in inverting, virtual ground concept so $V_1 = 0$)

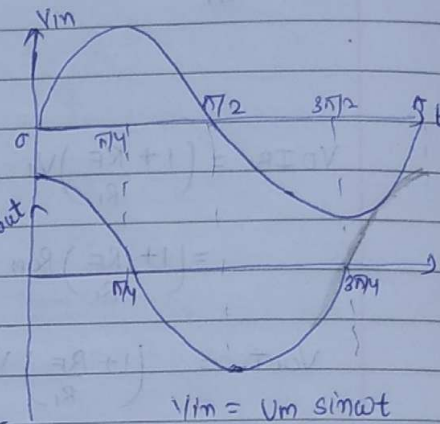
$V_1 = V_2$ (high gain)

So, $V_2 = 0$

in eqn ① $\quad V_{in} = -C_F R \frac{d(v_o)}{dt}$

$$\boxed{V_o = \frac{-1}{C_F R_1} \int V_{in}(t)\,dt}$$





$V_{in} = V_m \sin\omega t$

$V_{out_1} = [\cos\omega t]_0^{\pi/4}$

$= \left(\frac{1}{\sqrt{2}} - 1\right) = -0.29$

$V_{out_1} = \frac{V_m}{\omega}\left[\cos\frac{2\pi}{T}\times\frac{T}{4} - \cos 0\right]$

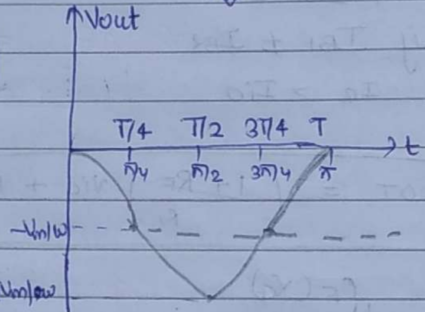
$= -V_m/\omega$

$V_{out_2} = \frac{V_m}{\omega}\left[\cos\frac{2\pi}{T}\times\frac{T}{2} - \cos\frac{2\pi}{T}\times\frac{T}{4}\right]$

$= -V_m/\omega$

$V_{out_3} = \frac{V_m}{\omega}\left[\cos\frac{2\pi}{T}\times\frac{3T}{4} - \cos\frac{2\pi}{T}\times\frac{T}{2}\right] =$

$= -V_m/\omega$



$V_{out_2} = [\cos\omega t]_{\pi/4}^{\pi/2} = 0 - 1/\sqrt{2} = -0.70$

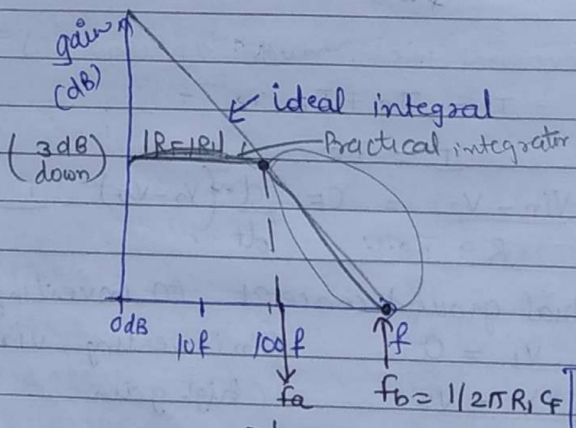
$V_{out_3} = [\cos\omega t]_{\pi/2}^{3\pi/4} = \frac{-1}{\sqrt{2}} - 0 = -0.70$

$V_{out_4} = (\cos\omega t)_{3\pi/4}^{\pi} = -1 + \frac{1}{\sqrt{2}} =$

$V_{out_4} = \frac{V_m}{\omega}\left[\cos\frac{2\pi}{T}\times T - \cos\frac{2\pi}{T}\times\frac{3T}{4}\right]$

$= \frac{V_m}{\omega}(1 - 0)$

- gain



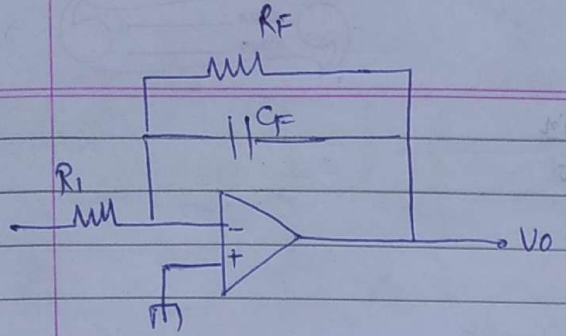
$A_F = \left|\frac{-X_F}{R_1}\right|$

$= \left|\frac{-1/j\omega C_F}{R_1}\right|$

$A_F = \frac{1}{\omega R_1 C_F}$

$\boxed{A_F \propto 1/f}$

- stability problem at low freq. bcuz $f = 0$, gain $= \infty$
  So we have to improve our circuit



$$A_F = \frac{X_C \parallel R_F}{R_1}$$

$$= \frac{\frac{1}{j\omega C_F} \times R_F}{\left(R_F + \frac{1}{j\omega C_F}\right) R_1}$$

$$A_F = \frac{R_F}{(R_F\, j\omega C_F + 1)\, R_1}$$

3 dB down

$$A_F = \frac{R_F}{R_1(1 + j\omega C_F R_F)} = \frac{1}{\sqrt{2}} \frac{R_F}{R_1}$$

$$\sqrt{2} = 1 + j\omega C_F R_F$$

$$0.065 = j\, C_F R_F \cdot f$$

$$f_a = \frac{1}{2\pi R_F C_F} \quad \text{(Practical)}$$

$$f_b = \frac{1}{2\pi R_1 C_F} \quad \text{(Ideal)}$$

- $f_b > f_a$ $\quad (f_b = 10 f_a)$

1. Select the range (f_a, f_b)
2. assume the capacitor value $(C < 1\mu F)$

$$C_F = 0.1\mu F$$

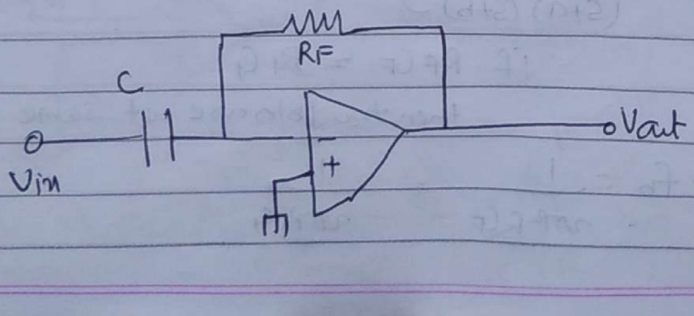
$$f_a = 1\,KHz = \frac{1}{2\pi R_F C_F} \quad ; \; f_b = 10\,KHz$$

$$R_F = 1.59\,K\Omega$$

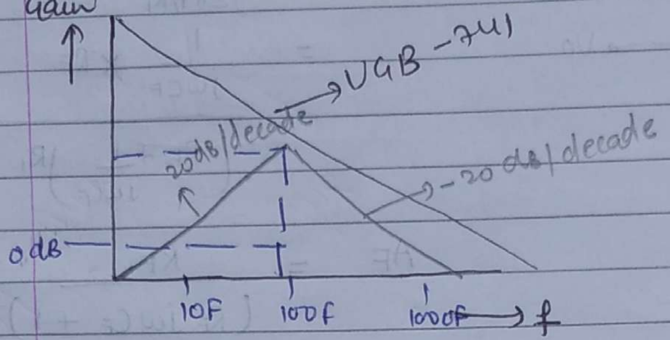
$$R_F = 10 R_1 \quad ; \; so \; R_1 = 159\,\Omega$$

3. $R_F > R_1$ and assume Value of R_1

⇒

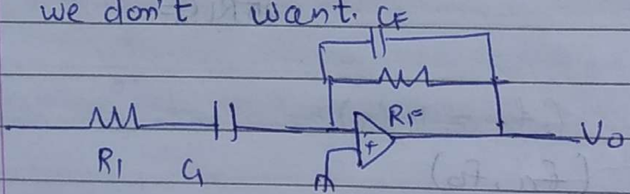


$$V_{out} = -R_F C_1 \frac{dV_{in}}{dt}$$



$$A_F = R_F / X_{C1}$$
$$= R_F\, j\omega C_1$$
$$A_F = 2\pi F R_F C_1 j$$
$$|A_F| = 2\pi F R_F C_1$$
$$\boxed{A_F \propto F}$$

- at high freq. it will may created problem bcuz at high freq. if noise will added then it also (transmitted) or amplify with the high gain, which we don't want.



