Date 18-July

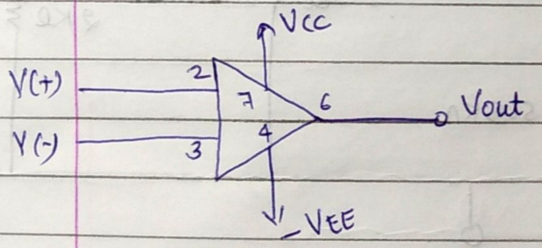
EC-502

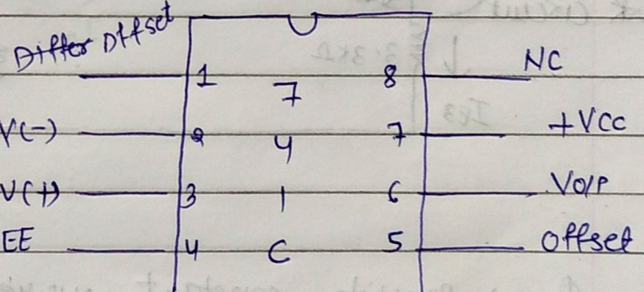
Ideal Char^c of amplifier:

ideal:
- Gain = ∞
- BW = ∞
- Zin = ∞
- Zout = 0
- Slew rate : change of o/p wrt ~~input~~ time = ∞

practically
- Gain = finite
- BW = finite
- Zin = finite (in MΩ) ~~<100Ω~~
- Zout = (< 100Ω)
- SR = (0.5 - 100 V/μsec)

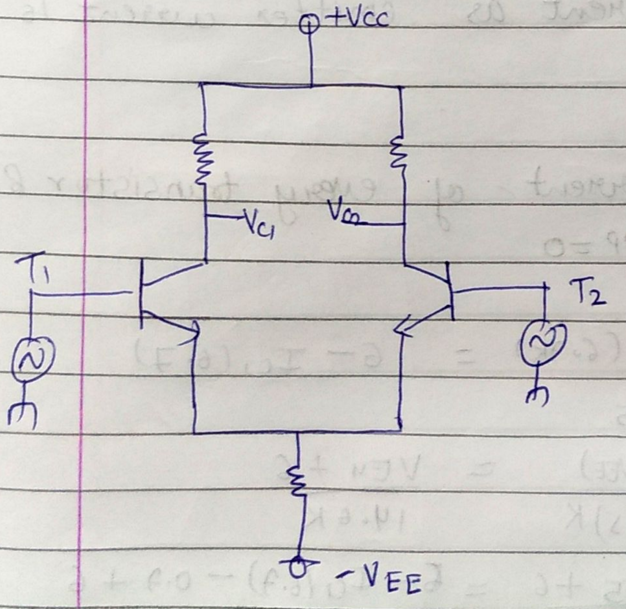
Block Diagram & circuit symbol of OP-amp:





741 C → commercial
↓ → single o/p

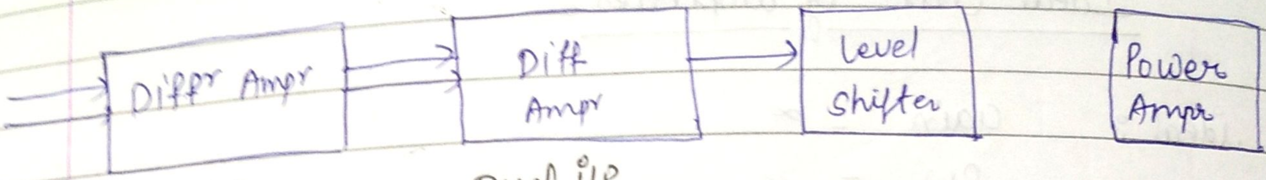
7 terminals is used



dual i/p ~~dual~~ balanced o/p (o/p Vc1 & Vc2)

