256

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ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electronics & Telecommunication Engineering

Test-1 : Network Theory + Electronic Devices and Circuits [All topics]

Name : ....

Roll No :

Test Centres

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Student's Signature

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	28
Q.2	28
Q.3	—
Q.4	52
Section-B	
Q.5	22
Q.6	/
Q.7	/
Q.8	35
Total Marks Obtained	165

Signature of Evaluator: Chirag (signature) Cross Checked by ....

- Good attempt.
- Avoid small mistakes.

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- Improve writing skills.

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

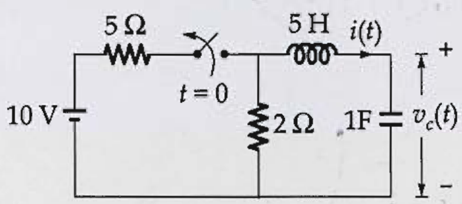
DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Do not write in this margin

Section A : Network Theory + Electronic Devices and Circuits

Q.1 (a) Consider the circuit shown below:



If the equation of current, $i(t) = e^{-\alpha t}[B_1 \cos\omega_d t + B_2 \sin \omega_d t]$ for $t \geq 0$.

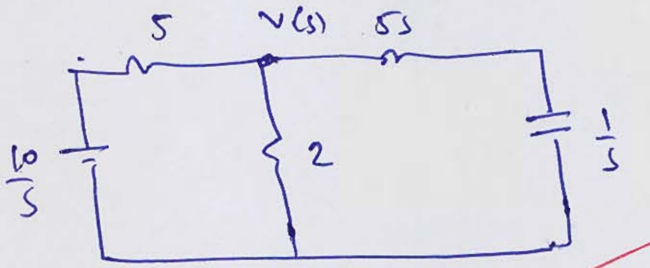
Then calculate the value of

(i) α (ii) B_1

(iii) B_2 (iv) ω_d

[12 Marks]

Ans. Laplace equivalent



$$\frac{V(s) - \frac{10}{s}}{5} + \frac{V(s)}{2} + \frac{V(s)}{5s + \frac{1}{s}} = 0$$

$$V(s)\left[\frac{1}{5} + \frac{1}{2} + \frac{s}{5s^2+1}\right] = \frac{10}{5s}$$

$$V(s)\left[\frac{7}{10} + \frac{s}{5s^2+1}\right] = \frac{10}{5s}$$

$$V(s)\left[\frac{35s^2 + 7 + 10s}{10(5s^2+1)}\right] = \frac{10}{5s}$$

$$V(s) = \frac{100(5s^2+1)}{5s(35s^2+10s+7)}$$

$$I(s) = \frac{V(s)}{5s + \frac{1}{s}} = \frac{V(s)\, s}{5s^2+1}$$

$$= \frac{\overset{20}{\cancel{100}}(\cancel{5s^2+1})}{\cancel{5}8(35s^2+10s+7)(\cancel{5s^2+1})} \times \frac{\cancel{8}}{}$$

$$I(s) = \frac{20}{35s^2+10s+7}$$

14s.

6

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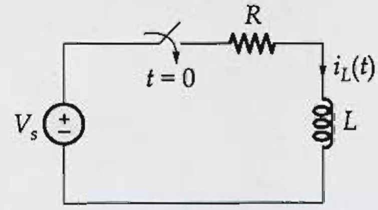
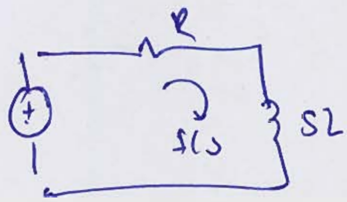
Q.1 (b) Prove that the efficiency of DC excited R-L series circuit is zero.



[12 Marks]

Ans. $I(s) = \frac{V_s}{s}$



$$I(s) = \frac{\frac{V_s}{s}}{R + sL}$$

$$= \frac{V}{s(R + sL)} = \frac{V/R}{s\left(s + \frac{L}{R}\right)}$$

$$= \frac{A}{s} + \frac{B}{s + \frac{L}{R}}$$

$$I(t) = \frac{V}{R}\left(1 - e^{-\frac{L}{R}t}\right) u(t)$$

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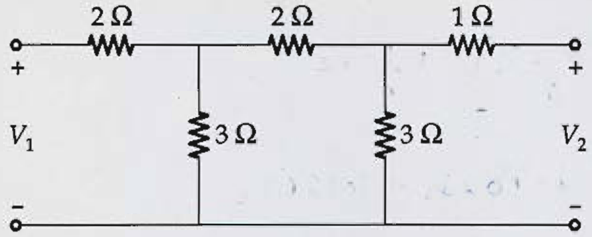
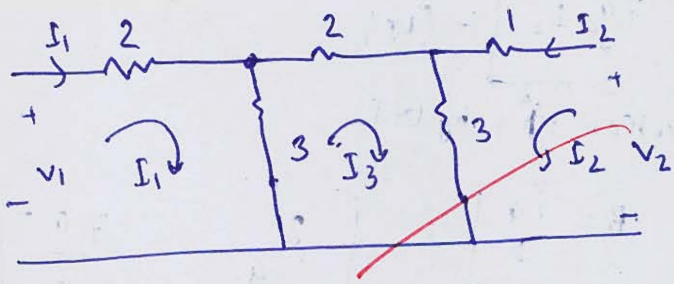
Q.1 (c) Obtain *ABCD* parameters for the network shown in figure.



[12 marks]

Ans.



