Operational Amplifiers :-

Input and output

Parameters of op-Amp

* Differential gain (Ad) :- it is gain with which differential Amplifier Amplifies the difference between two input signal so it is called Differential gain

$$\boxed{V_0 = A_d(V_1 - V_2)}$$

* Common mode Gain (A_c) :- The two input voltages which are equal in all aspect to the differential Amplifier ($V_1 = V_2$) for ideal case the o/p voltage

$$\boxed{V_0 = (V_1 - V_2) \cdot A_d = 0}$$

so

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

for practical differential Amplifier depends on Average common level of two inputs and such two input signals is called common mode signal denoted as V_c.

*Common mode Rejection Ratio (CMRR) :-

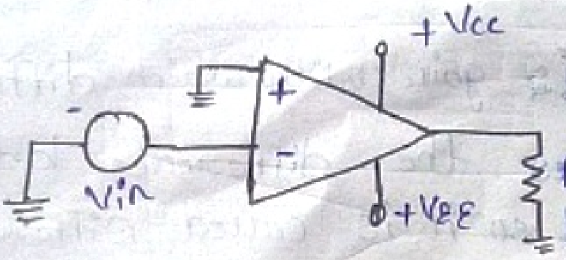
The ability of a differential Amplifier to Reject a common mode signal is expressed by a ratio called CMRR.

* it is defined as the ratio of differential voltage gain (A_d) to common mode Gain A_c.

$$\boxed{CMRR = \rho = \left|\frac{A_d}{A_c}\right|}$$

* Input offset Voltage :- it is the differential input voltage that adjust b/w two input terminals of an op-amp without any external supply

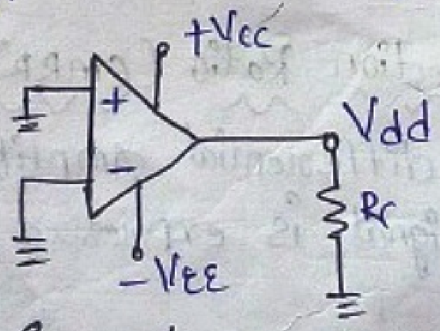
applied to made the output zero and denoted as (VIO)



output off set voltage :-

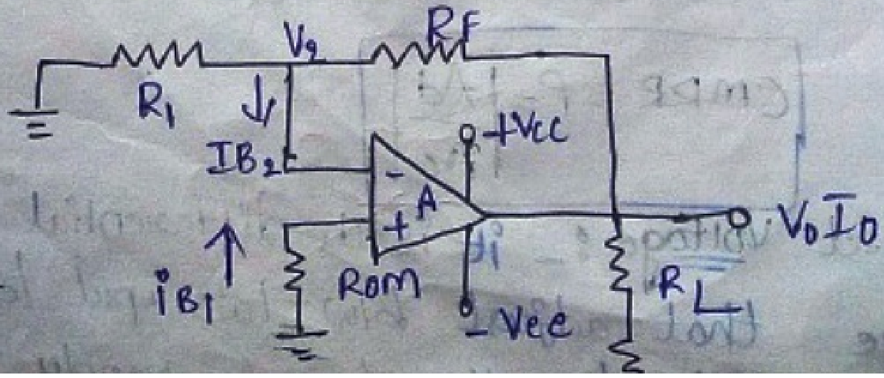
it is caused due to mix mapping b/w two input terminals because of collector current into two transistors or not Equal and causes differential output voltage from the 1st stage and it will be further Amplifier in next stage.

it is dc voltage either +Ve or -Ve, due to potential difference b/w two input terminals to reduce V_{00} to 0 make (VIO) of proper Amplification and polarity such circuit is called i/p off set voltage compensating Network.



