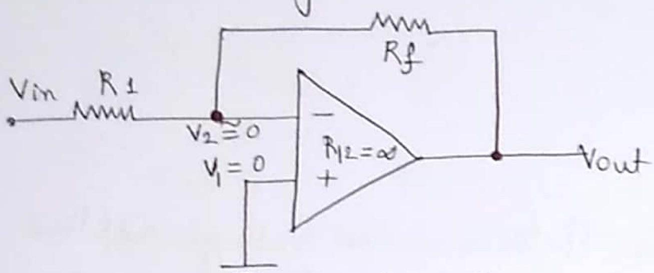
Virtual ground

VG means that the voltage at that particular node is almost equal to ground voltage (0V). It is not physically connected to ground.



For ideal op-amp voltage gain = ∞.
For real also voltage gain is high.

$$\therefore \text{Gain} = \frac{V_o}{V_{in}}$$

$$\text{Gain} = \infty, \quad V_{in} = 0.$$

$$V_{in} = V_2 - V_1$$

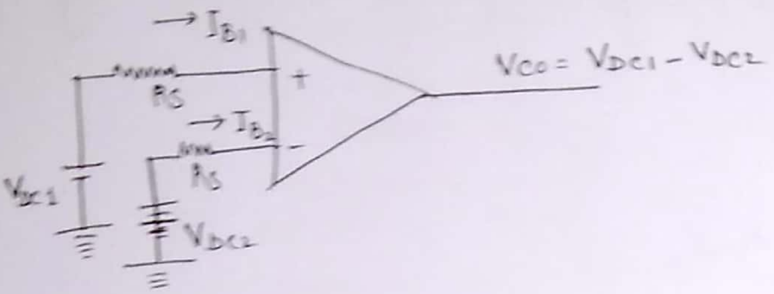
Here, V_1 = is connected to ground, so V_2 also will be at ground potential $\therefore V_2 = 0$.

V_2 = Virtual ground.

It is used in analysis of an op-amp when negative feedback is employed.

Virtual ground	Real ground
(i) Concept used in op-amp.	(i) Here one terminal is connected to ground and acts as the reference point for the entire ckt.
(ii) Voltage is approx. zero.	(ii) voltage is zero.
(iii) Not able to sink infinite current.	(iii) It is an infinite current sink.

Parameters of op-amp



(1) **Input offset voltage** :- It is defined as the voltage applied between two input terminals of an op-amp to make the o/p zero.

V_{DC1} & V_{DC2} = DC voltages.
R_S = source resistance

$$\boxed{V_{io} = V_{DC1} - V_{DC2}}$$

~~It~~ ~~Voi~~ V_{io} may be +ve or −ve.

For 741C → ± 6mV.

(2) **Input offset current** :-

I_{io} is the difference between the currents into inverting ~~of~~ and non inverting terminals of a balanced amplifier.

$$\boxed{I_{io} = |I_{B_1} - I_{B_2}|}$$

741C → 200nA. (max^m)
→ 6nA (precise amplifier)

(3) **Input bias current** :-

I_B is the average of the current entering the input terminals of a balanced amplifier.

$$\boxed{I_B = \frac{(I_{B_1} + I_{B_2})}{2}}$$

741C $I_{B(max)}$ = 700nA.
precision = ± 7nA.

(4) CMRR :-

It is the ratio of the differential voltage gain Ad to the common mode voltage gain ACM.

$$\boxed{CMRR = \frac{A_d}{A_{CM}}}$$

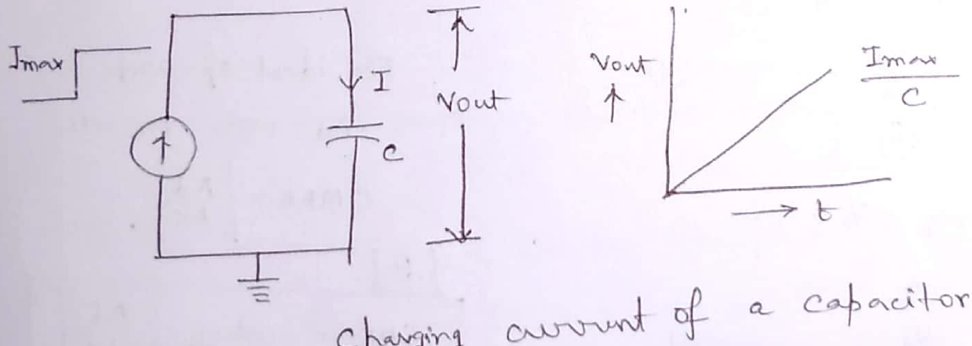
741 C → 90 dB.

Higher CMRR, better the matching b/w two input terminals and smaller is the output common mode voltage.