ABCD parameters are

$V_1 = AV_2 - BI_2$ — (i)

$I_1 = CV_2 - DI_2$ — (ii)

Apply KVL in loop 1

$V_1 = 5I_1 - 3I_3$ — (a)

Apply KVL in loop 2

$8I_3 - 3I_1 + 3I_2 = 0$

$8I_3 = 3I_1 - 3I_2$

$I_3 = \frac{3}{8}I_1 - \frac{3}{8}I_2$ — (1)

Apply KVL in loop 2

$V_2 = 4I_2 + 3I_3$ — b

put equation (1) in b

$V_2 = 4I_2 + 3\left[\frac{3}{8}I_1 - \frac{3}{8}I_2\right] = 4I_2 + \frac{9}{8}I_1 - \frac{9}{8}I_2$

$V_2 = 2.875\, I_2 + \frac{9}{8}I_1$

$I_1 = \frac{8}{9}V_2 - \frac{23}{9}I_2$ — (2)

compare (ii) and 2

$C = \frac{8}{9}, \quad D = \frac{23}{9}$

Put equation (1) in eq^n (a)

$V_1 = 5I_1 - 3\left(\frac{3}{8}I_1 - \frac{3}{8}I_2\right)$

$V_1 = 5I_1 - \frac{9}{8}I_1 + \frac{9}{8}I_2$

$V_1 = \frac{31}{8}I_1 + \frac{9}{8}I_2$ — (3)

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Substitute equation (2) in equation (1)

$$V_1 = \frac{31}{8}\left[\frac{8}{9}V_2 - \frac{23}{9}I_2\right] + \frac{9}{8}I_2$$

$$= \frac{31}{9}V_2 - 9.9025I_2 + 1.125I_2$$

$$\boxed{V_1 = \frac{31}{9}V_2 - \frac{79}{2}I_2} \quad -(4)$$

10

$\frac{79}{9}$

Compare equation (1) by (4)

$$\boxed{A = \frac{31}{9} \quad B = \frac{79}{2}}$$

$$[ABCD] = \begin{bmatrix} \frac{31}{9} & \frac{79}{2} \\ \frac{8}{9} & \frac{23}{9} \end{bmatrix}$$

9

Q.1 (d) Consider an n-channel MOSFET with source and drain doping concentrations of $N_d = 10^{19}$ cm^{-3} and a channel region doping of $N_a = 10^{16}$ cm^{-3}. Assume a channel length of $L = 1.2$ µm, and assume the source and body are at ground potential (i.e, $|V_{SB}| = 0$). Calculate the theoretical punch-through voltage assuming the abrupt junction approximation.

(Assume, $V_T = 0.0259$ V; $\epsilon_S = 11.7\epsilon_0$; $n_i = 1.5 \times 10^{10}$ cm^{-3} for Si)

[12 Marks]

Ans. Punch through voltage $(V_{pt}) = \frac{W_0^2 q N_a}{2\epsilon}$

$$W = \sqrt{\frac{2\epsilon}{q}\left(\frac{1}{N_a} + \frac{1}{N_D}\right)V_0}$$

Given $N_A = 10^{16}$

$N_D = 10^{19}$

$n_i = 1.5 \times 10^{10}$

4

$$V_0 = V_T \ln \frac{N_A N_D}{n_i^2}$$

$$V_0 = 0.0259 \ln \left(\frac{10^{16} \times 10^{19}}{2.25 \times 10^{20}}\right)$$

$$\boxed{V_0 = 0.874 \text{ volt}}$$

(a) width

$$W = \sqrt{\frac{2\epsilon}{q}\left(\frac{1}{N_a} + \frac{1}{N_D}\right) V_0}$$

$$= \sqrt{\frac{2 \times 11.7 \times 8.85 \times 10^{-14}}{1.6 \times 10^{-19}}\left(\frac{1}{10^{16}} + \frac{1}{10^{19}}\right) 0.874}$$

$$\boxed{W = 1.132 \times 10^{-9}\ m}$$

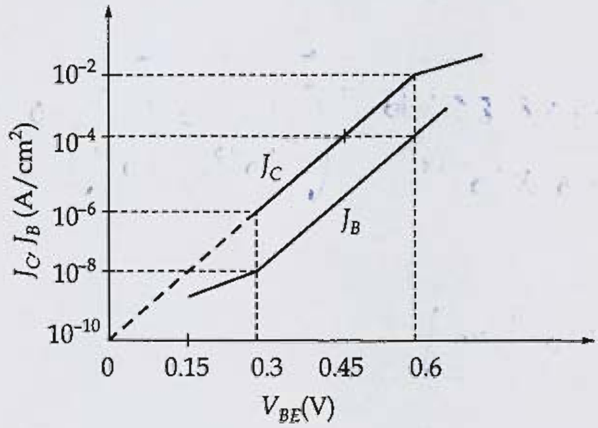
6

punch through voltage $V_{ix} = \frac{W^2 q N_a}{2\epsilon}$

$$= \frac{(1.132 \times 10^{-9})^2 \times 1.6 \times 10^{-19} \times 10^{16}}{2 \times 11.7 \times 8.85 \times 10^{-14}}$$

$$\boxed{V_0 = 9.906 \times 10^{-10}\ \text{volt}}$$

Q.1 (e) Consider an NPN transistor with Emitter, Base and Collector region width as $W_E = 0.5\ \mu m$, $W_B = 0.2\ \mu m$ and $W_C = 2\ \mu m$ respectively. Diffusion coefficient of carriers in base region, $D_B = 10\ cm^2/s$.



Calculate:

(i) Common Emitter Current gain, β.

(ii) Base doping concentration, N_B.

(iii) Base transit time, τ_B.

(Assume, $W_B << L_B$, $n_i = 10^{10}\ cm^{-3}$; $\frac{kT}{q} = 0.026\ V$)

[12 Marks]

Ans. (iii) Base transit time, τ_B

$$\tau_B = \frac{W_B^2}{2D_B}$$

$W_B = 0.2 \times 10^{-4}\ cm$

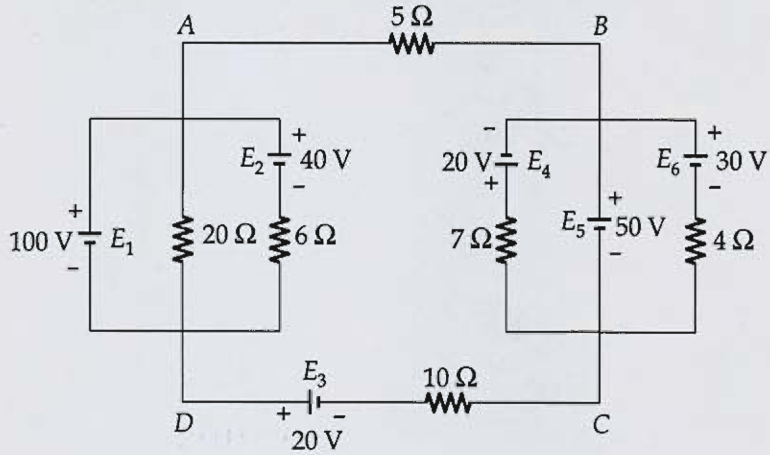
$D_B = 10$

$$\tau_B = \frac{0.2 \times 0.2 \times 10^{-8}}{2 \times 10}$$

$$\boxed{\tau_B = 2 \times 10^{-11}\ sec}$$

4

Q.2 (a) For the circuit shown in figure, find the current through 5 Ω resistor by using Thevenin's theorem and verify the same by using superposition theorem.

