Basic Electronic Circuits

Credit Structure (L-T-P-Cr): (3-0-3-4.5)

Course Code: EL103

Instructor Introduction:

Name: Dr. Rajib Lochan Das
Qualification: PhD, IIT Kharagpur

Research Interest:

- Graph Signal Processing
- Machine Learning
- Adaptive Signal Processing
- Compressive Sensing
- Image Processing
- Biomedical Signal Processing
- Hardware Implementation of Adaptive Algorithms

Teaching Interest:

- Signals and Systems
- Digital Signal Processing
- Analog Electronics
- Circuit Theory
- Digital Logic Design
- Control Systems
- Adaptive Signal Processing

TOPICS COVERED:

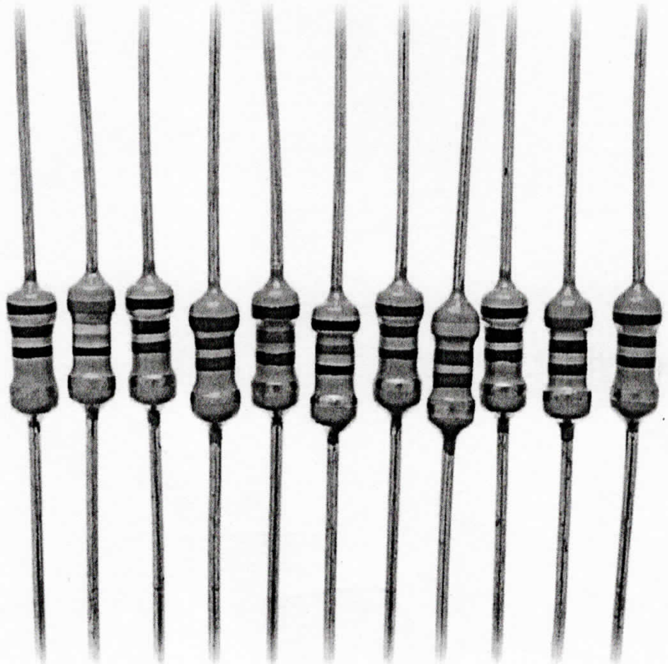
1. Resistive Electric Circuits:
   - I. Charge, current and voltage
   - II. Ohm's law and ideal sources
   - III. Kirchhoff's voltage & current Law
   - IV. Node analysis and Mesh analysis
   - V. Thevenin & Norton equivalents
2. Electric Circuits with Capacitors and Inductors
   - I. First and Second Order Circuits and its D.C Response
   - II. Laplace Transform and Sinusoidal Steady-State Analysis of RC, RL and RLC Circuits
   - III. Phasor Diagrams, Frequency Response and Filters
3. Two-Port Networks
4. Diode and Transistors
5. Operational Amplifiers

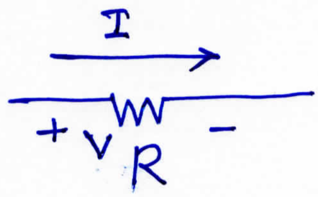
Books:

1. “Fundamentals of Electric Circuits” by Charles K Alexander and Matthew N. O. Sadiku
2. “Engineering Circuit Analysis” by W. H. Hayt and J. E. Kemmerley
3. “Network Analysis” by Van Valkenberg
4. “Network Analysis & Synthesis” by Franklin S. KUO
5. “Introduction to Electric Circuits” by R. C. Dorf and J. A. Svoboda
6. “Microelectronic Circuits: Theory And Applications” by Adel S. Sedra and Kenneth C. Smith
7. “Electronic Circuits: Analysis And Design” by Donald A. Neamen
8. “Integrated Electronics: Analog and Digital Circuits and Systems” by Jacob Millman and Christos Halkias
9. “Design with Operational Amplifiers and Analog Integrated Circuits” by Sergio Franco

Circuit Elements:

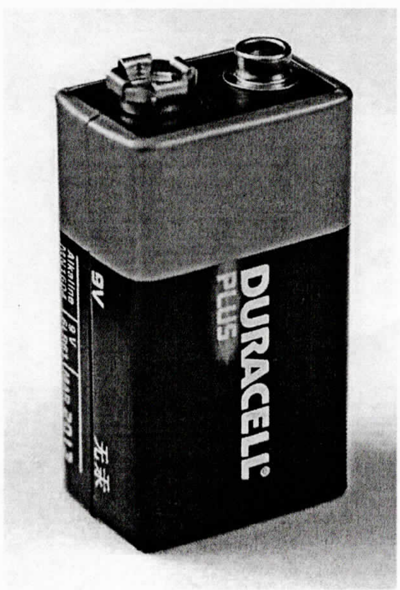
1. Resistors

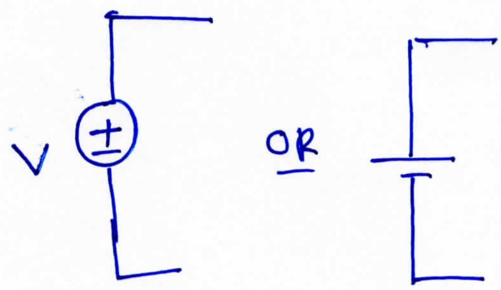




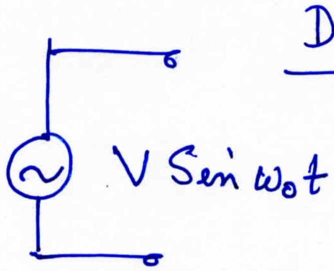
$V = IR$

2. Battery (Voltage Source)





D.C



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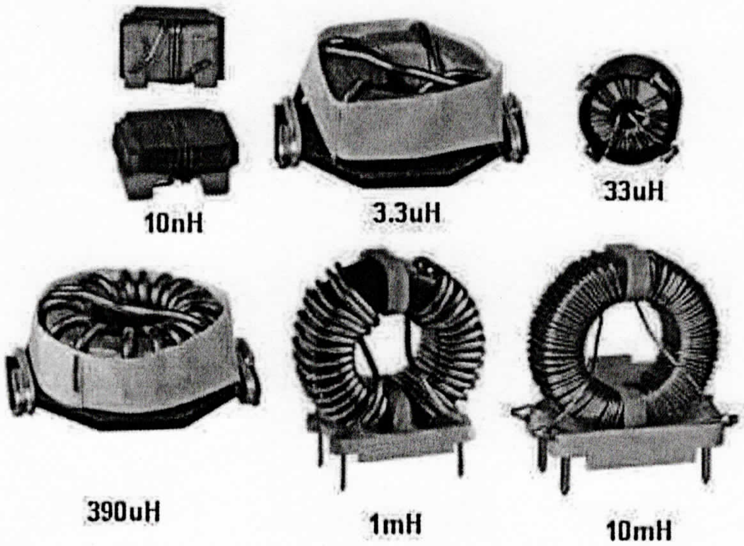
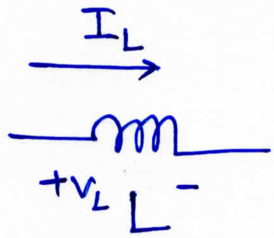
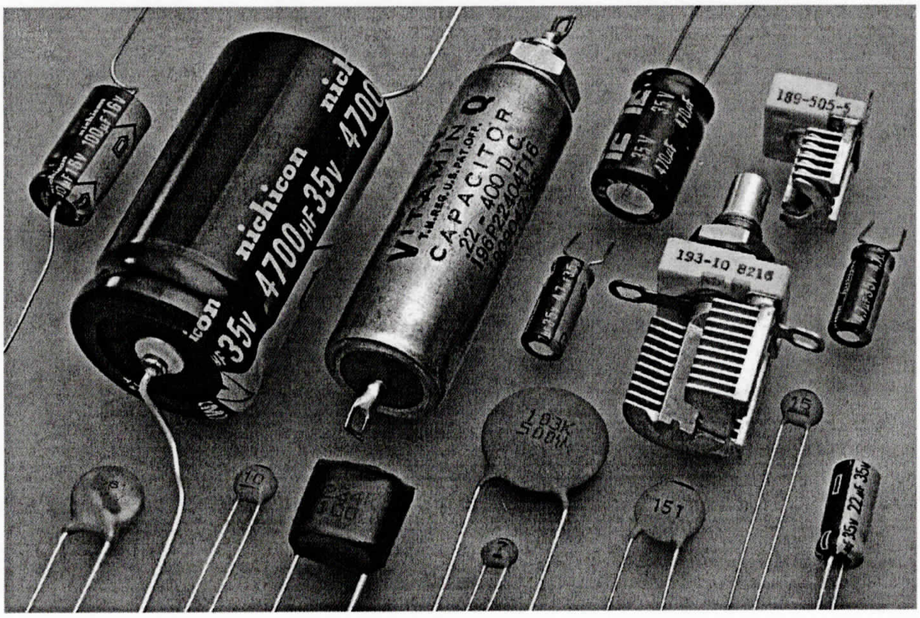
3. Inductors