$$A_F = \frac{(1/sC_F) \,||\, R_F}{R_1 + 1/sC_1}$$

$$A_F = \frac{R_F \cdot C_1 s}{(1 + R_F s C_F)(R_1 C_1 s + 1)}$$

$$\left[\because H(s) = \frac{1}{(s+a)(s+b)} \right]$$

if $R_F C_F = R_1 C_1$

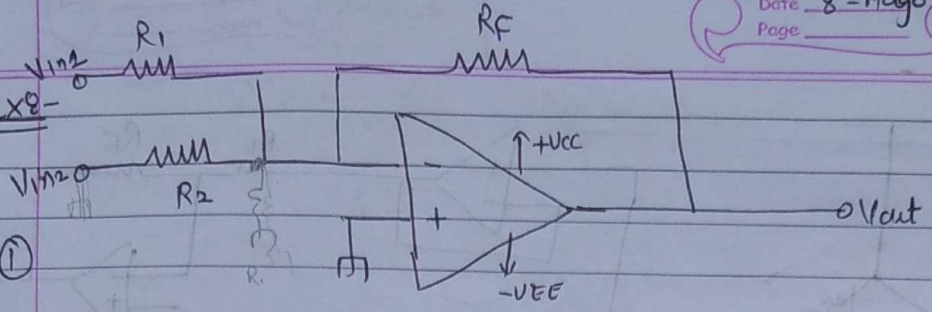
then two Poles are at same point]

$$f_b = \frac{1}{2\pi R_F C_F} = \frac{1}{2\pi R_1 C_1}$$

Date 8-Aug

Ex8-

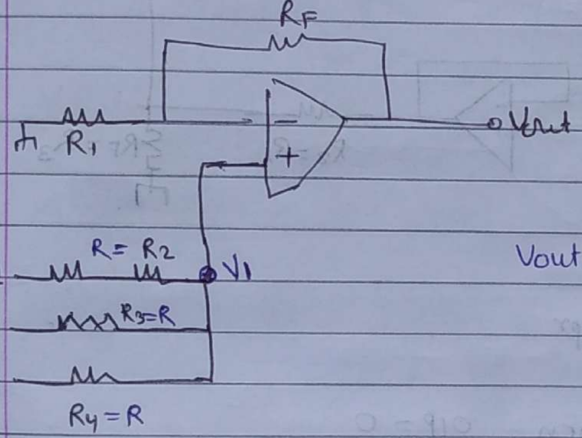
①



Sol: $V_{out} = -\frac{R_F}{R_1} V_{in1} - \frac{R_F}{R_2} V_{in2} = \frac{-R_F}{R_1}(V_{in1} + V_{in2})$

scaling
summing

②

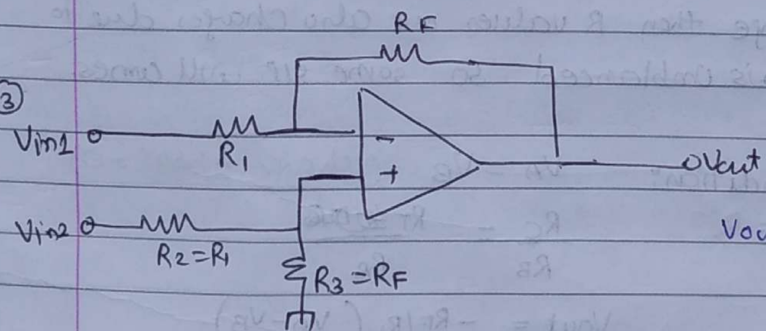


$V_1 = \frac{V_{in1} + V_{in2} + V_{in3}}{3}$

$V_{out} = \left(1 + \frac{R_F}{R_1}\right)\left(\frac{V_{in1} + V_{in2} + V_{in3}}{3}\right)$

"(Averaging Ampr)"

③

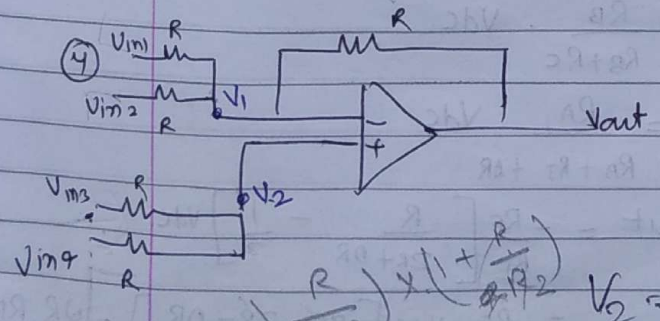


$V_{out} = -\frac{R_F}{R_1} V_{in1} + \left(1 + \frac{R_F}{R_1}\right)\left(\frac{R_F}{R_F + R_1}\right) V_{in2}$

$= \frac{-R_F}{R_1}(V_{in1} - V_{in2})$

(" Subtractor ")

④



$V_{out} = -V_{in2} - V_{in2} + \frac{3}{2}(V_{in3} + V_{in4})$

$\left(\frac{R}{R+R}\right) \times \left(1 + \frac{R}{R/2}\right)$

$\frac{1}{2} \times \frac{3}{1}$

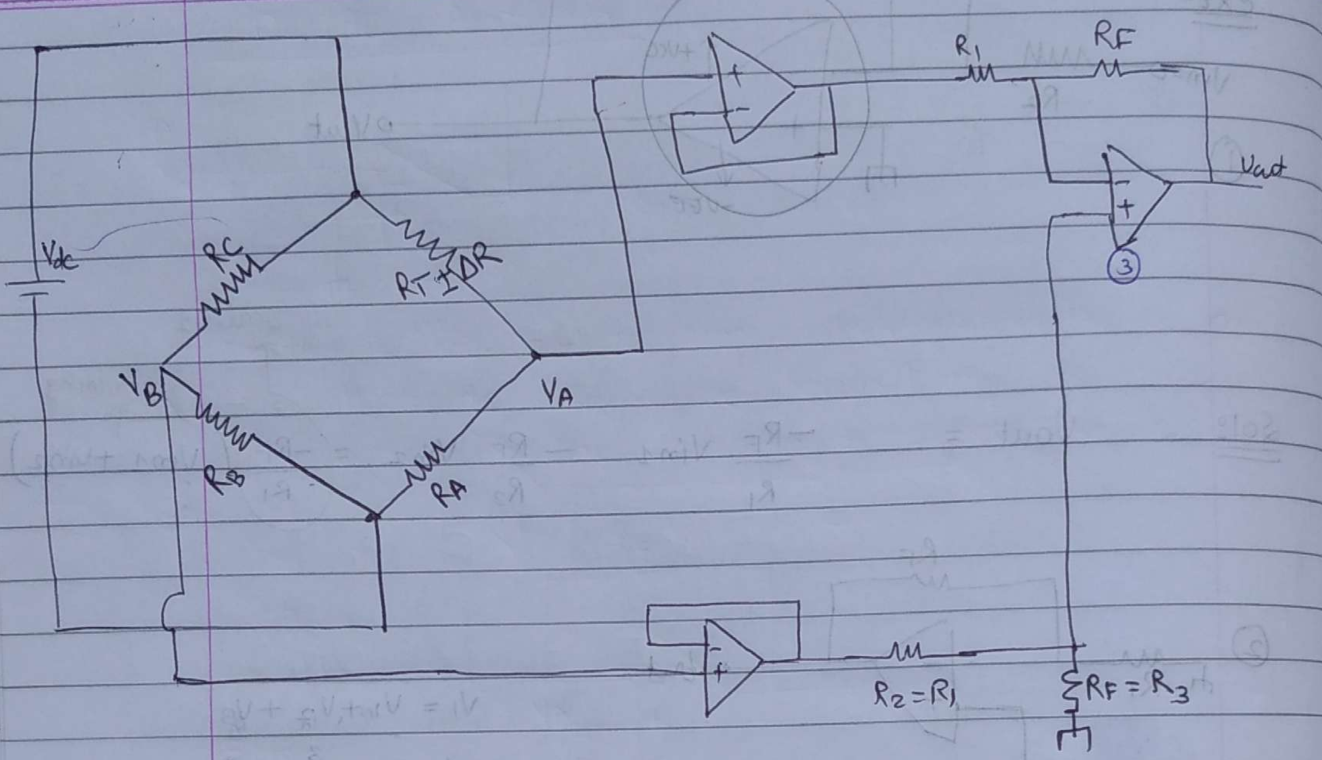
$V_2 = \frac{R}{R+R} V_{in3}$

$\left(1 + \frac{R_F}{R_1}\right) \frac{V_{in}}{2}$

comparator → non linear

all → linear

Gain = 1 Voltage Follower



Physical quantity

③ → differential ampr

if $V_A = V_B$ → then O/P = 0

if tempr is change then R values are also changes due to this bridge is unblanced so some o/p will comes.

— at balance condition: $V_A = V_B$ (Change in tempr = 0)

$R_A = R_B = R_C = R_T = R$

$$\frac{R_C}{R_B} = \frac{R_T}{R_B}$$

$V_A = \frac{R}{2R+\Delta R} V_{dc}$; $V_B = \frac{V_{dc}}{2}$

$$V_{out} = -R_F/R_1 (V_A - V_B)$$

— at Unblanced: $V_A \neq V_B$

$$V_B = \frac{R_B}{R_B + R_C} \cdot V_{dc}$$

$$V_A = \frac{R_A}{R_A + R_T + \Delta R} V_{dc}$$

$$V_{out} = -\frac{R_F}{R_1}\left[\frac{R}{2R+\Delta R} - \frac{1}{2}\right] V_{dc}$$

$$= \frac{-R_F}{R_1} \cdot V_{dc}\left[\frac{2R - 2R - \Delta R}{2(2R+\Delta R)}\right] = \frac{\Delta R}{4R}$$

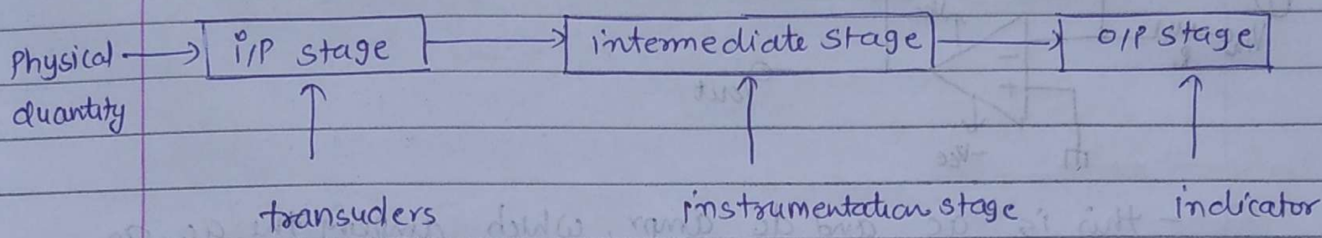
$$\boxed{V_{out} = \frac{\Delta R}{4R}\left(\frac{R_F}{R_1}\right) V_{dc}}$$

Scanned by CamScanner

$R = R'(1+\alpha\Delta T)$
$R - R' = \alpha \Delta T$
$\boxed{\Delta R = \alpha \Delta T}$

Date ______
Page ______

Instrumentation Amplifier :



$R = R'(1+\alpha\Delta T)$
$R - R' = \alpha\Delta T \cdot R'$
$\Delta R = R'\alpha\Delta T$

Ex :-

temp^r coff = $-1\,K\Omega/C$
Reference temp^r = $25^\circ C$
$R_F = 4.7\,K\Omega$; $R = 100\,K\Omega$
$R_1 = 1\,K\Omega$; $V_{dc} = 5V$