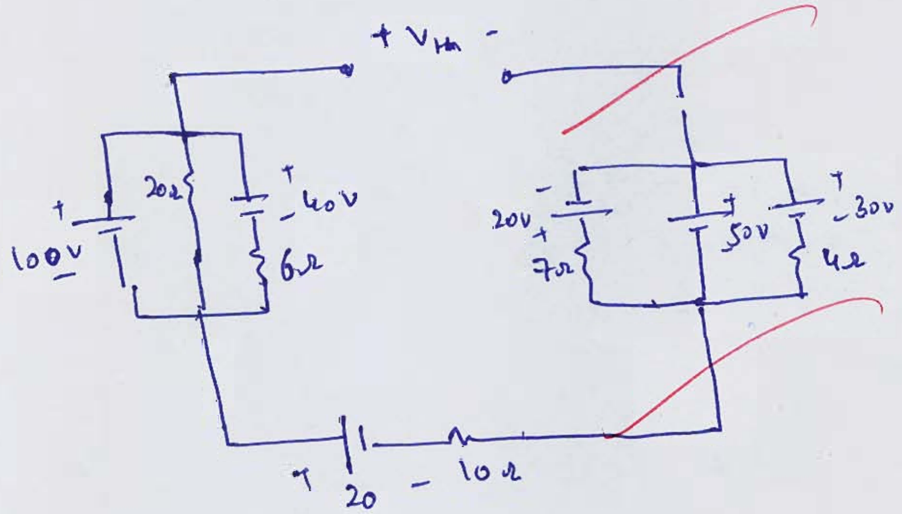


[20 marks]

Ans. Thevenin's theorem.

Open circuit load terminal 5 Ω

thevenin equivalent voltage - Redraw circuit



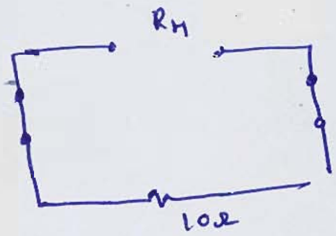
apply KVL $-100 + V_{th} + 50 + (10 \times 0) - 20 = 0$

$-100 + V_{th} + 50 - 20 = 0$

$V_{th} = 70\text{ V}$

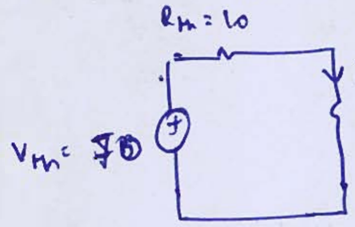
equivalent Resistance → voltage source act as short circuit

Redraw circuit



$R_{th} = 10\ \Omega$

thevenin equivalent circuit

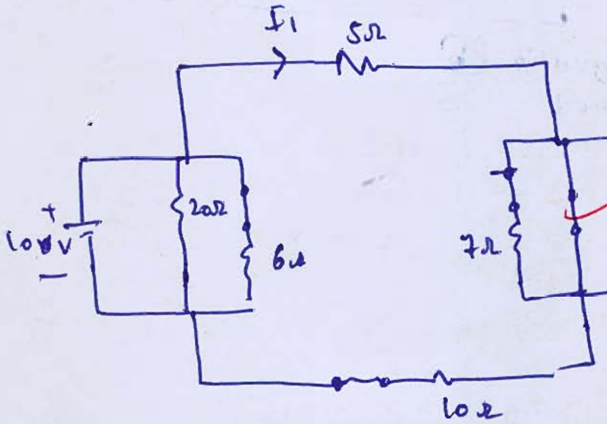


by apply KVL

$$I = \frac{70}{15} = 4.67 \text{ Amp}$$ — a

By using Superpocition theorem

For 100 V → other voltage source act as short circuit

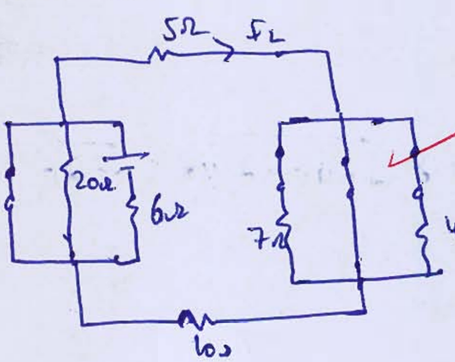


by apply KVL

$-100 + 5I_1 + 10I_1 = 0$

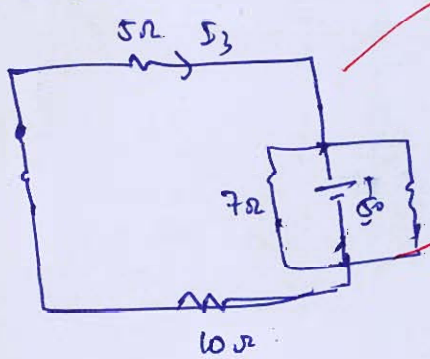
$$I_1 = \frac{100}{15} \text{ Amp}$$

For 40 V



$I_2 = 0$

For = 50 V

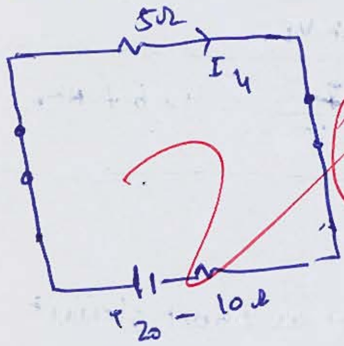


$15I_3 + 50 = 0$

$$I_3 = -\frac{50}{15}$$

For = 20 V }
For = 30 V } → No current flow

For = 20 V



by apply KVL

$15 I_4 - 20 = 0$

$I_4 = \frac{20}{15}$

By add I_1, I_3 and I_4

$= \frac{100}{15} + \frac{20}{15} - \frac{50}{15} = \frac{70}{15}$

$I = 4.67$ Amp — (b)

equation (a) = equation (b)

hence proved

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$

Q.2 (b) Consider an n-channel MOSFET with a doping of $N_a = 10^{15}$ cm^{-3}, an oxide thickness of $t_{ox} = 750$Å and an initial flat-band voltage of $V_{FB} = -1.5$ V.

