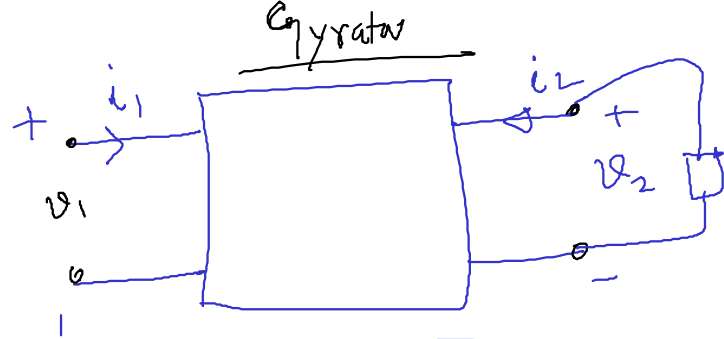
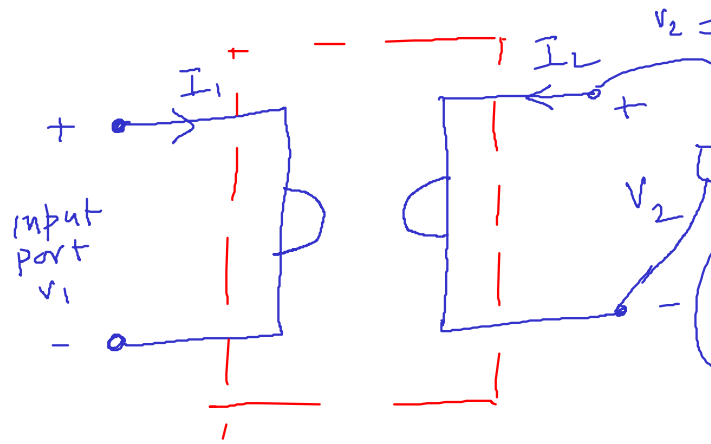




$$\begin{aligned} v_1 &= -k i_2 \\ v_2 &= k i_1 \end{aligned}$$



Dec-79

$\frac{v_2}{Z} = -I_2$

$$\begin{aligned} v_1 &= -k I_2 \\ v_2 &= k I_1 \\ \text{or } I_1 &= \frac{v_2}{k} \end{aligned}$$

$$\frac{v_1}{I_1} = -k^2 \frac{I_2}{v_2}$$

$$= \frac{k^2}{\left(\frac{v_2}{-I_2}\right)}$$

$$= \frac{k^2}{Z} \quad (\text{in } \Omega)$$

if $Z = 3 + j4 \Omega$

inductive
imp. $Z_{in} = \frac{k^2}{3 + j4} = \frac{k^2}{5 \angle 53^\circ}$

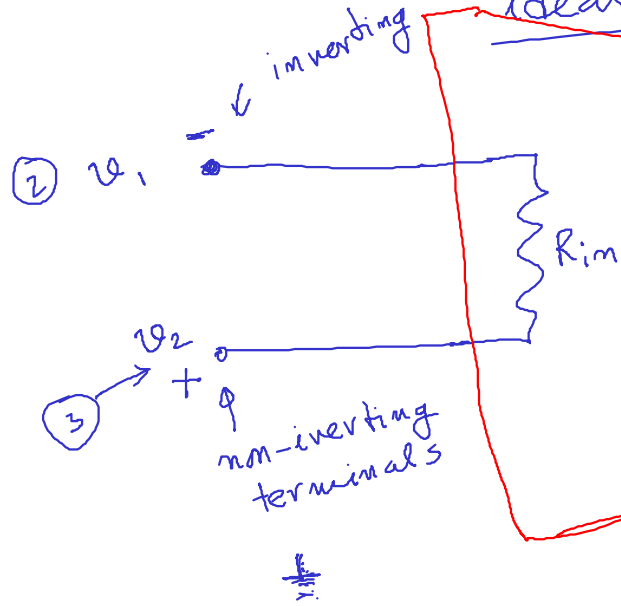
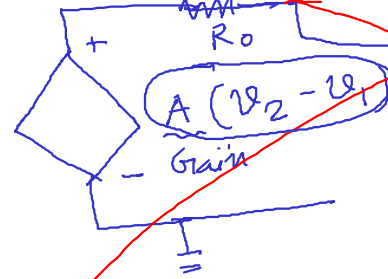
$= \frac{k^2}{5} \angle -53^\circ$

$=$ ↓ capacitive (R-C) imp.

$$Z_{in} = \frac{v_1}{I_1}$$

Circuits with OP-Amp (operational Amplifier)