" " Unblanced o/p

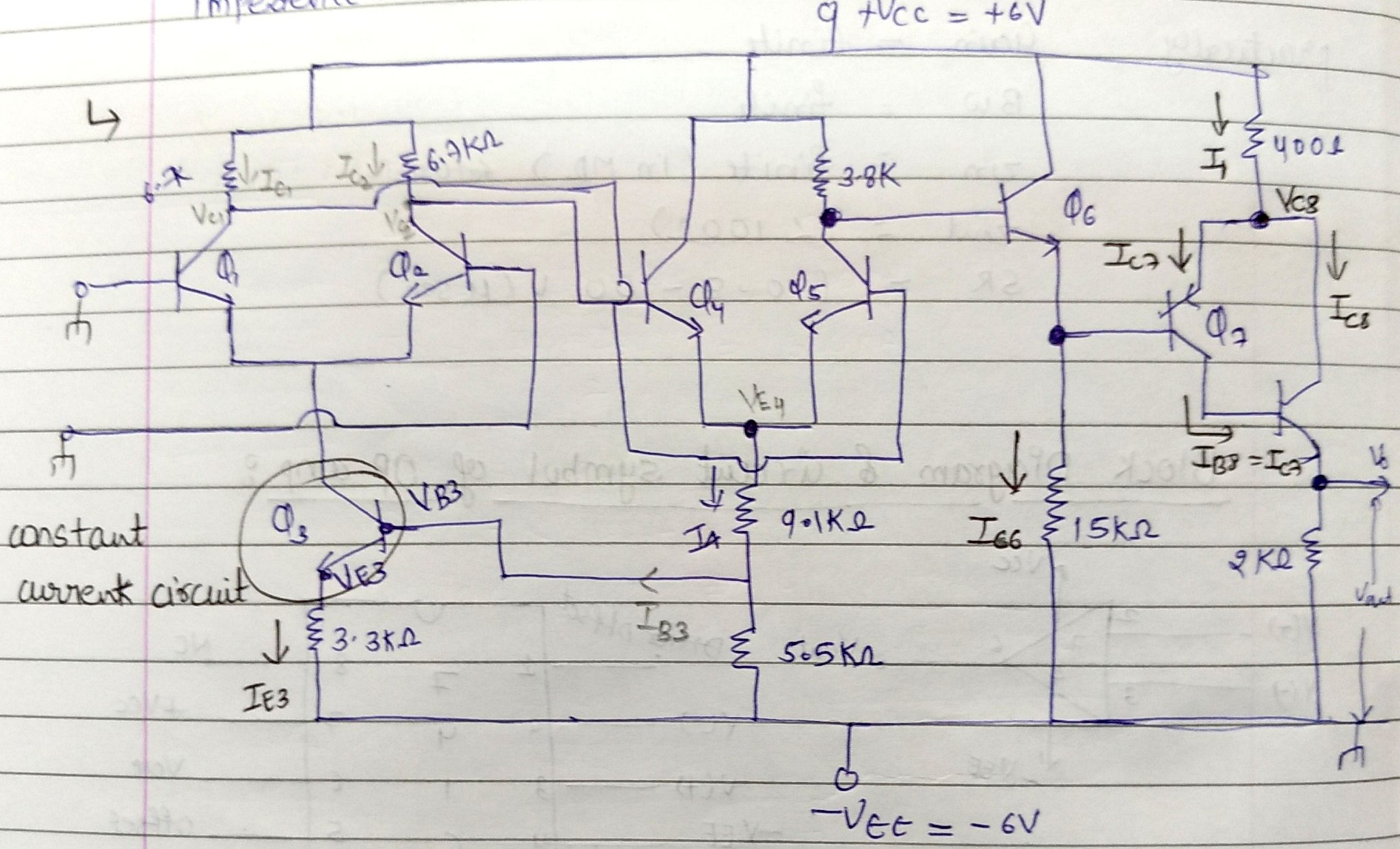
is taken



Dual i/p
Balanced o/p
D.Ampr

Dual i/p
Unblanced o/p
D.Ampr

* purpose of two differential ampr is high gain & high i/p impedence.



Q_3 → provide constant current as emitter current is constant.