Input Off set Current :-

The input bias current are not equal and I_{10} is



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called i/p

d I_{i0} is

input off set Current is used as indicator for mismatching b/w these two currents it is given by I_{i0} is modules.

$$\boxed{I_{i0} = |I_{B1} - I_{B2}|}$$

V_1 and V_2 can be expressed as.

$$\boxed{\begin{aligned} V_1 &= R_{om} I_{B1} \\ V_2 &= R_f I_{B2} \end{aligned}}$$

$$\boxed{R_{om} = R_f = \frac{R_1 R_f}{R_1 + R_f}} \quad \text{—(1)}$$

By applying Superposition theorem, o/p off set voltage due to V_1 & V_2 in terms of I_{B1} and I_{B2}

$$V_1 = R_{om} I_{B1}$$

$$V_o I_{B2} = -R_f I_{B2}$$

The o/p off set Voltage in terms of I_{B1} & R_f,

$$\boxed{V_o I_{B2} = V_1 \left[1 + \frac{R_f}{R_1}\right]} \quad \text{—(2)}$$

where V_1 at non-inverting terminal voltage:

$\left[1 + \frac{R_f}{R_1}\right]$ = Gain of non-inverting Amplifier

Sub eq (1) in eq (2) for the value of

$$V_o I_o = R_{om} I_{B1} \left[1 + \frac{R_f}{R_1}\right] = \frac{R_1 \times R_f}{R_1 + R_f} (I_{B1}) \frac{R_1 + R_f}{R_1}$$

$$V_o I_o + V_o I_{B2} = R_f I_{B1} - R_f I_{B2}$$

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

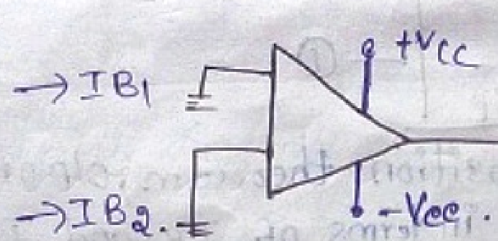
$$\boxed{\therefore V_o I_o = R_f I_B}$$

Input bias Current :- It is defined as Average of two input bias current ib_1 and IB_2

$$\boxed{IB = \frac{IB_1 + IB_2}{2}}$$

where IB_1 = i/p bias current flowing into non-inverting terminal.

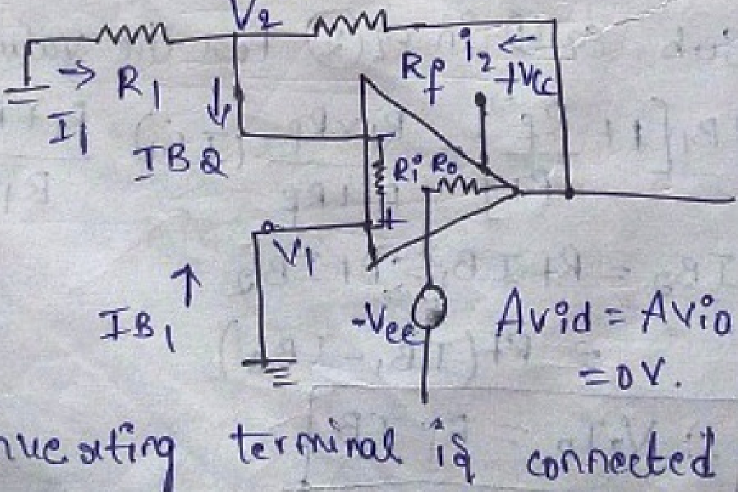
where IB_2 = " " " " " inverting terminal.



for the differential Ampr the bias current is not same so, it is equal to one of the bias current.

$$\boxed{IB = IB_1 = IB_2}$$

for getting the o/p off set voltage caused by the i/p bias current, IB in the inverting and non inverting Amplifier and the device is it to eleminate or minimize it.



$A_{vid} = A_{vio}$
$= 0V.$

Non inverting terminal is connected to ground so, $V_1 = 0V$

. $A_{vio} = 0V$, $V_{io} = 0V$ the voltages at V_2

Average of

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inverting terminal.

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V_2.

$$V_2 = (R_1 \| R_f)\, I_{B_2}$$

$$\boxed{V_2 = \frac{R_1 R_f}{R_1 + R_f} \cdot I_{B_2}} \quad —① $$

Nodel Equation at V_2

$$\boxed{I_1 + I_2 = I_{B_2}} \quad —②$$

$$\frac{0 - V_2}{R_1} + \frac{V_{oI_o} - V_2}{R_f} = \frac{V_2}{R_i} \quad —③$$

V_{oI_o} = o/p offset Voltage due to i/p bias Current

R_i = i/p Resistance

$$\frac{V_{oI_o}}{R_f} = V_2\left[\frac{1}{R_1} + \frac{1}{R_f} + \frac{1}{R_i}\right] \quad —④$$

