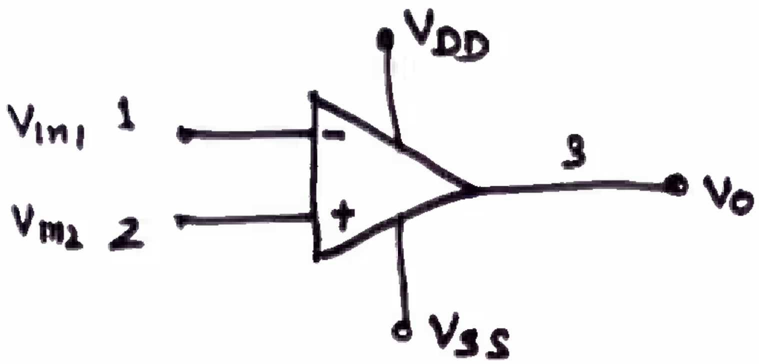
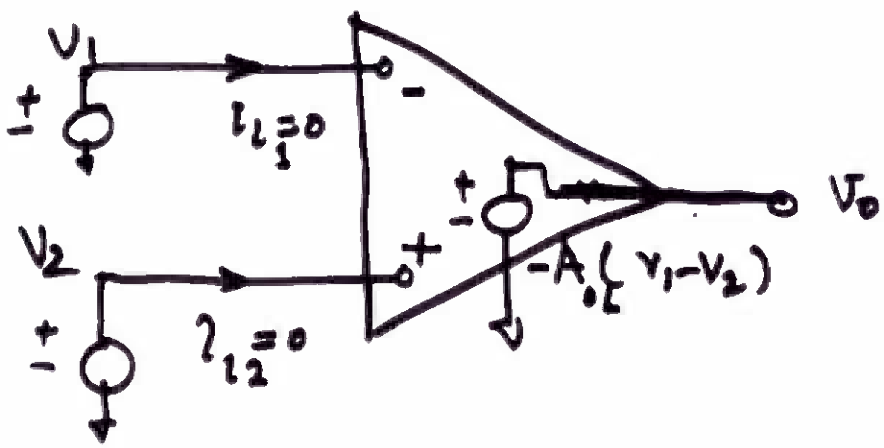
Slide No: 1

