* UNIT - II - *

* CHARACTERISTICS OF OP - AMP :- *

* Ideal OP - Amp characteristics.
* DC characteristics.
* AC characteristics.
* Offset voltage & current
* Voltage series f/b & shunt f/b amplifiers.
* Differential amplifier.
* Frequency - response of OP-Amp.
* Basic applications of OP-Amp — Summer, differentiator, integrator.

* Introduction :- *

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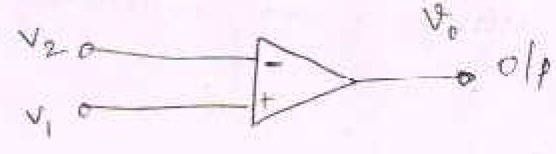
* OP - Amp is a operational amplifie
* It is one of the linear IC.
* It has 2 i/p terminals, and 1 o/p terminal.
* Symbol:-



v_1 → Non-inverting i/p terminal.

v_2 → inverting i/p terminal.

v_0 → o/p terminal.

* op-Amp performs various applications such as summer, differentiator, integrator, comparator, waveform generator.

* Ideal op-Amp characteristics :. *

→ open loop voltage gain, (A_{OL}) = infinity.

→ I/p impedance (Z_i) = infinity

→ o/p impedance (Z_o) = zero.

→ Bandwidth (BW) = infinity

→ zero offset (ie) $V_0 = 0$; when $V_1 = 0 = V_2$.

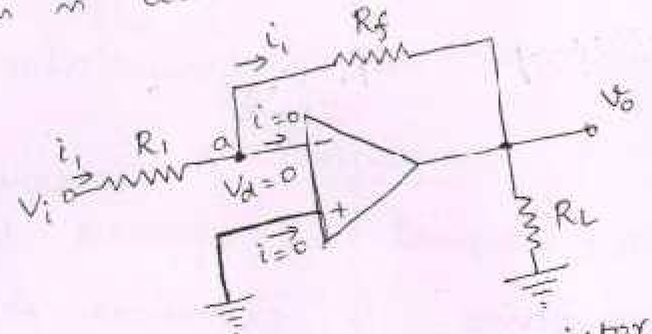
→ Slew rate = infinity

* Since i/p impedance is infinite, op-Amp draws no current from the source

* Since gain is infinite, so the voltage b/w inverting & Non-inverting i/p terminal is zero.

* Inverting Amplifier :- *

when the i/p is given to the inverting terminal of the op-amp, then the o/p is in 180° phase shift. This is called inverting amplifier.



$i_1 = \frac{V_i}{R_1}$

$v_o = -i_1 R_f$

$\frac{v_o}{V_i} = -\frac{R_f}{R_1}$

$R_f \rightarrow$ feed back Resistor.

$R_L \rightarrow$ Load Resistor.

* Important points for -ve f/b ckts :- *

→ The current drawn by either of the i/p terminal is negligible.

→ The differential voltage Vd b/w inverting & non-inverting i/p term must be zero.

For non-inverting i/p terminal, closed loop voltage gain will be

$$A_{cl} = \frac{V_o}{V_i} = -\frac{R_f}{R_1} \quad \rightarrow (1)$$

-ve Sign indicates the phase shift of 180 b/w V_i and V_o.

Eqn (1) is very much useful in application such as integrator & differentiator.

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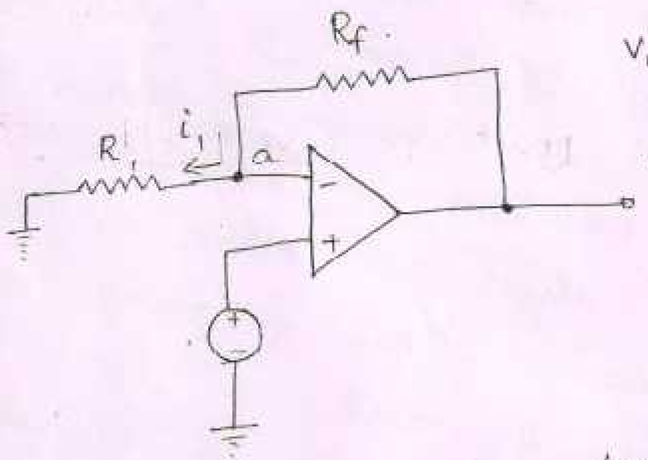
* Non-inverting amplifier:- *

If the signal is applied to the Non-inverting i/p terminal it is called Non-inverting amplifier.



$$V_i = V_o \cdot \frac{R_1}{R_1 + R_f}$$

$$\frac{V_o}{V_i} = \frac{R_1 + R_f}{R_1}$$

$$A_{cl} = 1 + \frac{R_f}{R_1}$$

Thus by simplifying the ckt, closed loop gain will be,

$$A_{cl} = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}$$

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* DC characteristics :- *

→ An ideal op-Amp draws no current from the source & its response is also independent of temperature.