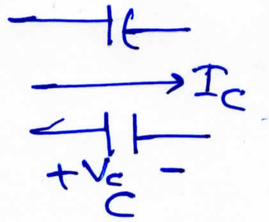




$$\boxed{V_L = L\frac{dI_L}{dt}}$$

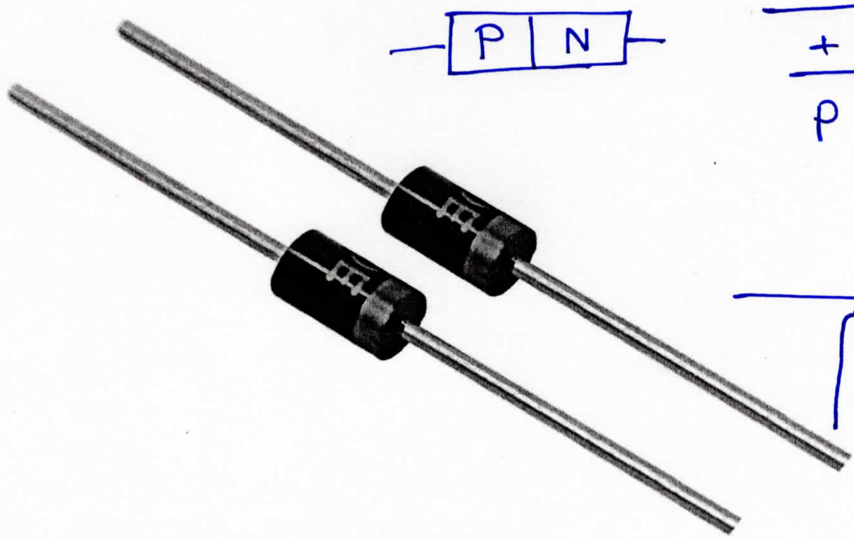
4. Capacitors

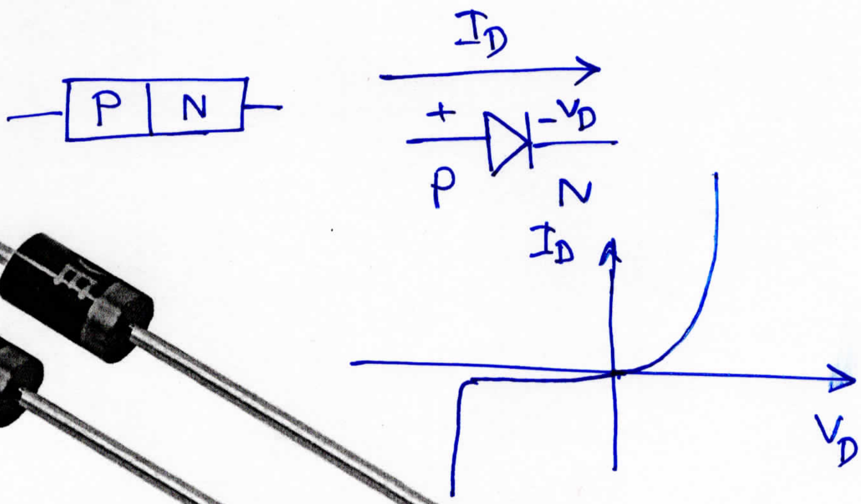




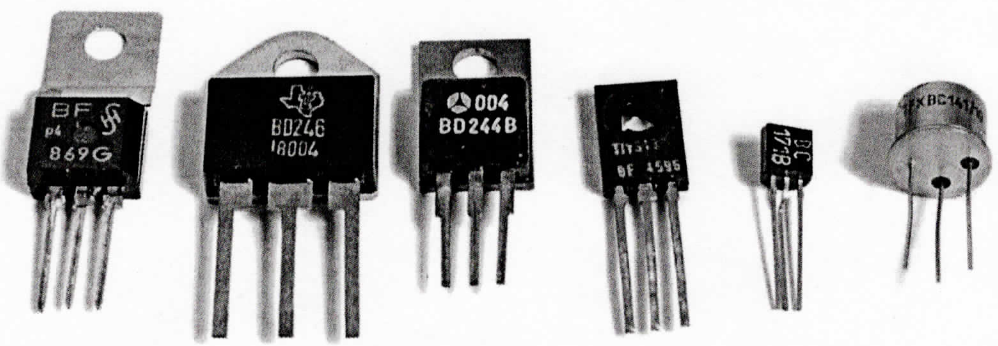
$$\boxed{I_c = C\frac{dv_c}{dt}}$$

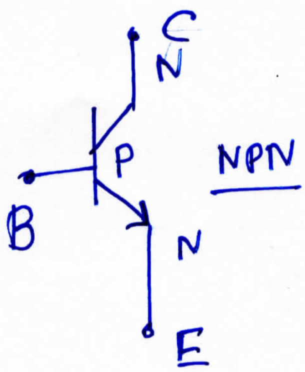
5. Diode

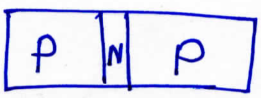


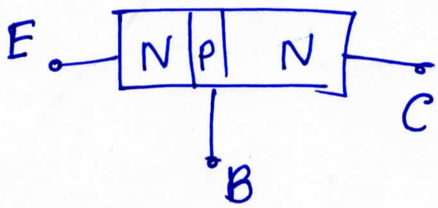


6. Transistors

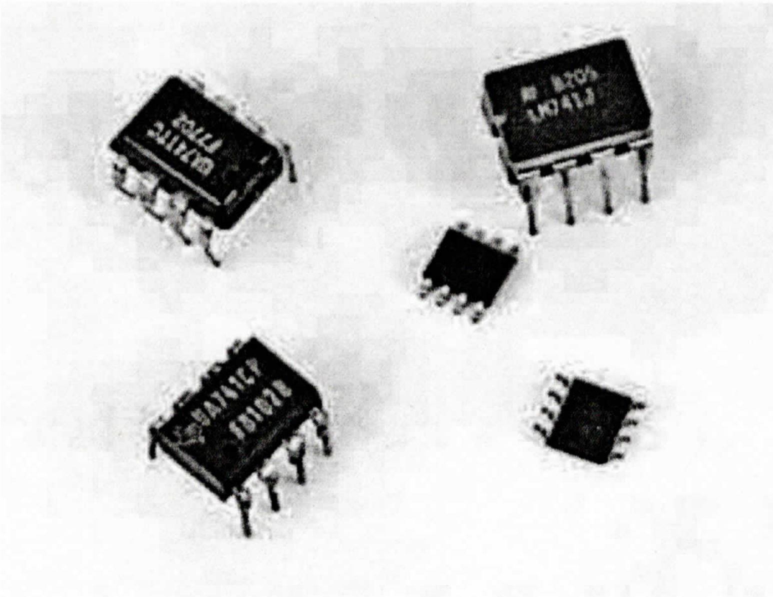








7. Operational Amplifiers



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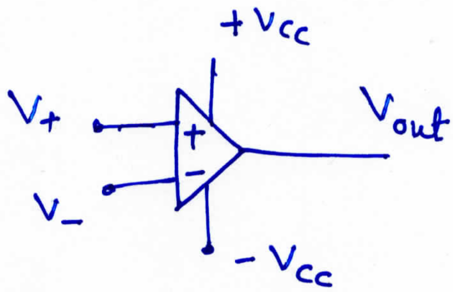
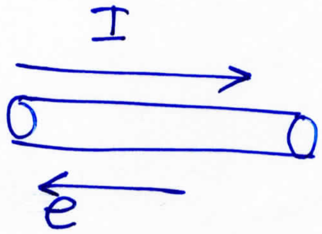
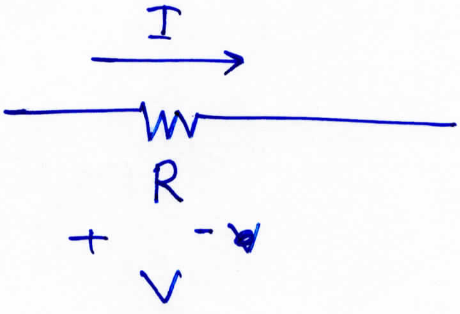


Resistive Circuits



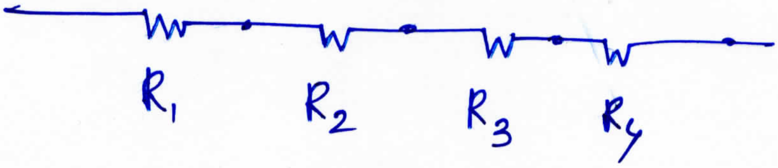
$$I = \frac{dq}{dt}$$



1) Ohm's law

$$V = IR$$

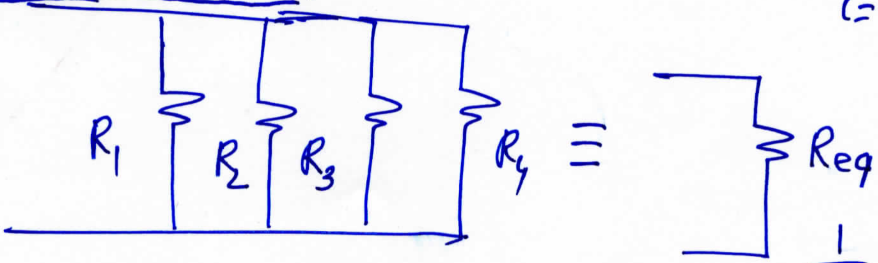
2) Series Connection of Resistances



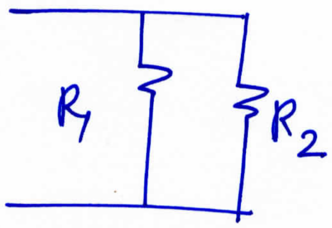
$$\equiv$$

$$R_{eq} = R_1 + R_2 + R_3 + R_4 = \sum_{i=1}^{4} R_i$$

3) Parallel Connection



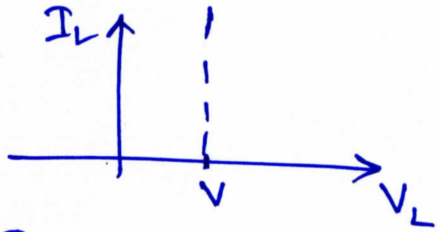
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