[Rearrangment of above Eq]

$$\frac{V_{oI_o}}{R_f} = V_2 \, \frac{R_1 + R_f}{R_1 R_f} \quad —⑤$$

Sub in Eq ⑤ the Value of V_2 from Eq ④

$$V_{oI_o} = \frac{R_1 R_f I_{B_2}}{R_1 + R_f}\left[\frac{R_1 + R_f}{R_1}\right]$$

$$V_{oI_o} = R_f I_{B_2}$$

$$\boxed{V_{oI_o} = R_f I_B.} \quad \text{from Eq ②}$$

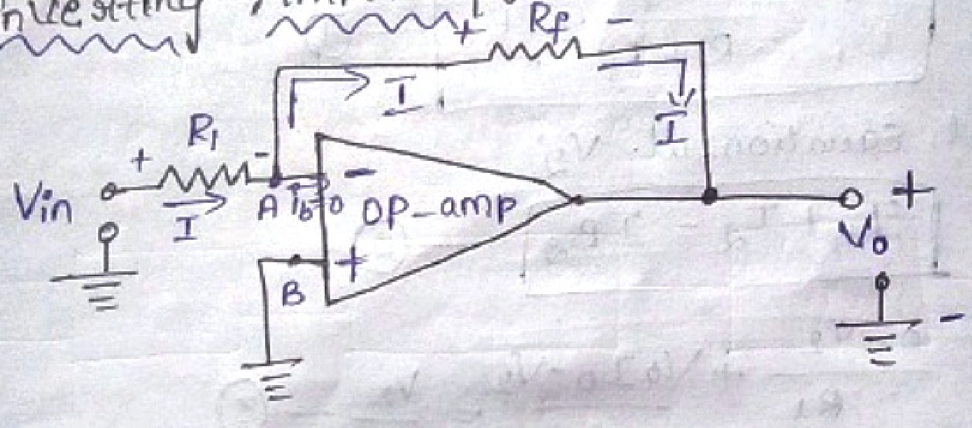
To reduce o/p offset voltage due to input bias Current I_B.

$$\boxed{V_2 = R_f \, I_{B_2}}$$

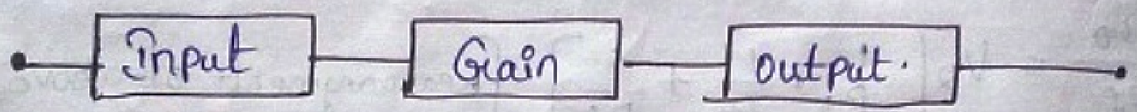
$$\boxed{R_f = \frac{R_1 R_f}{R_1 + R_f}}$$

Inverting Ampr and Non-inverting Ampr ideal

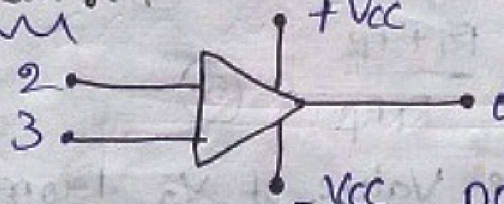
Inverting Amplifier :-



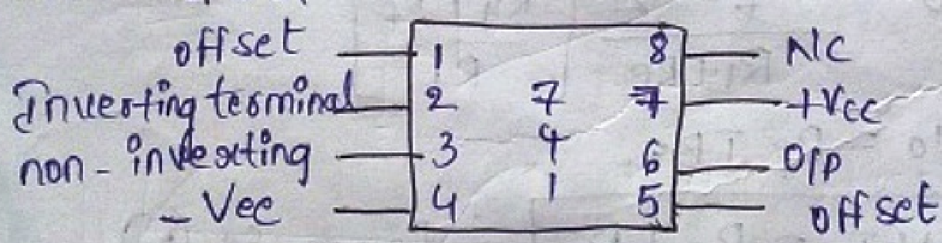
Operational Amplifier :-



circuit diagram :-



Pin diagram :-



[Ideal op-Amplifier]

Ideal-operation-Amplifier :- The ideal operation Amplifier identifies the differential b/w the t ilp signals appiled at the inverting and non-inver ilp terminals and amplifies the different and Produce an output Signals.