(i) Vout at $0^\circ C$
(ii) Vout at $100^\circ C$

$R' = R(1+\alpha\Delta T)$
$R' - R = R\alpha\Delta T$
$\Delta R = R\alpha\Delta T$

Sol: (i)

$$\Delta R = 25\,K\Omega$$

$$V_{out} = \frac{\Delta R}{4R}\left(\frac{R_F}{R_1}\right)V_{dc} = \frac{25\times10^3}{4\times100\times10^3}(4.7)\times5$$

$$= 1.46\ V$$

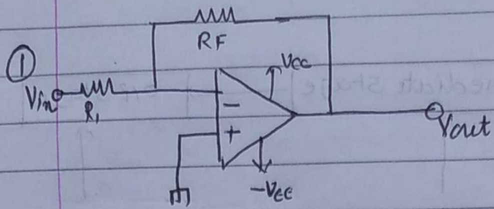
(ii)

$$\Delta R = -75\,K\Omega$$

$$V_{out} = \frac{-75\times10^3}{4\times100\times10^3}(4.7)\times5 = -4.38\ V$$

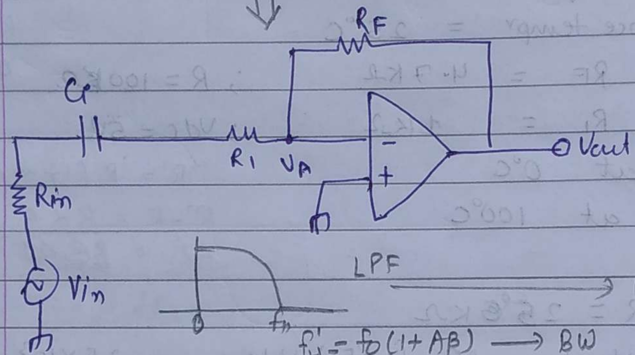
Date 12-Sep

DC / AC Amplifier :

① 

- this is ac and dc ampr, which amplify the ac as well as dc. So if we required only ac, then we have to use capacitor to remove the dc amplified

⇓

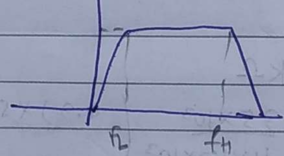


LPF ⟶ (without cap.)

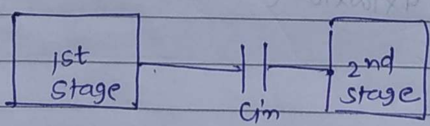
$f_H' = f_0(1+A\beta) \longrightarrow BW$

due to dc, its not amplify the dc signal due to cap.

so $BW = f_H - f_L$



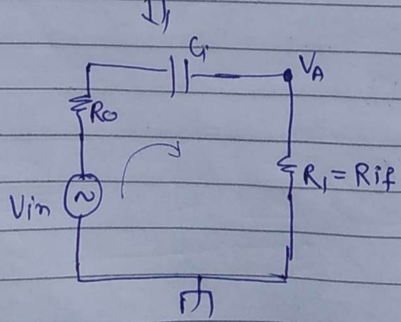
BPF ⟶ (with cap.)



$f_H = f_0(1+A\beta)$

$f_L = ?$

⇓



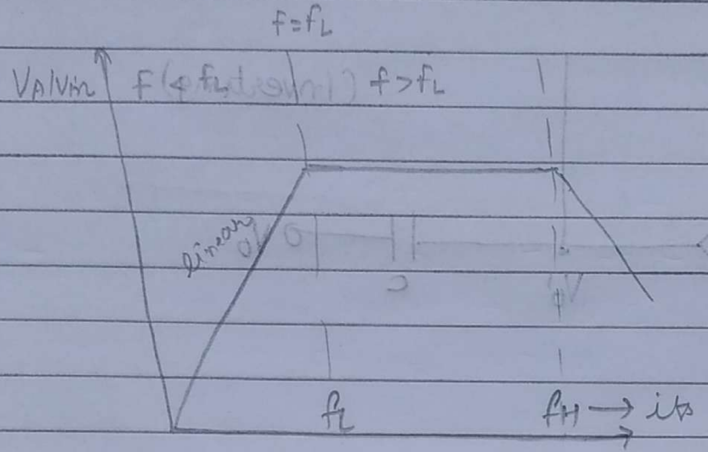
$$V_A = \frac{R_1}{R_1 + R_0 + 1/j\omega C_1} \cdot X_0$$

$$V_{out} = -\frac{R_F}{R_1} V_A$$

$$\therefore V_A = \frac{j\,2\pi f\,R_1 C_1}{j(f/f_L)+1} V_{in}$$

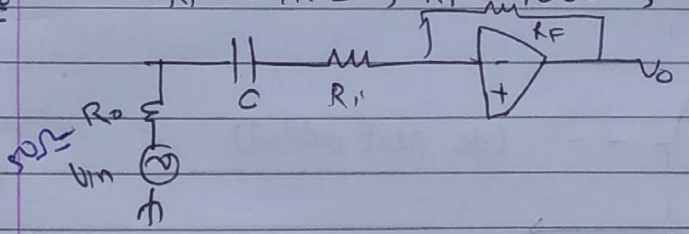
at $f = f_L$

$1/\sqrt{2} \rightarrow$ first cut off



$f_H \rightarrow$ its given by the closed loop gain of (inverting or non-inverting) Ampr.

Ex: $R_F = 1K\Omega$; $R_1 = 100\Omega$; $R_o = 50\Omega$; $C = 0.1\mu F$



where $f_L = \frac{1}{2\pi C_1 (R_1 + R_o)}$

Sol:

$f_F = f_o(1+A\beta)$

$UGB = 1MHz$

$f_f = \frac{(UGB)K}{A_F}$

$f_L = ?$

$F_H = ?$

$BW = ?$

$$K = \frac{R_1}{R_1+R_F} = \frac{100}{100+1K} = 0.1$$

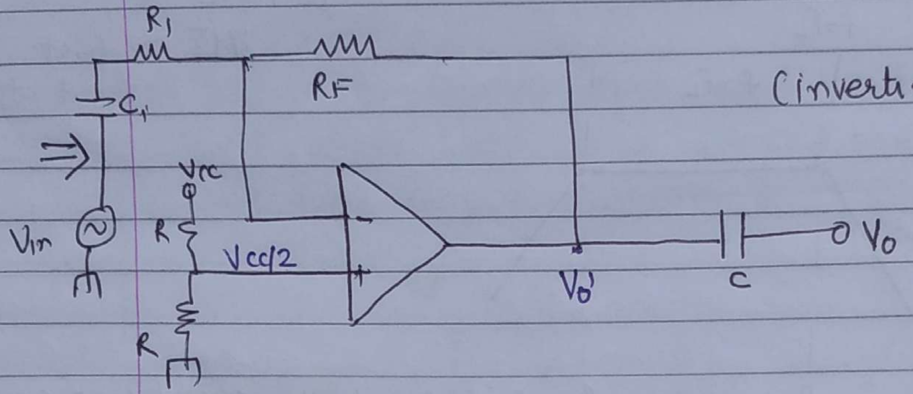
$$A_F = -R_F/R_1 = 1K/100 = 10$$

$$\text{so; } f_f = \frac{1\times10^6 \times 0.1}{10\times10}$$

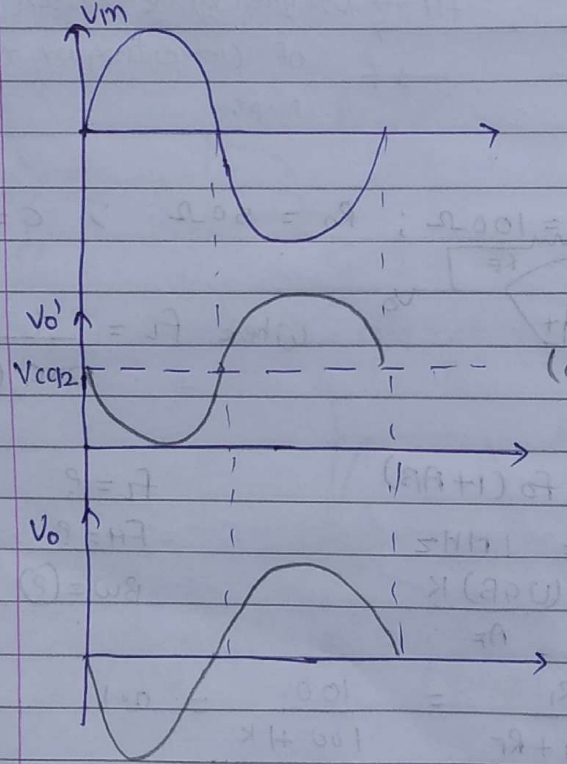
$$= \cancel{10.6\,KHz}\ 10^4$$

$$f_H = f_F(1+A\beta)$$

$$f_L = \frac{10^6}{2\pi(0.1)(100+50)}$$



(inverting)

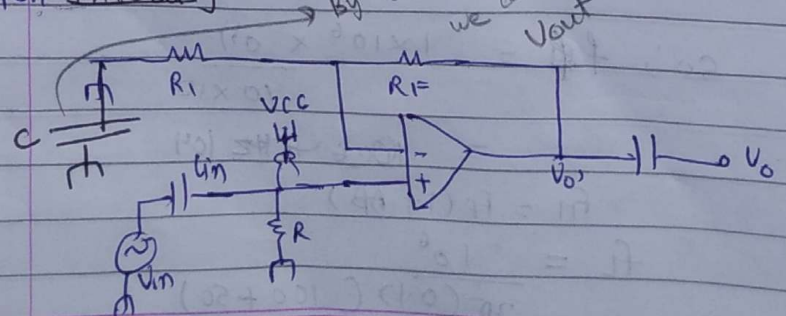


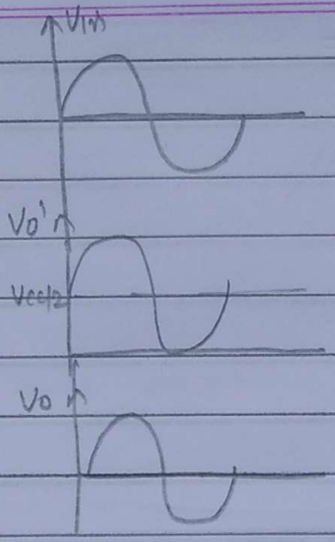
(dc part added)