Calculate:

$V_T = V_{T0} + \gamma\sqrt{2\phi_F + 2V_{SB}} - \sqrt{2\phi_F}$; $V_{T0} = \frac{\sqrt{2\epsilon q N_A}}{C_{ox}}$

(i) Threshold voltage, V_T.

(ii) The ion implant density 'D_I' required to achieve a threshold voltage of $V_T = +0.9\ V$ with $V_{SB} = 0$.

(iii) Using the result obtained in part (ii), determine the threshold voltage if source to body voltage, $V_{SB} = 2$ V is applied.

(Assume, $V_t = 0.026$ V, $\epsilon_s = 11.7\,\varepsilon_0$, $\epsilon_{0x} = 3.9\epsilon_0$, $n_i = 1.5 \times 10^{10}$ cm^{-3})

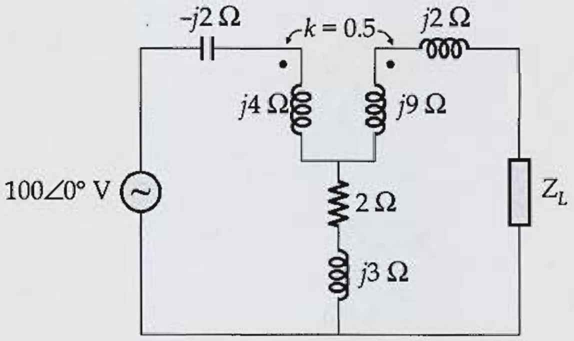
[8 + 4 + 8 marks]

Ans i) as threshold voltage

$V_T = V_{T0} + \gamma\sqrt{2\phi_F + 2V_{SB}} - \sqrt{2\phi_F}$.

Q.2 (c) **(i)** Find the Thevenin's equivalent of the circuit shown in figure below as seen from the load impedance Z_L.

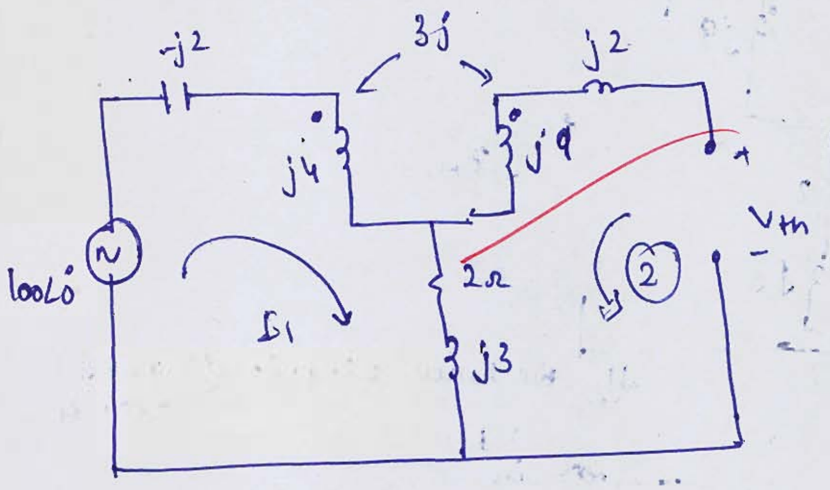
(ii) Find the value of Z_L for maximum power transfer and also the maximum power transfer to the load Z_L.



[12 + 8 marks]

Ans. i) Thevenin's equivalent circuit 'Z_L' is open circuit

Redraw circuit



$M = K\sqrt{L_1 L_2}$

$= 0.5\sqrt{j4 \times j9}$

$= 0.5 \times j6 =$

$M = 3j$

By apply KVL in Loop 1 $\quad I_2 = 0$

$100\angle 0 = [(-j2 + j4 + j3) + 2] I_1$

$100\angle 0 = (j5 + 2) I_1 \quad\quad I_1 = \left(\frac{100\angle 0}{2 + j5}\right)$

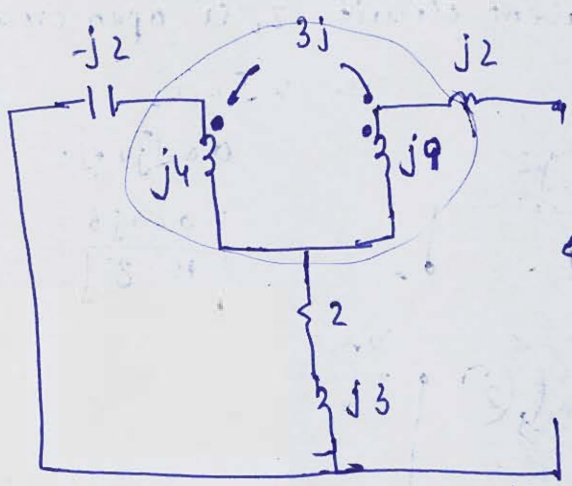
thevenin voltage → apply KVL in loop 2

$V_{th} = 0(j9 + j2) - 3j I_1 + (2 + j3) I_1$

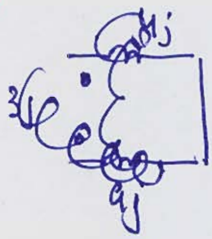
$V_{th} = 2 I_1 \quad\quad$ put value I_1

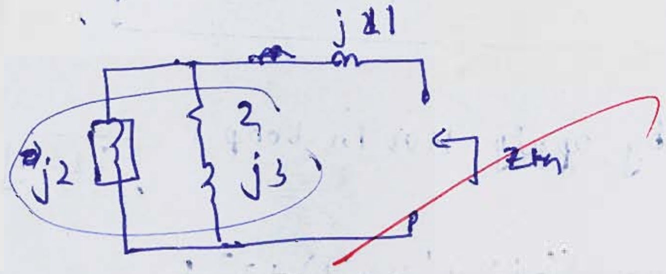
$V_{th} = \frac{200\angle 0}{2 + j5}$ volt $\quad 37.14\angle -68.2°$ Volt

Find equivalent resistance R_{th} voltage source act short circuit redraw circuit



