$$i_i = \frac{0 - v_i}{R_i} = \frac{v_i - v_o}{R_f}$$

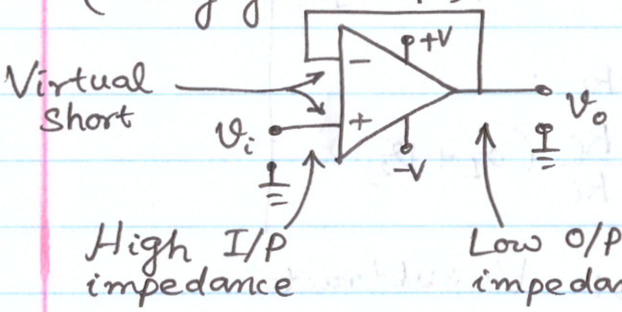
$$\Rightarrow v_o = +\left(1 + \frac{R_f}{R_i}\right) v_i$$

0° phase shift

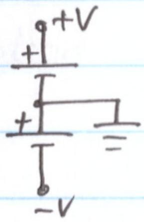
$$\text{Gain}(A_v) = +\left(1 + \frac{R_f}{R_i}\right)$$

I/P resistance $(R_I) = \infty$ (or GΩ)

→ Voltage follower: Special case of a non-inv. amp.
(Unity-gain amp.) (impedance converter)

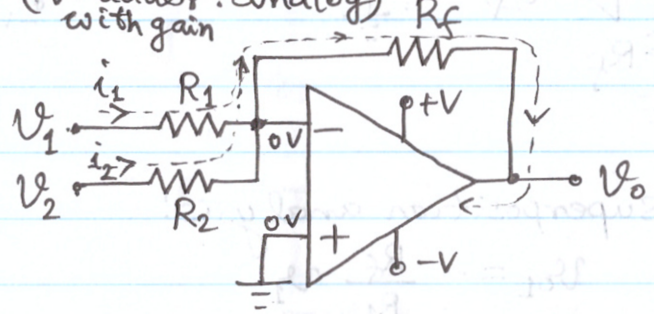


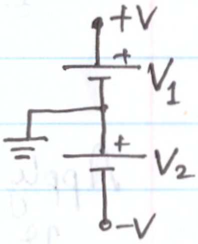
$$A_v = \frac{v_o}{v_i} = 1$$



$$v_o = \left(1 + \frac{R_f}{R_i}\right) v_i = \left(1 + \frac{0}{\infty}\right) v_i = v_i$$

iii) Summing amp: Special case of an inv. amp.
(V-adder: analog) with gain





Analyze by using superposition system.

Assume v_1 is applied while $v_2 = 0$

$$v_{o1} = -i_1 \cdot R_f = -\frac{R_f}{R_1} \cdot v_1$$

Assume, v_2 is applied while $v_1 = 0$

$$v_{o2} = -i_2 \cdot R_f = -\frac{R_f}{R_2} \cdot v_2$$

$\therefore$ $v_o = v_{o1} + v_{o2}$

$$\Rightarrow v_o = -\frac{R_f}{R_1} v_1 - \frac{R_f}{R_2} \cdot v_2$$

$$\Rightarrow v_o = -\left[\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} \cdot v_2\right]$$

If, $R_1 = R_2 = R_i$:

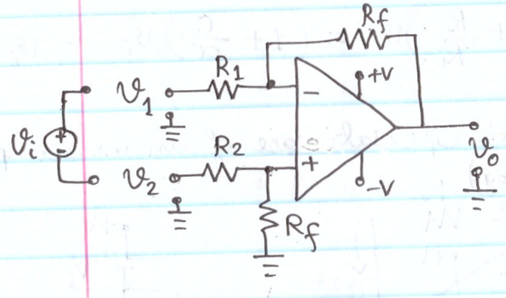
$$v_o = -\frac{R_f}{R_i}(v_1 + v_2)$$

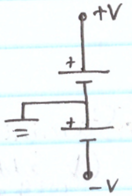
$R_f = R_i$ → V-adder

$R_f > R_i$ → Summing amp.

$R_f < R_i$ → Summing attenuator

iv) Difference amp: V-subtractor





Applying superposition analysis:

$v_2 = 0$: $v_{o1} = -\frac{R_f}{R_1} v_1$ (Inv. amp.)