→ But real op-Amp draws current.

→ Also 2 i/p's respond differently to current and voltage due to mismatch in transistors.

→ These non-ideal DC characteristics that add error to the DC o/p voltage are

* I/p bias current
* i/p offset current
* i/p offset voltage
* Thermal drift

① - I/p bias current :-

→ The op-Amp's i/p terminal is made up of BJT / FET.

→ We must give external bias current

to base region, in order to operate in Linear region.

→ But practically i/p terminals draw small value of DC current to bias the transistors.

→ The base current entering into the inverting & non-inverting i/p terminals are I_B^- & I_B^+ respectively.

→ I_B^+, I_B^- are not exactly equal, because of internal imbalances.

→ So average value $$I_B = \frac{I_B^+ + I_B^-}{2}$$

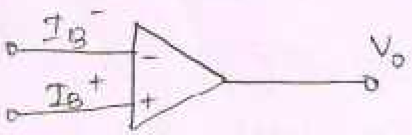


fig (a) i/p bias current.

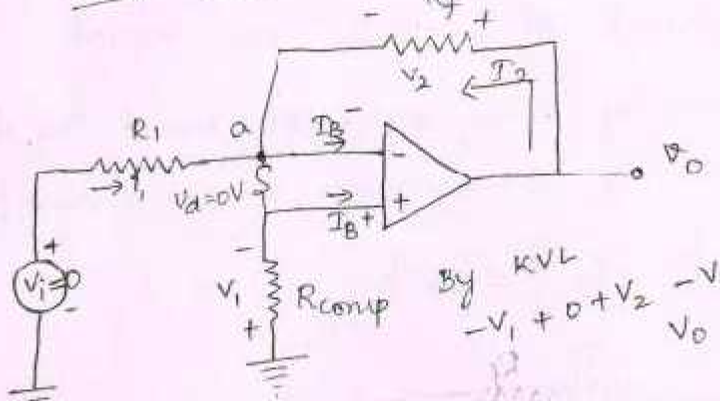
→ Due to bias current, when the i/p is zero, the o/p voltage will be some several millivolts.

→ This is unacceptable for some applications where signal levels are measured.

→ This is compensated by means of using

compensated resistor.

Bias current compensation:-



By KVL

$$-V_1 + 0 + V_2 - V_0 = 0$$

$$V_0 = V_2 - V_1 \rightarrow (1)$$

$$V_1 = I_B^+ R_{comp}$$

$$I_B^+ = \frac{V_1}{R_{comp}}$$

$V_0 = 0V$ for $V_i = 0$
From (1)

$$V_2 = V_1$$

$$I_1 = \frac{V_1}{R_1} \quad ; \quad I_2 = \frac{V_2}{R_f}$$

$$I_2 = \frac{V_1}{R_f}$$

$$I_B^- = I_2 + I_1 = \frac{V_1}{R_f} + \frac{V_1}{R_1} = V_1\left[\frac{R_1 + R_f}{R_f R_1}\right]$$

Assume $I_B^+ = I_B^-$

$$V_1\left[\frac{R_1 + R_f}{R_f R_1}\right] = \frac{V_1}{R_{comp}}$$

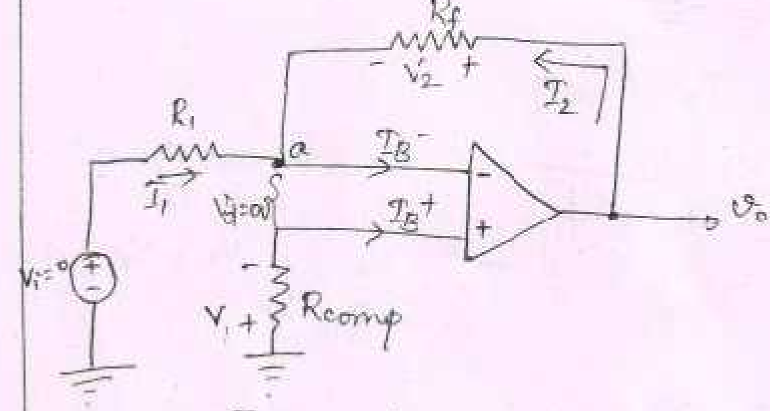
$$\boxed{R_{comp} = \frac{R_f \cdot R_1}{R_1 + R_f}}$$

* (II) Input offset current :- *

→ Bias current compensation will work, when both bias currents (ie) I_B^+ & I_B^- are equal.

