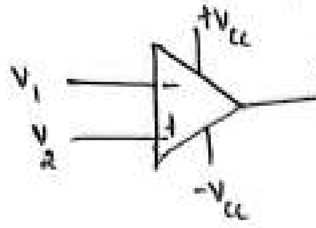
Op-Amp:

Large no of amplifiers are cascaded together → Gain is Infinite.

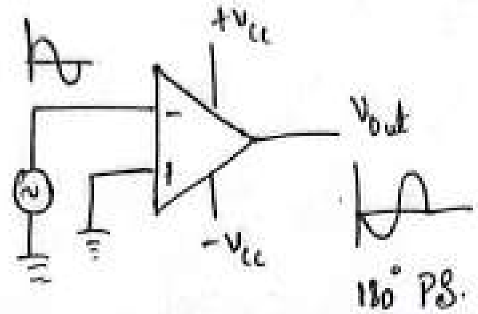


$V_{out} = A(V_2 - V_1) = AV_d$.

↳ open loop Gain

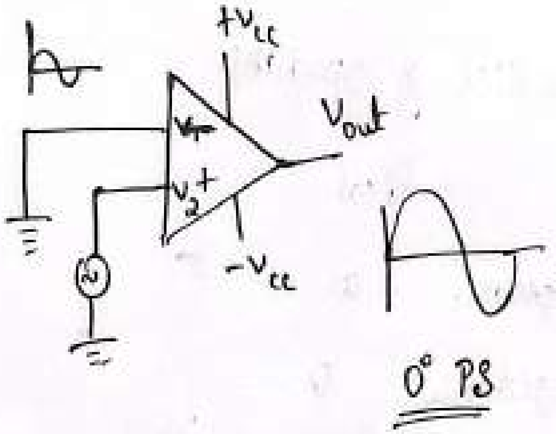
When I/p is applied to Inverting terminal with non-Inverting terminal being grounded then

$$V_{out} = A(0 - V_1)$$
$$= -AV_1$$



When I/p is applied to non Inverting terminal with Inverting terminal being grounded then

$$V_{out} = AV_2.$$



Common mode I/p Vtg $V_{iCM} = \frac{V_1 + V_2}{2}$.

Differential I/p Vtg $V_{id} = V_2 - V_1$.

Thus $V_1 = V_{iCM} - \frac{V_{id}}{2}$

$$V_2 = V_{iCM} + \frac{V_{id}}{2}.$$

$$\therefore V_0 = A_d V_{id} + A_{CM} V_{iCM}.$$

Problems:

i) $V_2 = 0V$, $V_0 = 2V$, $A = 10^3$, $V_1 = ?$ $V_{iCM} = ?$ $V_{id} = ?$

$$V_0 = A(V_2 - V_1) \Rightarrow V_2 - V_1 = \frac{V_0}{A} \Rightarrow V_1 = V_2 - \frac{V_0}{A} = 0 - \frac{2}{10^3} = -2mV$$

$$V_{iCM} = \frac{V_1 + V_2}{2} = -1mV$$

$$V_{id} = V_2 - V_1 = 2mV.$$

ii) $A = 10^3$, $V_2 = 5V$, $V_0 = -10V$; $V_1 = ?$; $V_{iCM} = ?$ $V_{id} = ?$

Soln:- $$V_1 = V_2 - \frac{V_0}{A} = 5 + \frac{10}{10^3} = 5 + \frac{1}{100} = 5 + 0.01 = 5.01V$$

$$V_{iCM} = \frac{5 + 5.01}{2} = 5.005V$$

$$V_{id} = V_2 - V_1 = 5 - 5.01 = -0.01V = -10mV$$

Characteristics of OP-AMP

	Ideal	Practical
i) I/p Impedance	∞	$2M\Omega$.
ii) O/p Impedance	0	$50-100\Omega$.
iii) Vtg Gain	∞	2×10^5.
iv) Bandwidth [Gain should be constant over the Entire range].	∞	1MHz.
v). CMRR	∞	86dB-100dB.

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

Common mode S/gs should be rejected thus $A_{CM} = 0$

$$\therefore CMRR = A_d/0 = \infty$$

vi> Slew Rate ∞ 1V/μsec @ 10V/μs.