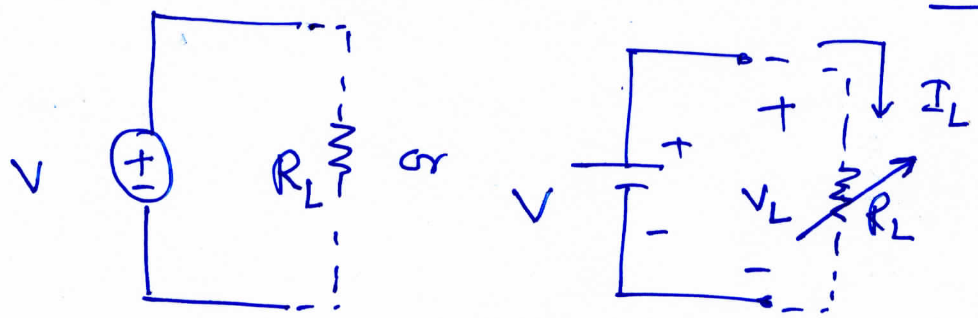


$$\Rightarrow \quad R_{eq} = \frac{R_1 R_2}{R_1 + R_2} < \min[R_1, R_2]$$

when $R_1 = R_2 = R$, $\quad R_{eq} = \dfrac{R}{2}$

9) Voltage Sources

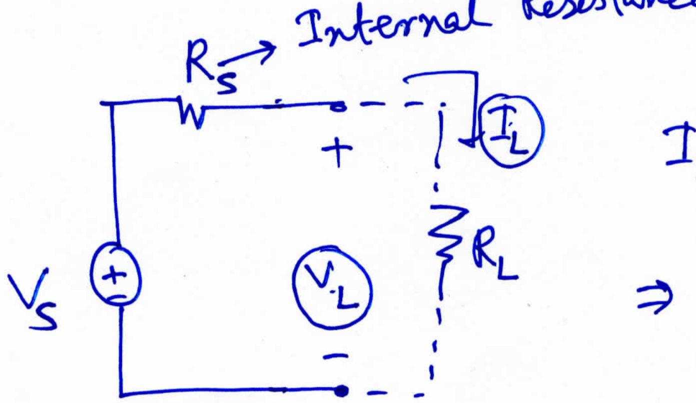




$$I_L = \frac{V}{R_L}$$

$$V_L = V$$

ideal DC Voltage Source $(R = 0)$



$$I_L = \frac{V_s}{R_s + R_L}$$

$$\Rightarrow \quad V_s = I_L R_s + I_L R_L$$

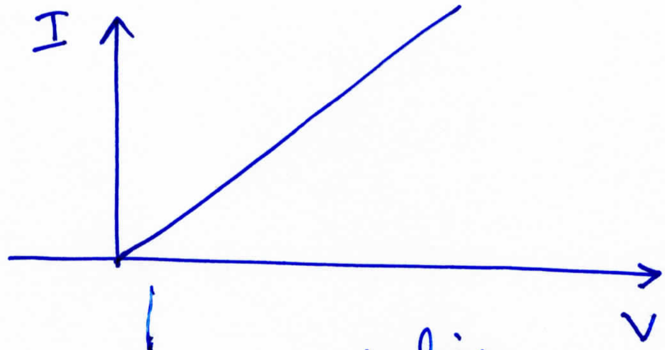
$$V_L = I R_L$$

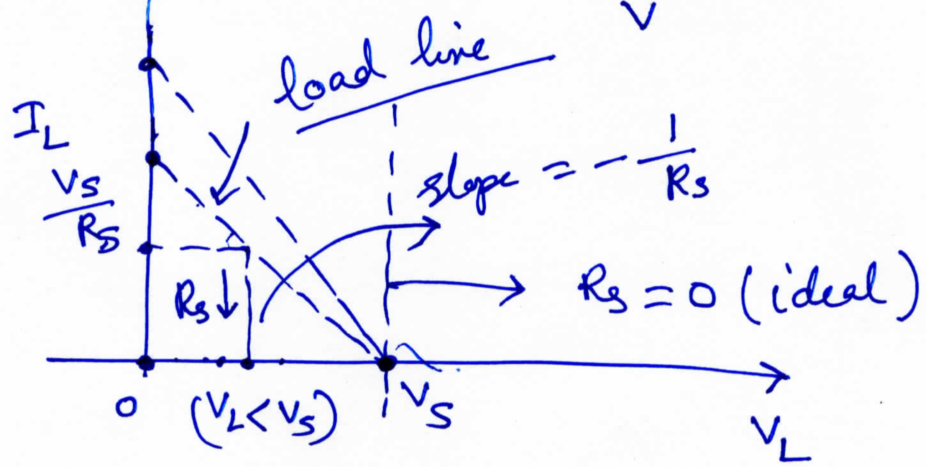
practical voltage Source

$(R \neq 0)$

$$V_L = I_L R_L$$

$$\boxed{R_L >> R_s}$$

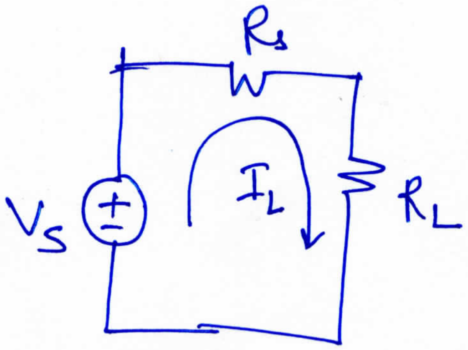




$$V_S = I_L R_S + I_L R_L = I_L R_S + V_L$$

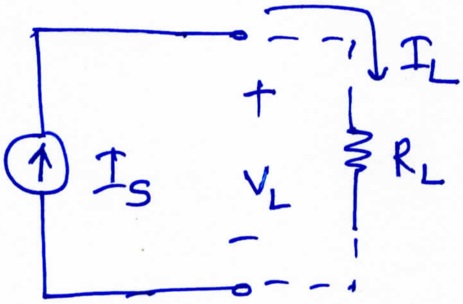
$$\Rightarrow \boxed{V_L + I_L R_S = V_S} \rightarrow \text{load line equation}$$

$V_S, R_S \rightarrow$ Constant



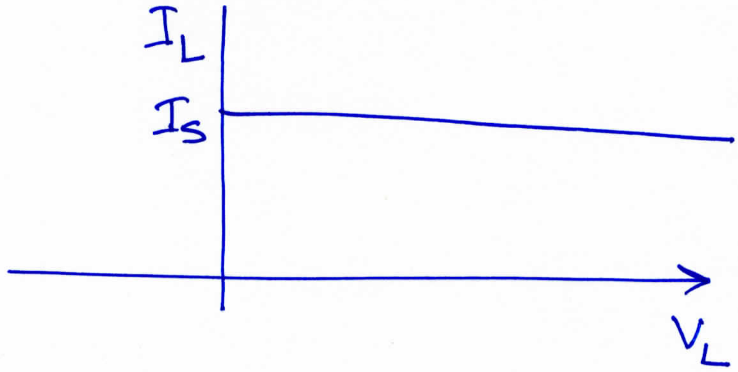
$$I_L = \frac{V_S}{R_S + R_L}$$

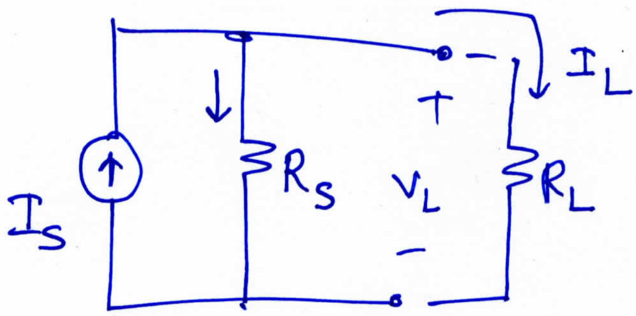
Current Source



$$I_L = I_S$$

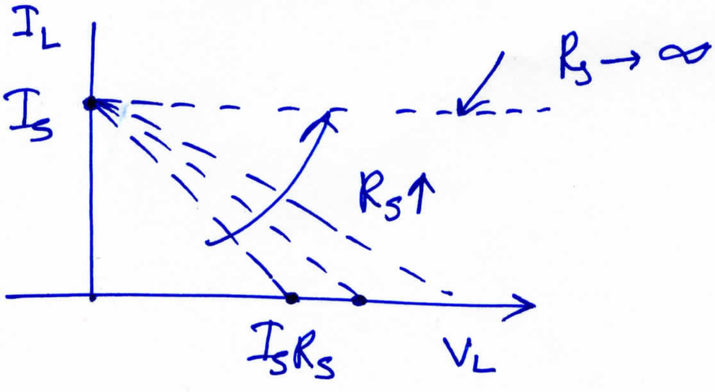
DC Current Source ($R_S \to \infty$)