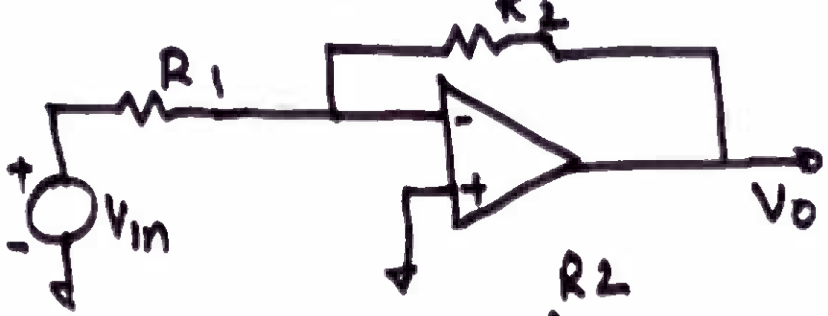
OPAMP as Circuit Element

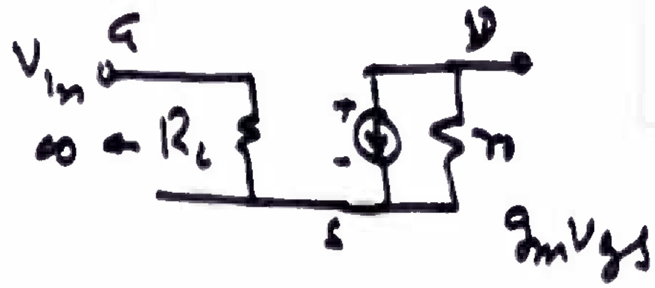


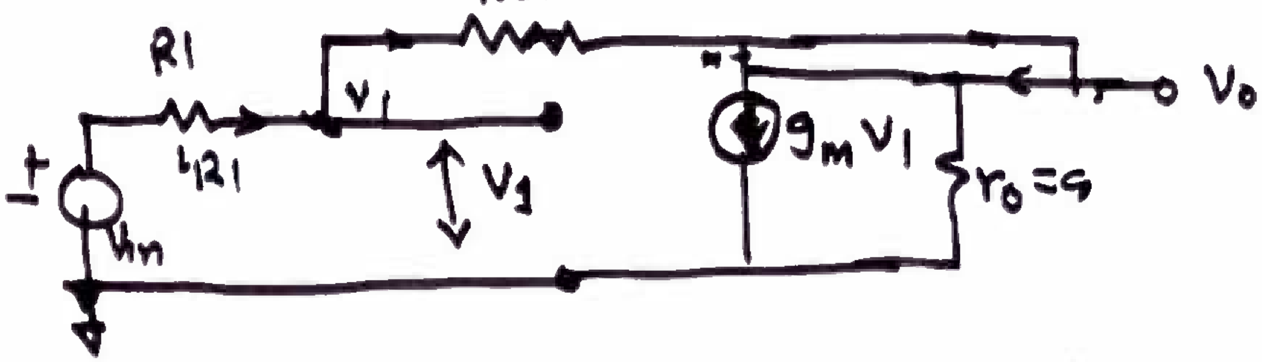
Equivalent Circuit
↓



Inverting & Non Inverting Amplifier







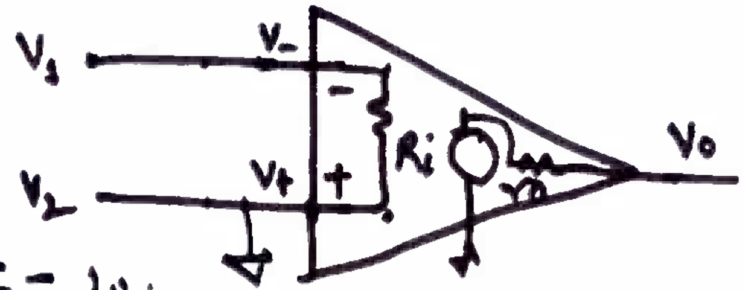
$$\frac{V_{in} - V_1}{R_1} = \frac{V_1 - V_o}{R_2} \quad \text{or} \quad \frac{V_{in}}{R_1} + \frac{V_o}{R_2} = \underline{\underline{V_1}}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

Ideal Parameters

$R_i \rightarrow \infty$

$r_o \rightarrow 0$

A_v is very large



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$\frac{V_1 - V_2}{R_i} = i_{R_i}$

$V_d = V_1 - V_2 = V_- - V_+$

$V_o = -A_v (V_- - V_+) = -A_v V_d$

or $V_d = -\frac{V_o}{A_v}$ If $A_v \rightarrow \infty$ $V_d \rightarrow 0$

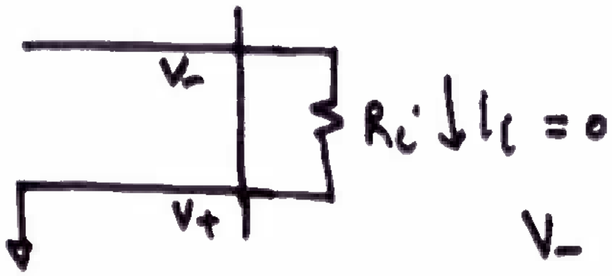
$\boxed{\text{Then } V_- = V_+}$

Hence if we Ground $V_+ \Rightarrow 0$

Then $V_- = 0$

This is Concept of Virtual Ground.

Alternatively as $R_i \to \infty$, no current passes through it



As $I_i = 0$

$\therefore V_- = V_+ = 0$

V_- getting 'zero' potential. This is called Virtual Ground.

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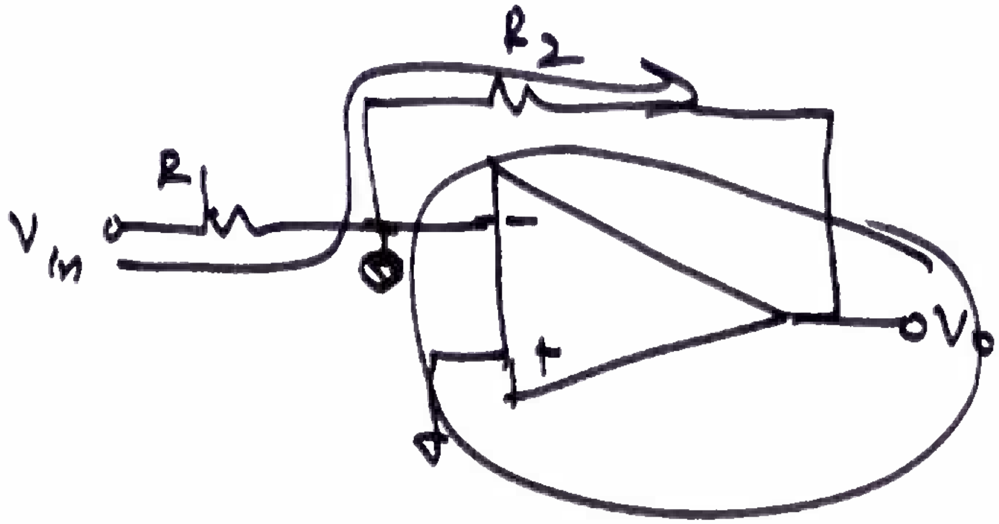