⇓ Redraw circuit -j2 and j9 in series





2j and (2+j3) in parallel and series with j11

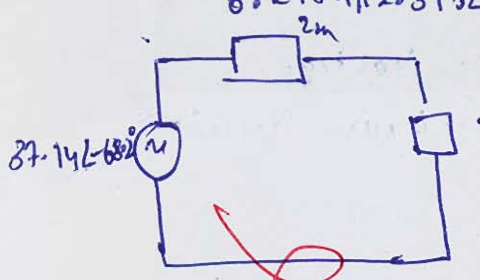
$$Z_{th} = \frac{(2j)(2+j3)}{2j+2+j3} + j11$$

$$= \frac{4j-6}{2+j5} + j11$$

$$\boxed{Z_{th} = 12.313 \angle 88.71 = 0.275 + 12.31 j\ \Omega}$$

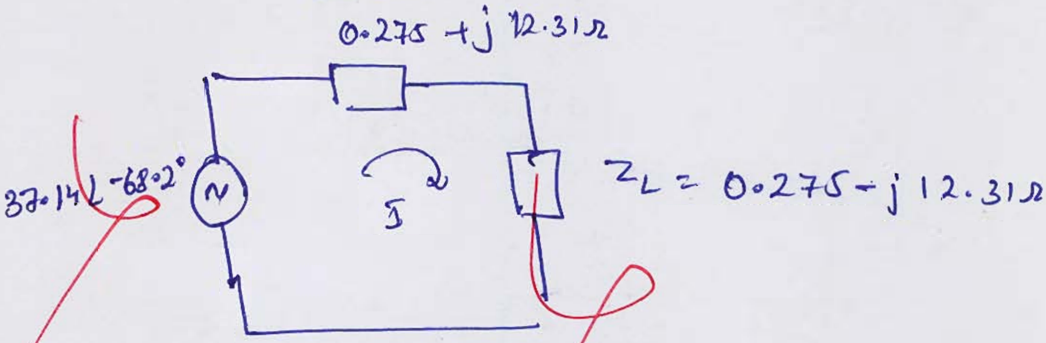
thevenin equivalent circuit

a_1.



(ii) For maximum power transfer theorem

$Z_L = Z_{in}^*$ Z_L



by apply KVL

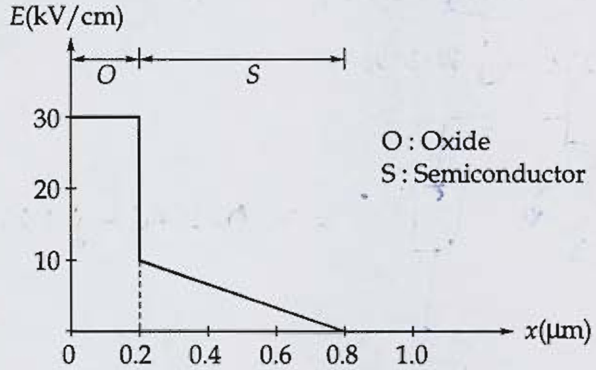
$$I = \frac{37.14\angle -68.2^\circ}{(0.275)*2} = 67.52\angle -68.2^\circ$$

$R_L = 0.275$

$$P_{max} = I^2 R_L = (67.52)^2 \times 0.275$$

Maximum Power = 1.253 KWatt

Q.3 (a) The figure shows the electric field distribution within a MOS structure (P-substrate) for a given potential V_G applied to the gate. Assume the flat band potential $V_{FB} = 0$.



Find:

(i) The potential in the bulk of the semiconductor ψ_B.

(ii) The potential at the surface of semi conductor, ψ_s.

(iii) The threshold voltage, V_T.

(iv) The value of the applied potential at Gate, V_G.

(Assume, $\epsilon_{si} = 10^{-12}$ F/cm; $\epsilon_{ox} = 3 \times 10^{-13}$ F/cm, $n_i = 1.5 \times 10^{10}$ cm^{-3}, $C_{ox} = 15$ nF/cm^2, $V_T = 26$ mV)

[20 marks]

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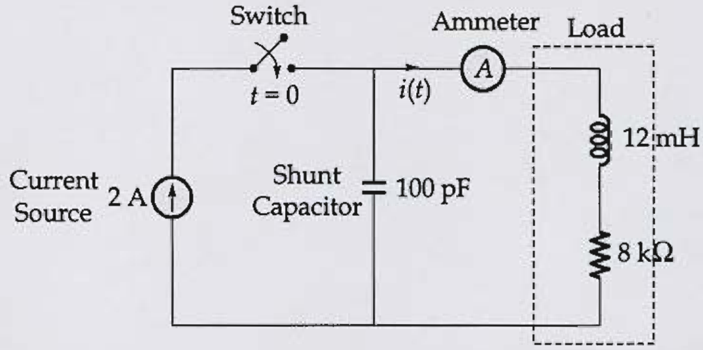
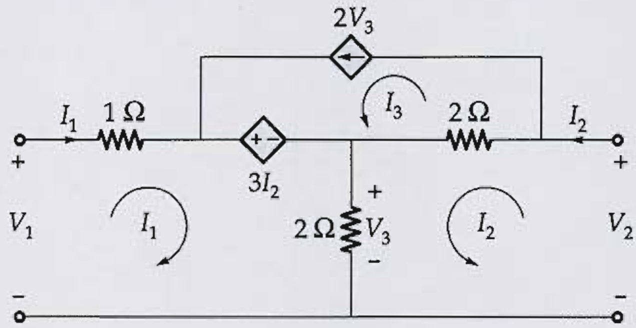
Q.3 (b) **(i)** The circuit in the figure contains a current source driving a load having an inductor and a resistor in series, with a shunt capacitor across the load. The ammeter is assumed to have zero resistance. The switch is closed at time $t = 0$.



Initially, when the switch is open, the capacitor is discharged and the ammeter reads zero ampere. After the switch is closed, the ammeter reading keep fluctuating for some time till it settle to a final steady value. Calculate the maximum ammeter reading that one will observe after the switch is closed.

(ii) Determine Z and Y-parameters of the network shown in figure.



[10 + 10 marks]

Q.3 (c) **(i)** Explain the working principle of a *pn*-junction solar cell.

(ii) Consider an ideal silicon *pn*-junction diode with the following parameters:

$\tau_{n_0} = \tau_{p_0} = 0.1 \times 10^{-6}$ s

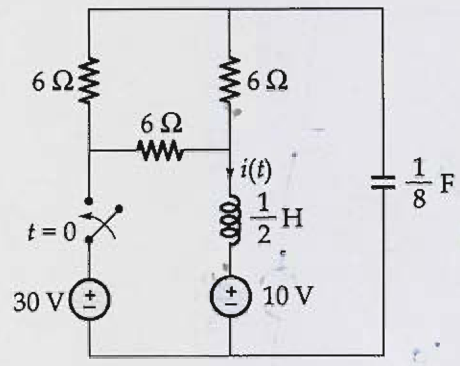
$D_n = 25$ cm^2/s

$D_p = 10$ cm^2/s

If N_d represents donor concentration and N_a represents acceptor concentration, what must be the ratio of $\frac{N_a}{N_d}$ so that 95 percent of the current in the depletion region is carried by electrons?