(dc removed)

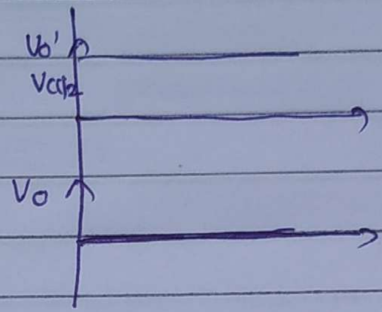
non-inverting

By using this we can get the value of Vout

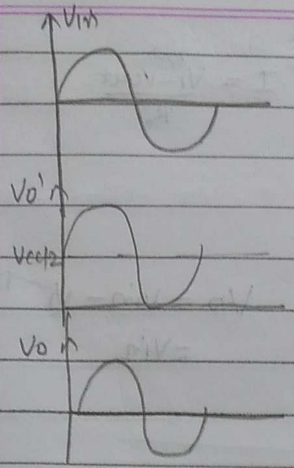




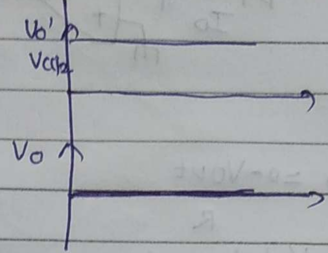
When Vin = 0



Date
Page



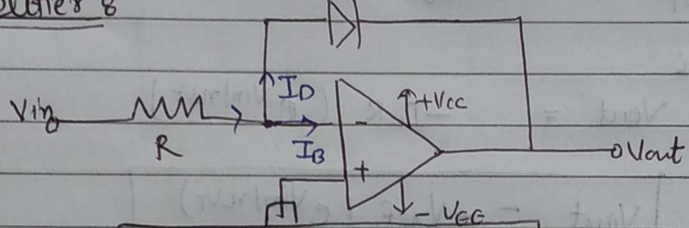
When $V_{in} = 0$



Log Amplifier :

19-Aug :

Ex :-



current across the diode $\boxed{i_d = I_0 (-1 + e^{V_D/nV_T})}$

$n = 1 \rightarrow Ge$
$\quad = 2 \rightarrow Si$

$V_D = 26\,mV$

By applying ~~node~~ Kirchoff's (KCL)

$V_D = 0 - V_{out}$

$$\frac{V_{in}}{R} - \cancel{I_B}^{\,0} - I_D = 0$$

$$\frac{V_{in}}{R} = I_0 \left(e^{V_D/nV_T} - 1 \right) \cong I_0 \cdot e^{V_D/nV_T}$$

$$\frac{V_{in}}{R} = I_0\, e^{-V_{out}/nV_T}$$

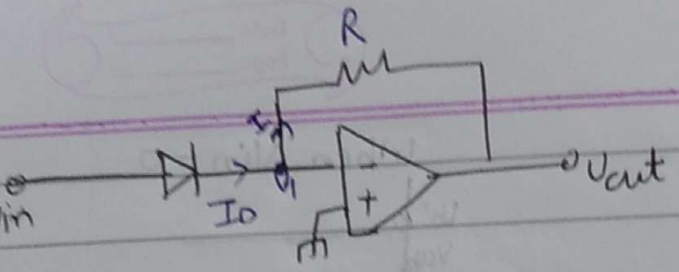
$$\ln\left(\frac{V_{in}}{R}\right) - \ln I_0 = \frac{-V_{out}}{nV_T}$$

$$V_{out} = nV_T \left[\ln \frac{I_0 R}{V_{in}} \right]$$ - thermal stability

logrithm aprx :

$$\boxed{V_{out} = nV_T \ln \frac{V_{in}}{V_{ref}}}$$

Ex:- Antilog Amplifier



$I = \frac{V_i^{0} - V_{out}}{R}$

$I_D = \frac{0 - V_{out}}{R}$

$V_D = V_{in} - V_1$ ⟶ Virtual Ground
$= V_{in}$

$I_0 \left(e^{V_D/nV_T} - 1 \right) = \frac{-V_{out}}{R}$

$I_0 \left(e^{V_{in}/nV_T} \right) = \frac{-V_{out}}{R}$

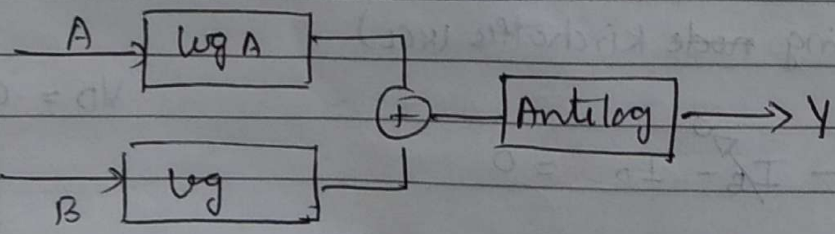
$\cancel{\frac{V_{in}}{nV_T} = \ln\left(\frac{-V_{out}}{RI_D}\right)}$

$\cancel{V_i}$

$V_{out} = -I_0 R \left(e^{V_{in}/nV_T} \right)$

antilog ampr: $\boxed{V_{out} = -V_{ref} \left(e^{V_{in}/nV_T} \right)}$

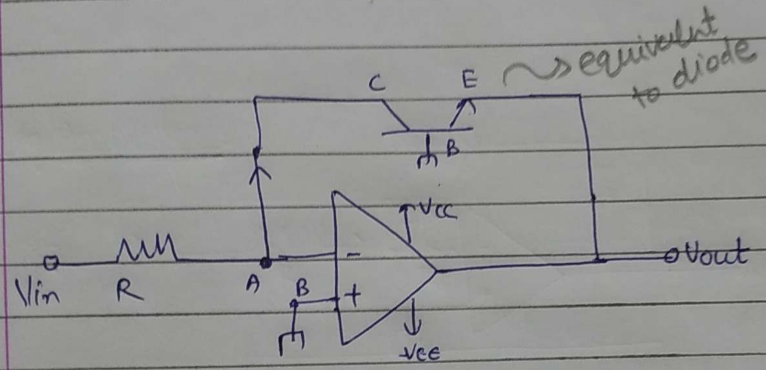
Ex: $y = A \cdot B$ "Multiplier"



- Analog weight scale

- square root
- square
- temp^r controller Ckt - (instrumentation)

Exs -



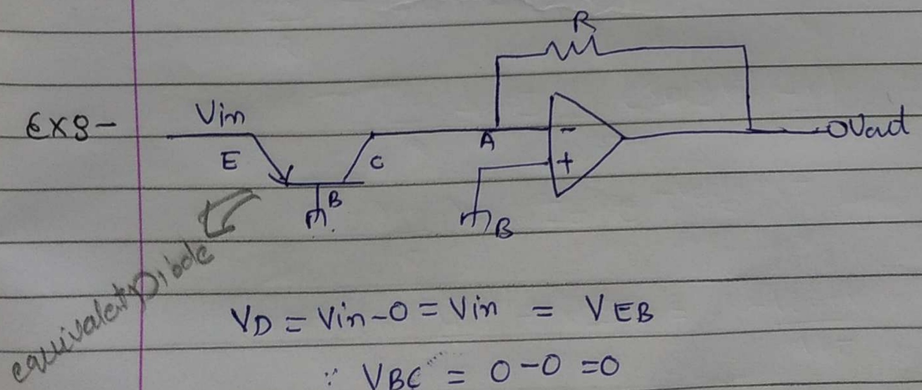
- common base NPN transistor

$V_{BE} = 0 - V_{out}$
$V_{CE} = V_1 - V_B$
$= 0 - 0 = 0$

$$I_C = \alpha I_S \left(e^{V_{BE}/V_T} - 1 \right)$$

- log Amp^r with transistor

Exs -

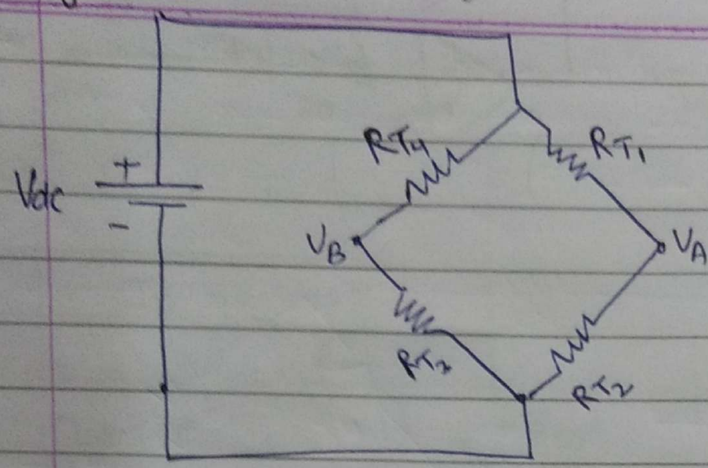


- common base PNP transistor

$V_D = V_{in} - 0 = V_{in} = V_{EB}$
$\because V_{BC} = 0 - 0 = 0$

- Anti log amp^r with transistor

⇒ Analog weight scale: (instrumentation amp)



R_{T1}, R_{T3} ↑ ΔR

R_{T2}, R_{T4} ↓ ΔR

$R = R_{T1} = R_{T2} = R_{T3} = R_{T4}$

$$V_A = \frac{R_{T2} - \Delta R . V_{dc}}{-\Delta R + R_{T2} + R_{T1} + \Delta R}$$

$$V_B = \frac{R_{T3} + \Delta R}{\Delta R + R_{T3} + R_{T4} - \Delta R} . V_{dc}$$

So, $V_{ab} = V_a - V_b$

$$= -\left(\frac{\Delta R}{R}\right) V_{dc}$$

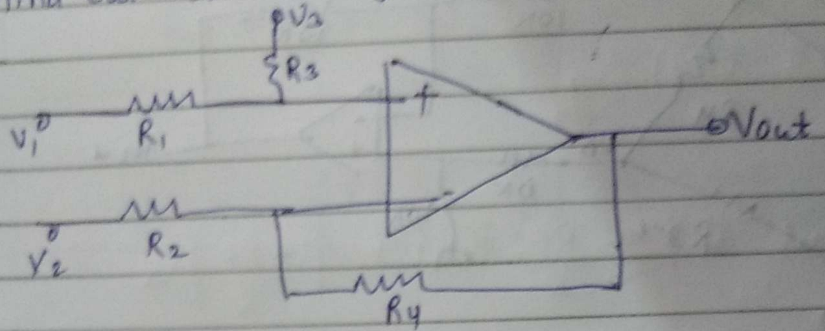
$$V_{out} = \left(\frac{-R_F}{R_1}\right) \cdot V_{ab}$$

$$= \frac{R_F}{R_1} \cdot \frac{\Delta R}{R} \cdot V_{dc}$$

Scanned by CamScanner

Date ______
Page ______

Ex8- for the ckt. shown in fig. O/P voltage $V_0 = a_1V_1 + a_2V_2 + a_3V_3$ (i) calculate a_1, a_2 & a_3 also (ii) find out O/P voltage if R_4 is short circuit, open circuit and (iii) find out O/P voltage R_1 is short circuit.