↓ Differential Amplifier

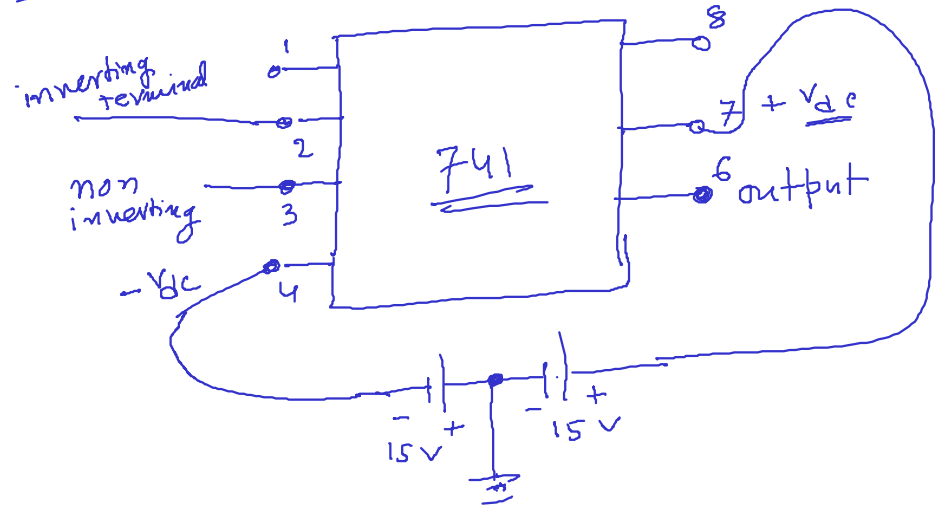


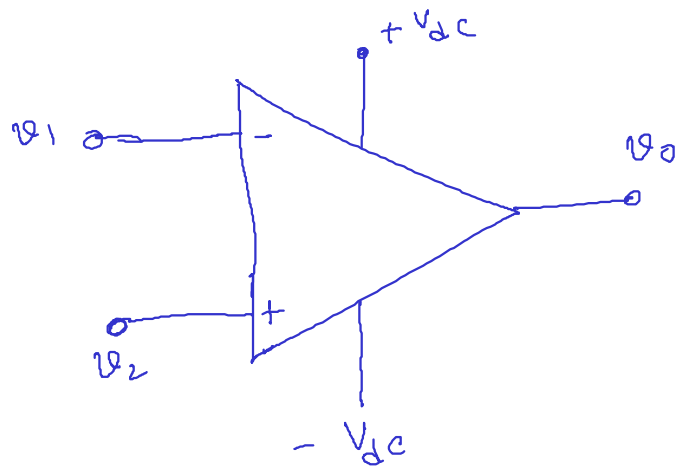
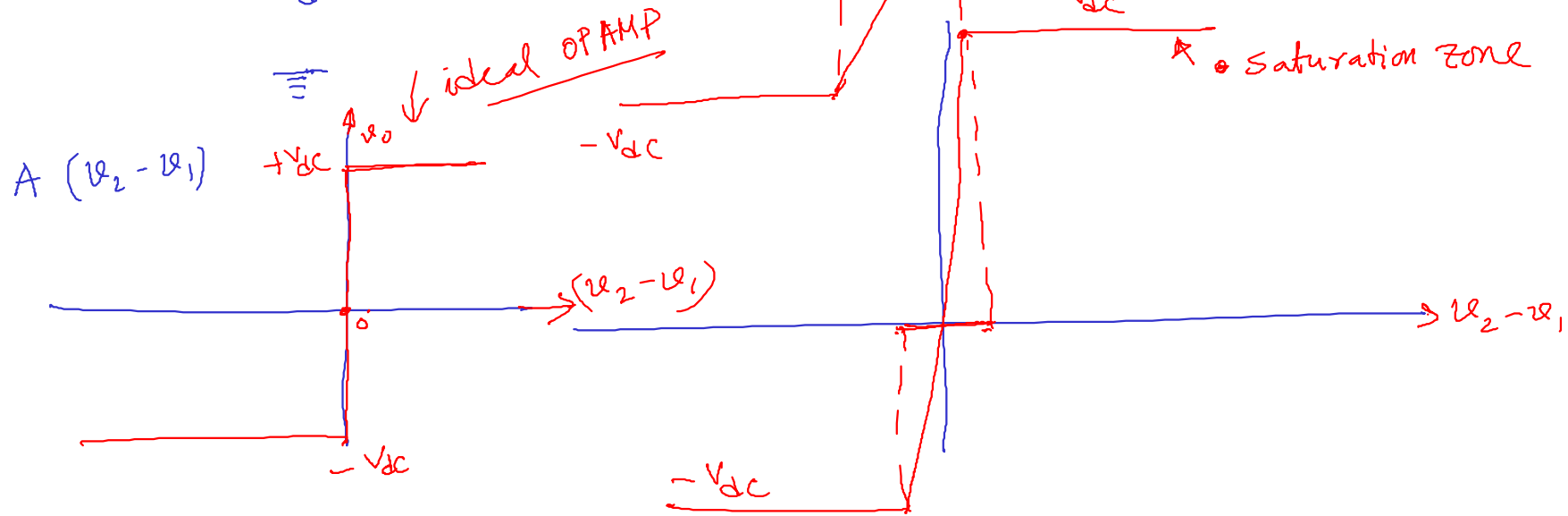
ideal OP Amp