(5) Slew rate :-

It is defined as the maxm rate of change of o/p voltage per unit time under large signal voltage condition and expressed as V/μs.

$$\boxed{SR = \left.\frac{dV_o}{dt}\right|_{max} \ V/\mu s}$$



Charging current of a capacitor. $I = C\frac{dv}{dt}$

$$\frac{dv}{dt} = I/c$$

If I more capacitor charges quickly. If I is limited to Imax, ~~that~~ rate of change is also limited.

Slew rate indicates how rapidly the output of an op-amp can ~~cha~~ change in response to changes in the i/p freq with input amplitude const.

Slew rate changes with change in voltage gain and normally specified ~~as~~ at unity gain.

$$\boxed{741C \rightarrow 0.5\ V/\mu s.}$$

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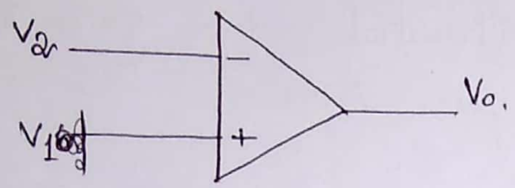
CMRR.



op-amp. amplifies the difference of input voltages V_1 and V_2 applied to the non inverting and inverting i/p terminals w.r.to ground. The o/p voltage V_o is measured w.r.to ground.

At output difference signal $\boxed{V_d = V_1 - V_2}$. and common mode signal. → (i)

$$\boxed{V_c = \frac{V_1 + V_2}{2}} \text{ — (2) both are amplified.}$$

As op-amp is a linear device, so output voltage

$$V_o = A_1 V_1 + A_2 V_2 \quad \text{—— (3)}$$

where, A_2, A_1 = voltage gain when input terminals are grounded.

Adding (i) and (ii)

$$V_d + 2V_c = V_1 - V_2 + V_1 + V_2.$$

$$\therefore V_d + 2V_c = 2V_1$$

$$\text{or } V_1 = V_c + \frac{V_d}{2} \quad \text{—— (4)}$$

Subtracting (i) from (ii)

$$2V_c - V_d = V_1 + V_2 - V_1 + V_2$$

$$\text{or } 2V_c - V_d = 2V_2$$

$$\therefore V_2 = V_c - \frac{V_d}{2} \quad \text{—— (5)}$$

For ideal op-amp.

$A_d \to \infty$, $A_c = 0$.

$$\therefore CMRR = \left|\frac{A_d}{A_c}\right|.$$

dB

$$\boxed{CMRR = 20 \log_{10}\left|\frac{A_d}{A_c}\right|}$$

From (3) we get,

$$V_o = A_1\left(V_c + \frac{V_d}{2}\right) + A_2\left(V_c - \frac{V_d}{2}\right)$$

$$\text{or } V_o = V_c(A_1 + A_2) + \frac{V_d}{2}(A_1 - A_2)$$

$$= A_c V_c + A_d V_d.$$

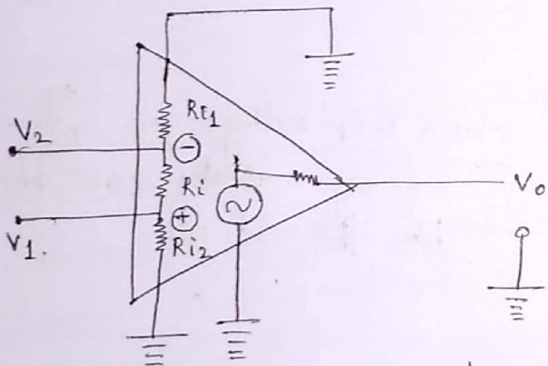
where, A_c = common mode gain = $(A_1 + A_2)$

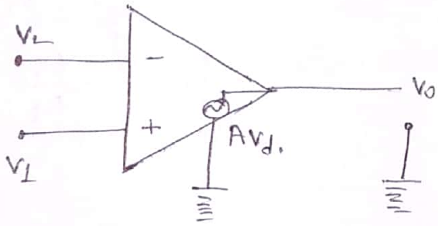
A_d = differential mode gain = $\frac{1}{2}(A_1 - A_2)$

op-amp characteristics

Ideal op-amp	Practical op-amp
(i) ~~&~~ Voltage gain = ∞	(i) Voltage gain 10^3 to 10^6
(ii) Input impedance = ∞	(ii) Input impedance = 150 KΩ to 100 MΩ
(iii) Output impedance = 0.	(iii) 0.75 to 100 Ω
(iv) Bandwidth = ∞	(iv) finite $\rightarrow$ 100 KΩ
(v) Perfect balance, when ~~oth~~ both i/p voltages are equal, $V_o = 0$.	(v) do not have perfect balance.
(vi) characteristics do not drifted with temp.	(vi) Characteristics drifted with temp.

AC equivalent ckt of op-amp





Ri_1 = i/p resistance b/w ~~inter~~ inverting & ground.