→ But both of them are not equal. The diff. b/w both of them gives offset current (I_{os})

$$|I_{os}| = |I_B^+| - |I_B^-|$$



From above figure,

$$V_1 = I_B^+ \cdot R_{comp}.$$

$$I_1 = \frac{V_1}{R_1}$$

KCl at node 'a'

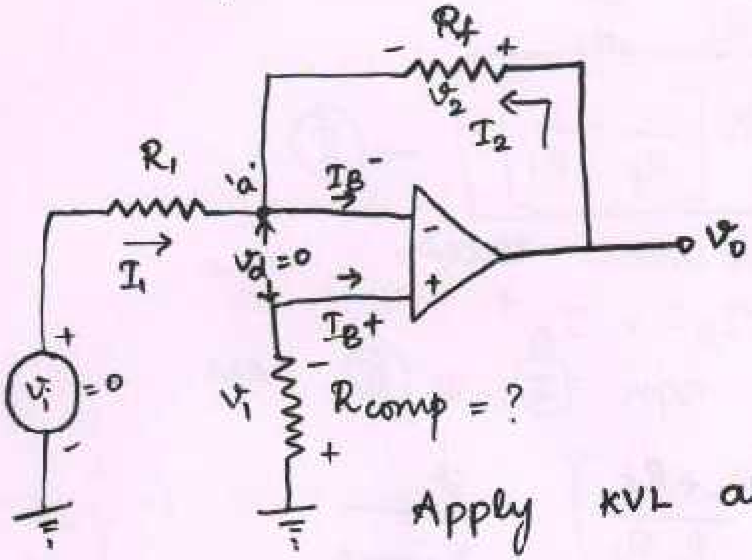
[note: $I_2 + I_1 = I_B^-$]

$$I_2 = I_B^- - I_1 = I_B^- - \left[I_B^+ \left(\frac{R_{comp}}{R_1} \right) \right] \rightarrow (A)$$

$$V_o = I_2 R_f - V_1$$

$$= I_2 R_f - I_B^+ R_{comp} \rightarrow (B)$$

Compensating N/w :- *



Apply KVL at i/p ckt,

$$-v_1 + 0 + v_2 - v_0 = 0$$

$$\boxed{v_0 = v_2 - v_1} \rightarrow (1)$$

* To find Rcomp :- *

$$v_1 = I_B^+ \cdot R_{comp} \Rightarrow \boxed{I_B^+ = \frac{v_1}{R_{comp}}} \rightarrow (I)$$

$$(4) \leftarrow \boxed{I_1 = \frac{v_1}{R_1}} \; ; \; I_2 = v_2 / R_f \rightarrow (2)$$

W.K.T, $\boxed{v_0 = 0}$ for $v_i = 0$

sub this in eqn (1) $\boxed{v_2 = v_1} \rightarrow (3)$

sub eqn (3) in eqn (2).

$$\boxed{I_2 = v_1 / R_f} \rightarrow (5)$$

$I_B^- = I_2 + I_1$ sub eqn (4) & (5) here

$$= \frac{v_1}{R_f} + \frac{v_1}{R_1}$$

$$\boxed{I_B^- = v_1\left[\frac{1}{R_f} + \frac{1}{R_1}\right]} \rightarrow \text{(II)}$$