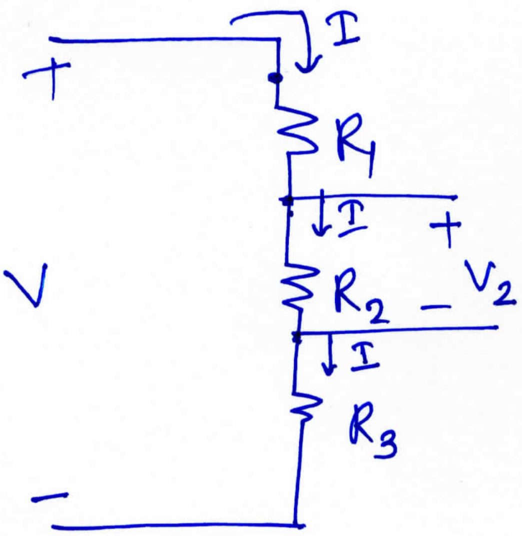


$$\boxed{R_S \gg R_L}$$

$$\boxed{I_S = \frac{V_L}{R_S} + I_L}$$



Voltage Divider



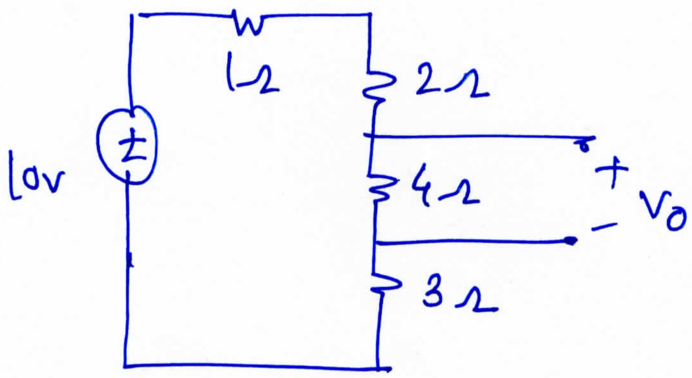
$$I = \frac{V}{R_1+R_2+R_3}$$

$$V_2 = I R_2$$

$$= \left(\frac{R_2}{R_1+R_2+R_3}\right) \times V$$

$$V_2 \propto R_2$$

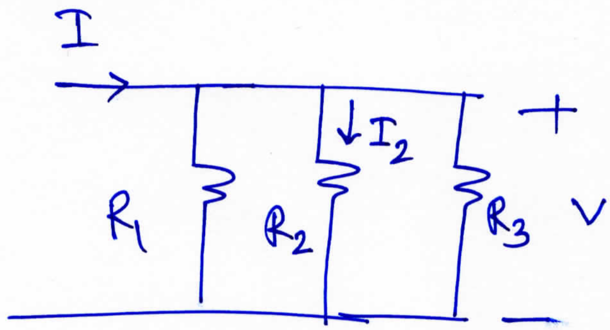
ex



$$V_o = \frac{4}{1+2+4+3} \times 10$$

$$= \frac{4}{10} \times 10 = 4V$$

Current Divider



$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$= y_1 V + y_2 V + y_3 V$$

where $y_i = \frac{1}{R_i}$, $i = 1, 2, 3$

$$= (y_1 + y_2 + y_3) V$$

$$\Rightarrow V = \frac{I}{y_1 + y_2 + y_3}$$

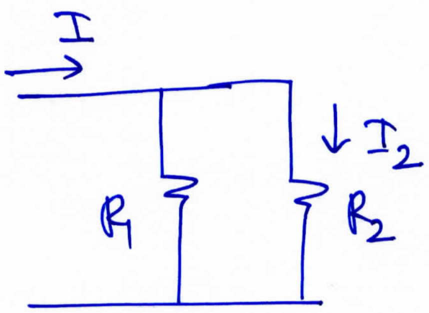
$$\Rightarrow I_2 = \frac{V}{R_2} = y_2 V$$

$$= y_2 \times \frac{I}{y_1 + y_2 + y_3}$$

$$= \left(\frac{y_2}{y_1 + y_2 + y_3} \right) \times I$$

$$I_2 \propto y_2$$

For two-resistances

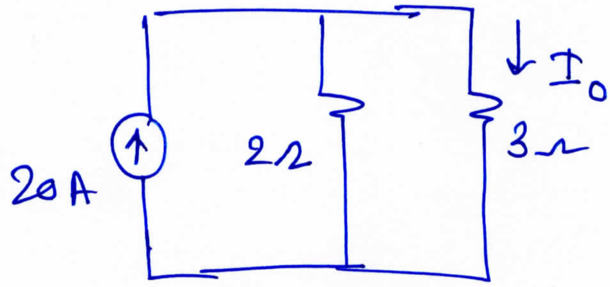


$$I_2 = \frac{Y_2}{Y_1+Y_2} \times I$$

$$= \frac{\frac{1}{R_2}}{\frac{1}{R_1}+\frac{1}{R_2}} \times I$$

$$= \frac{R_1}{R_1+R_2} \times I$$

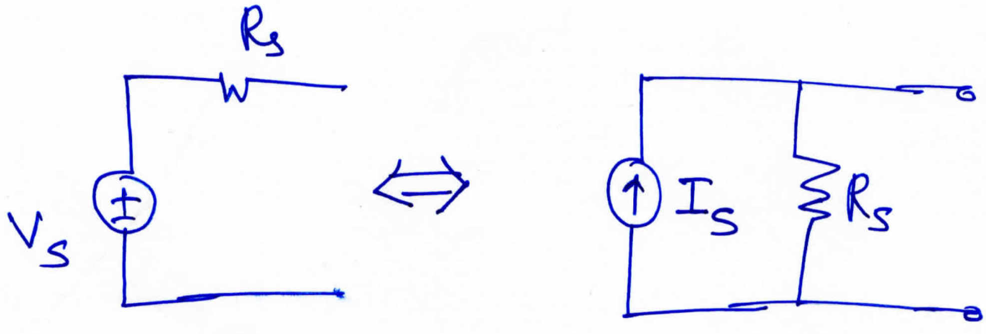
ex



$$I_0 = \frac{2}{2+3} \times 20$$

$$= 8A$$

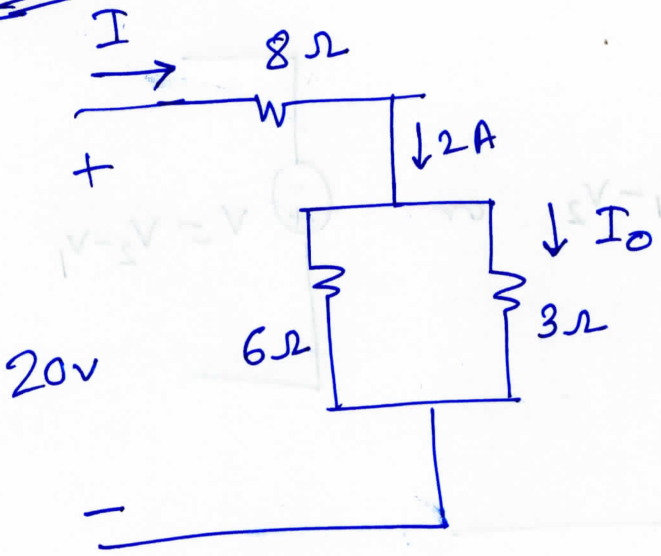
Source Transformation :-



$V_s = I_s R_s$

$I_s = \frac{V_s}{R_s}$

ex.1.



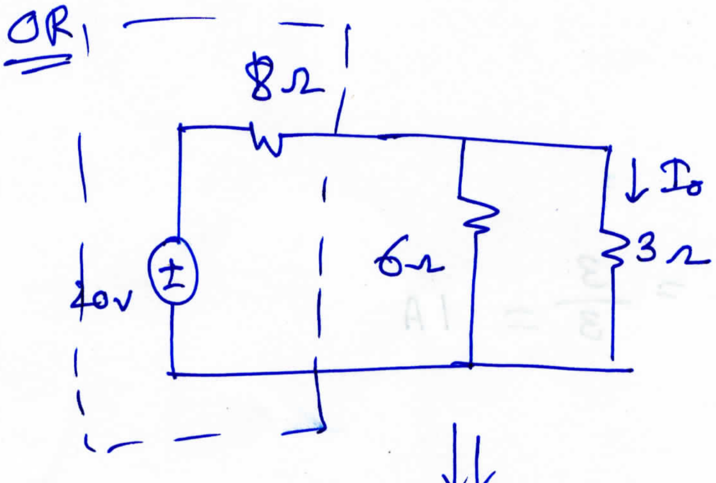
$$6 \| 3 = \frac{6 \times 3}{6+3} = 2\Omega$$

$$I = \frac{20}{8+2} = 2\,A$$

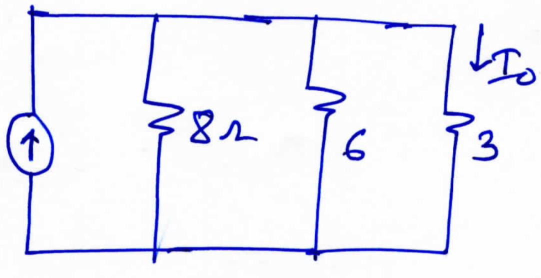
$$I_o = \frac{6}{3+6} \times I = \frac{\overset{2}{\cancel{6}}}{\underset{3}{\cancel{9}}} \times 2$$

$$= \frac{4}{3}\,A$$

OR,



$\Downarrow$

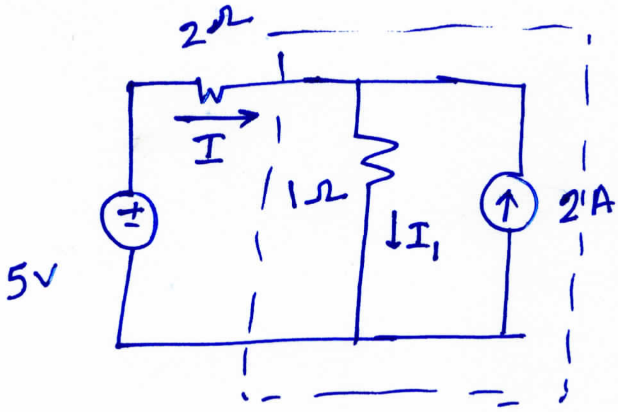


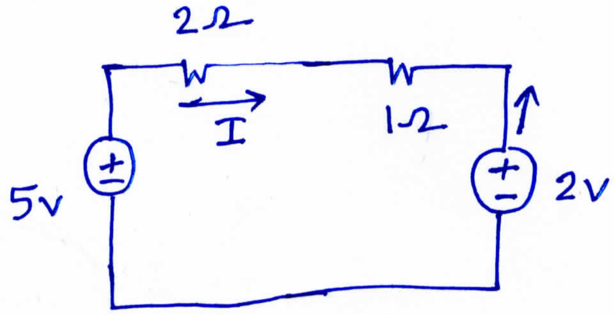
$$I_s = \frac{20}{8} = \frac{5}{2}A$$

$$I_o = \frac{\frac{1}{3}}{\frac{1}{8}+\frac{1}{6}+\frac{1}{3}} \times \frac{5}{2}$$

$$= \frac{4}{3}A$$

ex.