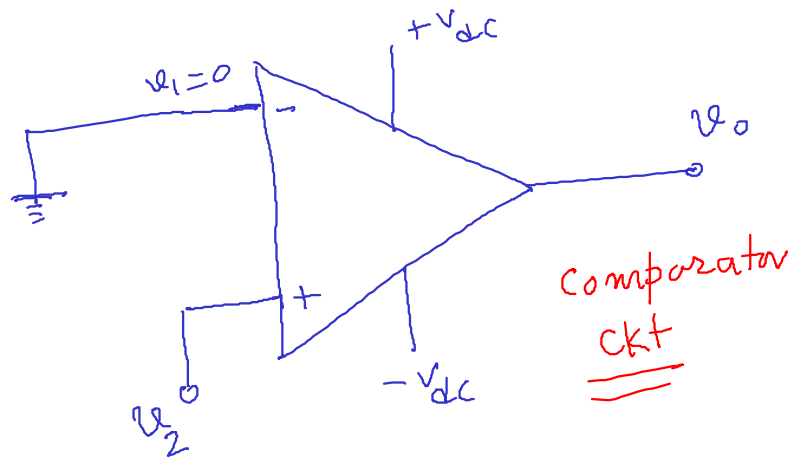
$A \rightarrow \infty$

$R_{im} \rightarrow \infty$

$R_o \rightarrow 0$



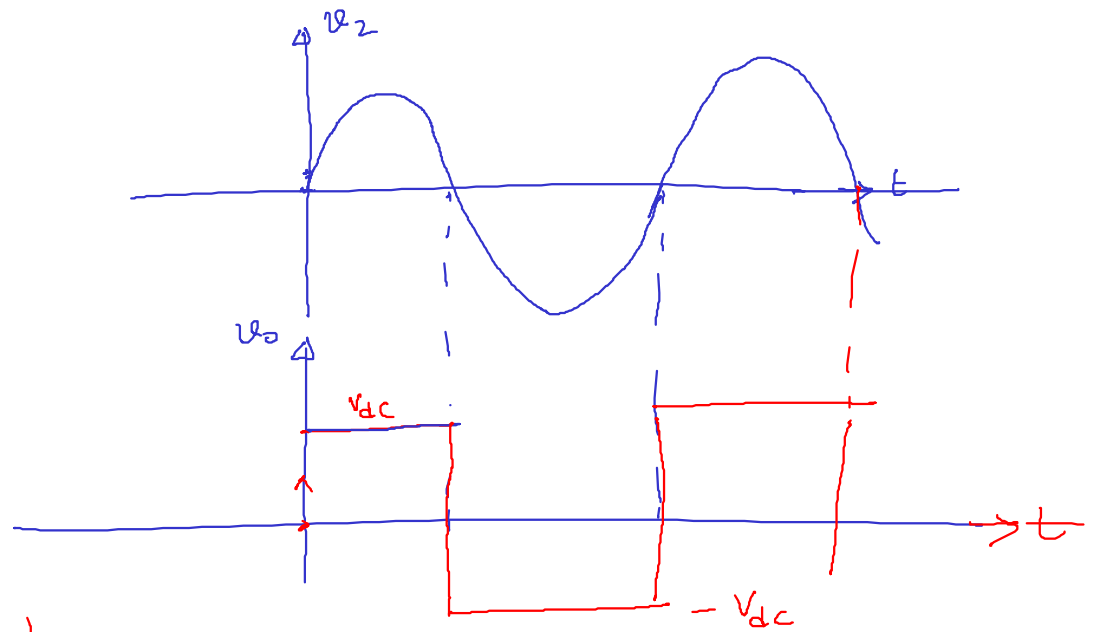


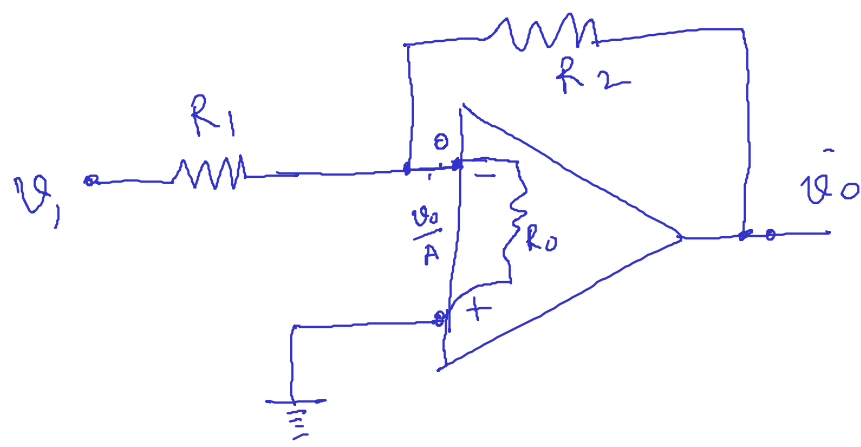


comparator
ckt

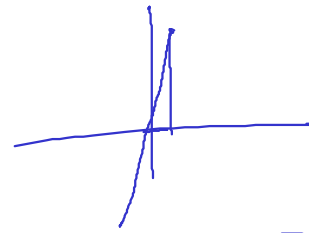
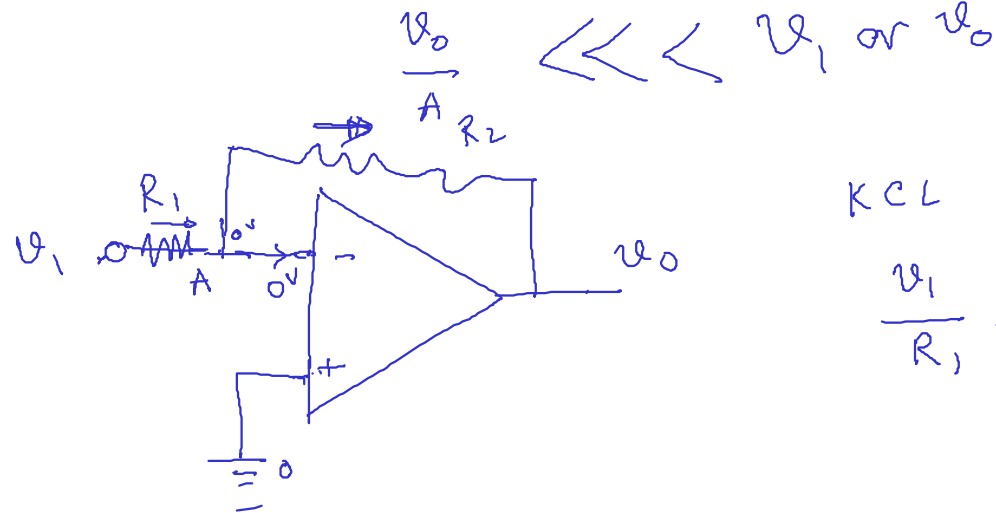
$$A(v_2 - 0)$$

$A(v_2 - v_1)$
only valid when
The op-amp
is not saturated



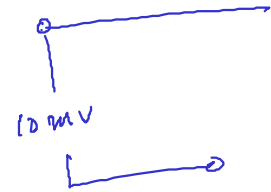