(i) superposition theorem

$$V_{01} = \left(1 + \frac{R_4}{R_2}\right) V_1 \times \frac{R_3}{R_3 + R_1} \quad a_1$$

$$V_{02} = \frac{-R_4}{R_1} V_2 \quad a_2$$

$$V_{03} = \left(1 + \frac{R_4}{R_2}\right) \frac{R_1}{R_1 + R_3} \cdot V_3 \quad a_3$$

$$V_{out} = V_{01} + V_{02} + V_{03}$$

(ii) $R_4 \rightarrow$ short circuit

then $R_4 = 0$

$$V_{out} = V_1\left(\frac{R_3}{R_3 + R_1}\right) + V_3\left(\frac{R_1}{R_1 + R_3}\right)$$

$R_4 \rightarrow$ open circuit

$R_4 = \infty$

open loop configuration

$V_{out} = V_{sat}$.

(iii)

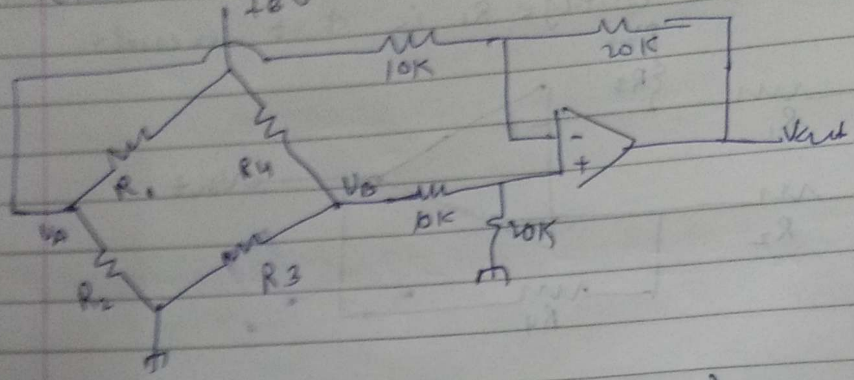
$R_1 \rightarrow$ short circuit

$R_1 = 0$

Ex :- for the ckt. shown in fig calculate o/p voltage

(i) $R_1 = R_2 = R_3 = R_4 = 2k\Omega$

(ii) $R_1 = R_2 = R_3 = 2k\Omega$, $R_4 = 2.2k\Omega$



Sol:

$$V_{out} = \frac{-R_F}{R_1} V_A + \left(1 + \frac{R_F}{R_1}\right) \times \frac{20}{20+10} V_B$$

i) ∵ bridge at balance $V_A = V_B = 0$

so, $V_{out} = 0$

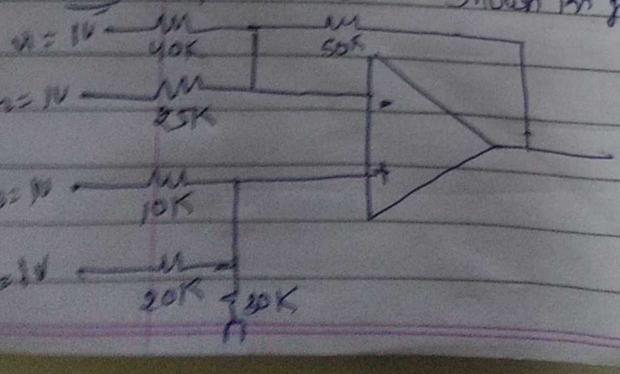
ii) bridge at unbalance

$$V_A = \frac{R_2}{R_1+R_2} \times 8 = \frac{2}{4} \times 8 =$$

$$V_B = \frac{R_3}{R_3+R_4} \times 8 = \frac{2}{2+2.2} \times 8 =$$

$V_{out} = -0.54V$

Ex 2- for the ckt. shown in figure calculate o/p voltage



Date ______
Page ______

Sol:- $V_{01} = \frac{-50}{40} \times (1)$

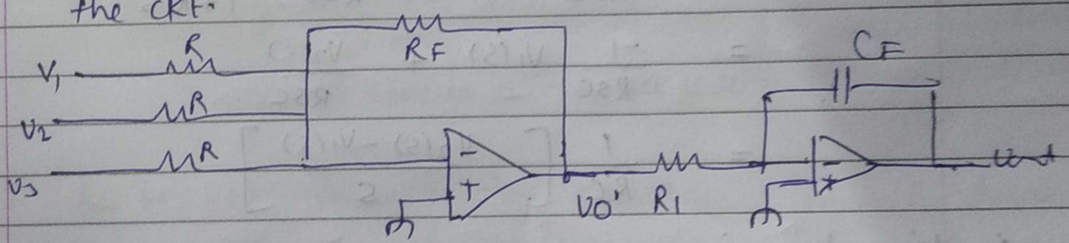
$$V_{02} = \frac{-50}{25}(1)$$

$$V_{03} = \left(1 + \frac{50}{40 \| 25}\right)\left(\frac{30K \| 20K}{30K \| 20K + 10K}\right) \times (1)$$

$$V_{04} = \left(1 + \frac{50}{40 \| 25}\right)\left(\frac{10K \| 30K}{30K \| 10K + 20K}\right) \times 1$$

$$V_{out} =$$

Q. Calculate o/p voltage V_0 also identify func of the ckt.



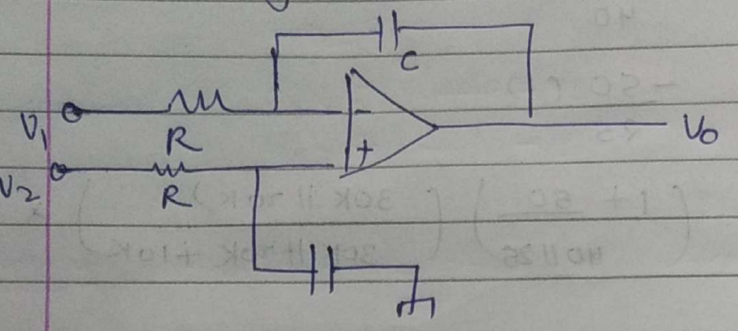
Sol:-

$$V_0' = \frac{-R_F}{R}\left(V_1 + V_2 + V_3\right)$$

$$V_{out} = \frac{-1}{C_F R_1} \int V_0'(t)\, dt$$

$$= \frac{R_F}{R_1} \int (V_1 + V_2 + V_3)\, dt$$

Ex:- identify the func



Sol: $$V_{out} = -\frac{R_F}{R} V_1(S) + \left(1 + \frac{R_F}{R}\right) V_x$$

$$= \frac{-1/SC}{R} V_1(S) + \left(1 + \frac{1/SC}{R}\right)\left(\frac{1/SC}{1/SC + R}\right) V_2(S)$$

$$= -\frac{V_1(S)}{RSC} + \left(1 + \frac{1}{RSC}\right) \frac{1}{1 + RCS} V_2(S)$$

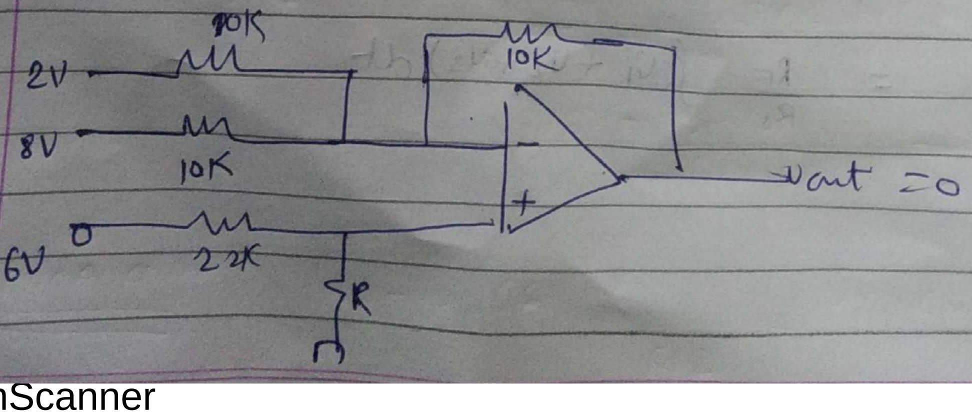
$$= \frac{-1}{RSC} V_1(S) + \frac{V_2(S)}{RSC}$$

$$= \frac{1}{RC}\left[\frac{V_2(S) - V_1(S)}{S}\right]$$

in time domain

$$V_0(t) = \frac{1}{RC} \int [V_2(t) - V_1(t)]\, dt$$

Ex:- Calculate the value of R for the circuit shown in fig. if O/P voltage is 0.