↳ It is a measure of how fast the op-amp's o/p can change in response to the changes in i/p level.

$$SR = \frac{dV_0}{dt}.$$

SR limits the max operating frequency of the op-amp.

vii> i/p offset vtg. 0 2mV

viii> i/p offset current 0 20nA.

Let the o/p be a sinusoid $V_m \cos\omega t$

then $SR = \frac{dV_0}{dt} = V_m \omega \sin\omega t$.

$SR = V_m \omega$

$SR = V_m 2\pi f$.

$$\boxed{f = \frac{SR}{2\pi V_m}}$$

i> If $A = 1$, $V_0 = 10 \sin 3.14 \times 10^5 t$ calculate SR ?

$$SR = \frac{dV_0}{dt} = 10(3.14 \times 10^5)$$

ii> $SR = 5V/\mu sec$, $f = 200KHz$, $V_m = ?$

$$f = \frac{SR}{2\pi V_m} \Rightarrow V_m = \frac{SR}{2\pi f} = \frac{5}{2\pi(200K)} = 3.98V.$$

iii> $SR = 3V/\mu sec$, $V_m = 2$, calculate the max o/p freq so that o/p is not distorted.

$$f = \frac{SR}{2\pi V_m} = \frac{3}{2\pi \cdot 2} = 238KHz.$$

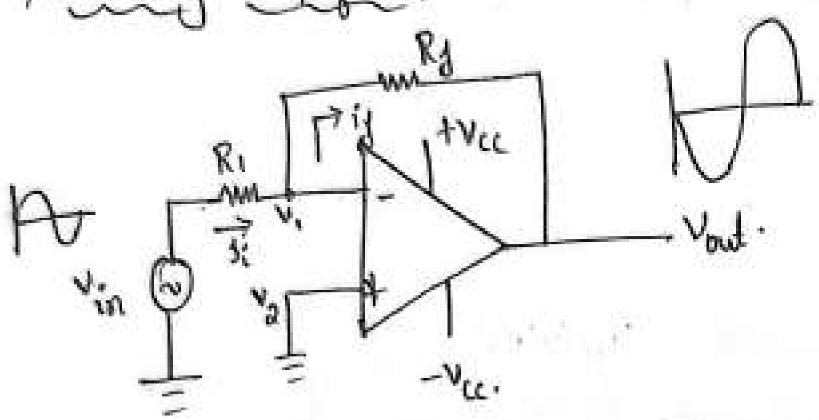
Virtual Short / Virtual Ground:

WKT $V_0 = A(V_2 - V_1)$ But $A = \infty$.

$$A = \frac{V_0}{V_2 - V_1} = \infty \Rightarrow V_2 - V_1 = 0$$

$$\boxed{\therefore V_2 = V_1}.$$

i) Inverting Amplifier:



V_2 is grounded $\therefore V_2 = 0$.

Due to virtual Short $V_1 = V_2$

Due to high I/p Impedance of op-amp current through op-amp is '0'.

Thus $I_1 = I_f$.

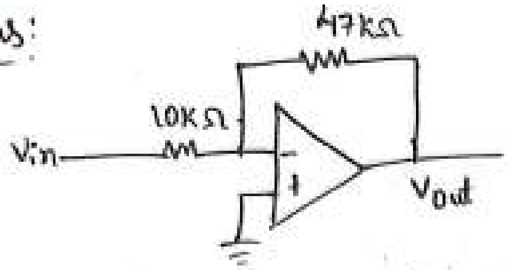
$$\frac{V_1 - V_{in}}{R_1} = \frac{V_{out} - V_1}{R_f} \quad \Bigg| \quad \frac{V_{in} - V_1}{R_1} = \frac{V_1 - V_{out}}{R_f}$$

But $V_1 = V_2 = 0$

$$\therefore \frac{V_{in}}{R_1} = -\frac{V_{out}}{R_f}$$

$$\boxed{\frac{V_{out}}{V_{in}} = A = -\frac{R_f}{R_1}}$$

Problems:



find A?

$$A = \frac{-R_f}{R_1} = \frac{-47K}{10K} = -4.7$$

ii) A 200mV peak to peak sine wave is applied to an op-amp with $\frac{R_f}{R_1} = 10$. Sketch the o/p w/f.