to get v_o The difference
voltage reqd. $= \frac{v_o}{A} \quad (A \rightarrow \infty)$



KCL at Point A

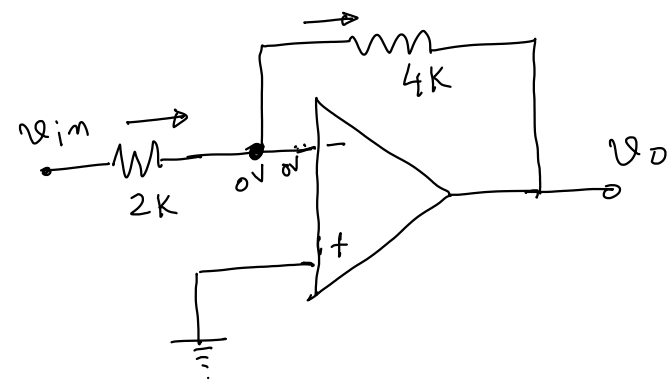
$$\frac{v_i}{R_1} = \frac{0 - v_o}{R_2}$$



or
$$v_o = -\frac{R_2}{R_1} v_i$$

Circuits with ideal OP-AMP

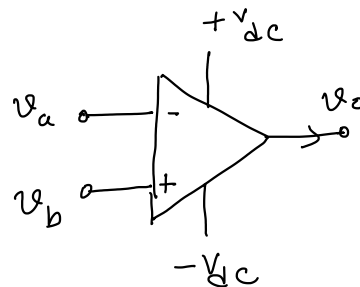
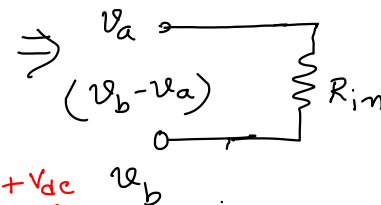
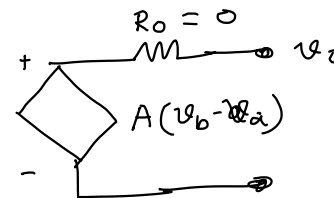
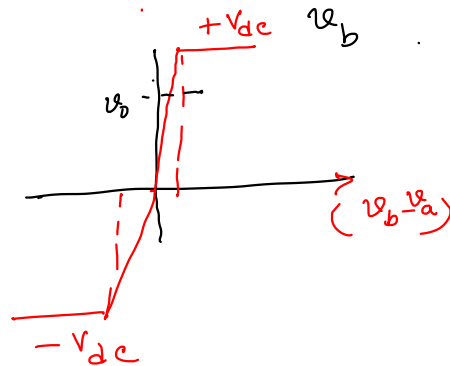
Lec-80