$v_1 = 0$: $v_{o2} = \left[\frac{R_f}{R_2 + R_f} \cdot v_2\right]\left[1 + \frac{R_f}{R_1}\right]$ (Non-inv. amp.)

$$\Rightarrow v_{o2} = \left(1 + \frac{R_f}{R_1}\right)\left[\frac{\frac{R_f}{R_2}}{1 + \frac{R_f}{R_2}}\right] v_2$$

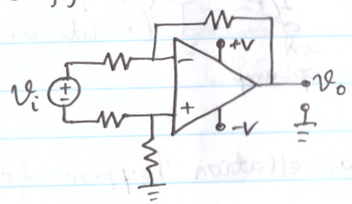
$$v_o = v_{o1} + v_{o2} = -\frac{R_f}{R_1} v_1 + \left(1 + \frac{R_f}{R_1}\right)\left[\frac{\frac{R_f}{R_2}}{1 + \frac{R_f}{R_2}}\right] v_2$$

If, $R_1 = R_2 = R_i$, or, $\frac{R_f}{R_1} = \frac{R_f}{R_2} = \frac{R_f}{R_i}$

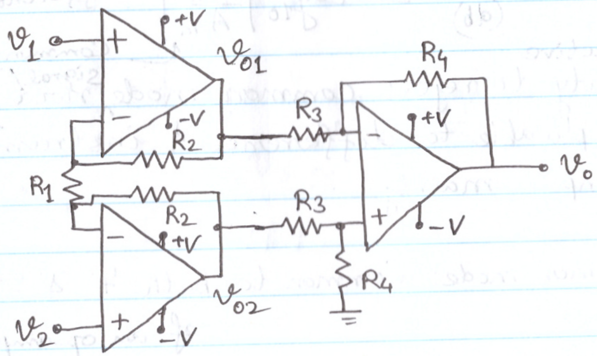
$$v_o = +\underbrace{\frac{R_f}{R_i}}_{\text{Differential Gain}}(v_2 - v_1)$$

I/P resistance $= 2 \cdot R_i = R_I$

Note: Differential I/P V may also be applied.



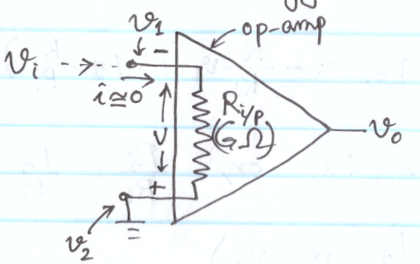
v) Instrumentation Amplifier: Special case of difference amp.



Special Notes

1. Virtual ground/short:

i) Open loop analogy:



If, $i = 0$, $R_{i/p} = G\Omega$

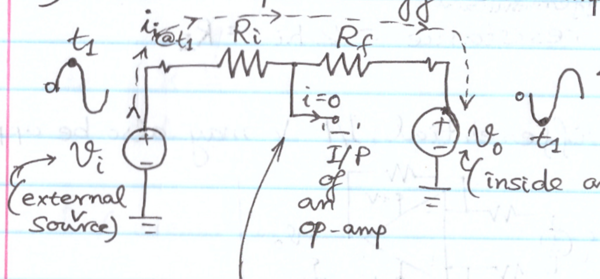
$V = v_2 - v_1$

$= i . R_{i/p}$

$= 0 . (G\Omega)$

$= 0$

ii) Closed loop analogy : Inv. amp.



180° phase shifted O/P (∵ I/P is applied at -ve I/P of an op-amp)

V-cancellation happens for v_i & v_o

2. Common Mode Rejection Ratio (CMRR):

$$\text{CMRR}_{(db)} = 20 . \log_{10} \left| \frac{A_d}{A_{cm}} \right|$$

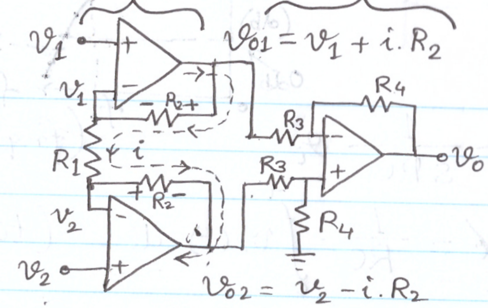
A_d ← Differential gain

A_{cm} ← Common-mode gain

(Selective Ability to reject common mode signal/noise)

Applicable to difference & instrumentation amps. mainly.

Common mode: Common to both '+' & '-' inputs of an op-amp/op-amp ckt.