Date ____
Page ____

Sol: $V_{out} = \frac{-10K}{10K}(2) + \left(\frac{-10}{+10}\right)(8) + \left(1+\frac{10K}{10K//10K}\right) \cdot \left(\frac{R}{R+22K}\right) \times 6$

$\because V_{out} = 0$

$$0 = -10 + \left(1+\frac{10K}{5K}\right)\left(\frac{R}{R+22K}\right)\times 6$$

$$10 = \frac{R}{(R+22K)} \cdot 18$$

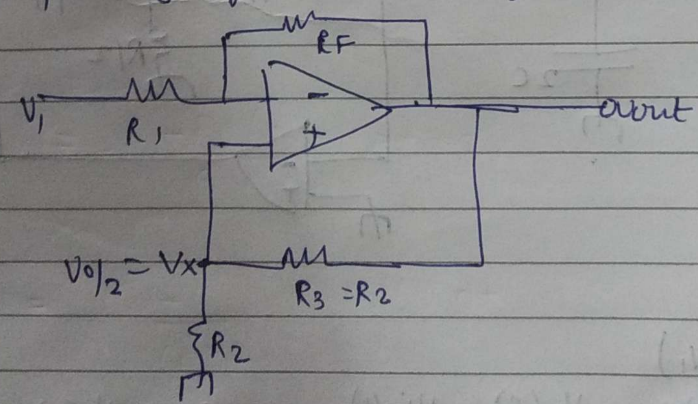
$$\frac{10}{18} = \frac{R}{R+22K}$$

$$10R + 220 = 18R$$

$$8R = 220$$

$$R = 220/8 = 6.62\,K\Omega$$

Ex:- for the ckt. shown in fig. identify which R decide the polarity of O/P voltage.



Sol: $V_{out} = -\frac{R_F}{R_1} V_1 + \left(1+\frac{R_F}{R_1}\right) V_x$

$$= -\frac{R_F}{R_1} V_1 + \left(1+\frac{R_1}{R_1}\right)\frac{R_2}{R_3+R_2} V_0$$

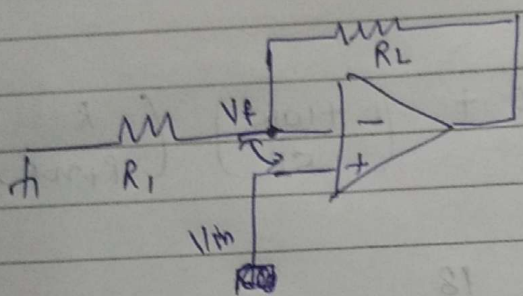
$$=$$

$$V_o = \frac{2R_F}{R_F - R_1} V_1$$

$R_1 < R_F \longrightarrow +ve$

$R_1 > R_F \longrightarrow -ve$

Example: identify the fun of figure



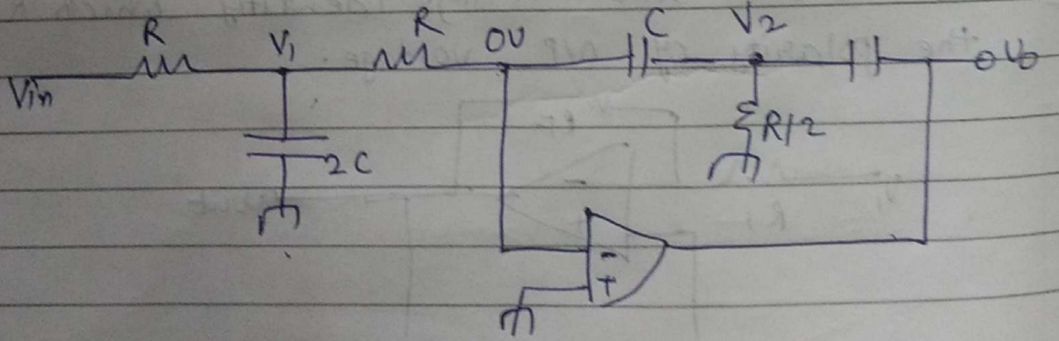
Sol: $V_f = V_{in}$ (Virtual ground)

$I_o R_L = V_{in}$

$I_o = V_{in} / R_L$

Voltage → current converter

Ex:



Sol: (Node at V_1)

$$\frac{V_1(s) - V_{in}(s)}{R} + 2CS\, V_1(s) + \frac{V_1}{R} = 0$$

$$V_1(s) = \frac{V_{in}(s)}{2(1+SRC)} \quad \text{— (1)}$$

node at V_2: $(V_2 - V_o)CS + \frac{V_2}{R/2} + V_2 \cdot CS = 0$

Date ______
Page ______

$$V_2(s) = \frac{RCS\ V_0(s)}{2(1+RCS)}$$

at O node

$$V_1(S) = -RCS\ V_2(S) \quad \text{--- (3)}$$

~~By~~ ~~[illegible]~~ solving the eq^n (1), (2) & (3)

$\Rightarrow$ $\therefore V_0(S) = \frac{-1}{R^2C^2S^2} V_{in}(s)$

Double integrator

time domain

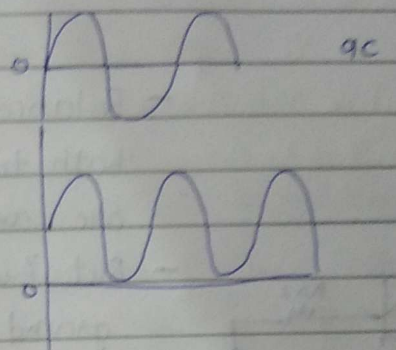
$V(t) =$ double integration ($s^2 \to$ double integral

Date 29-july
Page

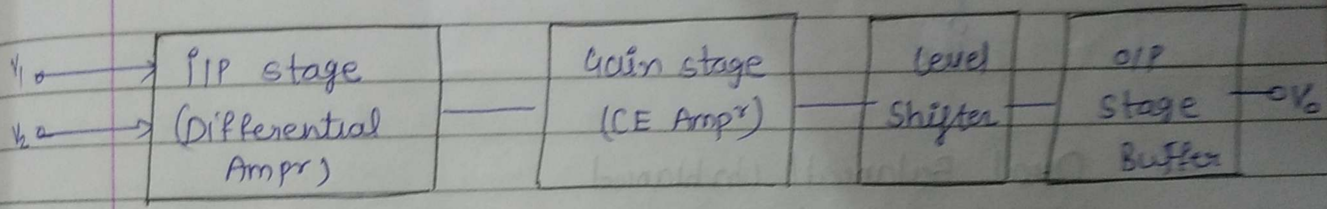
⇒ By Using level shifter, we can remove dc from ac

pure ac signal

dc off set signal



Block Diagram of OP-AMP :



↳ common mode signal $V_{cm} = \frac{V_1 + V_2}{2}$

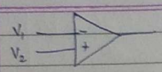
↳ differential signal $V_{id} = V_1 - V_2$

↳ Differential gain A_D is high [10^4 to 10^5]
Common mode gain A_{CM} is low [0]

↳ Common mode regulation ratio (CMRR) $= \frac{A_D}{A_{cm}} \cong \infty$

↳ $Z_{in} = (1 \text{ to } 2\,M\Omega)$

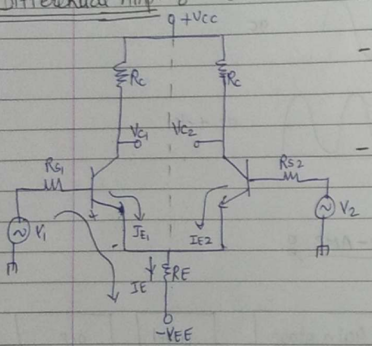
- In op-amp we don't have coupling capacitor so op-amp can amplify the ac and dc both.
- A_{CM} is attenuation, not gain
- op-amp would always amplify the $V_{id} = V_1 - V_2$



$V_o = V_{id} A_d + V_{cm} A_{cm}$

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

Differential Ampr : (PN-2)



- Balanced O/P because both terminal in V_{c1} & V_{c2} pottentials are same.
- But if we take O/P from V_2 & ground then its unbalanced O/P because between V_2 & ground Pott. are not same.

— Dual Balanced / Unblanced
Single " / "

dc analysis:

I_{EQ}

* V_1 & V_2 ac supply $= 0$

— $I_{E1} = I_{E2}$

$I_E = I_{E1} + I_{E2}$

— $I_C = I_E \ (\alpha = 1)$

$I_E = \beta I_B$

Applying Kirchoff's Law

$I_B R_S + V_{BE} + 2 I_E R_E - V_{EE} = 0$

$R_S \frac{I_E}{\beta} + I_E R_E \times 2 + V_{BE} - V_{EE} = 0$

$$I_E \left(\frac{R_S + 2\beta R_E}{\beta} \right) = V_{EE} - V_{BE}$$

$$\boxed{I_{EQ} = \frac{V_{EE} - V_{BE}}{(2R_E + R_S/\beta)}}$$

— $V_{CE} = V_C - V_E$

$= V_{CC} - I_C R_C - (-V_{BE})$

$$\boxed{V_{CE} = V_{CC} + V_{BE} - I_C R_C}$$

ac analysis:

- Small signal gain A_d, A_{cm}
  all dc value are ground.

(A) for calculating A_d;

$V_o = A_d V_d + A_{cm} \cancel{V_{cm}} \to 0$

$V_1 = V_s/2$ & $V_2 = -V_s/2$

↳ in Unblanced

$V_{id} = \frac{V_s}{2} + \frac{V_s}{2} = V_s$

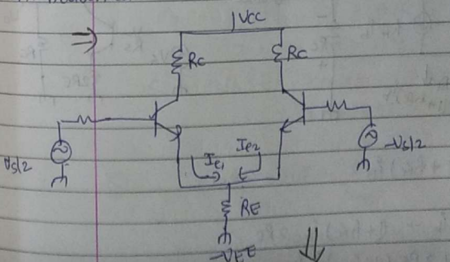
$V_{cm} = 0$

So then $A_d = \frac{V_o}{V_{id}} = \frac{V_o}{V_s}$

↳ in balanced

$A_{d1} + A_{d2} = A_d = 2A_{d1}$

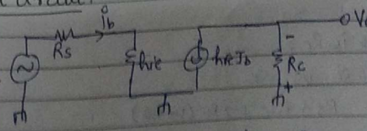
⇒



$I_{e1} \downarrow$, $I_{e2} \uparrow$
so pottential drop across $R_E = 0$
so emitter terminal will be ground.