Let us assume that,

$$I_B^- = I_B^+$$

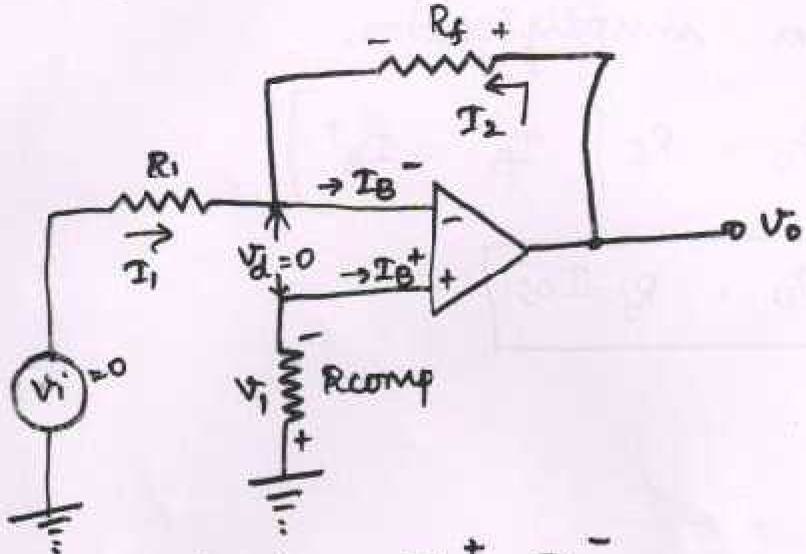
sub eqn (I) & (II), here,

$$\cancel{v_1}\left[\frac{R_1 + R_f}{R_1 R_f}\right] = \frac{\cancel{v_1}}{R_{comp}}$$

From this,

$$R_{comp} = \frac{R_1 R_f}{R_1 + R_f}$$

* I/P offset current :- *



$$|I_{os}| = I_B^+ - I_B^-$$

$$\boxed{V_1 = I_B^+ \cdot R_{comp}} \rightarrow (1)$$

$$\boxed{I_1 = V_1 / R_1} \rightarrow (2)$$

KCL at node 'a' gives,

$$I_1 + I_2 = I_B^-$$

$$I_2 = I_B^- - I_1 \quad \Rightarrow \text{sub eqn (2) here.}$$

$$= I_B^- - \frac{V_1}{R_1} \Rightarrow \text{sub eqn (1) here.}$$

$$\boxed{I_2 = I_B^- - I_B^+ \cdot \frac{R_{comp}}{R_1}} \rightarrow (3)$$

W.K.T,

$$V_0 = V_2 - V_1$$

$$= I_2 \cdot R_f - V_1$$

(2) or (1) respectively

$$v_0 = \left[I_B^- - I_B^+ \cdot \frac{R_{comp}}{R_1} \right] R_f - I_B^+ \cdot R_{comp}$$

After simplification,

$$v_0 = R_f \left[I_B^- - I_B^+ \right]$$

$$\boxed{v_0 = R_f \cdot I_{OS}}$$

Sub eqn (A) in eqn (B)

$$V_o = \left[I_B^- - I_B^+ \cdot \frac{R_{comp}}{R_1} \right] R_f - I_B^+ R_{comp}$$

$$= I_B^- R_f - I_B^+ \cdot R_{comp} \frac{R_f}{R_1} - I_B^+ R_{comp}$$

Sub $R_{comp} = \frac{R_1 R_f}{R_1 + R_f}$ & simplify.

$$V_o = R_f \left(I_B^- - I_B^+ \right)$$

$$\boxed{V_o = R_f \cdot I_{os}}$$

The effect of offset current can be minimized by keeping f/b resistances small.

III Input offset Voltage:- *

→ Though we provide many compensation technique, the o/p voltage will not be zero, when the i/p is zero.

→ This can be made zero, by applying small voltages at the i/p terminal, so that the o/p voltage is zero.

→ This voltage is called I/p offset Voltage (V_{os})

IV Thermal Drift:- *

Bias current, offset current, offset voltage change with temperature

* A ckt nulled at 25°c, but may not be so when the temperature is 35°C. This is called drift.
* offset current drift is expressed in nA/°c & offset voltage drift in mV/°c.

Minimization method:-

→ careful printed circuit board
→ Forced air cooling.

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* Ac characteristics :- * | SESSION - 14 & 15 |

* In Dc characteristics we find I/p bias current, I/p offset current, I/p offset Voltage, Thermal Drift.

* If we want to find the response of o/p in the form of small s/l (or) high freq. Signal, Ac characteristics of op-Amp must be Known.

* Main Ac characteristics are

→ Frequency Response
→ ~~Bandwidth~~ Slew Rate.

* Frequency response : *

→ Ideal op-Amp has Infinite bandwidth.
(i.e) If open loop gain is 90dB for Dc s/l

then the same 90dB gain is maintained for AC o/p of op-Amp which is small (or) high frequency signal.

* But practical op-Amp has a gain $\downarrow$ses and it may be roll-off at high frequency.