rting Ampr

g o/p

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b/w the two
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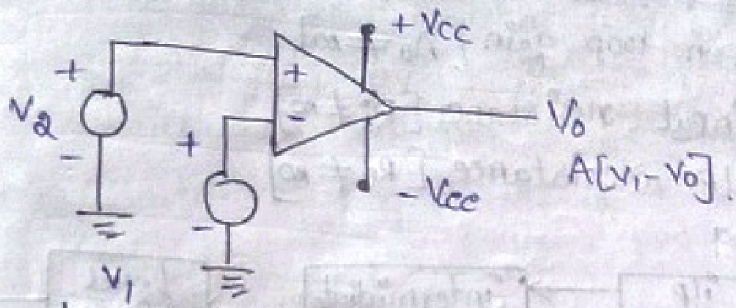
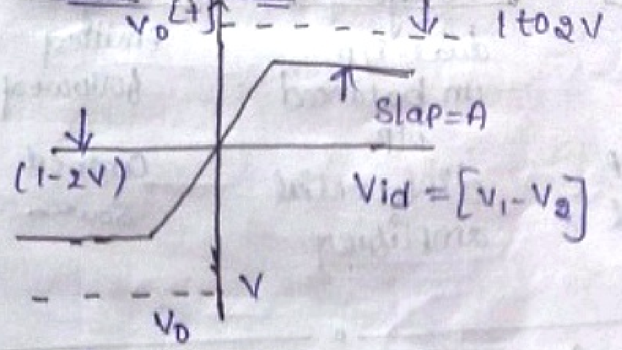
Equivalent Circuit of op-Amp :-

Symbol: -



Transfer characteristics :-

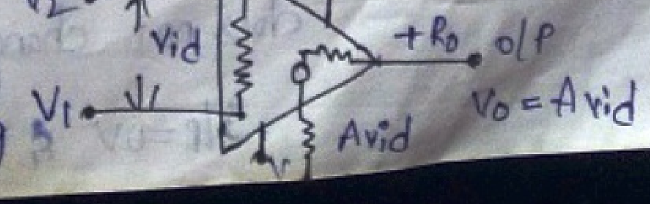


Differential o/p.

Ideal op-Amp characteristics :-

Infinite Input Resistance [$R_i = \infty$]
Zero output resistance [$R_0 = 0$]
Infinite voltage gain [$A_v = \infty$]
Infinite Band width [$BW = \infty$]
∞ common mode Rejection ratio [$CMRR = \infty$]
∞ slew rate = ∞
Zero offset ; when [$V_1 = V_2$] [$V_0 = 0$]
Characteristics do not shift with temperature.