Q01 Determine collector current of every transistor & dc o/p voltage ; when i/p = 0

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

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

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

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

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

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

$$V_{E3} = V_{B3} - V_{BE3} \qquad = 10.25 - 2.52K I_{C1}$$

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

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

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

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

$$I_{E3} = 2 I_{C1} \qquad 2.75 I_C = 1.07 \times 10^{-3}$$

$$I_C = 388.02 \mu A$$

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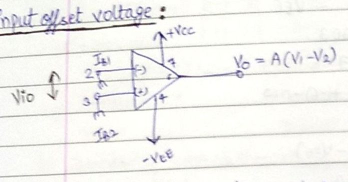
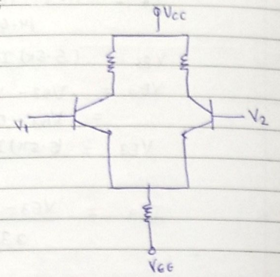
Date 21-july

OP-amp Ic-741 parameters :

Input offset voltage :





- i/p offset is dc voltage

for Ic 741 $V_{io} = 5mV$

i/p offset current :

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

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

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

$R_{i/p} = 1M\Omega$

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

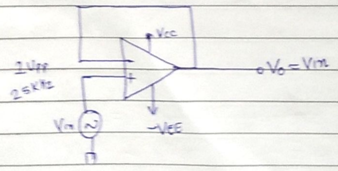
open loop voltage gain $= \frac{\text{o/p voltage}}{\text{diff}^r \text{ i/p voltage}}$

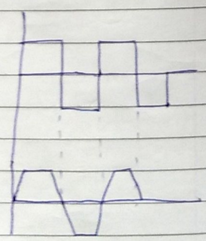
$= \frac{V_0}{V_{id}}$

$= 2 \times 10^5$

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

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





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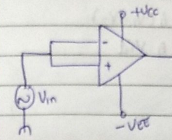
Output Voltage $|V_o| < |V_{cc}|$

$V_{out} = \pm 13V$

CMRR :



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

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

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

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

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 dissipation $I_{source} = 2.8mA$

- its analogue 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 Knowledge about the how efficient the op-amp for rejection of noise

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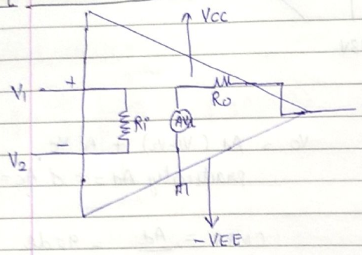
Equivalent circuit :

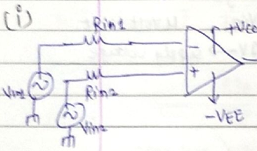


$V_o = A(V_1 - V_2)$
$= A\,V_{id}$

Open loop configuration :

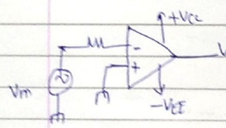
(i) Differential Amp.
(ii) inverting
(iii) non-inverting

(i)

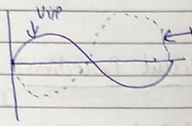


$V_o = A(V_{in1} - V_{in2})$

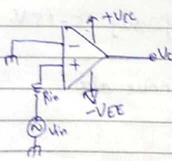
(ii)



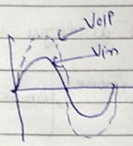
$V_o = A(V_1 - V_2)$
$= -A\,V_{in}$



(iii)



$V_o = A(V_1 - V_2)$
$= A\,V_{in}$



↳ $V_o = A(V_1 - V_2) = AV_d$

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

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

$V_{cc} = 15V$
$A = 2 \times 10^5$

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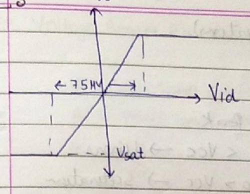
Char^c :



- for linear application, $V_{id} \leq 75\mu V$
  $V_{id} > 75\mu V$, then op-amp will ~~we~~ 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 $A = 2\times10^5$