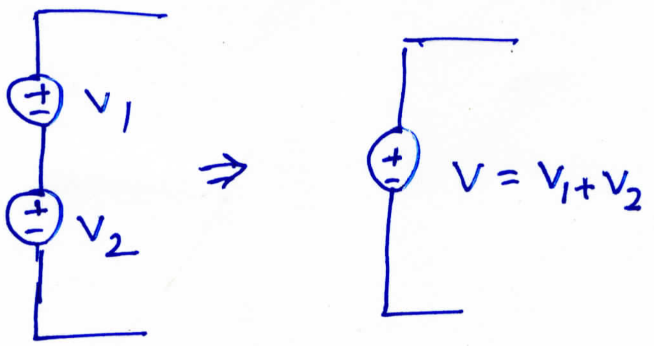


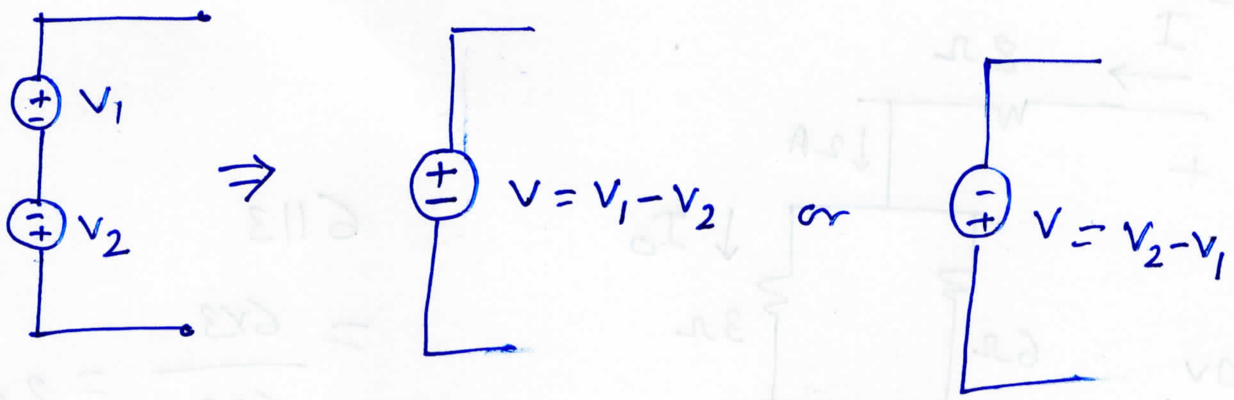


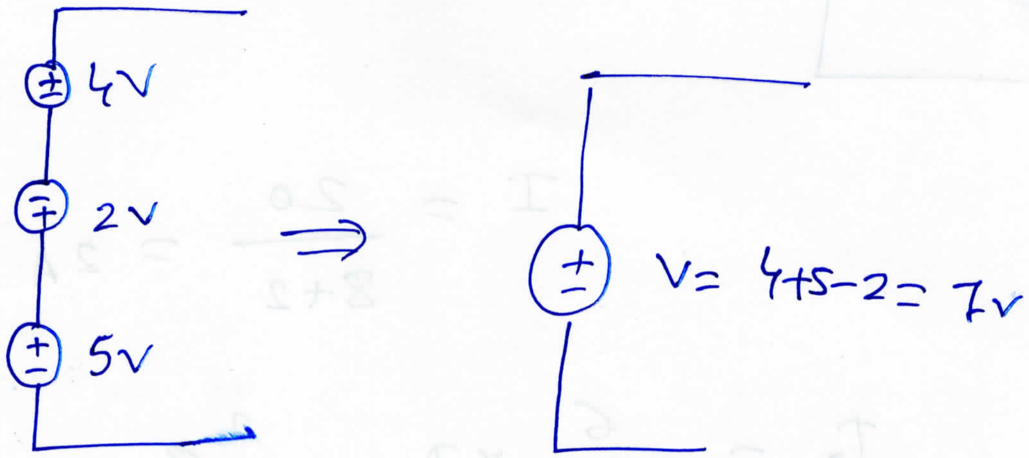
$$I = \frac{5-2}{2+1} = \frac{3}{3} = 1A$$

$$I_1 = 1+2 = 3A$$

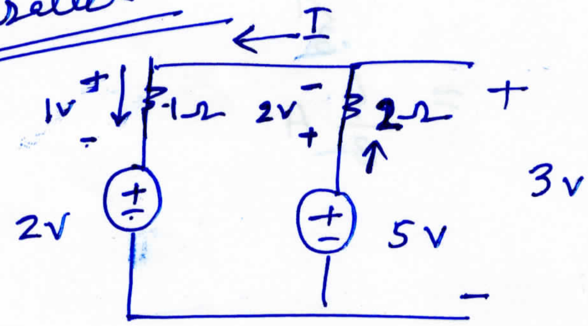
Series Connection of voltage sources





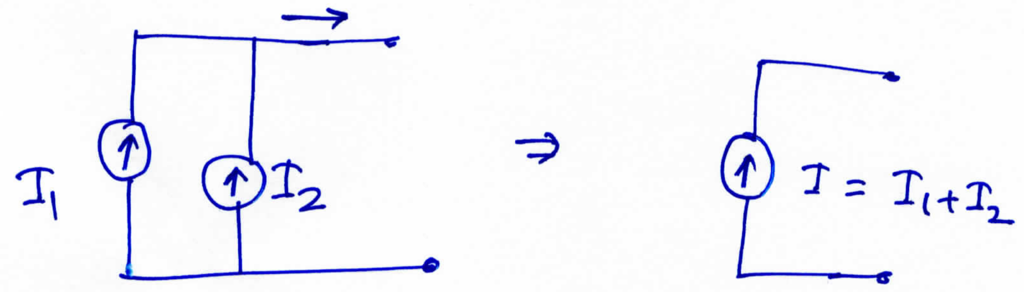


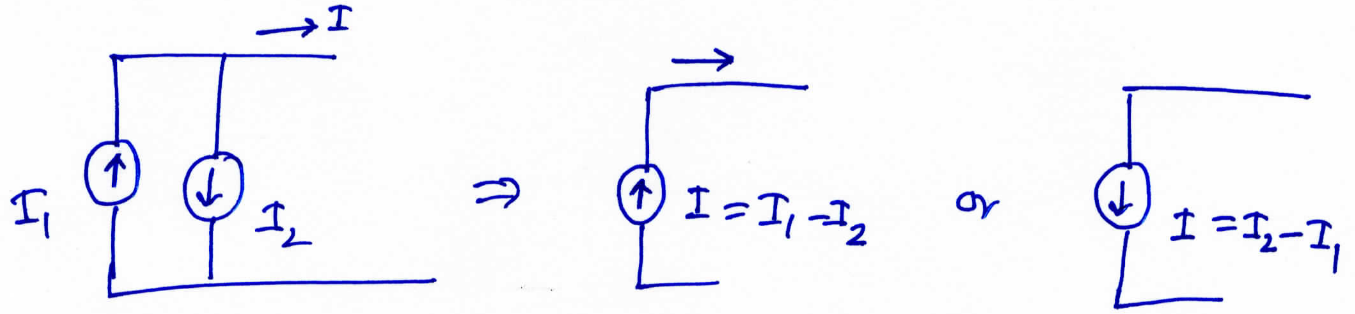
parallel



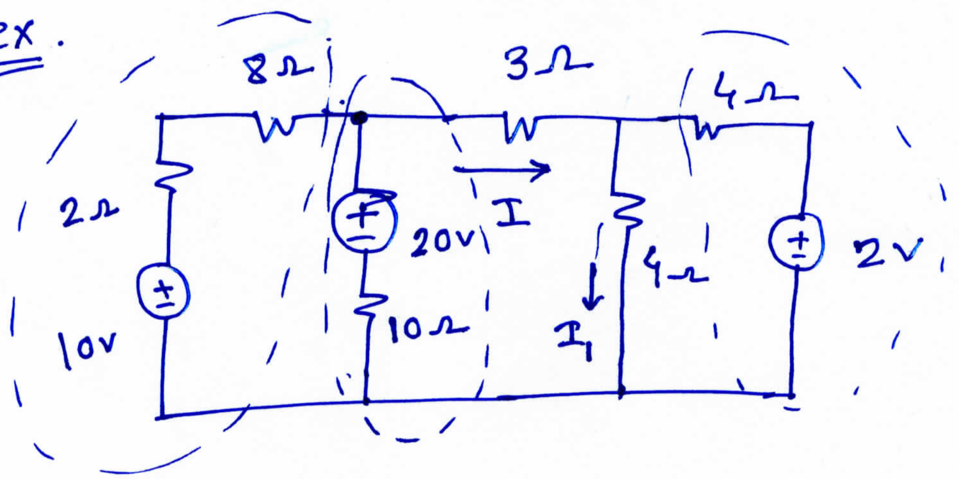
$$I = \frac{5-2}{1+2} = \frac{3}{3} = 1A$$

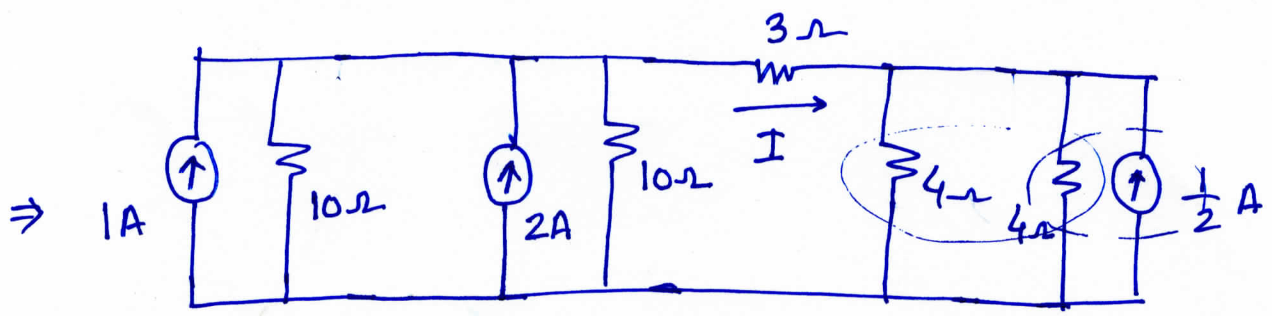
parallel connection of current sources :

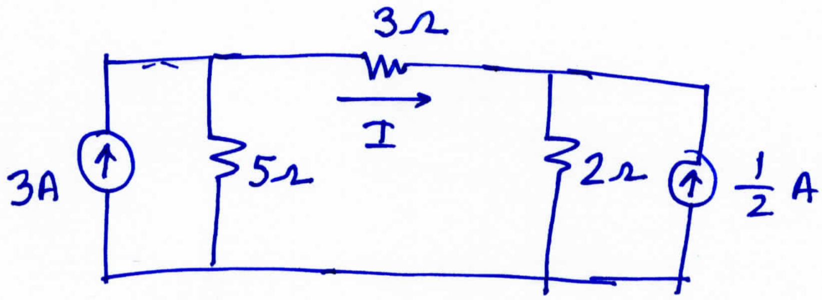


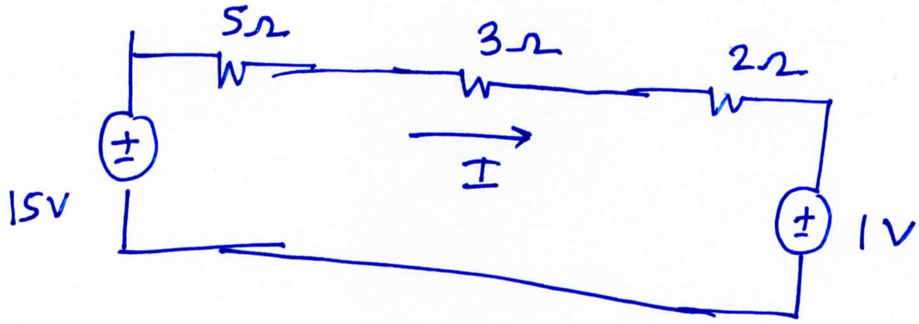


ex.