Pratical op-amp :-

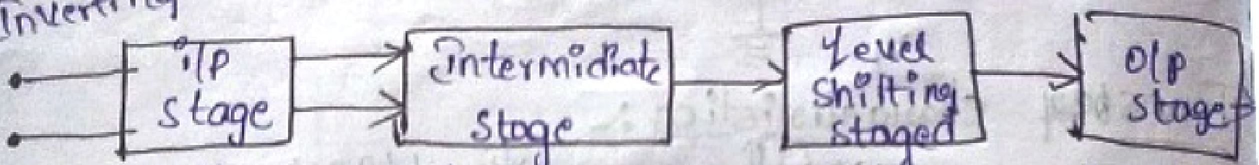


Characteristics of Practical op-Amp :-

open loop gain $[A_0 \neq \infty]$

input resistance $[R_i \neq \infty]$

O/P resistance $[R_0 \neq \infty]$



Non-inverting

Dual i/P Balance of O/P differential amplifiers

dual i/P un balanced O/P differential amplifier

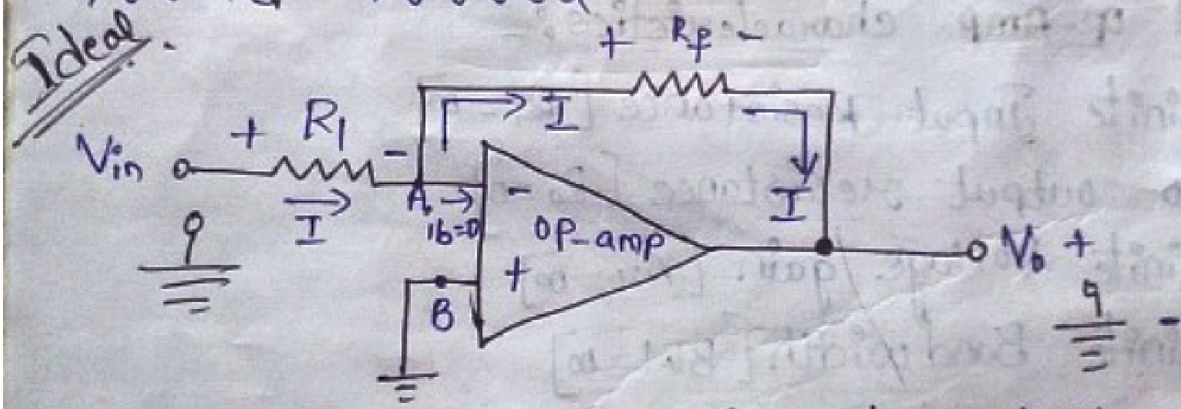
emitter follower

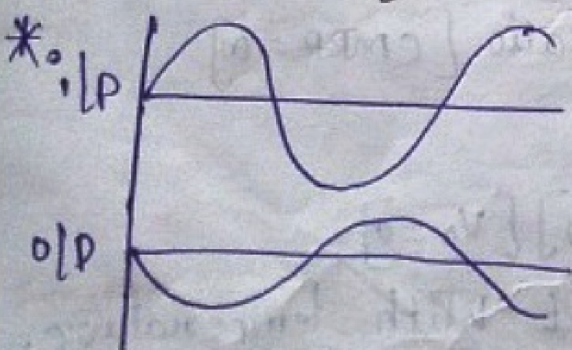
Current Source

complementary System Push-Pull Amplifier

Inverting Amplifier :- (ideal inverting Amplifier).

Ideal.





* The phase shift of the inverting Amplifier is 180°.

* The phase shift of the non-inverting Amplifier does not change

i/P = 0V & O/P = 0V

O/P stage

complementary System Push-Pull Amplifier

...ting Amplifier).

shift of the Amplifier is

shift of the ...g Amplifier ...ange

O/P = 0V

* An Amplifier is inverted as compare to the i/p signal, the inverted o/p signal means having a phase shift of 180° compare to the i/p signal.

* The phase shift b/w i/p & o/p is 180°, such an Amplifier is called inverting Amplifier.

Closed loop voltage gain :-

→ At node B is grounded, node A is also at the ground potential of virtual ground.

$$\boxed{V_A = 0}$$

* The Current

$$\boxed{I = \frac{V_{in} - V_A}{R_1}}$$

$$I = \frac{V_{in}}{R_1} \quad \boxed{V_A = 0}$$

i/p side.

o/p side :-

$$I = \frac{V_A + V_0}{R_f}$$

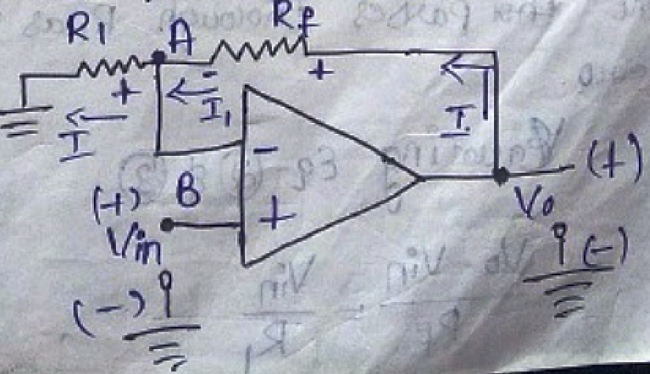
$$\because V_A = 0$$

$$\boxed{I = -\frac{V_0}{R_f}}$$

Gain formula of inverting Amplifier

$$\boxed{A_{vf} = \frac{V_0}{V_{in}} = \frac{-R_f}{R_1}}$$

Non-inverting Amplifier :- (ideal).



* The Amplifier which Amplifies without producing any phase shift b/w input and output is called non-inverting Amplifier
* So the i/p is applied to non-inverting terminal of op-amp.

closed loop Gain :-

* The node 'B' at potential Vin, the potential of point A, Same as 'B' which is Vin from the concept of virtual ground.