for ideal

$$\frac{v_{in} - 0}{2} = \frac{0 - v_o}{4}$$

$$\text{or } \boxed{v_o = -2v_{in}}$$

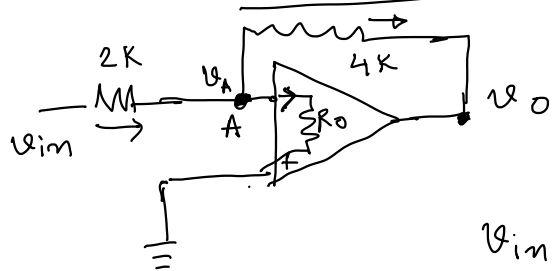


Let The OPAMP is ideal

$$R_o = 0$$

$$R_{in} = 100K$$

$$A = 10000$$



KCL at A

$$\frac{v_{in} - v_A}{2} = \frac{v_A - v_o}{4} + \frac{v_A}{1000} = 0$$

$$\frac{v_{in} - v_o/10000}{2} = \frac{(v_o/10000) - v_o}{4} + \frac{v_o}{1000 \times 10000} = 0$$

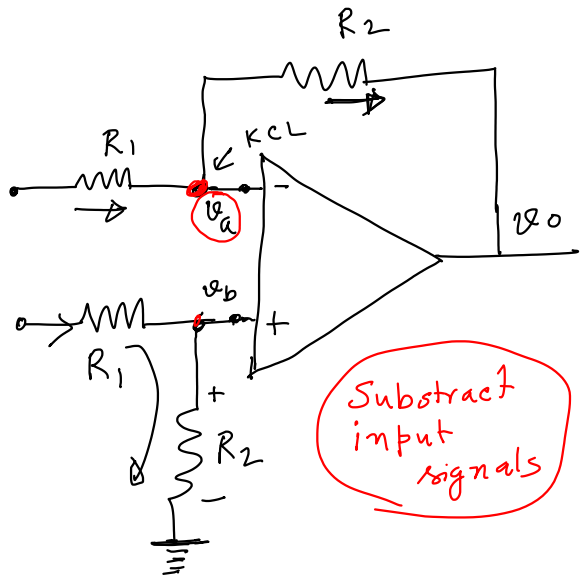
$$v_o = A(v_A - 0)$$

$$\text{or } v_o = 10000 v_A$$

$$\text{or } v_A = v_o / 10000$$

$$v_o \approx 2v_{in}$$

input signals
 v_1
 v_2



Subtract
input
signals

Ideal OPAMP

$$v_a = v_b$$

$$v_b = \frac{v_2 R_2}{(R_1 + R_2)} = v_a$$

$$\frac{v_1 - v_a}{R_1} = \frac{v_a - v_0}{R_2}$$

$$\frac{v_1}{R_1} - \frac{v_a}{R_1} = \frac{v_a}{R_2} - \frac{v_0}{R_2}$$

v_a & v_b

or

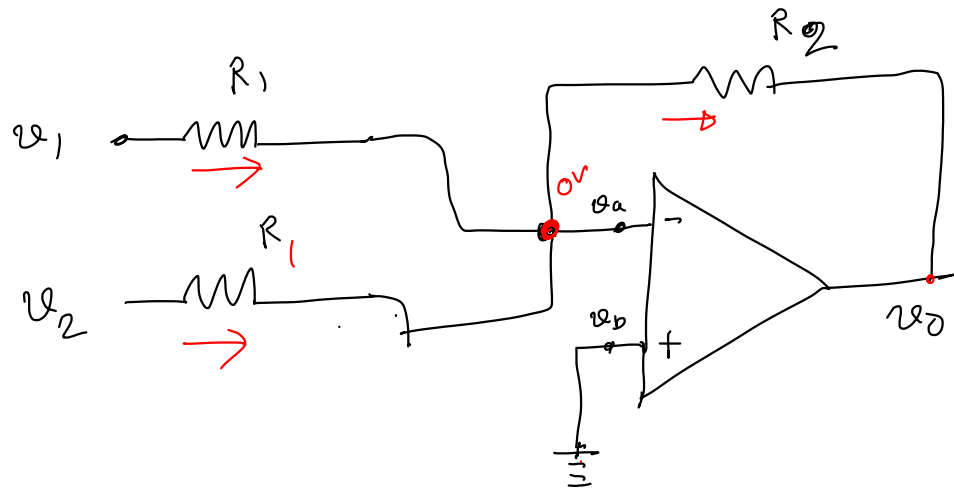
$$\frac{R_2}{(R_1 + R_2)} \left(\frac{1}{R_1} + \frac{1}{R_2} \right) v_2 - \frac{v_1}{R_1} = \frac{v_0}{R_2}$$

$$\text{or } v_a \left(\frac{1}{R_1} + \frac{1}{R_2} \right) - \frac{v_1}{R_1} = \frac{v_0}{R_2}$$

$$\text{or } \frac{R_2}{R_1 R_2} v_2 - \frac{v_1}{R_1} = \frac{v_0}{R_2}$$

$$\text{or } \frac{(v_2 - v_1)}{R_1} = \frac{v_0}{R_2} \text{ or } v_0 = \frac{R_2}{R_1} (v_2 - v_1)$$