[10 + 10 marks]

Q.4 (a) For the network shown in figure, solve for $i(t)$ for $t > 0$.

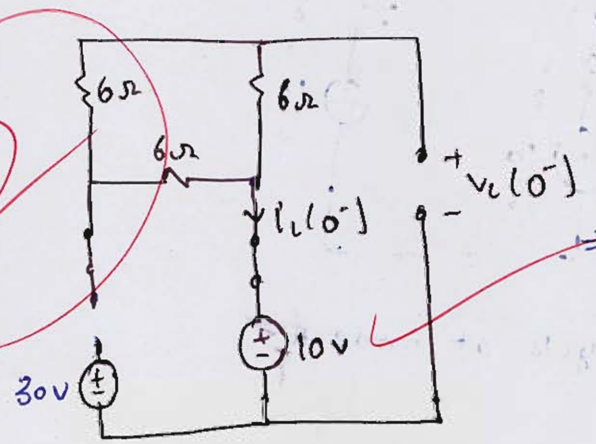


[20 marks]

as $t = 0^-$ switch is ~~closed~~ open.

at steady state inductor act as short circuit and capacitor act as open circuit ; Redraw the circuit

12



$\Rightarrow$ $i_L(0^-) = 0$

$v_c(0^+) = 10\,V$

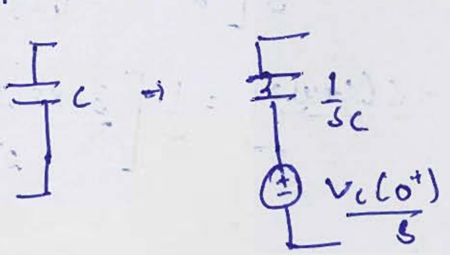
at $t = 0^+$, switch closed.

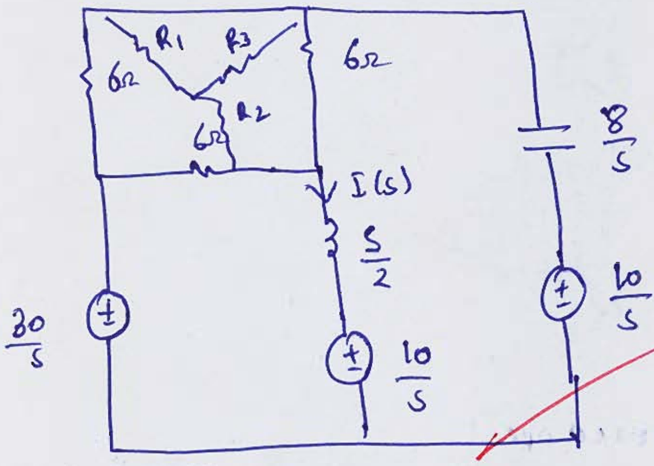
inductor doesn't allowed sudden change current

$i_L(0^-) = i_L(0^+) = 0$

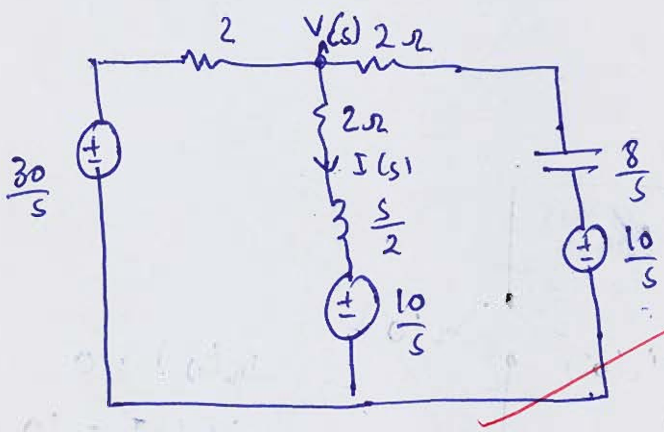
- capacitor doesn't allowed sudden change of voltage $v_c(0^-) = v_c(0^+) = 10$.

- ~~Repl~~ Draw Network in Laplace equivalent





Make star connection $R_1, R_2, R_3 = 2\Omega$



Apply nodal analysis at node A

$$\frac{V(s)-\frac{30}{s}}{2}+\frac{V(s)-\frac{10}{s}}{2+\frac{s}{2}}+\frac{V(s)-\frac{10}{s}}{8/s}=0$$

$$V(s)\left[\frac{1}{2}+\frac{1}{2+\frac{s}{2}}+\frac{1}{8/s}\right]=\frac{30}{2s}+\frac{\frac{10}{s}}{2+s/2}+\frac{\frac{10}{s}}{8/s}$$

$$V(s)\left[\frac{1}{2}+\frac{2}{4+s}+\frac{s}{8}\right]=\frac{1}{s}\left[\frac{30}{2}+\frac{10\times 2}{4+s}+\frac{10s}{8}\right]$$

$$V(s)\left[\frac{8(s+4)+4\times 8+s(s+4)2}{2(4+s)8}\right]=\frac{1}{s}\left[\frac{30\times 8(s+4)+20\times 16+20s(s+4)}{2(s+4)8}\right]$$

$$V(s)\left[2s^2+64+16s\right] = \frac{1}{s}\left[20s^2+320s+1280\right]$$

$$V(s) = \frac{[20s^2+320s+1280]}{s[2s^2+64+16s]} = \frac{[10s^2+160s+640]}{s[s^2+8s+32]}$$