$$V_o = -\frac{R_2}{R_1} V_{in}$$

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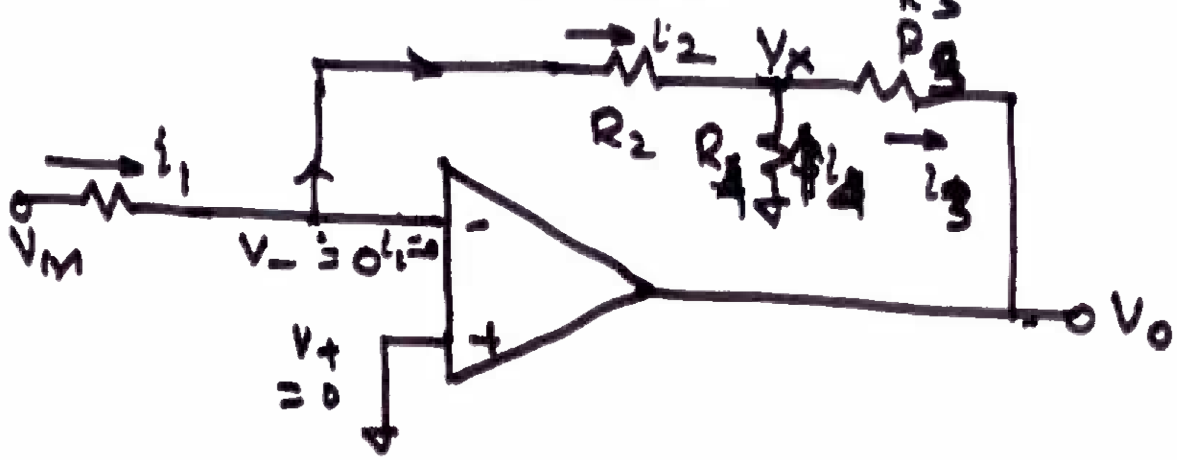
Amplifier with T-network in Feedback



$i_1 = i_2$ as $V_- = 0$ (VG)

No current enters OPAMP inputs.

$$V_x = 0 - i_2 R_2 = -i_1 R_2 = -\frac{V_{in}}{R_1} \cdot R_2$$

At node V_x: $\quad i_2 + i_4 = i_3$

$$\text{or} \quad -\frac{V_x}{R_2} - \frac{V_x}{R_4} = \frac{V_x - V_0}{R_3} \quad \text{or} \quad V_x\left[\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right] = \frac{V_0}{R_3}$$

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or $$-\frac{V_{in}}{R_1}R_2\left[\frac{1}{R_2}+\frac{1}{R_3}+\frac{1}{R_4}\right]=\frac{V_o}{R_3}$$

or $$\frac{V_o}{V_{in}} = A_V = -\frac{R_2}{R_1}\left[1+\frac{R_3}{R_4}+\frac{R_3}{R_2}\right]$$

Why T-Network ?

Larger Gain with . . . values of Resistors.

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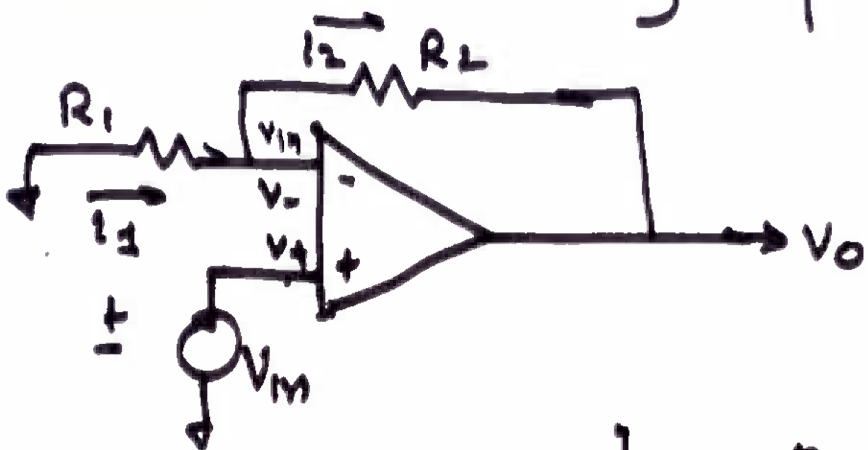
NonInverting Amplifier