$$v_0 = \frac{R_2}{R_1} (v_2 - v_1)$$



$$v_a = v_b = 0$$

• KCL

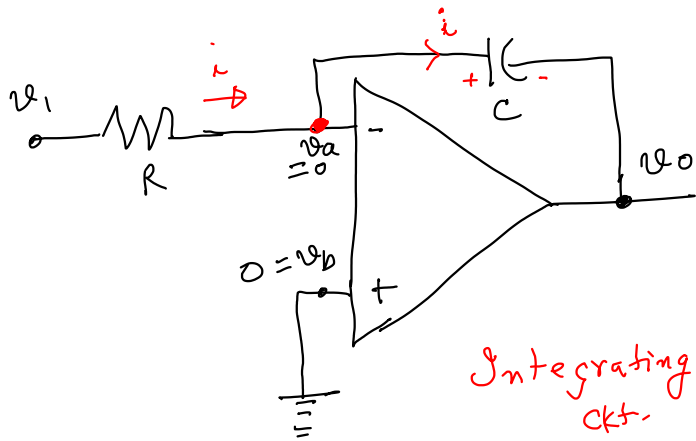
$$\frac{v_1}{R_1} + \frac{v_2}{R_1} = \frac{0 - v_o}{R_2}$$

or

$$v_o = -\left(\frac{R_2}{R_1} v_1 + \frac{R_2}{R_1} v_2\right)$$

$$\boxed{v_o = -\frac{R_2}{R_1} (v_1 + v_2)}$$

dec-81



$$v_a - v_b = 0 \text{ for ideal OPAMP}$$

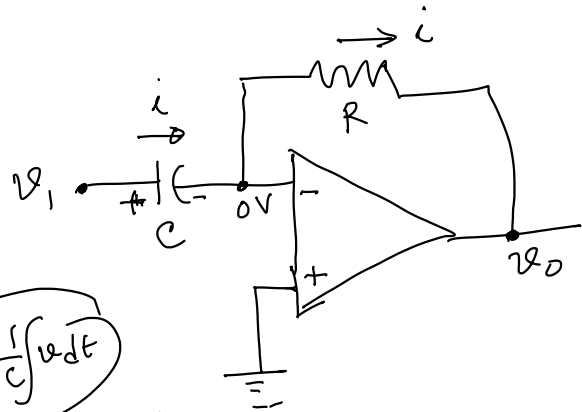
KCL at •

$$\frac{v_1 - v_a}{R} = \frac{v_1}{R} = i$$

$$(v_a - v_o) = \frac{1}{C} \int i dt$$

$$\text{or } v_o = - \frac{1}{C} \int i dt$$

$$v_o = - \frac{1}{RC} \int v_1 dt$$



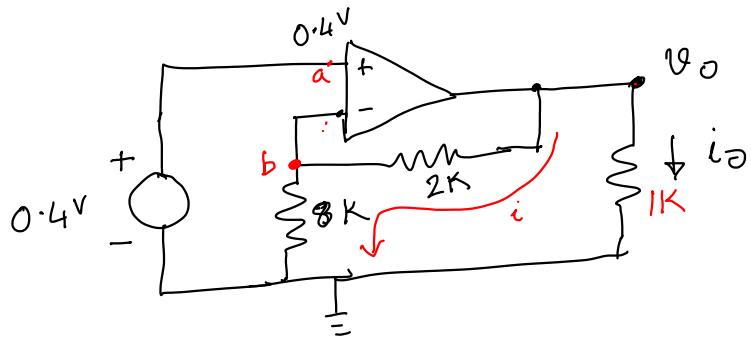
$$i = \frac{1}{C} \int v dt$$

$$i = C \frac{dv}{dt}$$

$$i = C \frac{dv_1}{dt} \parallel \parallel = \frac{0 - v_o}{R} = C \frac{dv_1}{dt}$$

$$\text{or } v_o = - RC \frac{dv_1}{dt}$$

Differentiator



$$V_a = V_b$$

$$V_a = 0.4$$

$$i = \frac{V_o}{8+2} = \frac{V_o}{10}$$

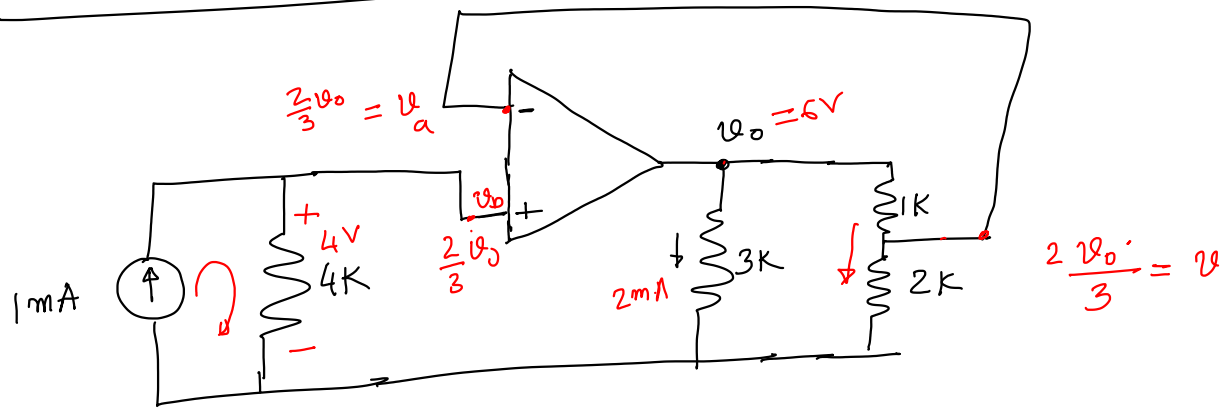
$$V_b = \frac{8V_o}{10} = \frac{4V_o}{5}$$