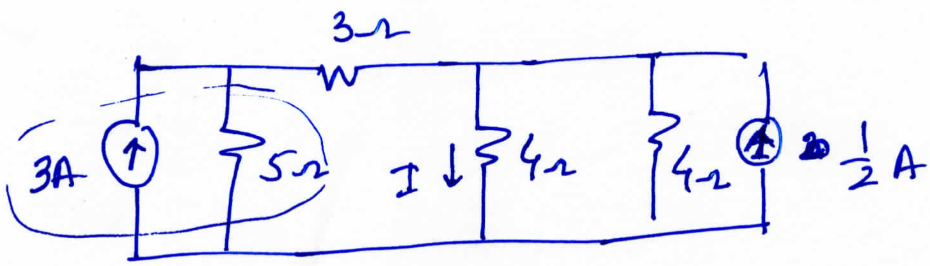


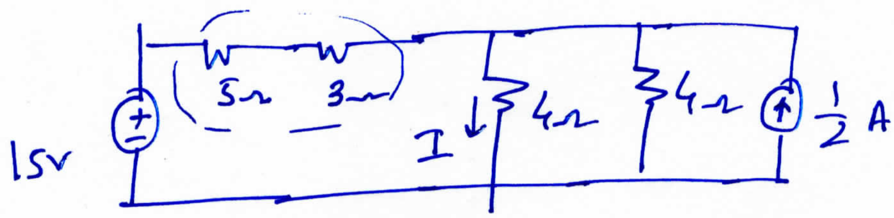


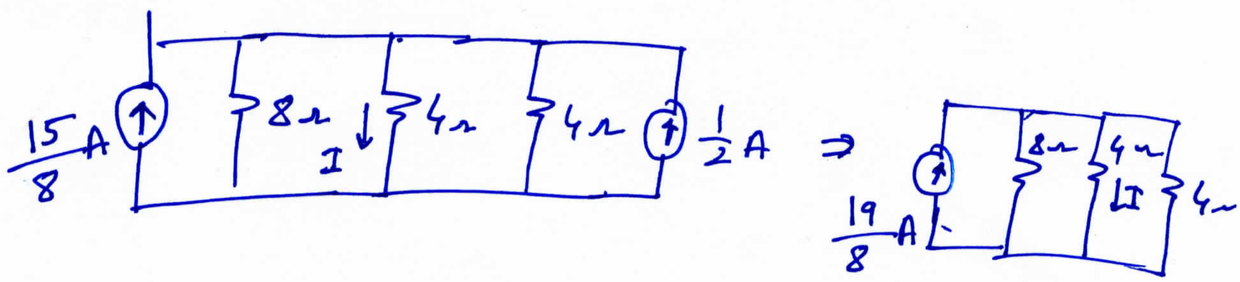




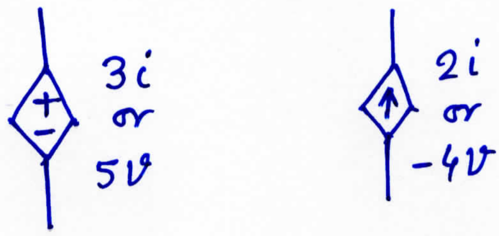
$$I = \frac{15-1}{5+3+2} = \frac{14}{10} = 1.4\,A$$





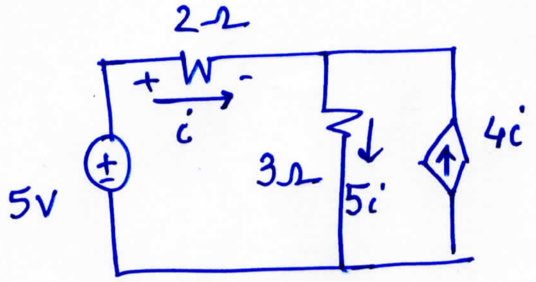


Dependent Sources



1) Current Controlled Current Source (CCCS):

ex.



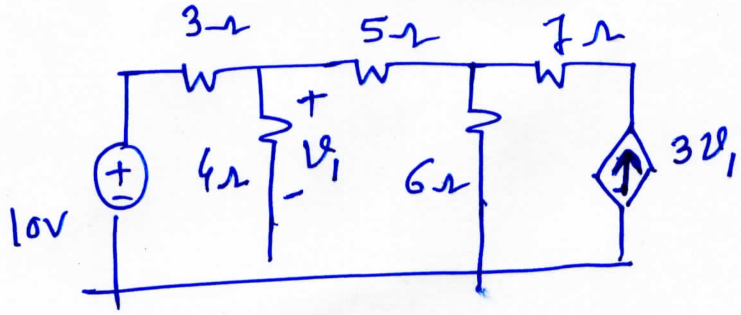
$\longrightarrow \quad i = ?$

$$5 - 2i - 3 \times 5i = 0$$

$$\Rightarrow 5 - 17i = 0$$

$$\Rightarrow i = \frac{5}{17}\ \text{A}$$

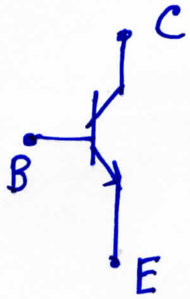
2) Voltage Controlled Current Source (VCCS):



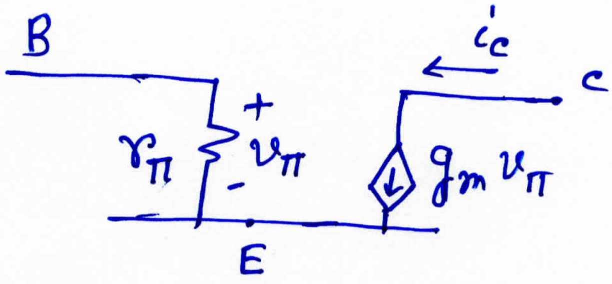
3) Current controlled voltage Source (CCVS)

4) Voltage Controlled Voltage Source (VCVS)

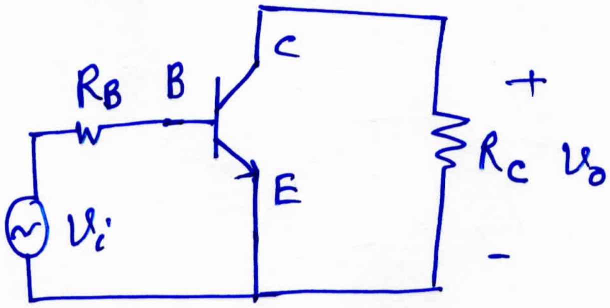
ex

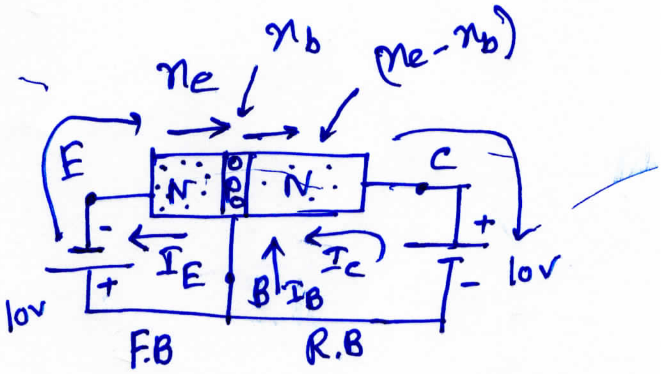


$\Rightarrow$



(Small signal mode)
(ac)