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Assumption :

$R_1 \to \infty$ ∴ no current enters OPAMP inputs. ∴ $V_- = V_+$

$$i_1 = \frac{0 - V_-}{R_1} = -\frac{V_-}{R_1} = -\frac{V_+}{R_1} = -\frac{V_{in}}{R_1}$$

Then $$i_2 = \frac{V_- - V_o}{R_2} = \frac{V_{in} - V_o}{R_2}$$

But $i_1 = i_2$

or $$\frac{V_{in} - V_o}{R_2} = -\frac{V_{in}}{R_1} \quad \text{or} \quad \frac{V_o}{V_{in}} = \left(1 + \frac{R_2}{R_1}\right)$$

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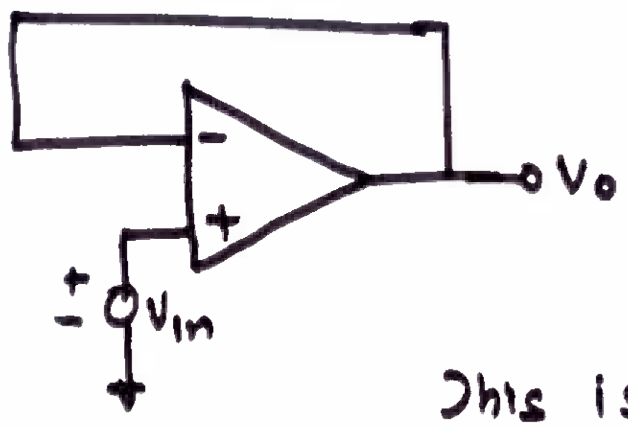
Interesting Circuit