*

input side :- $V_A = V_B = V_{in}$ —— ①

output Side :- $I = \frac{V_0 - V_A}{R_f}$

$$\boxed{I = \frac{V_0 - V_{in}}{R_f}} \quad —— ②$$

At the inverting terminal I,

$$I = \frac{V_A - 0}{R_1}$$

$$I = \frac{V_A}{R_1} = \frac{V_{in}}{R_1}$$

$$\boxed{I = \frac{V_{in}}{R_1}} \quad —— ③$$

enter ~~Entire~~ Current ~~the~~ passes through R_1 as i/p current is zero.

Equating Eq ② & ③

$$\frac{V_0 - V_{in}}{R_f} = \frac{V_{in}}{R_1}$$

without
t and output
erting terminal
potential of
from the
as i/p curr

$$\frac{V_0}{R_f} = \frac{V_{in}}{R_f} + \frac{V_{in}}{R_1}$$

$$\frac{V_0}{R_f} = V_{in}\left[\frac{R_1 + R_f}{R_1 R_f}\right]$$

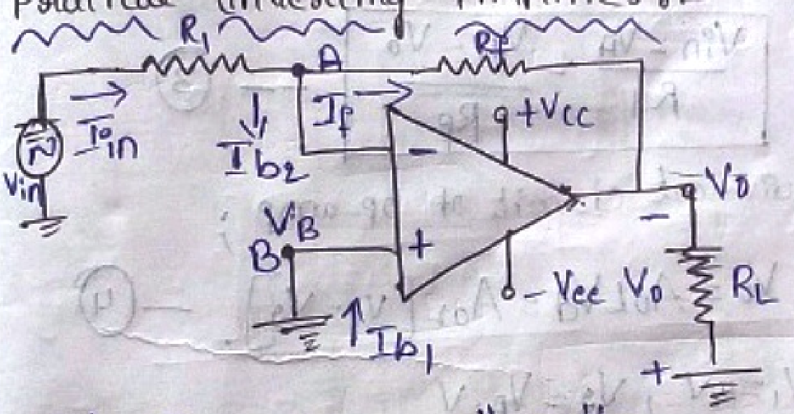
$$\frac{V_0}{V_{in}} = \frac{R_1 + R_f}{R_1 R_f} \times R_f$$

$$\boxed{\frac{V_0}{V_{in}} = \frac{R_1 + R_f}{R_1}}$$ Gain of the non-inverting terminal.

$$\boxed{A_{vf} = \frac{V_0}{V_{in}} = 1 + \frac{R_f}{R_1}}$$

Practical :-

Practical Inverting Amplifier :-



* its i/p resistance "R_{in}" is less than (∞), so op-amp i/p current is (∞).
* open loop voltage Gain (A_{OL}) less than (∞).
* its o/p resistance is "R_0" is not zero.
* System "R_f" forms feedback circuit, The Amplified inverted o/p voltage appiled to inverting terminal through feed back resistance "R_f". The o/p voltage which is fed back opposite to the polarity of i/p

voltage.

* So the feedback said to be Negative.

Closed loop voltage Gain :-

* The closed loop voltage Gain (A_{CL}) ratio of o/p voltage to i/p voltage with feedback.
* Applying KCL at node "A"

$$I_{in} = I_{b2} + I_f \quad — ①$$

$$I_{in} \cong I_f \quad (R_{in} \neq \infty)$$

I_{b2} is neglected

$$I_{in} \cong I_f \quad — ②$$

$$\boxed{\frac{V_{in} - V_A}{R_1} = \frac{V_A - V_0}{R_f}} \quad — ③$$

* from the equivalent circuit of op-amp ;

$$V_0 = A_{OL} V_d = A_{OL}[V_1 - V_2] \quad — ④$$

$$V_1 = 0V, \quad V_2 = V_A \, V$$

$$\boxed{V_0 = -A_{OL} V_A} \quad — ⑤$$

Sub Eq ⑤ in Eq ③.

$$\frac{V_{in} + \frac{V_0}{A_{OL}}}{R_1} = \frac{\frac{-V_0}{A_{OL}} - V_0}{R_f}$$

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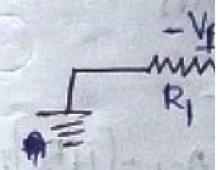
$= \frac{-A_{OL}V_A}{\dots}$

Practical



* The inpu
op-amp, so
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input.
Closed lo