⇓

equivalent circuit:



$V_{out} = -h_{fe} I_b R_c$ —— (1)

$\frac{V_s}{2} = i_b (R_s + h_{ie})$ —— (2)

So; $V_{out} = \frac{-h_{fe} R_c V_s}{2(R_s + h_{ie})}$

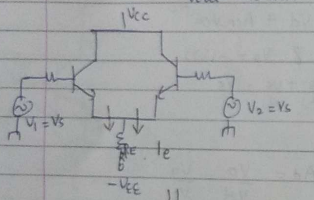
Scanned by CamScanner

$$\boxed{A_d = \frac{V_{out}}{V_s} = \frac{-h_{fe} R_C}{2(h_{ie} + R_s)}}$$

(B) <u>for calculating A_{cm}</u>;

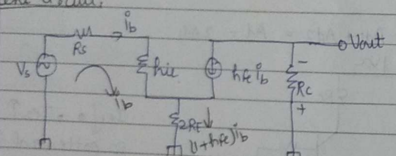
$V_1 = V_s$; $V_2 = V_s$

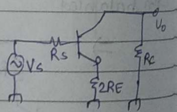
$$V_{id} = 0$$
$$V_{CM} = V_s$$
$$V_{out} = V_{cm} A_{cM}$$
$$V_{out} = V_s A_{cm}$$



- current is double $2i_e$ so voltage across RE is $2R_E I_e$

<u>Equivalent circuit:</u>





$$i_e = (1 + h_{fe}) i_b$$

$$V_s = [R_s + h_{ie}] i_b + (1+h_{fe}) i_b \cdot 2R_E$$
$$V_s = [R_s + h_{ie} + 2R_E(1+h_{fe})] i_b$$

$$V_{out} = -h_{fe} i_b R_C$$
$$= -h_{fe} R_C \cdot \frac{V_s}{R_s + h_{ie} + 2R_E(1+h_{fe})}$$

$$\frac{V_{out}}{V_s} = \boxed{A_{cm} = \frac{-h_{fe} R_C}{R_s + h_{ie} + 2R_E(1+h_{fe})}}$$

(C) <u>O/P impedence:</u>

$$Z_{out} = R_C$$

(D) <u>I/P impedence:</u>

$$i_b = \frac{V_s}{2(R_s + h_{ie})} \quad \text{from (A)}$$

$$\boxed{Z_{in} = 2(R_s + h_{ie})}$$

- By removing the second signal $V_2 = 0$
$V_1 = V_s$

<u>Example:</u> Determine diffr ampr O/P voltage when $V_1 = 300\,\mu V$, $V_2 = 240\,\mu V$; diff. gain $= 5000$; CMRR $=$ (a) 100 (b) 10^5
Calculate O/P voltage.

<u>Sol:</u>

$$V_{id} = V_1 - V_2 = 60\,\mu V$$
$$V_{cm} = \frac{V_1 + V_2}{2} = 270\,\mu V$$

(a)
$$CMRR = 100 = \frac{A_d}{A_{cm}}$$
$$\Rightarrow A_{cm} = 50$$
$$\text{So, } V_0 = 60 \times 5000 + 270 \times 50$$
$$= \cancel{14.1\,mV}\ \cancel{1.95\,mV}\ \cancel{31.35\,m}V\ 0.313\,V$$

(b)
$$CMRR = 10^5 = \frac{A_D}{A_{cm}}$$
$$\Rightarrow A_{cm} = \frac{5000}{10^5} = \cancel{5 \times 10^{-3}}\ 5 \times 10^{-2}$$

$$V_0 = 60 \times 5000 + 5 \times 10^{-2} \times 270$$
$$= \cancel{0.03 + 4.35 + 30{,}000}$$
$$= \cancel{30\,mV}\ 0.3\,V$$

<u>Example:</u> dual i/p balanced O/P Diff. ampr $h_{ie} = 2.8\,K\Omega$

$V_{S1} = 70\,mV$ P-P 1 KHz

$V_{S2} = 40\,mV$ P-P 1 KHz

$V_{CC} = 15V$; $V_{EE} = -15V$

$R_C = 4.7\,K$; $R_E = 6.8\,K$; $R_s = 100\,\Omega$; $h_{fe} = 100$

Date ____
Page ____

Calculate A_D, A_{CM}, Operating Point, CMRR, Vout, Rin, Rout

Sol:

Operating Point

$$I_{EQ} = \frac{V_{EE} - V_{BE}}{(2R_E + R_S/\beta)}$$

$$= \frac{+15 - 0.7}{(6.8K + 100/100)} = 1.05 \text{ mA}$$

$I_C \cong I_E$

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

$$= 15 + 0.7 - 4.7K \times 2.30m$$

$$= 4.89V$$

$$A_D = \frac{-h_{fe} R_C}{2(h_{ie} + R_S)}$$

$$= \frac{-100 \times 4.7K}{2[2.8K + 100]}$$

$$= -81.03$$

$$A_{cm} = \frac{-h_{fe} R_C}{R_S + h_{ie} + 2R_E[1 + h_{fe}]}$$

$$= \frac{-100 \times 4.7K}{100 + 2.8K + 2 \times 6.8K(1+100)}$$

$$= -0.34$$

$$CMRR = \frac{A_D}{A_{cm}} = 238.32$$

$$R_{in} = 2(R_S + h_{ie})$$

$$= 2[100 + 2.8K] = 5.6 K\Omega$$

$$R_{out} = R_C = 4.7K$$

$$V_{out} = A_d V_{id} + V_{cm} A_{cm}$$

$$V_{id} = V_{S1} - V_{S2} = 30mV$$

$$V_{cm} = \frac{70 + 40}{2} = 55 mV$$

$$V_{out} = 2.4 \text{ V}$$

Date 5-Aug
Page ____

Example: In a Differential ampr $R_C = 2.2K$, $R_E = 4.7K$, $R_{in1} = R_{in2} = R_S = 50\Omega$, $\beta = 100$; $V_{CC} = 10V$; $-V_{EE} = -10V$; $V_{BE} = 0.715$ V find out operating point

Sol:

$$I_{EQ} = \frac{V_{EE} - V_{BE}}{(2R_E + R_S/\beta)}$$

$$= \frac{+10 - 0.715}{(2 \times 4.7K + 50/100)} = 0.98 mA$$

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

$$= 10 + 0.7 - (0.98 \times 2.2) = 8.54 V$$

Example: I/P Voltages V_1 = 300 µV, V_2 = 240 µV

Diff^r gain is 3000 and CMRR i) 10^3 ii) 10^4 Calculate Vout:

Sol:

$$V_d = V_1 - V_2 = 60 \mu V$$

$$V_{cm} = \frac{V_1 + V_2}{2} = 270 \mu V$$

(a)

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

$$\Rightarrow A_{cm} = \frac{3000}{10^3} = 3$$

$$V_{out} = V_d A_d + V_{cm} A_{cm}$$

$$= 60 \times 3000 + 270 \times 3$$

$$= 0.18 V$$

(b)

$$\Rightarrow A_{cm} = \frac{3000}{10^4} = 0.3$$

$$V_{out} = 60 \times 3000 + 0.3 \times 270$$

$$= 0.18 V$$

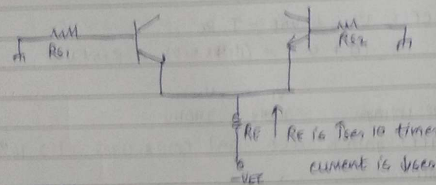
Improvement in CMRR:

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

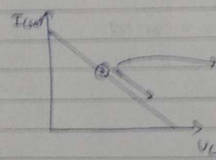
$$A_d = \frac{-h_{fe} R_C}{2(R_s + h_{ie})} \qquad A_{cm} = \frac{-h_{fe} R_C}{h_{ie} + R_s + 2R_E(1+h_{fe})}$$

$$CMRR = \frac{R_s + h_{ie} + 2R_E(1+h_{fe})}{2(R_s + h_{ie})}$$

$100\,dB \longrightarrow 20 \log 10^5$



R_E ↑ R_E is ↑ses 10 times
current is ↓ses



Operating Point shifted (some part may will clip) distortion occur

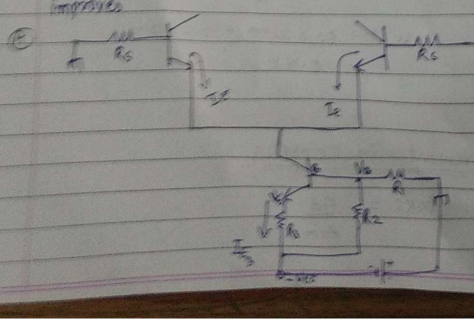
in order to maintain current,
we ↑ses Power supply $\boxed{V_{EE}}$
But that is not preferable.

– so we change R_E (Passive resistor) with Active resistor → "constant current source"
→ current mirror ckts

Constant Current Bias:

– By ↑ing the R_E, A_d is not change, A_{cm} is ↓ses, then CMRR improves.

(E)



$$V_B = \frac{V_{EE}}{R_1+R_2} \cdot R_1$$

12-Aug

$V_E = V_B - V_{BE}$

$$I_{E3} = \frac{V_E + V_{EE}}{R_3} \qquad I_{C3} = \frac{V_{EE} - \left(\frac{R_2 V_{EE}}{R_2+R_1}\right) - V_{BE3}}{R_E}$$

When $V_{EE} = -10V$; $R_1 = R_2 = 4.9K$; $V_{BE} = 0.9V$; $R_3 = 2.2K$

$$V_B = \frac{10 \times 1}{2} = 5V$$

$V_E = 5 - 0.9 = 4.3V$

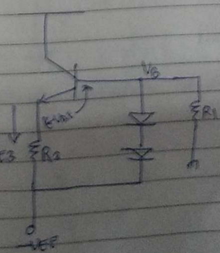
$$I_{E3} = \frac{4.3 + 10}{2.2K} = 6.5\,mA$$

- this constant current source offers high I/P impedence and we can also maintaince the current flowing from this circuit, By changing or set the value of Active components.
- By ↑ing the value of R_E, current ↓ses, so neg. part will clipped
- By ↑ing the Tempr, current will ↑ses, so pos part may be clipped.