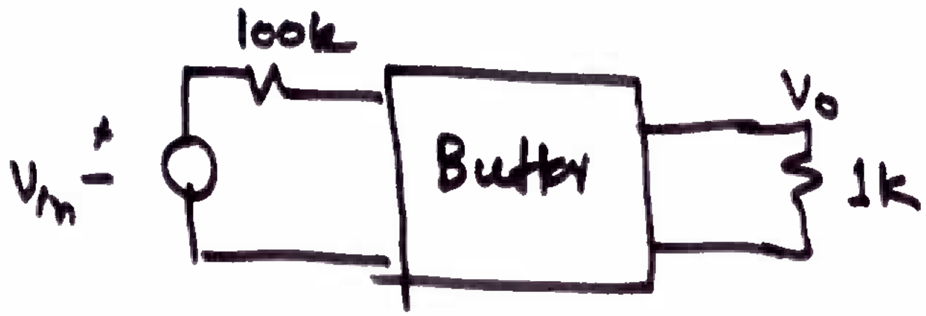


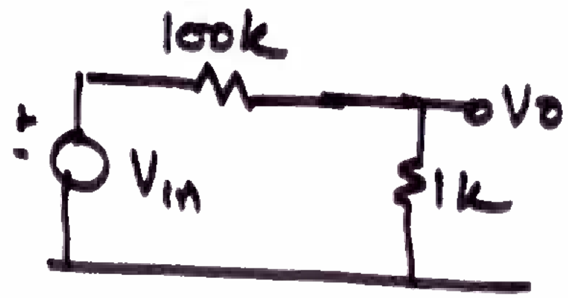
Here $V_o = V_- = V_+$

or $V_o = V_{in}$

$\therefore \quad A_V = \frac{V_o}{V_{in}} = 1$

This is called Voltage Follower or Buffer





$$\frac{V_o}{V_{in}} = \frac{1k}{101k} = 0.01$$

Severe Loading

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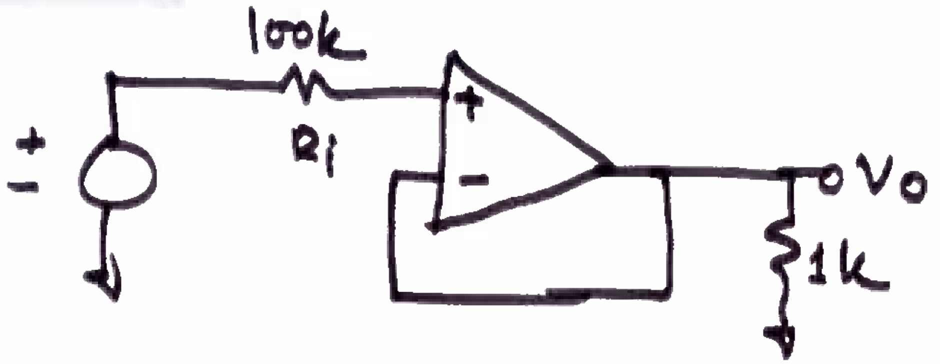
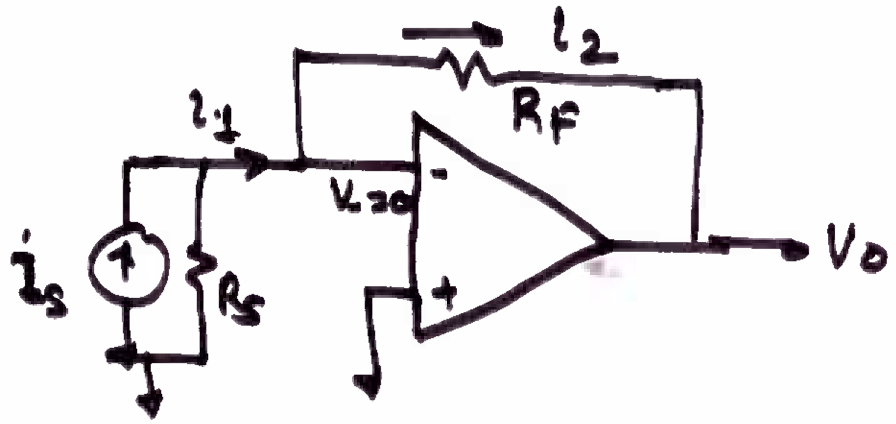


$R_i >> 100k \quad \therefore \quad V_o \cong V_{in}$

(iii) I-V Convertor



$i_1 = i_2 = I_s \qquad \text{But } i_2 = \dfrac{0 - V_o}{R_F} \qquad \therefore V_o = -i_2 R_F = -i_s R_F$

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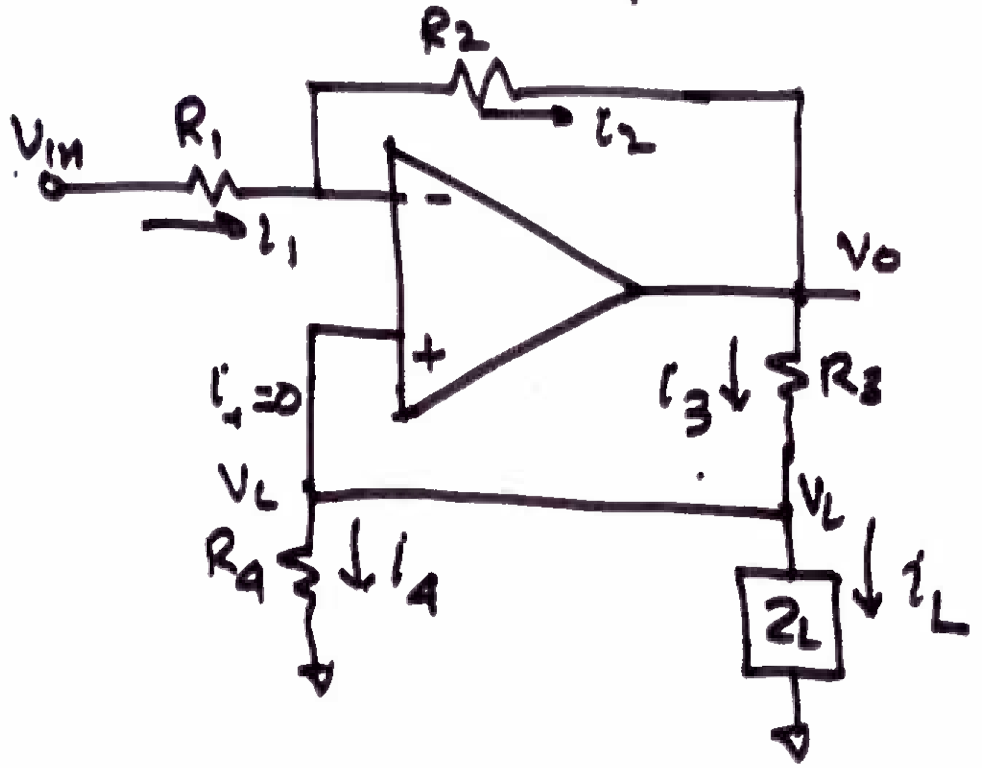
V-I Converter

Requirement : I in Load should be independent of Load Value.