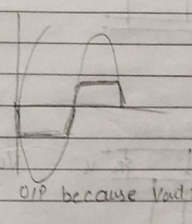
Sol:
$V_{out} = A[V_{in1} - V_{in2}]$
$= 2\times10^5[5+7]\mu$
$= 24\times10^5\times10^{-6}$
$= 2.4\ V$ dc

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

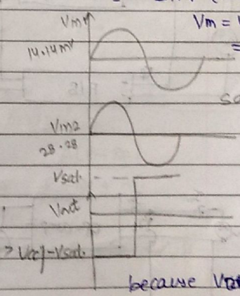
$V_{out} = 2\times10^5[-10]m$
$= -2\times10^5\times10^{-2}$
$= -2kV$ (rms)

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

Linear

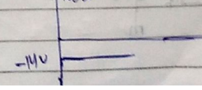


Clip the O/P because $V_{out} > V_{cc} - V_{sat}$



because $V_{out} > V_{cc}$

(iii) $V_{in1} = 20mV$ dc (inverting amp^r)
$V_{out} = A(V_{in1} - V_{in2})$
$= -A\,V_{in2}$
$= -2\times10^5\times20\times10^{-3}$
$= -40\times10^2 = -4000V$ dc



Saturation

single Power → dual / — power supply ?

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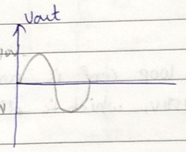
(iv) $V_{in} = -50\ \mu V$ Peak (inverting)

$V_o = -AV_{in}$

$= 2 \times 50 \times 10^{-6} \times 105$

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



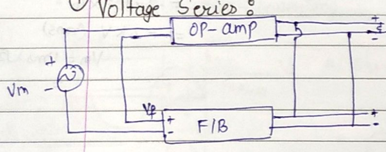
$V_o < V_{cc} \rightarrow$ linear

$V_o > V_{cc} \rightarrow$ saturation

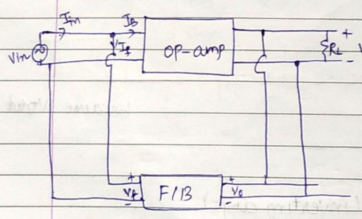
linear

feed back configuration:

① Voltage Series:

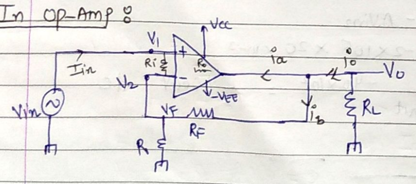


② Voltage Shunt:



In Op-Amp:

①



By dot

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

gain:

A – open loop gain

A_F – close loop or Feedback gain

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

$V_1 = V_{in}$

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

$V_o = A(V_1 - V_2)$

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

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

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

$A_F\left[1 + \dfrac{AR_1}{R_1 + R_F}\right) = A$

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

$\because AR_1 >> R_1 + R_F$

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

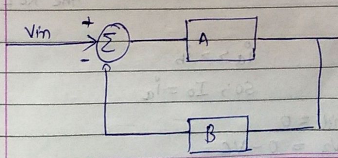
if $A_F = 11$

then $R_F = 10R_1$

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

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

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



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$$\beta = \frac{V_f}{V_o} = \frac{R_1}{R_1+R_F}$$

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

In ideal condition :

$$V_o = A V_{id}$$

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 :

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

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

$$V_o = A V_{id}$$

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

$$\cancel{\frac{1 - V_{id}}{V_{in}}} \quad \frac{1}{A\beta+1} \frac{V_{in}}{I_{in}} = \frac{V_{id}}{I_{in}}$$

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

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, $I_o = i_a$

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

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

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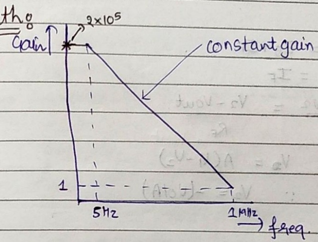
$$\Rightarrow V_{id} = -V_f$$

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

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

Bandwidth :



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

for open loop op-amp : $A = 2 \times 10^5$; $f_o \rightarrow$ single break away freq.