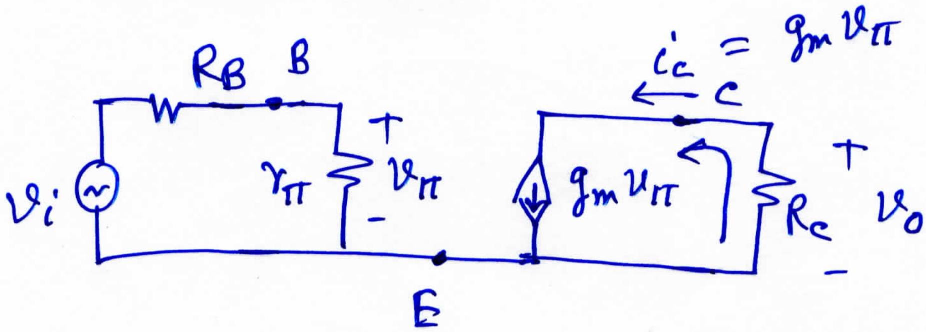




$$\frac{I_c}{I_B} = \frac{n_e - n_b}{n_b} = \beta$$

$$\boxed{I_c = \beta I_B}$$

$$I_E = I_B + I_c$$



$$\Rightarrow \quad v_\pi = \frac{r_\pi}{R_B + r_\pi} \times v_i$$

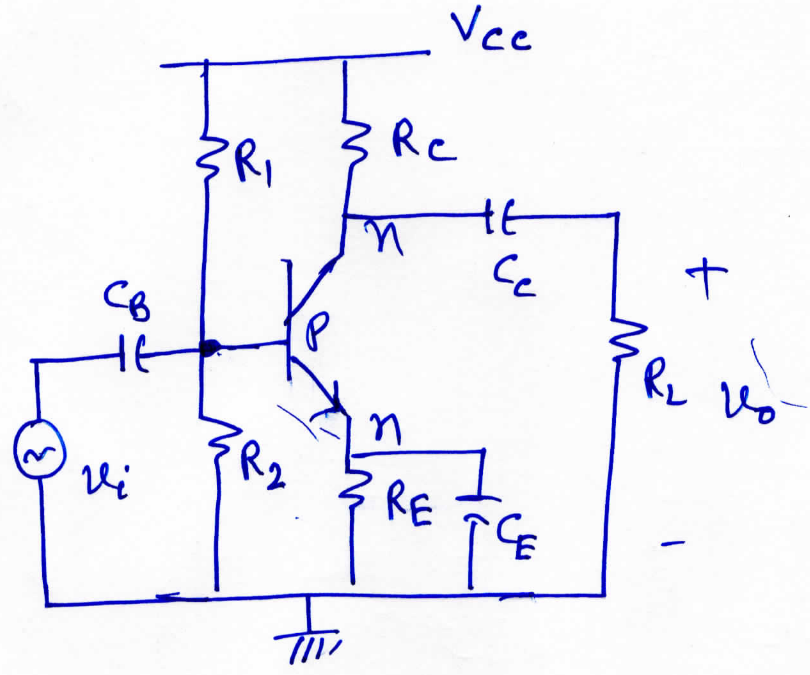
and

$$v_o = (-i_c) R_c$$

$$= -g_m v_\pi R_c$$

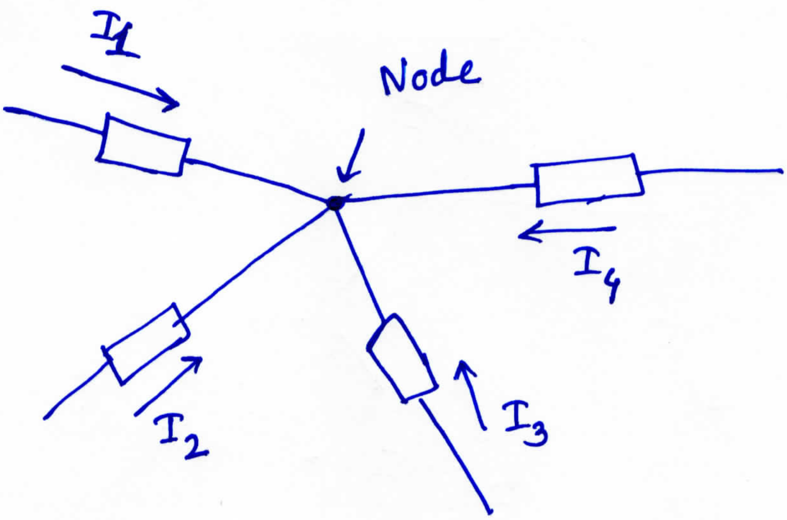
$$= -g_m R_c \frac{r_\pi}{R_B + r_\pi} v_i$$

$$\Rightarrow \frac{v_o}{v_i} = -\frac{g_m r_\pi R_c}{R_B + r_\pi} = \text{voltage gain } (\gg 1)$$



CE

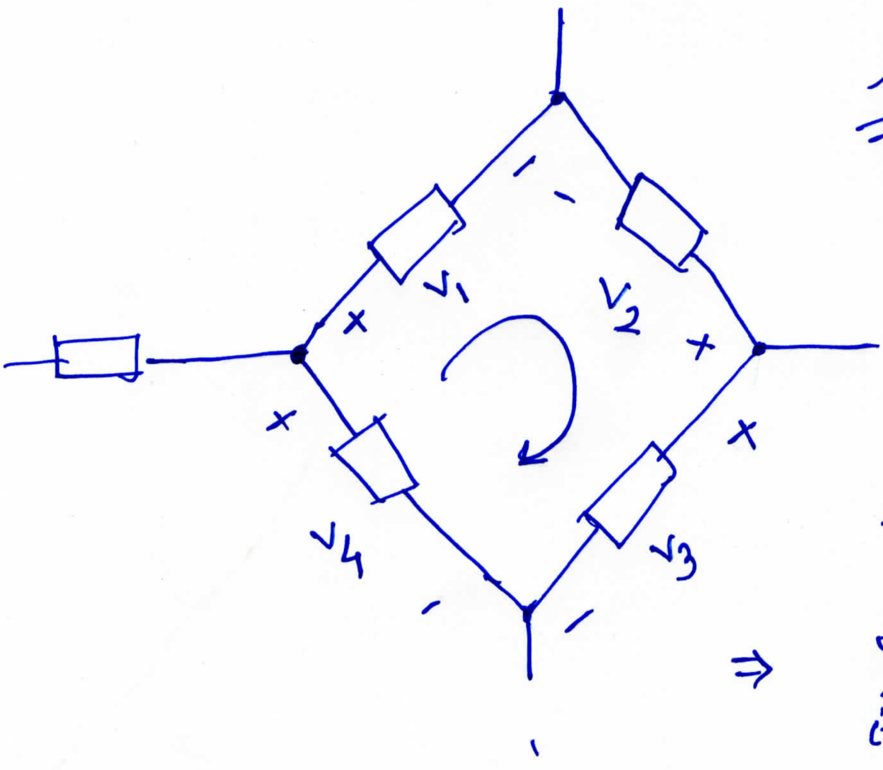
Kirchhoff's Current law (KCL):



$$I_1 + I_2 + I_3 + I_4 = 0$$

In general, $\sum_{i=1}^{N} I_i = 0$

Kirchhoff's Voltage law (KVL):

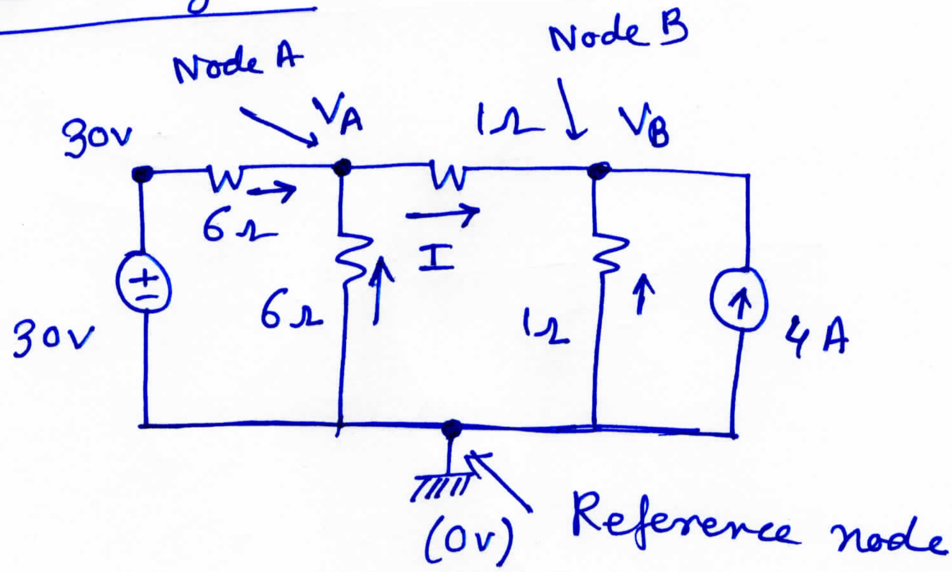


loop → closed path

$$+V_1 - V_2 + V_3 - V_4 = 0$$

$$\Rightarrow \sum_{i=1}^{N} V_i = 0$$

Node Analysis :-



Apply KCL at node A

$$\frac{30 - V_A}{6} + \frac{0 - V_A}{6} + \frac{V_B - V_A}{1} = 0$$

$$\Rightarrow \quad 30 - V_A - V_A + 6V_B - 6V_A = 0$$

$$\Rightarrow \quad 30 - 8V_A + 6V_B = 0$$

$$\Rightarrow \quad 4V_A - 3V_B = 15 \quad \text{---} \quad (1)$$

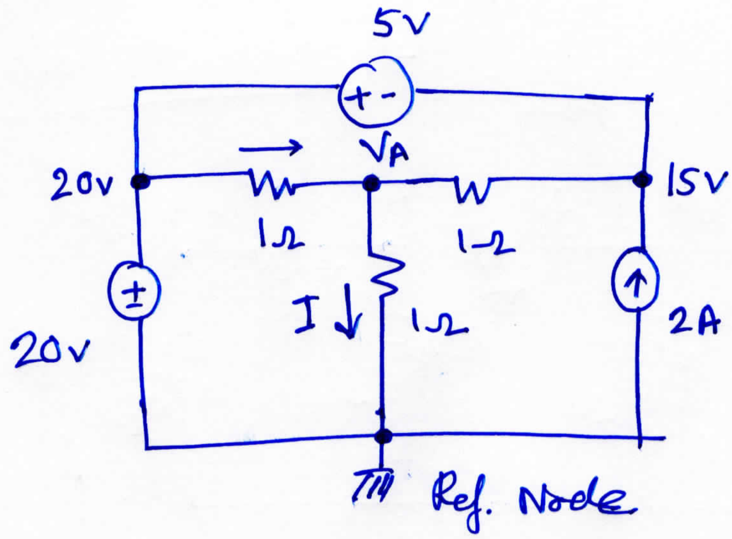
Apply KCL at node B

$$\frac{V_A - V_B}{1} + \frac{0 - V_B}{1} + 4 = 0$$

$$\Rightarrow \quad V_A - 2V_B = -4 \quad \text{---} \quad (2)$$

$$\left.\begin{aligned} V_A &= \frac{42}{5} \\ V_B &= \frac{31}{5} \end{aligned}\right\} \qquad I = \frac{V_A - V_B}{1} = \frac{42 - 31}{5} = \frac{11}{5}\,A$$