Clearly $V_- = V_+ = V_L \neq 0$

$\therefore V_- = V_+ = i_L Z_L = V_L$

Also $i_1 = i_2$

(No current enters inputs)

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or $$\frac{R_2}{R_1}\cdot\left(\frac{i_L Z_L - V_{in}}{R_3}\right) = i_L + \frac{i_L Z_L}{R_4}$$

$$i_L\left[\frac{R_2}{R_1}\,\frac{Z_L}{R_3} - 1 - \frac{Z_L}{R_4}\right] = V_{in}\,\frac{R_2}{R_1 R_3}$$

For i_L to be independent of Z_L

$$\frac{R_2}{R_1 R_3} = \frac{1}{R_4}$$

Then $$\boxed{i_L = -\frac{1}{R_4}\cdot V_{in}}$$

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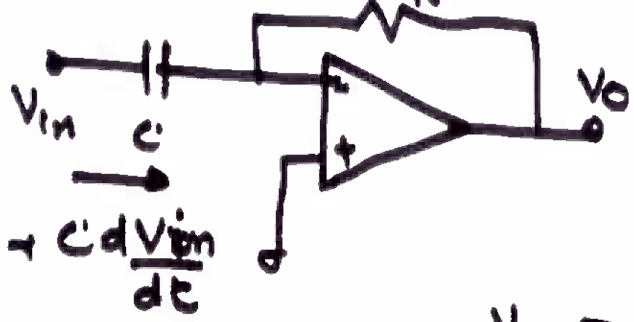
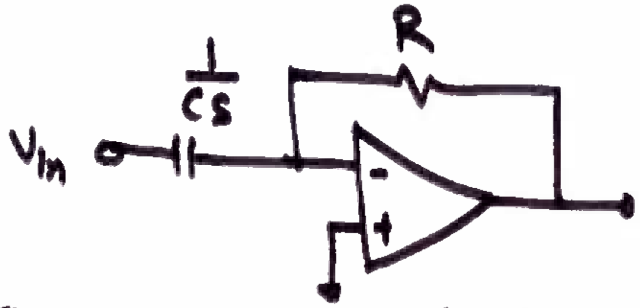
OPAMP Differentiator & Integrator



$$V_o(t) = -RC\frac{dV_{in}}{dt}$$



$$\frac{V_{in}-0}{1/Cs} = \frac{0-V_o}{R}$$

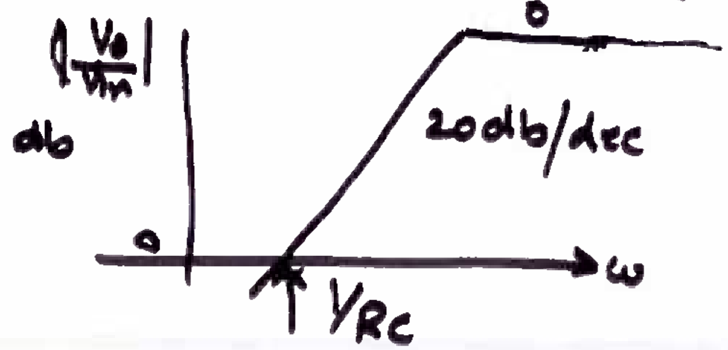
or $V_o = -RCs\,V_{in}$

$$\frac{V_o(s)}{V_{in}(s)} = RCs = -j\omega RC$$

$$\left|\frac{V_o(s)}{V_{in}(s)}\right| = \omega CR$$

$$\phi = \tan^{-1}\frac{-\omega RC}{0} = -\tan^{-1}\infty = -\pi/2$$

$$H(s) = \frac{V_o(s)}{V_{in}(s)} = RC\cdot s$$



RC ⇒ Time constant

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$$\therefore \quad \frac{V_{in} - V_L}{R_1} = \frac{V_L - V_o}{R_2}$$

$$\text{or} \quad \frac{V_{in} - i_L Z_L}{R_1} = \frac{i_L Z_L - V_o}{R_2} \quad - (1)$$

$$i_3 = \frac{V_o - V_L}{R_3} = \frac{V_o - i_L Z_L}{R_3} \quad - (2)$$

But $i_3 = i_L + i_4$ But $i_4 = \dfrac{i_L Z_L}{R_4}$

$$\therefore \quad \frac{V_o - i_L Z_L}{R_3} = i_L + \frac{i_L Z_L}{R_4} \quad - (3)$$