$BW = 5 Hz$

Bandwidth is ↑ses in non-inverting feedback ampr

$2 \times 10^5 \times 5 = 1 MHz$ = for open loop

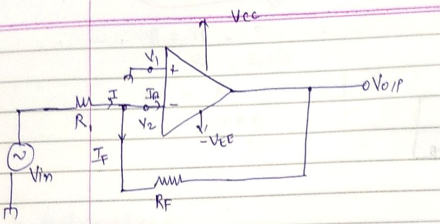
Unity gain $BW = 1 \times 1 MHz$

$$* \quad \boxed{\begin{aligned} UGB \text{ (Unity gain Bandwidth)} &= A f_o \\ &= A_F f_F \end{aligned}}$$

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

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

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



$I = I_B + I_F$

$I = I_F$

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

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

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

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

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

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

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

$R_1(1+A) + R_F = A_F$

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

$\because AR_1 >> R_1 + R_F$

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

IIo $AV_{id} = V_o$

ideally very high gain $A = \infty$

$V_{id} = 0$

$V_1 = V_2$ (virtually ground)

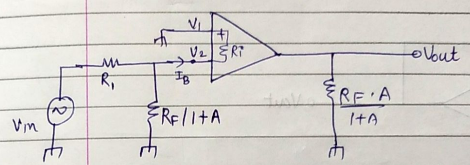
so $I = I_F$

O/P impedence : – Vin is shorted

– same as non-inverting

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

I/P impedence :



$R_{iF} = R_I + \left(\frac{R_F}{1+A} \,||\, R_i\right)$ $\therefore A \cong \infty$

$R_{iF} \cong R_1$

Gain:

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

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

frequency:

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

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

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

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

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

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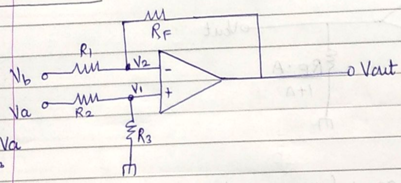
- BW is higher for non-inverting amp^r. because $0<K<1$

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

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

By eq^n ① & ②

Differential Amp^r :



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

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.

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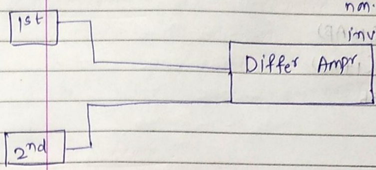
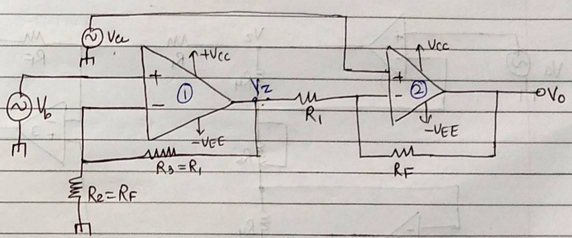
non. invert V(+) : $R_{IF1} = R_1(1+A\beta)$
inverting V(-) : $R_{IF2} = R_1$



- Loading impedence matching is not done for Differen Ampr

↳



OP-amp ① is non-inverting amp^r

OP-amp ② is differential amp^r

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

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

(when $V_a = 0$) (when $V_z = 0$)