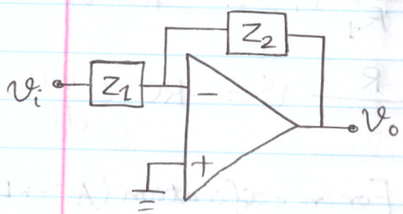
$$v_{o1} = v_1 + i . R_2 = \left(1 + \frac{R_2}{R_1}\right) v_1 - \frac{R_2}{R_1} v_2$$

$$v_{o2} = v_2 - i . R_2 = \left(1 + \frac{R_2}{R_1}\right) v_2 - \frac{R_2}{R_1} v_1$$

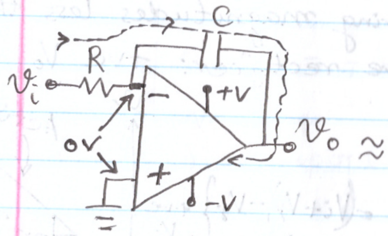
Also, $v_o = \frac{R_4}{R_3}(v_{o2} - v_{o1})$

$$\Rightarrow v_o = \underbrace{\frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right)}_{\text{Differential gain}} (v_2 - v_1)$$

vi) Integrator (LPF): Freq. dependent gain



$$\frac{v_o}{v_i} = -\frac{Z_2}{Z_1}$$



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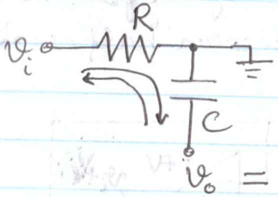
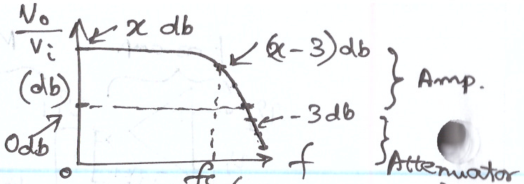


$\tau = RC$

$= -\frac{Z_2}{Z_1} v_i$

Phase inversion of 180 is independent of f

$X_c = \frac{1}{2\pi f C}$



$v_o = -\frac{1}{sRC} v_i$ (freq. domain)

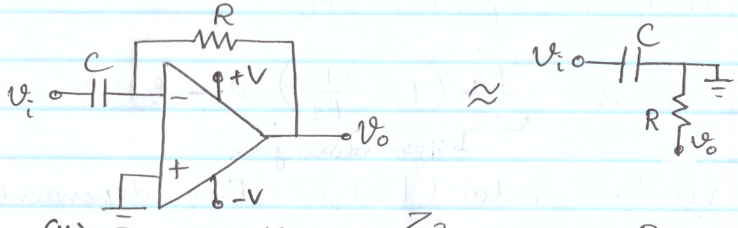
$\Rightarrow v_o = V_c - \frac{1}{RC}\int_0^t v_i(t).\,dt$ (time domain)

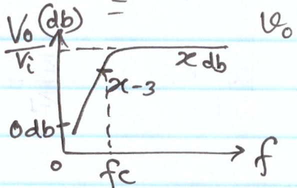
V_c: Initial voltage across 'C' @ $t=0$

If, $V_c = 0$ at $t=0$;

$$v_o = -\frac{1}{RC}\int_0^t v_i(t).dt$$

vii) Differentiator: HPF



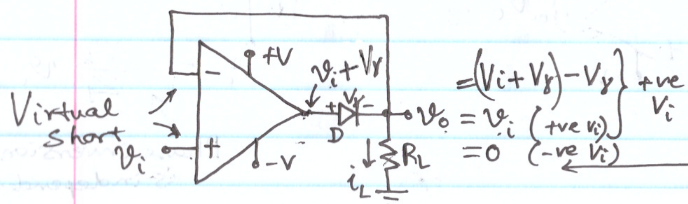


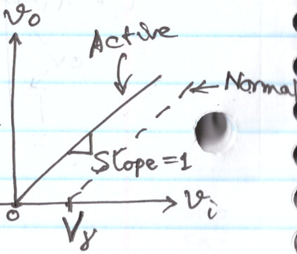
$v_o = -\frac{Z_2}{Z_1} v_i = -sRC.v_i$

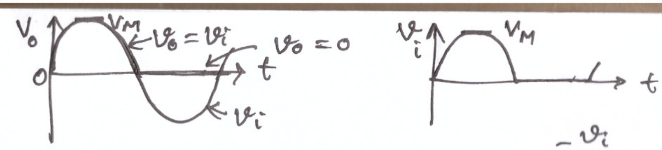
$v_o = -RC.\frac{d\,v_i(t)}{dt}$

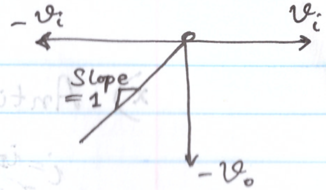
viii) Active rectifiers: For rectification (AC → DC) of signals having magnitudes less than V_γ.