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Integrator

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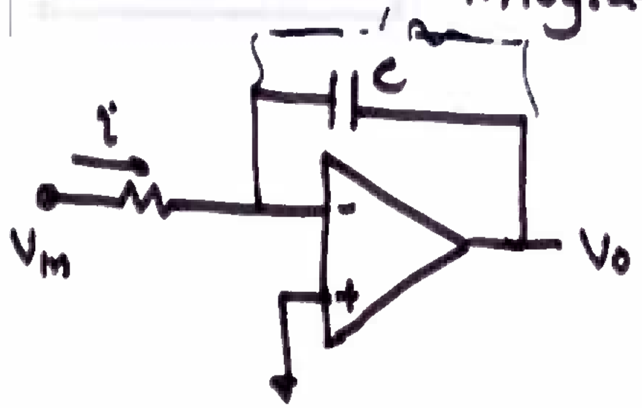


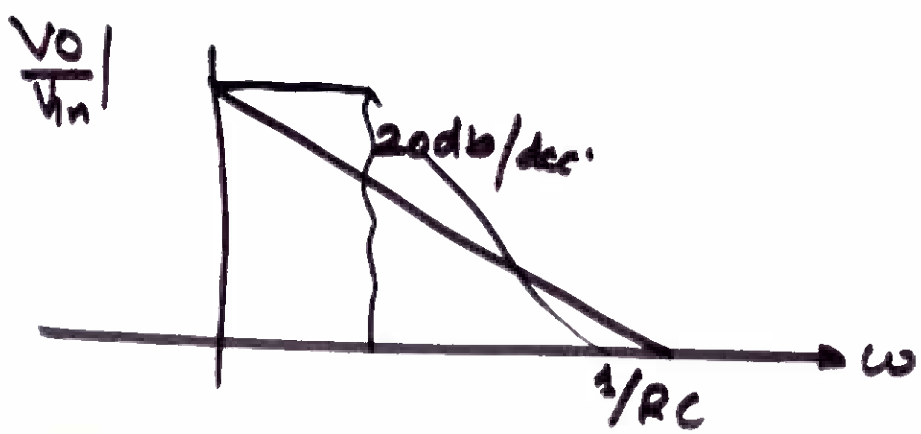
$$\frac{V_{in}}{R} = -C\frac{dV_o}{dt}$$

or $$V_o = -\left[+\frac{1}{RC}\int V_{in}\,dt + V_{co}\right]$$

$$\frac{V_o(s)}{V_{in}(s)} = -\frac{1}{sCR} = -\frac{1}{j\omega RC}$$

$$\left|\frac{V_o}{V_{in}}\right| = \frac{1}{\omega RC}$$

& $\phi = +90^0$



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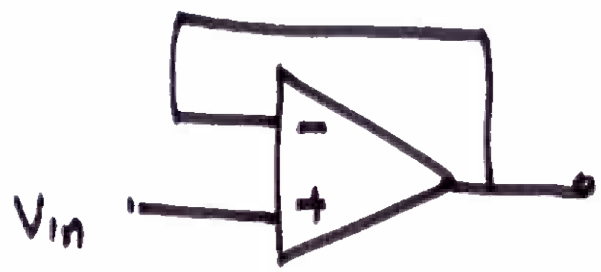
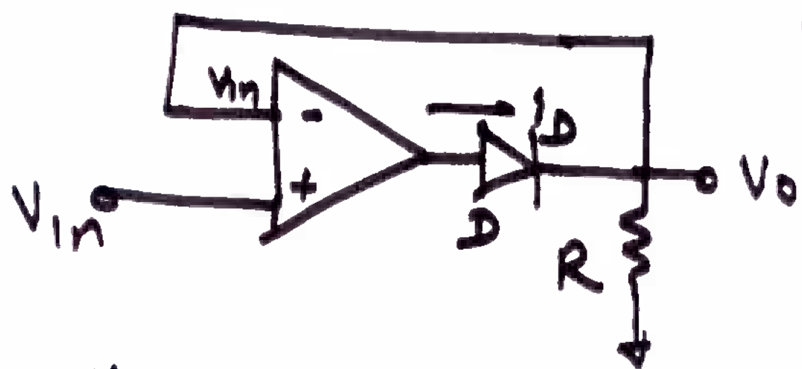
Precision Half Wave Rectifier