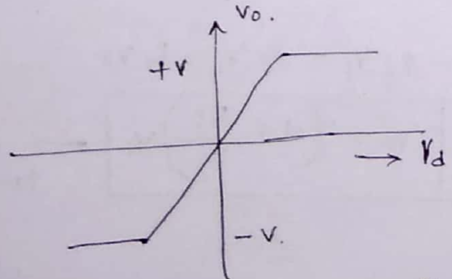
Ri_2 = i/p " " " non " " "

Ri = Resistance b/w two i/p terminals.

Ideal Ri_1, Ri_2 & $Ri \longrightarrow \infty$.

The diff of i/p voltage $V_d = (V_1 - V_2)$ is amplified at the o/p and taken through o/p resistance R_o which is $R_o \cong 0$.

open loop characteristics



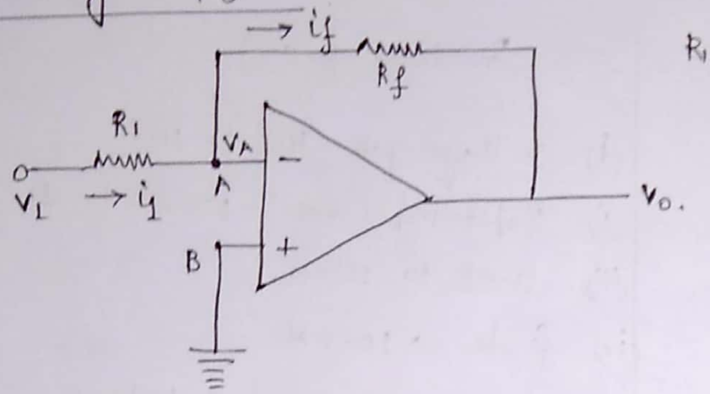
A_d is very high. $A = \frac{V_o}{V_d}$.

V_d slightly +ve, V_o goes to nearly +V.
If $V_d \uparrow$, V_o remains saturated.

V_d slightly −ve, V_o attains nearly −V and remains saturated.

−V and +V is called +ve & −ve saturated voltages.

Inverting amplifier



R_1 & R_f external resistances at i/p and feedback path.

V_1 is i/p voltage applied to inverting terminal through R_1

~~V~~ ~~A~~ +ve is grounded.

∴ −ve is virtually grounded.

∴ $V_A = 0$.

Again i/p impedance is very high ($\cong \infty$) so no current enters into the op-amp.

At point A, applying Kirchoff's current law (KCL)

$$i_1 = i_f$$

or, $$\frac{V_1 - 0}{R_1} = \frac{0 - V_o}{R_f}$$

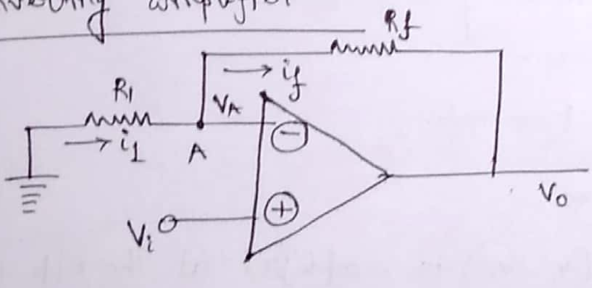
or, $$-\frac{V_o}{R_f} = \frac{V_1}{R_1}$$

∴ $$\boxed{V_o = -\frac{R_f}{R_1} V_1}$$

closed loop voltage gain $\frac{R_f}{R_1}$.

−ve sign indicates 180° phase shift b/w i/p and o/p.

Non inverting amplifier



Input applied to +ve terminal, R_f provides negative feedback.

Voltage gain of op-amp = ∞.

KCL at A

$$i_1 = i_f$$

or, $$\frac{0 - V_1}{R_1} = \frac{V_1 - V_o}{R_f}$$

or, $$-R_f V_1 = R_1 V_1 - R_1 V_o$$

or, $$\boxed{V_o = \left(1 + \frac{R_f}{R_1}\right) V_1}$$ → +ve & −ve terminal phase shift 0°

Operational Amplifier :- (OP AMP)

OPAMP is general purpose linear integrated circuit. It was developed by Robert Widlar in 1964. It is a direct coupled, high gain, differential input amplifier.

The term operational signifies that various mathematical operations such as addition, subtraction, integration, differentiation can be performed by using op-amp.

It can be used in →

waveform forming
active filters
oscillators
A/D and D/A converters.

Advantages :-

→ Here -ve feedback is applied so performance of the op-amp with negative feedback is controlled by the feedback elements independent of the characteristics of the transistors and other elements that constitute of the ~~amp~~ op-amp.

→ Feedback elements are usually passive so ckt operation is very stable and predictable.

→ IC of ~~op~~ op-amp is inexpensive and have temperature stabilization.

Block diagram of OP-AMP :-