superposition theorem

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

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

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

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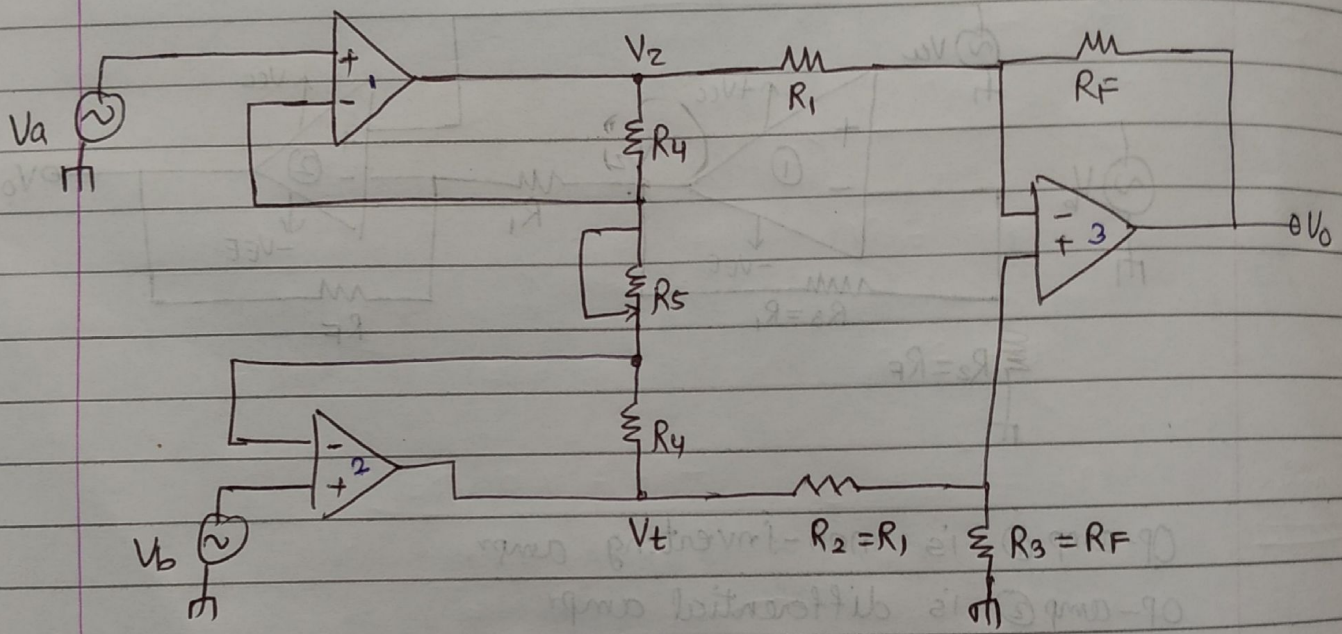
$R_{iFa} = R_i(1+A\beta)$

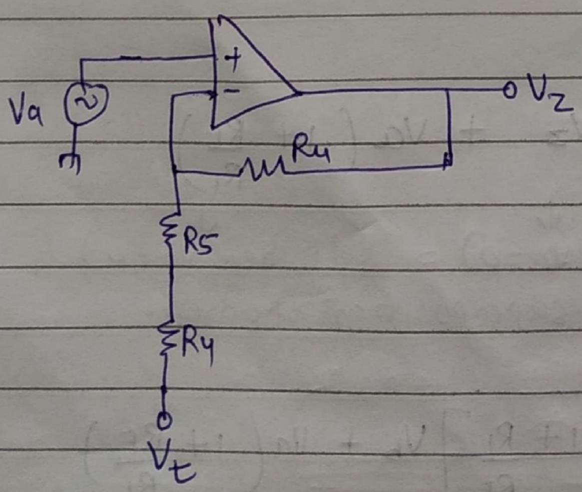
$R_{iFb} = R_i(1+A\beta)$

$R_{iFa} \neq R_{iFb}$

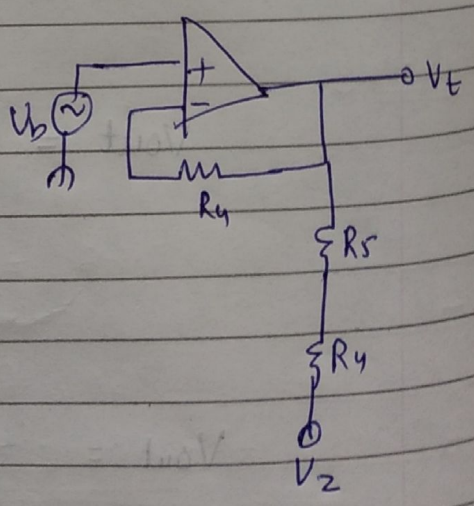
$\Rightarrow$



① When $V_b = 0$



② When $V_a = 0$



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 are coming from op-amp)