Follower

Modified V. Follower. Circuit



$V_{in} = +\text{tive}$

& $V_+ = V_{in} = V_-$

Diode current $I = I_S\left(e^{\frac{qV_f}{\eta kT}} - 1\right) \simeq I_S\, e^{qV_f/\eta kT}$

$\therefore \log I = \log I_S + \frac{qV_f}{\eta kT}$

$\therefore V_f = \eta\left(\frac{kT}{q}\right)\left[\log I - \log I_S\right]$

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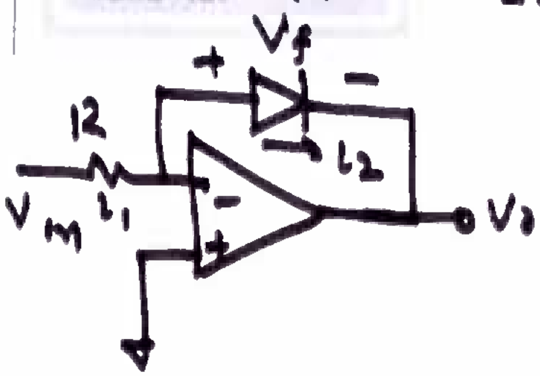
Logarithmic Amplifier



$$i_1 = \frac{V_{in}}{R} = i_2 = i_D$$

If $i_D = 0$ then $i_2 = 0$

then $V_0 = 0$

But if Diode conducts ($V_- > V_0$)

Then $V_f + V_0 = 0$ or $V_0 = -V_f = -\frac{\eta KT}{q}\left[\log i_2 - \log I_s\right]$

or $V_0 = -\frac{\eta KT}{q}\left[\log V_{in} - \log R - \log I_s\right]$

$$V_0 = -\frac{\eta KT}{q}\left[\log \frac{V_{in}}{R I_s}\right]$$

$\therefore V_0 \propto \log(V_{in})$

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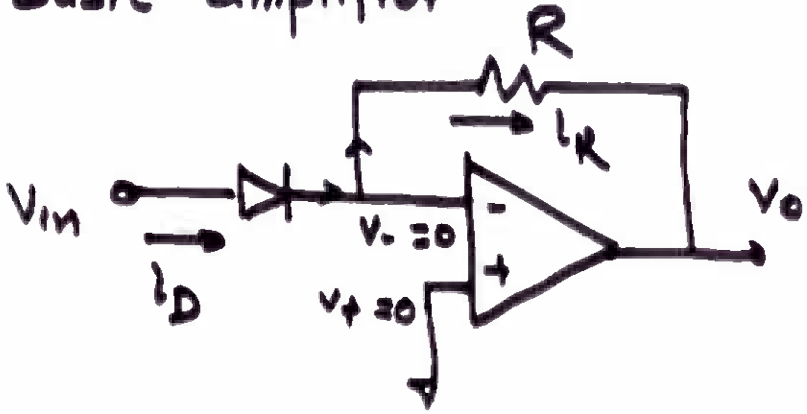
Antilog Amplifier

Basic amplifier



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We have

$$i_D = I_S \exp\left(\frac{q V_f}{\eta k T}\right)$$

As $V_- = 0$, Hence $i_R \cdot R = -V_0 = + i_D \cdot R$

$$\therefore \quad V_0 = - I_S R \exp\left(\frac{q V_f}{\eta k T}\right) \qquad \therefore \quad V_0 \propto \exp(V_f)$$

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Analog Multiplier

Mathematically $\log(AB) = \log A + \log B$

Also $AB = \text{Antilog}(AB)$

$= \text{Antilog}[\log A + \log B]$

Clearly we can get Multiplication of AB by using three amplifier and an Adder.

① Create $\log A$ ② Create $\log B$

③ Create $(\log A + \log B)$

④ Create Antilog of $[\log A + \log B]$

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We want Multiplication of V_1 & V_2