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$$V_{in}R_f + \frac{V_0}{A_{OL}} = \frac{-R_1}{A_{OL}} V_0 - R_1 V_0 .$$

$$V_{in}R_f = -V_0 \frac{R_1}{A_{OL}} + R_1 + \frac{R_f}{A_{OL}}$$

$$A_{CL} = \frac{V_0}{V_{in}}$$

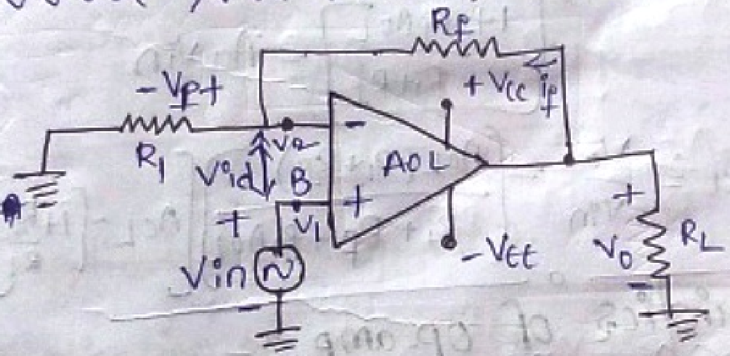
$$\boxed{A_{CL} = \frac{A_{OL}R_f}{R_1 + R_f + R_1 A_{OL}}}.$$

$$= \frac{-A_{OL}V_A}{-V_0\left[\frac{R_1}{A_{OL}} + \frac{R_f + R_f}{A_{OL}}\right]}.$$

$$V_{in}R_f = -V_0\left[\frac{R_1 + R_1 A_{OL} + R_f}{A_{OL}}\right]$$

$$\boxed{V_{in} = -V_0\left[\frac{R_1 + R_1 A_{OL} + R_f}{A_{OL} \cdot R_f}\right]}$$

Practical Non-inverting Amplifier :-



* The input is given at the non-inverting input of the op-amp, so op-amp always amplifies the difference input voltage V_d. The difference b/w the voltages V_{in} & V_f where V_f is feedback voltage opposes the input voltage, that is 180° out of phase with respect to the input.

Closed loop voltage gain :-

$$A_{CL} = \frac{V_0}{V_{in}} \quad \text{--- (1)}$$

$$V_0 = A_{OL} V_d \quad -(1)$$

$$V_0 = A_{OL}(V_1 - V_2) \quad -(2)$$

$V_1 = V_{in}$ as i/p applied

$V_2 = V_f$ voltage across R_1

using voltage divider rule

$$\boxed{V_f = \frac{V_0}{(R_1+R_f)} R_1 \text{ as } R_{in} \to R_1}$$

Substituting in Eq (2)

$$V_0 = A_{OL}\left[V_{in} - \frac{R_1 V_0}{R_1+R_f}\right]$$

$$V_0 = A_{OL} V_{in} - \frac{R_1 A_{OL} V_0}{R_1+R_f}$$

$$V_0\left[1 + \frac{R_1 A_{OL}}{R_1+R_f}\right] = A_{OL} V_{in}$$

$$A_{CL} = \frac{V_0}{V_{in}} = \left(\frac{A_{OL}(R_1+R_f)}{R_1+R_f+R_1 A_{OL}}\right) \left[A_{CL} = \left[1+\frac{R_f}{R_1}\right] \text{id}\right.$$

DC characteristics of op-amp :-

1) input bias current
2) input offset current
3) input offset voltage
4) Thermal drift.

Thermal drift :-

The op-amp parameters i/p offset voltage (V_{ios}) input bias current (I_b) and i/p offset current (I_{ios}) are not constant, varying with the facto one) temperature 2) two Supply voltage change 3) time.

Ac characteristic of op-amp :-

1) slew rate
2) frequency Response.

Power Supply Rejection Ratio :- (PSRR)

* it is defined as ratio of change in i/p offset voltage due to change in Supply voltage producing it keeping other power Supply voltage constant it is also called power Supply Sensitivity.

$$PSRR = \frac{\Delta V_{ios}}{\Delta V_{EE}}\Big|_{V_{CC} = \text{constant}}$$

Unit - II

~~Application of op-amp.~~

Application of op-amp :-

1) Summer (or) Adder Circuit :-

Inverting Summer :-