ex



KCL at node A

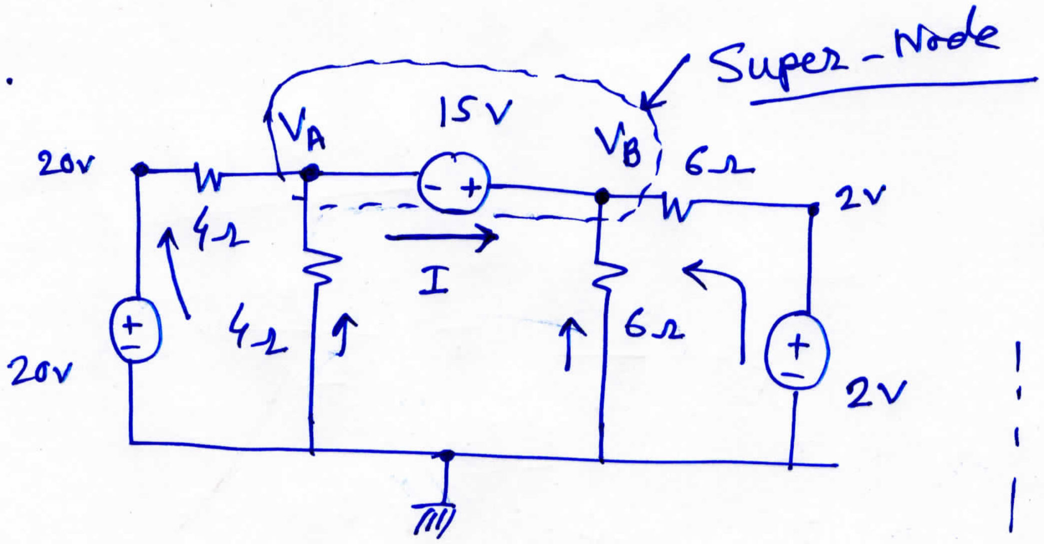
$$\frac{20-V_A}{1} + \frac{0-V_A}{1} + \frac{15-V_A}{1} = 0$$

$$\Rightarrow \quad 20+15-3V_A = 0$$

$$\Rightarrow \quad V_A = \frac{35}{3}\ V$$

$$I = \frac{V_A - 0}{1} = \frac{35}{3}\ \text{Amp.}$$

ex.



$$V_B - V_A = 15$$

$$\Rightarrow V_A + 15 = V_B$$

Node A

$$\frac{20-V_A}{4} + \frac{0-V_A}{4} - I = 0 \quad \text{--- (i)}$$

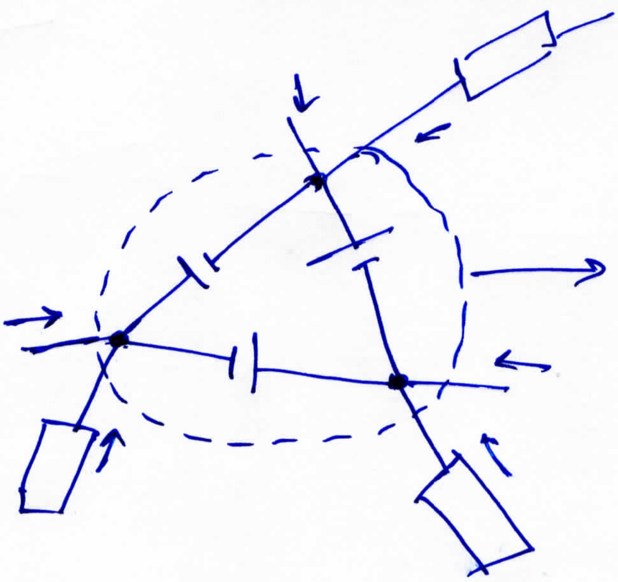
Node B

$$\frac{2-V_B}{6} + \frac{0-V_B}{6} + I = 0 \quad \text{--- (ii)}$$

Adding (i) & (ii),

$$\frac{20-V_A}{4}+\frac{0-V_A}{4}-\cancel{I}+\frac{2-V_B}{6}+\frac{0-V_B}{6}+\cancel{I}=0$$

$$\Rightarrow \frac{20-V_A}{4}+\frac{0-V_A}{4}+\frac{2-V_B}{6}+\frac{0-V_B}{6}=0$$

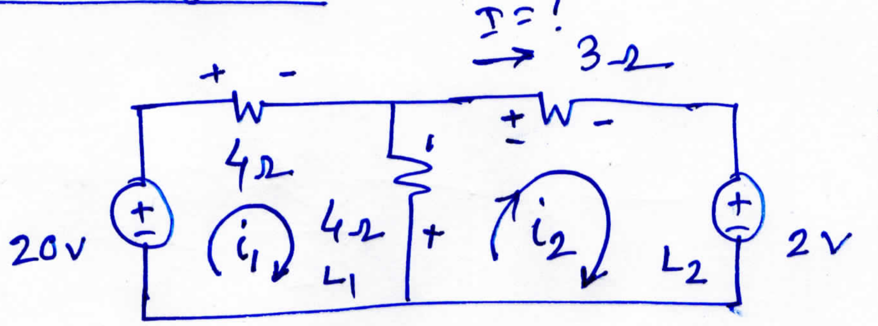


$V_A = ?$

$V_B = ?$

Super-Node

Mesh Analysis :-



$I = i_2$

For L_1 $\quad 20-4i_1-4(i_1-i_2)=0$

For L_2 $\quad 2+3i_2+4(i_2-i_1)=0$

$$\Rightarrow \quad 8i_1 - 4i_2 = 20$$

$$\Rightarrow \quad 2i_1 - i_2 = 5 \quad \cdots (i)$$

Again,

$$2 + 7i_2 - 4i_1 = 0$$

$$\Rightarrow \quad 4i_1 - 7i_2 = 2 \quad \cdots (ii)$$

$(i) \times 2 - (ii)$

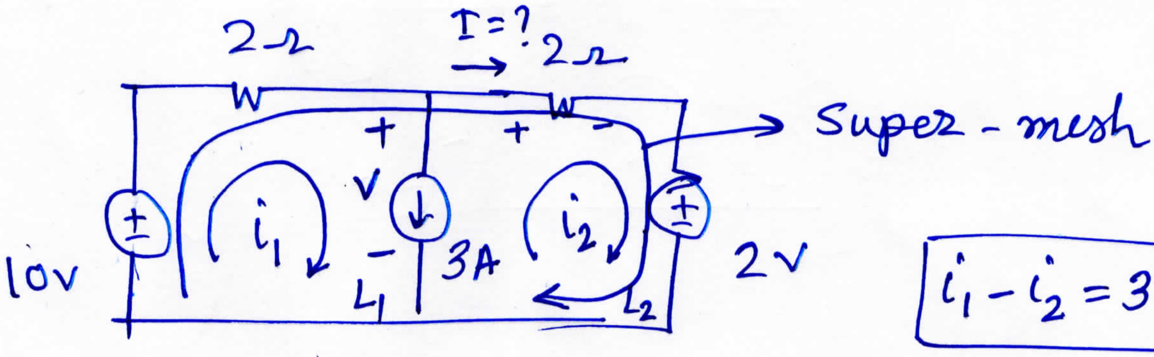
$$-2i_2 + 7i_2 = 10 - 2$$

$$\Rightarrow \quad 5i_2 = 8$$

$$\Rightarrow \quad i_2 = 8/5 \text{ A}$$

$$\Rightarrow \quad I = i_2 = 8/5 \text{ A}$$

ex



$$\boxed{i_1 - i_2 = 3}$$

L_1: $\quad 10 - 2i_1 - V = 0$

L_2: $\quad V - 2i_2 - 2 = 0$

Adding

$$\boxed{10 - 2i_1 - 2i_2 - 2 = 0}$$

KVL for bigger loop

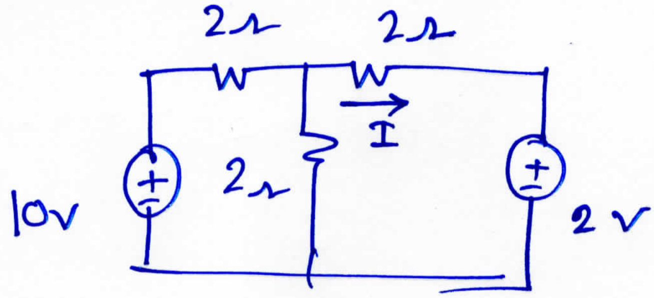
Superposition Theorem :-

Replacement

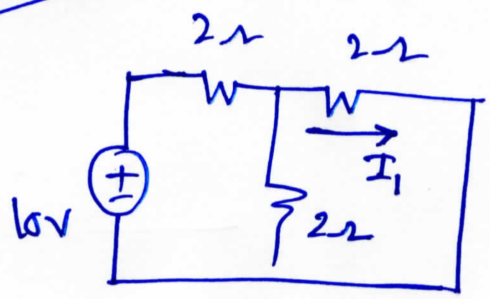
Voltage source → shorted

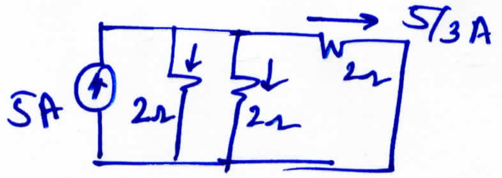
Current source → opened

ex



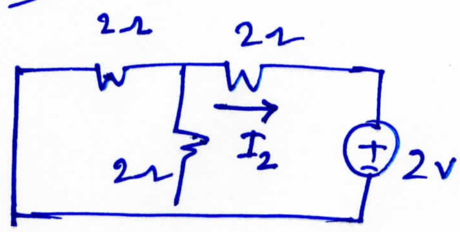
10v is acting





$\Rightarrow I_1 = 5/3\,A$

2v is acting



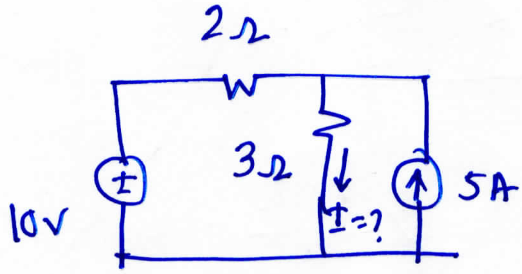
$I_2 = -\frac{2}{3}\,A$

by Superposition theorem,

$$I = I_1 + I_2$$

$$= \frac{5}{3} - \frac{2}{3} = \frac{3}{3} = 1A$$

ex



$$I = \frac{10}{5} + \frac{2}{2+3} \times 5$$

$$= 2 + 2 = 4\,A$$