$$V_a = V_b = \frac{4V_o}{5} = 0.4$$

$$V_o = 0.5 \text{ V}$$

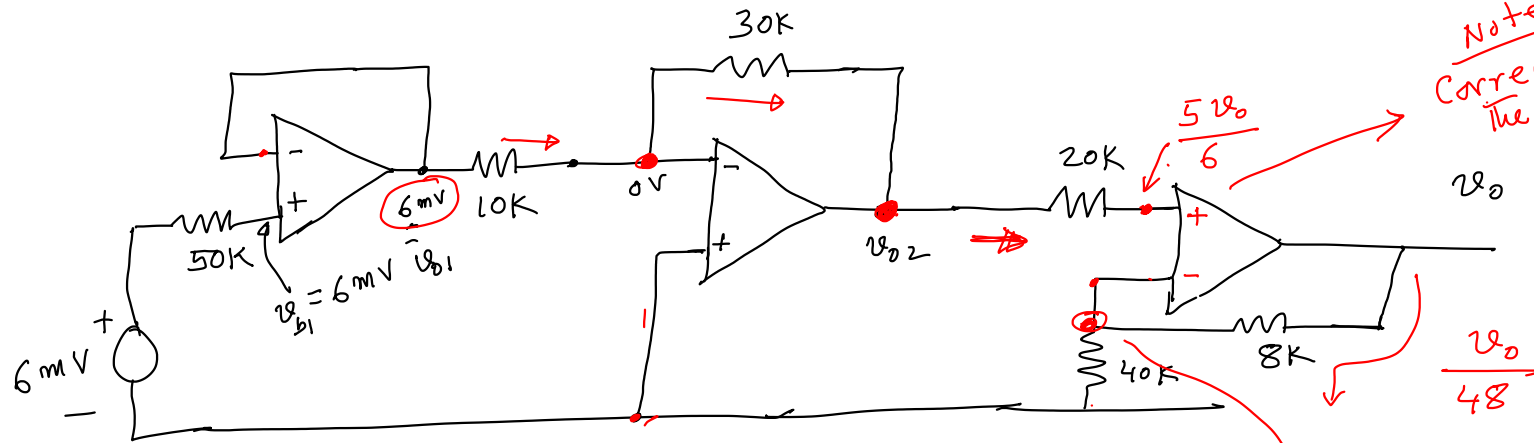
$$\therefore i_o = \frac{0.5 \text{ V}}{1 \text{ K}} = 0.5 \text{ mA}$$

Another Example



$$\frac{2}{3}v_o = 4 \quad \text{or} \quad v_o = \frac{12}{2} = \underline{\underline{6\text{ V}}}$$

Example :-



Note:
Correct
the inverting
& non-inverting
terminals

$$\text{eg. } \frac{6 \times 10^{-3} - 0}{10} = \frac{0 - v_{o2}}{30}$$

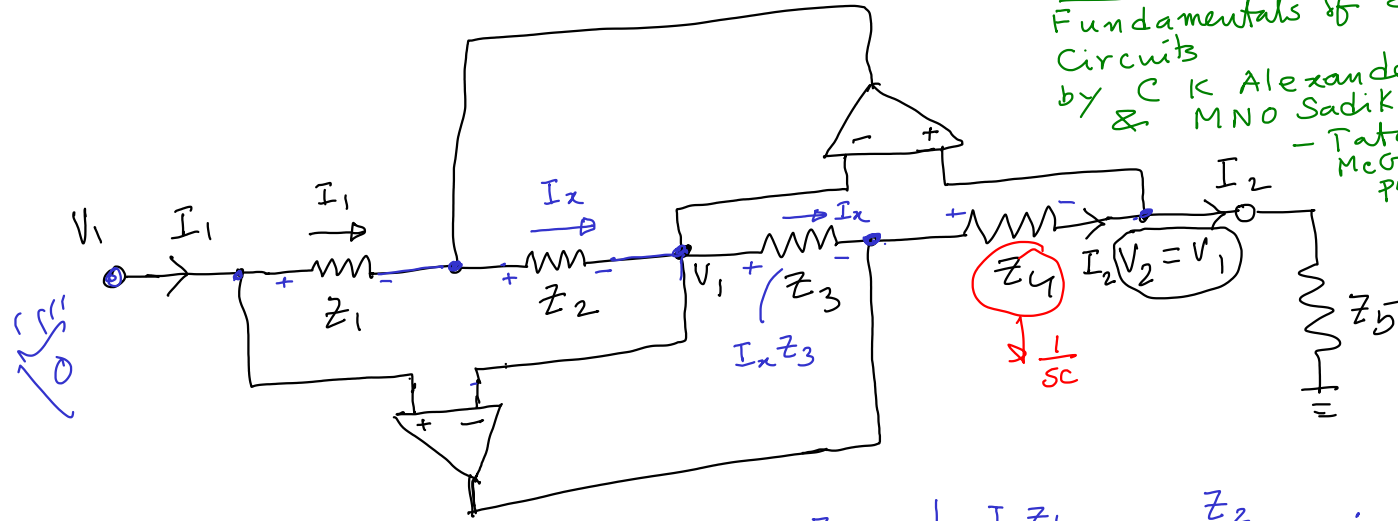
$$\therefore \boxed{v_{o2} = -18 \text{ mV}}$$