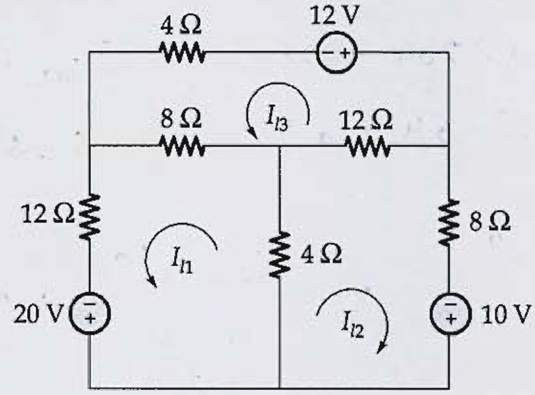
$$I(s) = \frac{V(s) - \frac{10}{s}}{2+\frac{s}{2}} = \frac{V(s)-\frac{10}{s}}{\frac{4+s}{2}} = \frac{2V(s) - \frac{5}{s}}{(s+4)}$$

$$= V($$

$$= \frac{2\left[\frac{10s^2+160s+640}{s(s^2+8s+32)}\right] - \frac{5}{s}}{(s+4)}$$

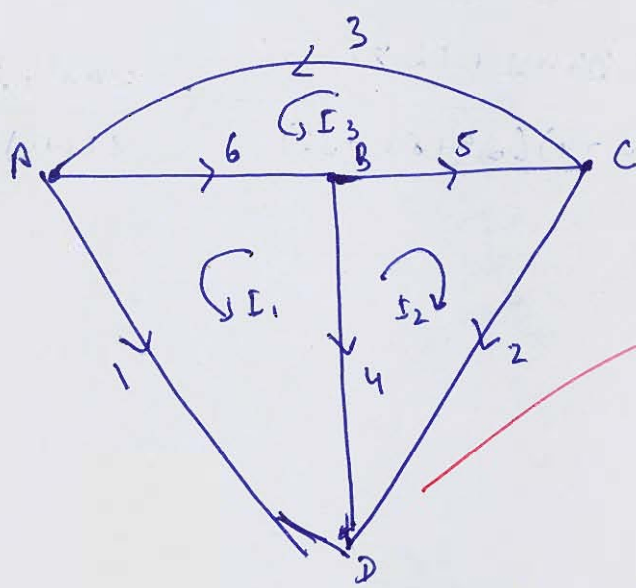
$$= \frac{20s^2+320s+1280-5}{s(s+4)(s^2+8s+32)} = \frac{20s^2+320s+1275}{s(s+4)(s^2+8s+32)}$$

Q.4 (b) For the network shown in figure, write down the tie set matrix, obtain the network equilibrium equations in matrix form using the tie-set matrix and calculate loop currents.



[20 marks]

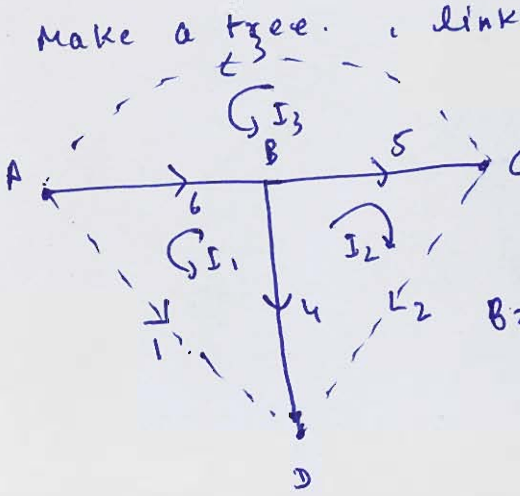
Ans. Draw Graph, voltage source replace by short circuit. ~~and~~ B



~~No~~ Number of fundamental loops are $= b-(N-1)$

$= 6-(4-1) = 3$

- Make a tree. , links $= b-(N-1) = 3$



tie set matrix is

B =

	1	2	3	4	5	6
I_1	1	0	0	-1	0	-1
I_2	0	1	0	-1	1	0
I_3	0	0	1	0	1	1

Tie-set matrix

$$B = \begin{bmatrix} 1 & 0 & 0 & -1 & 0 & -1 \\ 0 & 1 & 0 & -1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$$

$[Z_L] = [B][Z_B][B^T]$

Z_B = Impedance matrix

$$= [Z_B][B^T]$$

$$= \begin{bmatrix} 12 & 0 & 0 & 0 & 0 & 0 \\ 0 & 8 & 0 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 12 & 0 \\ 0 & 0 & 0 & 0 & 0 & 8 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -1 & -1 & 0 \\ 0 & 1 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$

$\Rightarrow Z_L \Rightarrow [B][Z_B][B^T]$

=

$$Z_L = \begin{bmatrix} 1 & 0 & 0 & -1 & 0 & -1 \\ 0 & 1 & 0 & -1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} 12 & 0 & 0 \\ 0 & 8 & 0 \\ 0 & 0 & 4 \\ -4 & -4 & 0 \\ 0 & 12 & 12 \\ -8 & 0 & 8 \end{bmatrix}$$

$$Z_L = \begin{bmatrix} 24 & +4 & -8 \\ 4 & 24 & 12 \\ -8 & 12 & 24 \end{bmatrix}$$

$[I_s] \rightarrow$ current source

as the

$$[Z_L][I_s] = [B][V_s] - [B][Z_B][I_s]$$

$$\begin{bmatrix} 24 & +4 & -8 \\ +4 & 24 & 12 \\ -8 & 12 & 24 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & -1 & 0 & -1 \\ 0 & 1 & 0 & -1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} 20 & 0 & 0 \\ 0 & 40 & 0 \\ 0 & 0 & -12 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$\begin{bmatrix} 24 & 4 & -8 \\ 4 & 24 & 12 \\ -8 & 12 & 24 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 20 \\ 10 \\ -12 \end{bmatrix}$$

$$24 I_1 + 4 I_2 - 8 I_3 = 20$$

$$4 I_1 + 24 I_2 + 12 I_3 = 10$$

$$-8 I_1 + 12 I_2 + 24 I_3 = -12$$

$I_1 = 0.5$ Ampere

$I_2 = \frac{2}{3}$ Ampere

$I_3 = -\frac{2}{3}$ Ampere

Am.

20

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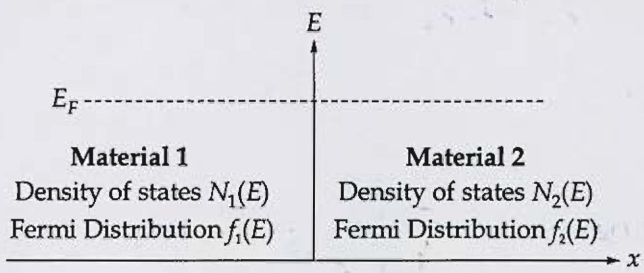
Q.4 (c) **(i)** Consider a semiconductor in thermal equilibrium (no current). Assume that the donor concentration varies exponentially as,

$$N_d(x) = N_{d_0} e^{-\alpha x}$$

over the range $0 \le x \le \frac{1}{\alpha}$ where N_{d_0} is a constant.