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

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

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

$V_o = -\left(1 + \frac{2R_4}{R_5}\right)\frac{R_F}{R_1} V_{ab}$

$V_{ab} = V_a - V_b$

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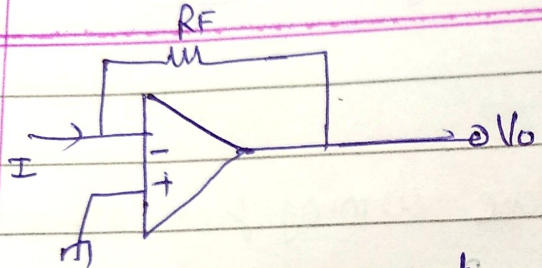

I/P → current

O/P → voltage

Application :

- Solar Panel
- fiber optic commⁿ
- DAC

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

$$= -R_F \cdot I_{in}$$

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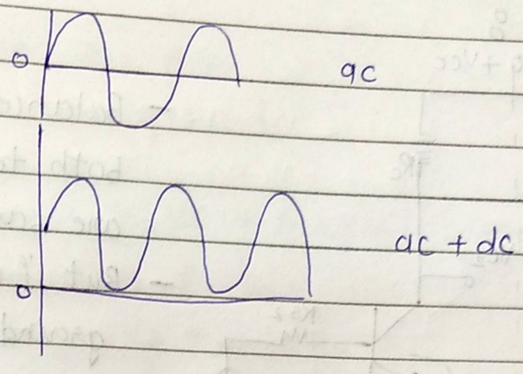
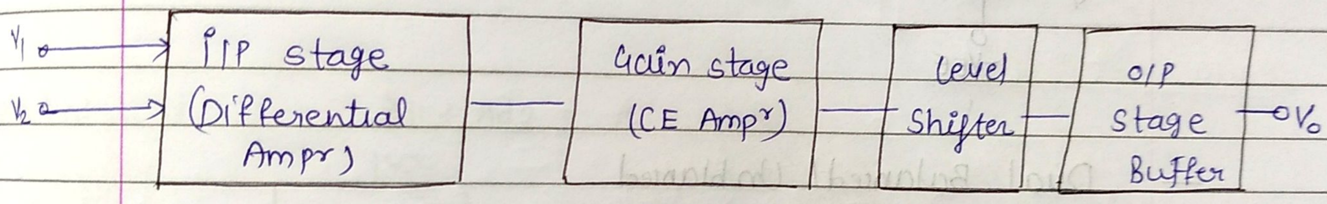
⇒ By Using level shifter, we can remove dc from ac

pure ac signal

dc off set signal



Block Diagram of OP-AMP :



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

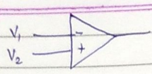
↳ differential signal $V_{id} = V_1 - V_2$

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

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

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

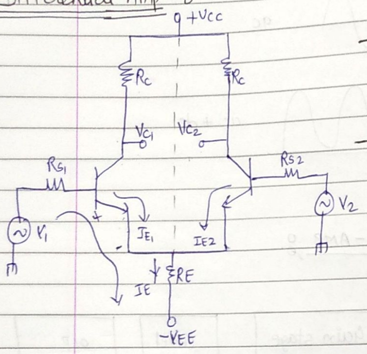
- In op-amp we don't have coupling capacitor so op-amp can amplify the ac and dc both.
- A_{CM} is attenuation, not gain
- op-amp would always amplify the $V_{id} = V_1 - V_2$



$V_0 = V_{id} A_d + V_{cm} A_{cm}$

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

Differential Ampr :



- Balanced O/P because both terminal V_{c1} & V_{e2} 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 :

IEQ

* 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

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

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

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

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

— $V_{CE} = V_C - V_E$

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

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

ac analysis :

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

Ⓐ for calculating A_d ;