Sol: P-P → $2V_m = 200mV$

$V_m = 100mV$.

$$V_0 = \frac{-R_f}{R_1} \times V_{in} = -1000mV.$$

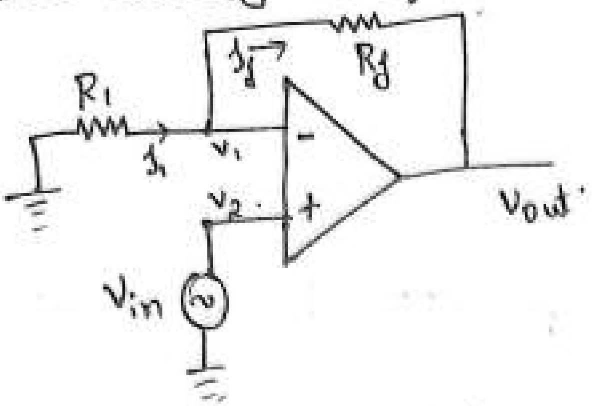
iii) Design an inverting amp with a closed loop vty gain of -15

$$A_f = -15 = -\frac{R_f}{R_1}$$

$R_f = 15R_1$

If $R_1 = 1K\Omega$ then $R_f = 15K\Omega$.

Non-Inverting Amplifier:



$$v_2 = v_1 = v_{in}$$

$$I_1 = I_f$$

$$\frac{v_1 - 0}{R_1} = \frac{v_{out} - v_1}{R_f}$$

or $$\frac{0 - v_1}{R_1} = \frac{v_1 - v_{out}}{R_f}$$

But $v_1 = v_2 = v_{in}$.

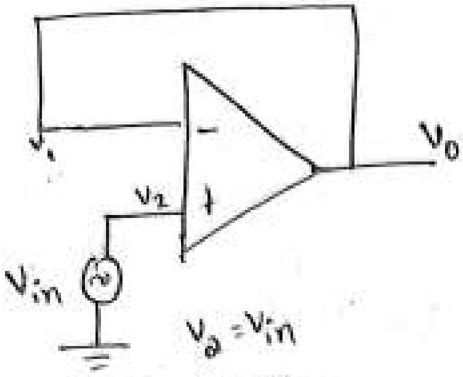
$$\frac{-v_{in}}{R_1} = \frac{v_{in} - v_{out}}{R_f}$$

$$\frac{-v_{in}}{R_1} = \frac{v_{in}}{R_f} - \frac{v_{out}}{R_f}$$

$$\frac{v_{out}}{R_f} = \frac{v_{in}}{R_f} + \frac{v_{in}}{R_1} = v_{in}\left[\frac{1}{R_f} + \frac{1}{R_1}\right].$$

$$A = \frac{v_{out}}{v_{in}} = R_f\left[\frac{1}{R_f} + \frac{1}{R_1}\right] = 1 + \frac{R_f}{R_1}$$

Voltage follower:



$$v_o = AV_d = A(v_2 - v_1) = A(v_{in} - v_o)$$

$$v_o = Av_{in} - Av_o$$

$$v_o(1+A) = Av_{in}$$

$$v_o / v_{in} = \frac{A}{1+A}$$

$$v_2 = v_{in}$$

$$v_1 = v_2$$

$$V_1 = V_{in}$$

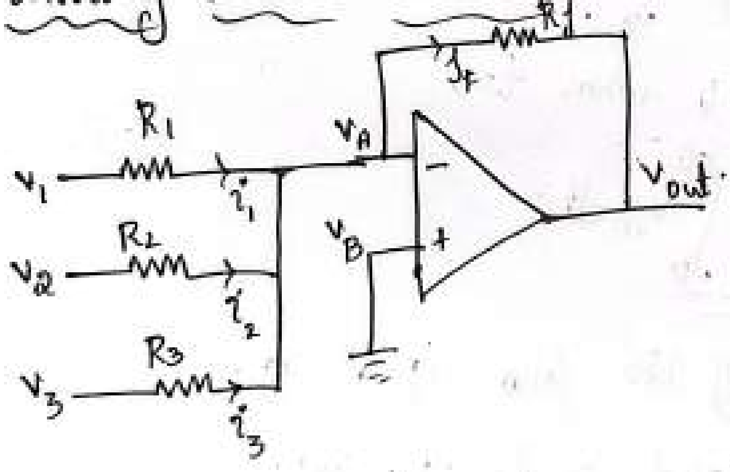
$$V_o = V_1 = V_{in}.$$

$$A = \frac{V_o}{V_{in}} = 1$$

→ O/P follows the I/p Vtg.