Precision half-wave rectifier: +ve V_o

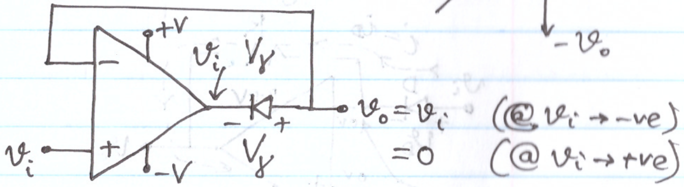




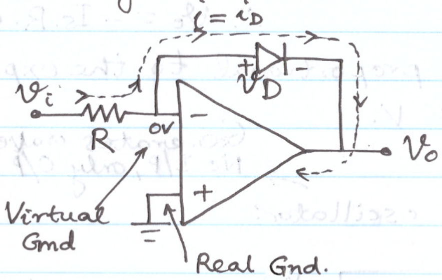




−ve V_o:



ix) Logarithmic amplifier: Natural log computer (Analog)



Diode current eqn:

$i_D = I_s\left(e^{\frac{v_D}{V_T}} - 1\right)$

$\approx I_s.\,e^{\frac{v_D}{V_T}}$

(Under sufficient forward bias condition)

$i_D = I_s.e^{\frac{v_D}{V_T}} = \frac{v_i}{R}$

$\Rightarrow I_s.\,e^{\frac{-v_o}{V_T}} = \frac{v_i}{R} \Rightarrow e^{-\frac{v_o}{V_T}} = \frac{v_i}{I_s.R}$

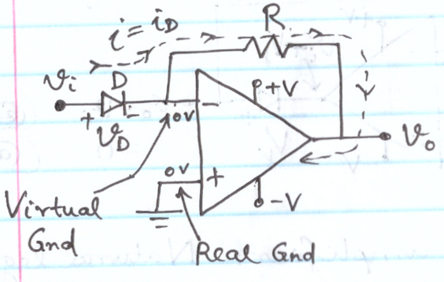
Taking natural log on both sides:

$-\frac{v_o}{V_T} = \ln\left[\frac{v_i}{I_s.R}\right]$

$\Rightarrow v_o = -V_T.\ln\left[\frac{v_i}{I_s.R}\right]$

Note: O/P V is proportional to natural log of I/P V.

x) Anti-log or exponential amp:

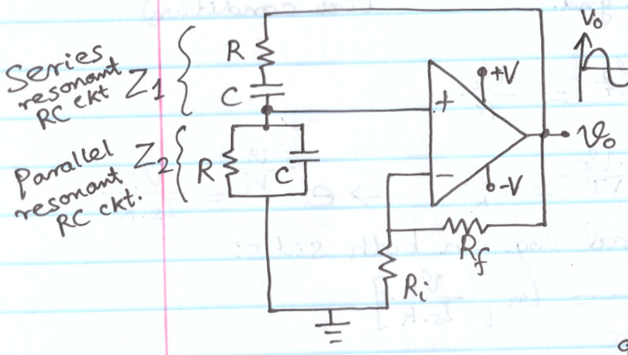


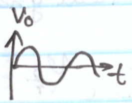
$$i_D \cong I_s . e^{\frac{v_D}{V_T}}$$
$$= I_s . e^{\frac{v_i}{V_T}}$$

$$v_o = -i.R = -i_D.R$$
$$\Rightarrow v_o = -I_s.e^{\frac{v_i}{V_T}}.R$$
$$\therefore v_o = -I_s.R.e^{\frac{v_i}{V_T}}$$

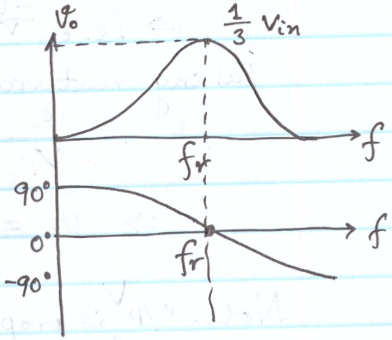
Note: O/P V is proportional to the exponent of the I/P V.

xi) Wein bridge oscillator: → Generates waveform; No I/P, only O/P





$$f_r = \frac{1}{2\pi \underbrace{RC}_{\tau}}$$

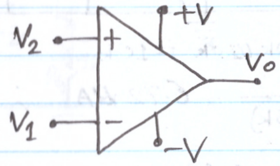


Barkhausen criterion:

1. Total $\phi = 0°$ or $360°$
2. +ve f.b. ($|A\beta| = 1$)

Gain; Feedback factor / A combination of +ve & -ve f.b.

xii) Comparator: Open-loop V-comparator.



If, $V_2 > V_1 \Rightarrow V_o = +V_{sat}$
If, $V_2 < V_1 \Rightarrow V_o = -V_{sat}$
(assuming $A_{od} = \infty$)