19-Aug

⟹ To avoid effect of ↑se in current due to tempr, diodes are added instead of resistors R_2

(B)



$$I_{E3} = \frac{2V_D - V_{BE}}{R_3}$$

here V_D & V_{BE} varies with tempr but as difference is taken ⟹ tempr affected on I_{E3} becomes less.

Techniques used for controlling current rise due to tempr is called tempr compensation.

$V_B = -V_{EE} + 2V_D$

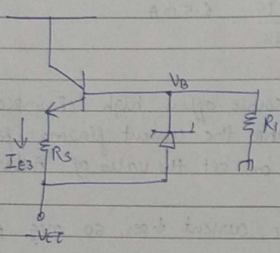
$V_E = V_B - V_{BE}$

$= -V_{EE} + 2V_D - V_{BE}$

$I_{E3} = \frac{V_E + V_{EE}}{R_3} = \frac{-V_{EE} + 2V_D - V_{BE} + V_{EE}}{R_3}$

⟹ instead of 2 diodes, a zener diode can also be used

(c)

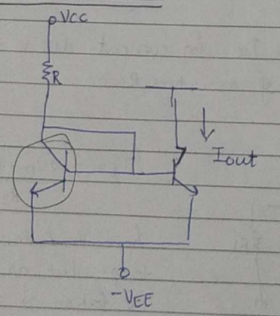


$V_E = -V_{EE} + V_Z - V_{BE}$

$I_{E3} = \frac{-V_{EE} + V_Z - V_{BE} + V_{EE}}{R_3}$

$= \frac{V_Z - V_{BE}}{R_3}$

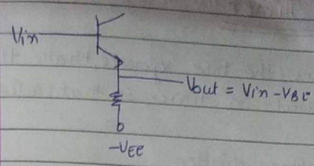
Current Mirror:



— Used for biasing purpose.

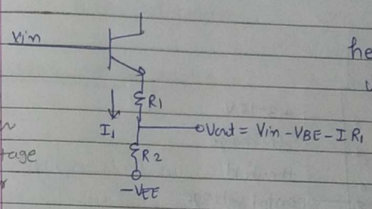
Level Shifter: (PN 42)

(1)



(2)

Emitter follower with voltage divider

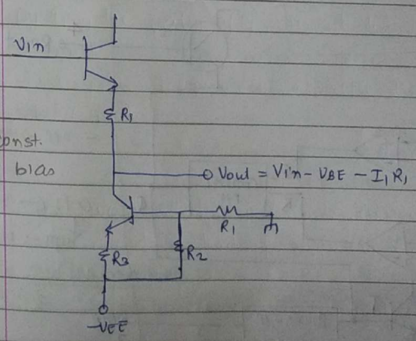


here as resistors are unaware about dc or ac signals. So, it may attenuate ac signal to which are required.

∴ we use active resistors.

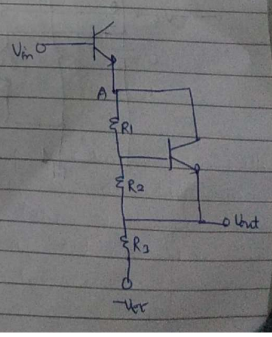
(3)

with const. current bias



(4) Completely removes dc offset.

— thermal runaway
heat sinks

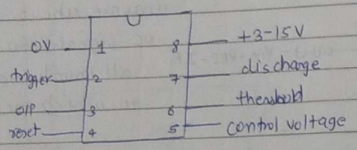


555 Timer

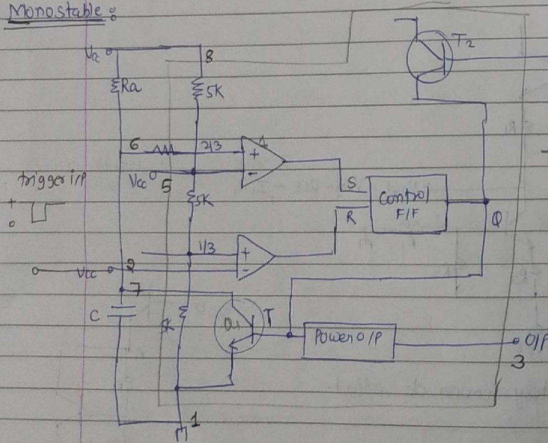
Date 26-Sep

- a device which gives the time reference, that's timer.
- 3 resistors of 5kΩ is used in timer, so that's called as 555 timer
- they are used for voltage divider.

pin diagram:



Monostable:

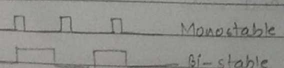


- o/p → High → Q_1=0V ↓ cap. charge

o/p 1 ← 2/3 Vcc ← charge

High → Reset = 1 → Q=0 ↓

disch cap. ← o/p 0



Set → 1
Reset → 0

- when Q = 1 ; o/p = 0 ; T_1 → cap discharge, set
- Q = 0 ; o/p = 1 ⇒ T_1 → s/w open, capacitor charge

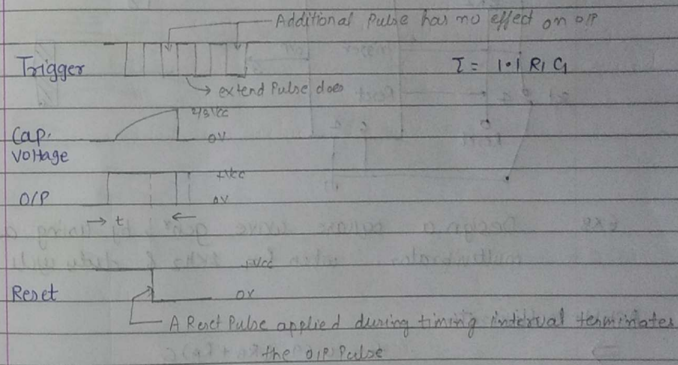
Reset $V_c \leq \frac{2}{3} V_{cc}$

$T_P = 1.1 R_a C$

Application:

- Random flashers
- A light dimmer
- A car techometer
- traffic lights
- infra red remote control

Monostable o/p voltage:



9-Sep

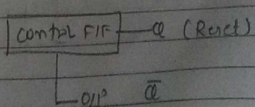
Astable multivibrator:

cap. is charged : C(Ra + Rc) → charging time

1/3 Vcc → 2/3 Vcc

- at starting $V_c = \frac{1}{3} V_{cc}$ → op-amp ② → control FF (0) ↓ Reset

high = o/p ← transistor s/w OFF ← T_1 (0)



Q	Q̄	
1	0	→ Set
0	1	→ Reset

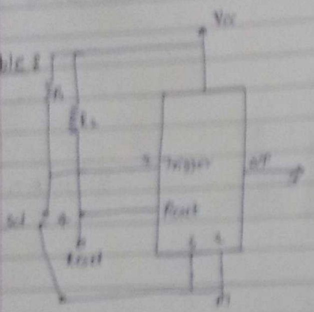
Ex2- Monostable 555 Timer is required to produce a time delay within a ckt of a 10 µF timing cap is used. Calculate the value of the resistor required to produce a min o/p time delay of 500 ms.

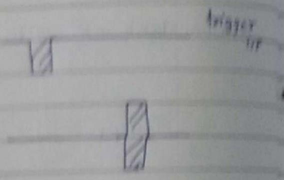
Sol:

$$T = 1.1 RC$$

$$R = \frac{T}{1.1 \times C} = \frac{500 \times 10^{-3}}{1.1 \times 10 \times 10^{-6}} =$$

Bistable:





Ex3 Design a square wave gen^r, by using astable multivibrator when f = 1kHz & duty cycle 50%.

Astable multivibrator

⇒

$$t_c = 0.69\,(R_A + R_B)C$$

$$t_d = 0.69\,R_B C$$

$$T = 0.69\,(R_A + 2R_B)C$$

$$f_0 = 1/T = 1.45 / (R_A + 2R_B)C$$

$$\%\text{ duty cycle} = \frac{t_c}{T} = \frac{R_A + R_B}{R_A + 2R_B} \times 100$$

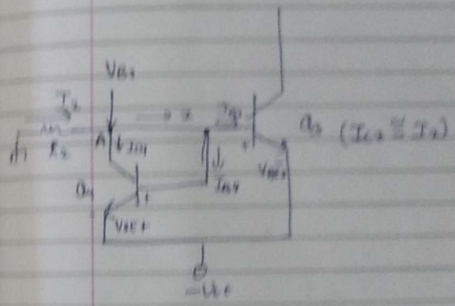
Current Mirrors (Pg 82)

The circuit in which the o/p current is forced to equal the i/p current is said to be a current mirror circuit.

I_{source} → [current mirror] ← I_{sink}

$$I_s = I_{sink}$$

Q_3 & Q_4 → identical



$$V_{BE3} = V_{BE4}$$

$$I_{C3} = I_{C4}$$

$$I_{B3} = I_{B4}$$

at node A ;

$$I_2 = I + I_{C4}$$

$$= I_{C4} + I_{B3} + I_{B4} = I_{C3} + 2 I_{B3}$$

$$= I_{C3} + 2\left(\frac{I_{C3}}{\beta_{dc}}\right)$$

$$I_2 = I_{C3}\left[1 + \frac{2}{\beta_{dc}}\right]$$ → is very small

$$I_2 \cong I_{C3}$$

Kirchoff's voltage law's

$$-I_2 R_2 - V_{BE3} + V_{EE} = 0$$

$$I_2 = \frac{V_{EE} - V_{BE}}{R_2}$$

* for satisfactory operation of the circuit, two identical transistors are necessary.