→ Derived from non-inverting amplifier by setting $R_1 = \infty$ & $R_f = 0$
($R_1 = \infty$ ↓ Open Ckt. ; $R_f = 0$ ↓ Short Ckt.)

Inverting Summer CKt:



WKT $V_A = V_B = 0$

$$i_1 + I_2 + I_3 = I_F$$

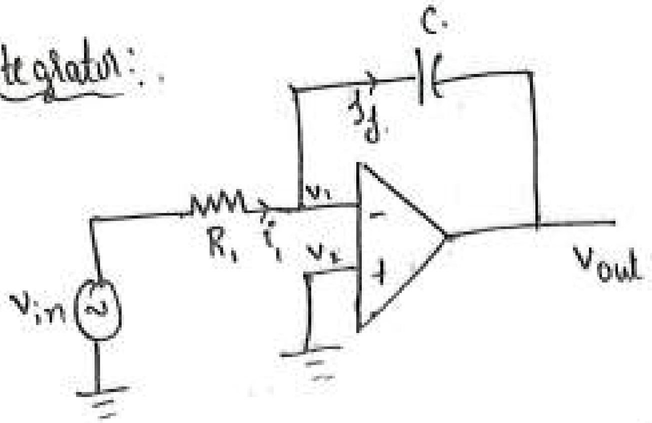
$$\frac{V_1 - V_A}{R_1} + \frac{V_2 - V_A}{R_2} + \frac{V_3 - V_A}{R_3} = \frac{V_A - V_{out}}{R_f}$$

But $V_A = V_B = 0$

$$\therefore \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = \frac{-V_{out}}{R_f}$$

$$V_{out} = -R_f\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right].$$

Integrator:



WKT $V_1 = V_2 = 0$.

$$i_1 = i_f$$

$$\frac{V_{in} - V_1}{R_1} = C \frac{d}{dt}(V_1 - V_{out}).$$

But $V_1 = V_2 = 0$.

$$\therefore \frac{V_{in}}{R_1} = C \frac{d}{dt}(-V_{out}).$$

$$\frac{V_{in}}{R_1} = -C \frac{dV_{out}}{dt}$$

$$\frac{dV_{out}}{dt} = -\frac{1}{R_1 C}\left[\frac{V_{in}}{\cancel{R_1}}\right].$$

$\int$ BS wrt t.

$$V_{out} = -\frac{1}{RC}\int_0^t V_{in}\, dt + V_0(0).$$

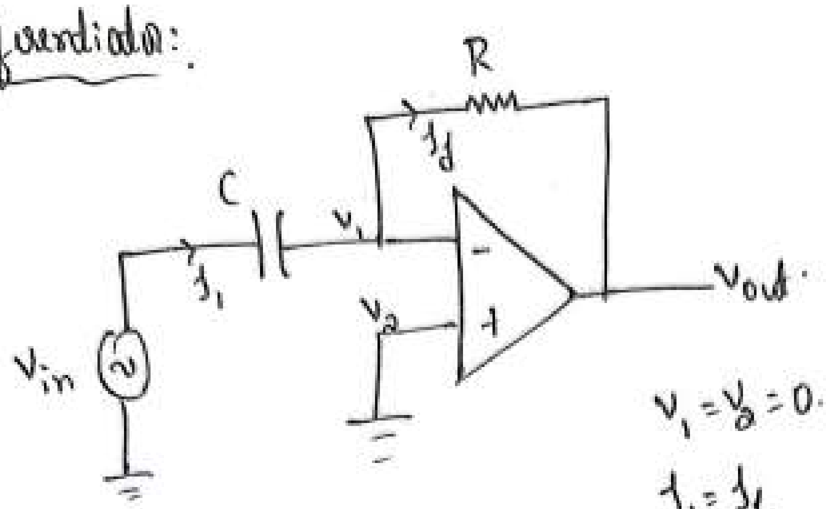
$V_0(0)$ is constant & $V_0(0) = 0$ when $t = 0$.

$$\therefore V_{out} = \frac{-1}{RC}\int_0^t V_{in}\, dt.$$

-ve sign indicates PS of 180° b/w i/p & o/p.

RC is called time constant of the integrator.