$$\frac{-18 - \frac{5v_o}{6}}{20} = 0$$

$$\therefore \frac{5v_o}{6} = -18 \quad \text{or} \quad v_o = -\frac{18 \times 6}{5} = -21.6 \text{ mV}$$

Book:
Fundamentals of Electric
Circuits
by C K Alexander
& MNO Sadiku
- Tata
McGraw Hill
pub.

$$\frac{V_1}{I_1} = ?$$



Z_1 & Z_2 in parallel: $I_1 Z_1 = -I_x Z_2$
 Z_3 & Z_4 in parallel: $I_2 Z_4 = -I_x Z_3$

$$\frac{I_1 Z_1}{I_2 Z_4} = \frac{Z_2}{Z_3}$$

$$I_2 = \frac{Z_1 Z_3}{Z_2 Z_4} I_1$$

or Impedance seen
from the input side

$$Z_{in} = \frac{V_1}{I_1} = \frac{Z_1 Z_3 Z_5}{Z_2 Z_4}$$

Let $Z_1 = Z_3 = Z_5 = R$
 and $Z_4 = \frac{1}{sC}$

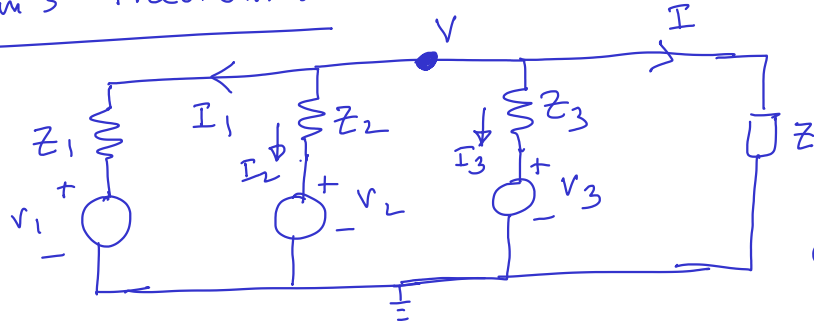
Then $Z_{in} = \frac{R^3}{1/sC} = R^2 C = R^2 L_{eq}$

$$Z_{in} = \frac{R^3}{R} \frac{1}{Z_4} = R^2 / Z_4$$

$$Z_4 = \bar{R} + j\bar{X}$$

$$\frac{1}{Z} = R_{eq} - j\bar{X}$$

Millman's Theorem :-



KCL gives

$$\frac{V - V_1}{Z_1} + \frac{V - V_2}{Z_2} + \frac{V - V_3}{Z_3} + \frac{V}{Z} = 0$$

or

$$V \left(\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} + \frac{1}{Z} \right) = \frac{V_1}{Z_1} + \frac{V_2}{Z_2} + \frac{V_3}{Z_3}$$

Concluding Remarks :-

KVL, KCL, Mesh Analysis, Nodal analysis

Sources :- voltage source & current source

Solⁿ of differential Equⁿ. (Classical way)

Laplace Transform to s domain network $\xleftarrow{\substack{sL \\ 1/sC}}$

Response of circuit due to an impulse (current)

$$V = \frac{\frac{V_1}{Z_1} + \frac{V_2}{Z_2} + \frac{V_3}{Z_3}}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} + \frac{1}{Z}}$$

$$v(t) \rightarrow V(s)$$

$$i(t) \rightarrow I(s)$$

$$V(s) = Z(s) I(s)$$

$$I(s) = \frac{V(s)}{Z(s)}$$

- Network Theorem:-
- Substitution Theorem ✓
 - Thevenin & Norton's Theorem ✓✓
 - Theory of Reciprocity
 - Millman's Theorem.

Network Analysis with graph Theorem. : ✓

Two Port Network

$$[Z], [Y], [T]_{ABCD}, [h], [g]$$

ideal transformer, gyrator as two port network

Circuit using ideal ~~OP-AMP~~ OPAMP
with -ve feed back.

— 0 —