* Roll-off occurs mainly due to the capacitive component in the circuit.

* This capacitive component is due to the physical characteristics of semi-conductor device and due to internal construction of op-Amp.

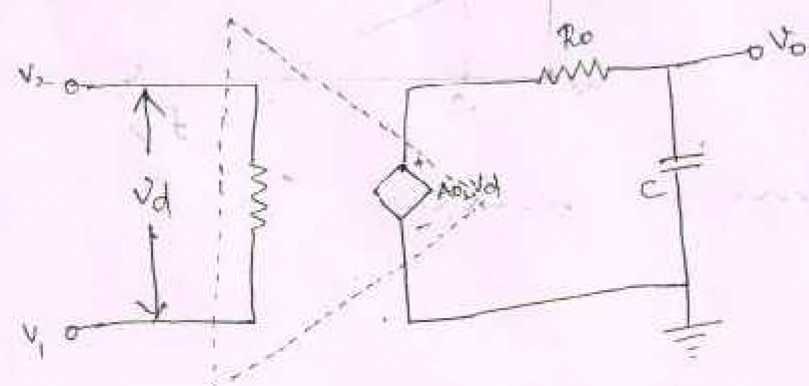
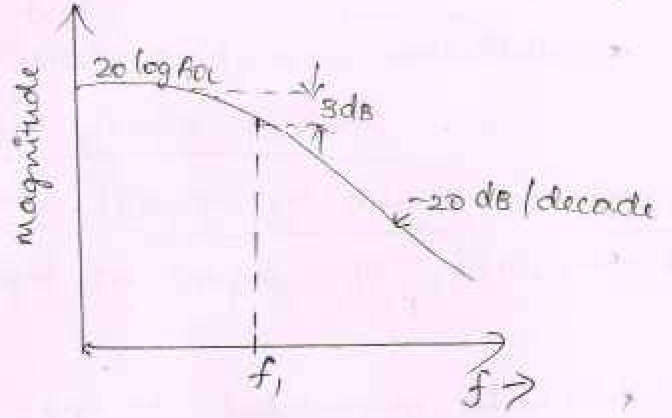
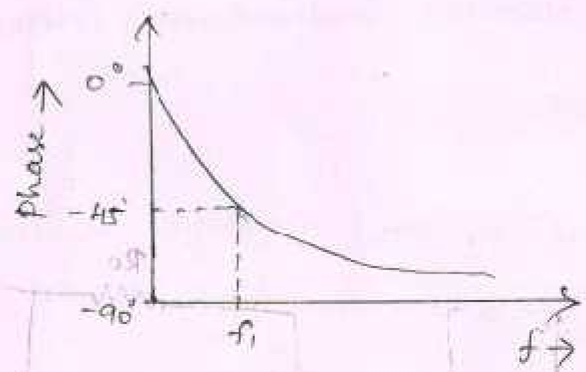


fig High frequency model of an op-Amp with single corner frequency.

The open loop voltage gain of an op-Amp with single corner frequency is,

$$A = \frac{A_{OL}}{1 + j(f/f_1)}$$ where $$f_1 = \frac{1}{2\pi R_o C}$$





* Frequency compensation :- *

In order to obtain large bandwidth and low voltage gain, compensation is required. There are mainly 2 types of compensation involved. They are

→ External frequency compensation.

→ Internal frequency compensation.

Internal compensation:-

→ In some applications, we require broad bandwidth, and to amplify slow changing signals.

→ For these applications, internal compensated op-Amps are used. These have internal shunt capacitance.

→ The capacitance shunts off signal current and thus reduces available o/p signal at higher frequencies.

Some internally compensated op-Amp's are Fairchild's μA 741, National Semiconductor's LM741, & Motorola's MC1558.

Slew Rate:-

→ The rise time of an amplifier is the time, the o/p changes from 10 to 90% of the o/p for a step i/p.

→ Slew Rate is defined as the max rate of change of o/p voltage for a step i/p voltage. It's unit is V/μs.

→ Slew Rate mainly caused due to capacitor within or outside the op-Amp. This prevents the o/p voltage from responding immediately to a fast changing i/p.