Differentiator:



$V_1 = V_2 = 0.$

$I_1 = I_f.$

$$C\frac{d}{dt}\left(V_{in} - V_1\right) = \frac{V_1 - V_{out}}{R}.$$

But $V_1 = V_2 = 0$

$$C\frac{d}{dt}(V_{in}) = \frac{-V_{out}}{R}.$$

$$\boxed{V_{out} = -RC\frac{d}{dt}(V_{in}).}$$

V_0 is proportional to the derivative of i/p. vtg V_{in}.

Design an adder circuit using an op-amp to obtain an o/p Expression $V_0 = 2(0.1V_1 + 0.5V_2 + 20V_3)$ where, V_1, V_2 & V_3 are I/p's.

Sol^n:- $V_0 = 0.2V_1 + 1V_2 + 40V_3$.

WKT $V_0 = \frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3$.

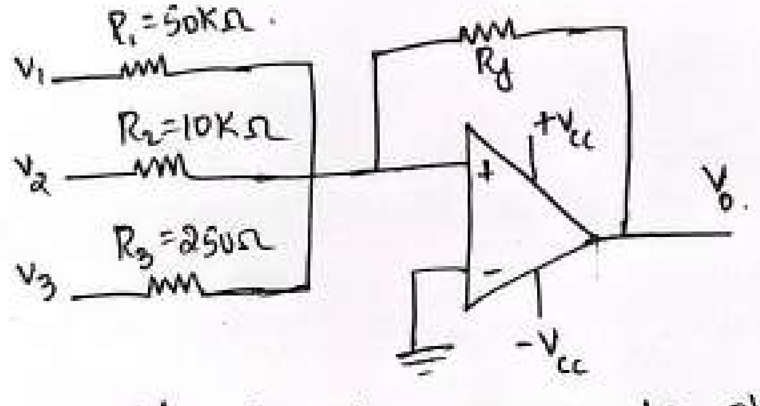
Assuming $R_f = 10K\Omega$.

then $\frac{R_f}{R_1} = 0.2 \Rightarrow R_1 = \frac{10K\Omega}{0.2} = 50K\Omega$.

$R_f/R_2 = 1 \Rightarrow R_2 = \frac{10K\Omega}{1} = 10K\Omega$.

$R_f/R_3 = 40 \rightarrow R_3 = \frac{10K\Omega}{40} = 250\Omega$.

The Supply Vtg V_{cc} & $-V_{cc}$ may be $\pm 15V$.



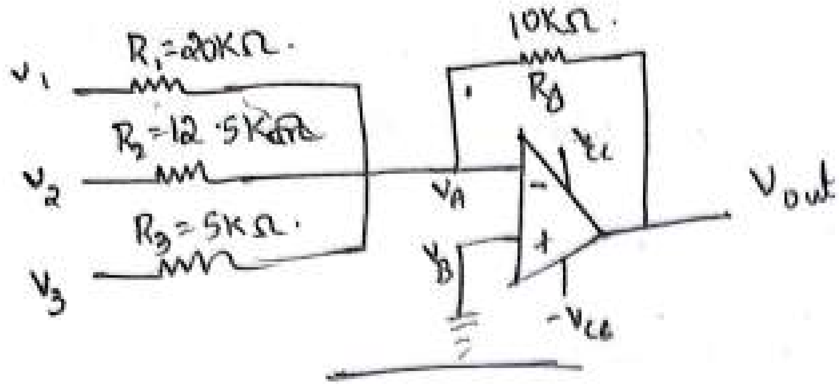
Design an adder ckt using op-amp to obtain an o/p vtg given $V_0 = -[0.5V_1 + 0.8V_2 + 2V_3]$.

Sol^n:- WKT $V_0 = -\left[R_f/R_1\, V_1 + R_f/R_2\, V_2 + R_f/R_3\, V_3\right]$

$R_f/R_1 = 0.5$ $\quad R_f/R_2 = 0.8$ $\quad R_f/R_3 = 2$.

Assume $R_f = 10K\Omega$.

$R_1 = \frac{10K}{0.5} = 20K\Omega$; $R_2 = \frac{10K}{0.8} = 12.5K\Omega$; $R_3 = \frac{10K}{2} = 5K\Omega$.


$R_1 = 20K\Omega$
$R_2 = 12.5K\Omega$
$R_3 = 5K\Omega$
$10K\Omega$
R_f
V_1
V_2
V_3
V_A
V_B
V_{out}
$-V_{CC}$