$V_0 = A_d V_d + A_{cm} \cancel{V_{cm}}^0$

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

↳ in unblanced

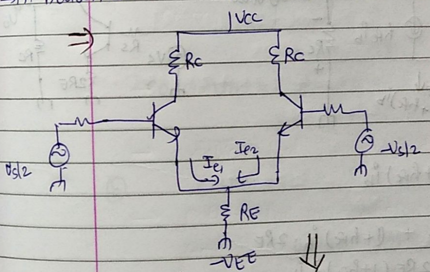
$V_{id} = \frac{V_s}{2} + \frac{V_s}{2} = V_s$

$V_{cm} = 0$

So then $A_d = \frac{V_0}{V_{id}} = \frac{V_0}{V_s}$

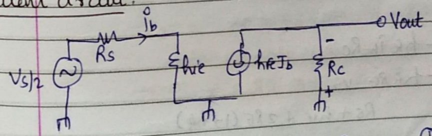
↳ in balanced

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



$I_{E1} \downarrow$, $I_{E2} \uparrow$
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; $V_{out} = \frac{- h_{fe} R_c V_s}{2 (R_s + h_{ie})}$

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

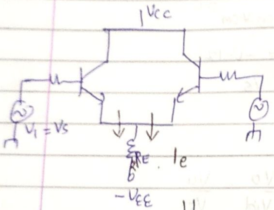
Ⓑ <u>for calculating A_{cm};</u>

$V_{id} = 0$

$V_1 = V_s \; ; \; V_2 = V_s$ $\qquad V_{CM} = V_s$

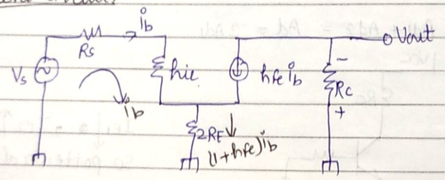
$V_{out} = V_{cm} A_{CM}$

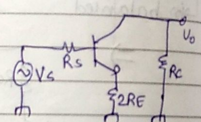
$V_{out} = V_s A_{cm}$



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

<u>Equivalent circuit:</u>





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

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

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

$$V_{out} = -h_{fe} i_b R_C$$

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

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

Ⓒ <u>O/P impedence:</u>

$$Z_{out} = R_C$$

Ⓓ <u>I/P impedence:</u>

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

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

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

<u>Example:</u> Determine diff^r amp^r O/P voltage when $V_1 = 300\,MV$
$V_2 = 240\,MV$; diff. gain $= 5000$; CMRR = ⓐ 100 ⓑ 10^5
Calculate O/P voltage.

<u>Sol:</u>

$V_{id} = V_1 - V_2 = 60\,MV$

$V_{cm} = \frac{V_1 + V_2}{2} = 270\,MV$

ⓐ

$CMRR = 100 = \frac{A_d}{A_{cm}}$

$\Rightarrow A_{cm} = 50$

So, $V_o = 60 \times 5000 + 270 \times 50$

$= \cancel{1.401\,mV}\ \cancel{1.95\,mV}\ \cancel{31.35\,m}V\ \ 0.313\,V$

ⓑ

$CMRR = 10^5 = \frac{A_D}{A_{cm}}$

$\Rightarrow A_{cm} = \frac{5000}{10^5} = \cancel{5 \times 10^{-3}}\ \ 5 \times 10^{-2}$

$V_o = 60 \times 5000 + 5 \times 10^{-2} \times 270$.

$= \cancel{0.0014 + 1.35 + 30,000}$

$= \cancel{30\,mV}\ \ 0.3\,V$

<u>Example:</u> dual I/P balanced O/P Diff. amp^r $h_{ie} = 2.8\,K\Omega$

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

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

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

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

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

Sol:

Operating Point $I_{EQ} = \dfrac{V_{EE} - V_{BE}}{(R_E + R_S/\beta)}$

$= \dfrac{-15 - 0.7}{(6.8K + 100/100)} = 2.30\ mA$

$I_C \cong I_E$

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

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

$= 4.89V$

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

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

$= -81.03$

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

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

$= -0.34$

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

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

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

$R_{out} = R_C = 4.7K$

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

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

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

$V_{out} = 2.4\ V$