Slew Rate = $2\pi f V_p$ V/s

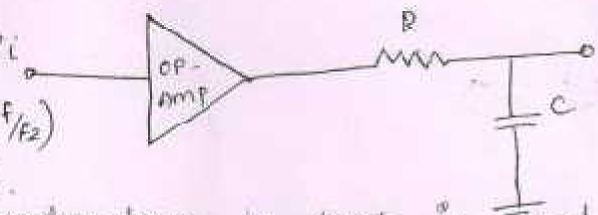
External frequency compensation is of 2 types. They are

* Dominant - pole compensation.
* pole - zero compensation.

* Dominant - pole external compensation :- *

In External compensation method, compensating network is present externally to the circuit. In dominant pole method, RC n/w may be added externally (or) suitable capacitor 'C' must be connected from a high resistance point to ground.

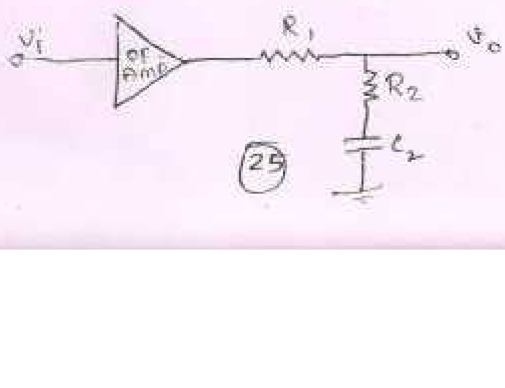
$$\frac{A_{OL}}{\left(1+j\frac{f}{f_d}\right)\left(1+j\frac{f}{f_1}\right)\left(1+j\frac{f}{f_2}\right)\left(1+j\frac{f}{f_3}\right)}$$

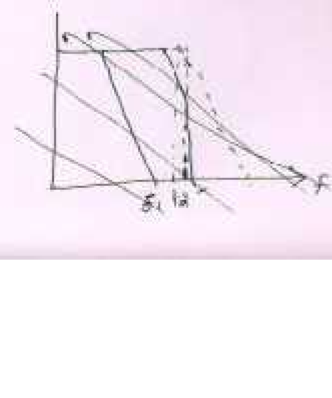


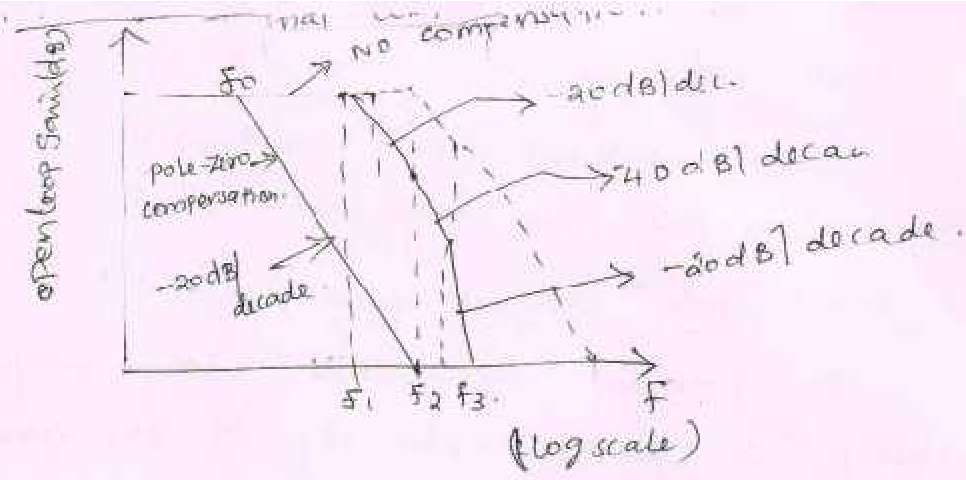
$f_1 < f_2 < f_3$. One disadvantage is that, it reduces open-loop bandwidth. But the noise immunity is improved.

* Pole-zero external compensation :- *

Here the uncompensated transfer function is altered by adding both pole and zero. The zero should be at a higher frequency than pole.







$$A' = \frac{A_{OL}}{\left(1+j\,f/f_0\right)\left(1+j\,f/f_2\right)\left(1+j\,f/f_3\right)}$$

* Differential Amplifier :- *

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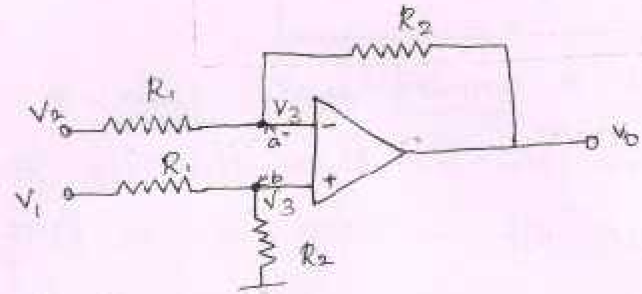
A ckt that amplifies the difference b/w 2 signals is called is called differential amplifier. This type is very much useful in instrumentation amplifier.



Since differential voltage at the i/p terminal is zero, nodes 'a' and 'b' are at the same Potential. The nodal eqn at 'a' is,

$$\frac{V_3 - V_2}{R_1} + \frac{V_3 - V_o}{R_2} = 0 \rightarrow ①$$

and at 'b' is,

$$\frac{V_3 - V_1}{R_1} + \frac{V_3}{R_2} = 0 \rightarrow ②$$

From eqn ①,

$$V_3 \left[\frac{1}{R_1} + \frac{1}{R_2} \right] - \frac{V_2}{R_1} = \frac{V_o}{R_2} \rightarrow ③$$

From eqn ②,

$$V_3\left[\frac{1}{R_1}+\frac{1}{R_2}\right]-\frac{V_1}{R_1}=0 \rightarrow (4)$$

subtracting (4) from (3),

$$\frac{1}{R_1}\left[V_1-V_2\right]=\frac{V_o}{R_2}$$

$$\boxed{V_o=\frac{R_2}{R_1}\left[V_1-V_2\right]}$$

* Difference mode & common-mode gain:- *

* If $V_1 = V_2$; then $V_o = 0$, then the i/p gets cancelled and o/p is zero. This is true for ideal op-Amp.

→ But for practical op-Amp, exhibits some small response due to common mode component of i/p voltage.

→ The o/p voltage not only depends on the difference s/l, but also affected by average value of i/p s/l, called common-mode s/l (V_{cm})

$$\boxed{V_{cm}=\frac{V_1+V_2}{2}}$$

In frequency domain, the eqn becomes,

$$V_o(s) = -\frac{1}{sR_1C_f} V_i(s)$$

Put $s = j\omega$

$$V_o(j\omega) = -\frac{1}{j\omega R_1 C_f} V_i(j\omega)$$

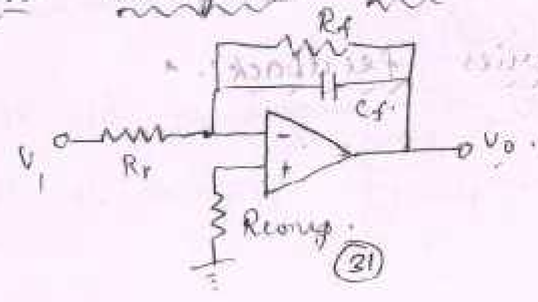
$$|A| = \left|\frac{V_o(j\omega)}{V_i(j\omega)}\right| = \frac{1}{\omega R_1 C_f}$$

* Limitations:- *

→ True integration is not possible, because of the presence of offset voltage and bias current in the absence of i/p signal.

→ Small DC offset at the i/p, can force the o/p into saturation. To avoid this, Resistor is placed in ||el with the capacitor.

* Practical integrator ckt :- *



* For good differentiator, Time period 'T' must be greater than or equal to R_f

$$T \geq R_f C_1$$

And it must follow the following Ste

→ choose 'f_a' equal to the highest frequency of the i/p signal. Assum practical value of $C_1 < 1\mu F$ & cal R_f

→ choose $f_b = 10 f_a$. calculate the Valu of R_1 & C_f, so that $R_1 C_1 = R_f C_f$.

* Applications :- *

→ The differentiators are used in waveshaping circuits.

→ They are used as Edge detectors in FM demodulators.

→ They are used in combination with adders and amplifiers to f analog computers.

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* Integrators :- *

→ Integrator ckt is a ckt, in which

* Applications :- *

→ They are used in combination with adders and amplifiers to form analog computers.

→ They are used in waveshaping ckts.

→ They are used for solving differential equations in a A/D converters & ramp generators.

Voltage Series feedback amplifier :- * SESSION-13

Depending upon whether voltage / current is fed back either in series or in llel, there are 4 types of f/b connections. They are

→ Voltage Series feedback.
→ Voltage shunt f/b
→ current Series f/b
→ current Shunt f/b

*Voltage Series Feedback :- *

In this ckt, a sample of o/p voltage connected in series in opposition to the i/p s/l.