1. Calculate the electric field as a function of 'x' for $0 \le x \le \frac{1}{\alpha}$.
2. Calculate the potential difference between $x = 0$ and $x = \frac{1}{\alpha}$.

(ii) Consider two materials in intimate contact at equilibrium as shown below.



Assume the net motion of electrons is zero, show that the equilibrium Fermi level must be constant throughout, that is, $E_{F_1} = E_{F_2}$ (or) show that no gradient exists in the Fermi level at equilibrium, $\frac{dE_F}{dx} = 0$

[10 + 10 marks]

Ans. ii) Given

material = 1

Density of states = $N_1(E)$

Fermi Distribution $f_1(E) = \frac{1}{1 + e^{(E-E_F)/kT}}$

material = 2

Density of states = $N_2(E)$

Fermi Distribution $f_2(E) = \frac{1}{1 + e^{(E-E_F)/kT}}$

N_x = Electron concentration of material '1' $= N_1 f_1 \Rightarrow N_x$

Electron concentration of material '2' = $N_2 f_2$ 'N_y'

P_x = hole concentration of material 1 $= N_1(1 - f_1)$

Hole concentration of material 2 = $N(1-f_2)$ 'P_y'

at under steady state :
equilibrium. Net electron concentration
∴

$$N_x P_y = N_y P_x$$

$$(N_1 f_1)[N_2(1-f_2)] = (N_2 f_2)[N_1(1-f_1)]$$

$$f_1(1-f_2) = f_2(1-f_1)$$

$$f_1 - f_1 f_2 = f_2 - f_1 f_2$$

$$\boxed{f_1 = f_2}$$

$$\frac{1}{1+e^{(E-E_{F_1})/kT}} = \frac{1}{1+e^{(E-E_{F_2})/kT}}$$

$$\therefore \boxed{E_{F_1} = E_{F_2}}$$

2

8

Ans · i) Given $N_d(x) = N_{do} e^{-\alpha x}$

i) at equilibrium no current

$$0 = ne\mu_n E + eD_n \frac{dn}{dx}$$

$$E = \frac{-V_t}{n} \frac{dn}{dx}$$

Given ⇒ $n = N_{do} e^{-\alpha x}$

$$E = \frac{-V_t}{N_{do} e^{-\alpha x}} \frac{d(N_{do} e^{-\alpha x})}{dx}$$

$$= \frac{-V_t}{N_{do} e^{-\alpha x}} N_{do} (e^{-\alpha x})(-\alpha)$$

$$\boxed{E = \alpha V_t} \ V/m$$

10

W.K.T

$$E = \frac{-d\phi}{dx}$$

$$\int_0^\phi d\phi = -\int E \cdot dx$$

Put value of E

$$= \int_0^{1/\alpha} \alpha V_t \, dx$$

$$\phi = \alpha V_t [x]_0^{1/\alpha}$$

$$\boxed{\phi = -V_t}$$

$\phi = -V_T$

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Section B : Network Theory + Electronic Devices and Circuits

Q.5 (a) Consider a sample of silicon at T = 300 K. A hall effect device is fabricated with the following geometry:

$d = 5 \times 10^{-3}$ cm

$W = 5 \times 10^{-2}$ cm

L = 0.50 cm

The electrical parameters measured are:

I_x = 0.50 mA

V_x = 1.25 V

B_z = 650 gauss = 6.5×10^{-2} tesla

The Hall field is E_H = –16.5 mV/cm

Determine:

(i) the Hall voltage,

(ii) the conductivity type,

(iii) the majority carrier concentration,

(iv) the majority carrier mobility.

[12 marks]

Ans. i) Hall voltage

$V_H = \frac{BI}{\rho W}$ $E = +16.5$ mV/cm

$E_H = \frac{V_H}{L}$ $V_H = -\frac{16.5 \times 10^{-3} \times 10^2}{0.50}$

$V_H = -33$ mV.

ii) $V_H = \frac{BI}{\rho W}$

$\sigma = ne\mu$

$\frac{1}{ne} = \rho$

$\rho = \frac{-33 \times 5 \times 10^{-2}}{6.5 \times 10^{-2} \times 0.50}$

$\rho = -50.76$

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Q.5 (b) Consider a long silicon *pn*-junction photodiode at $T = 300\ K$ with the following parameters:

$N_a = 2 \times 10^{16}\ cm^{-3}$ $\quad N_d = 10^{18}\ cm^{-3}$

$D_n = 25\ cm^2/s$ $\quad D_p = 10\ cm^2/s$

$\tau_{n_0} = 2 \times 10^{-7}\ s$ $\quad \tau_{p_0} = 10^{-7}\ s$

Assume a reverse-bias voltage of $V_R = 5$ volts is applied and assume a uniform generation rate of $G_L = 10^{21}\ cm^{-3}\ s^{-1}$ exists throughout the entire photodiode.

Calculate:

(i) The prompt photocurrent density and

(ii) The total steady-state photocurrent density.

Given: n_i for $Si = 1.5 \times 10^{10}\ cm^{-3}$

$\varepsilon_{r_{si}} = 11.7$

[12 marks]

Ans. i) $G_L = 10^{21}$

at steady state

$\Delta p = 10^{21} \times 2 \times 10^{-7}$
$= 2 \times 10^{14}$

$\Delta n = 10^{21} \times 10^{-7}$
$\Delta n = 10^{14}$

$N_a = 2 \times 10^{16} + 2 \times 10^{14}$

$N_a \simeq 202 \times 10^{14}$

$N_D = 10^{18} + 10^{14}$

$N_D = 10^{18}$

$J = Aq n_i^2 \left[\frac{1}{N_D} \sqrt{\frac{D_p}{\tau_p}} + \frac{1}{N_A} \sqrt{\frac{D_n}{\tau_p}} \right] \left(e^{-\frac{V_R}{\eta V_T}} - 1 \right)$

$J_s =$

0

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5 (c) **(i)** Calculate the temperature at which there is a 10^{-6} probability that an energy state 0.55 eV above the Fermi energy level is occupied by an electron.

(ii) A silicon n^+p junction is biased at $V_R = 10$ V. Determine the ΔV_{bi} (Change in built-in potential), if the doping in the p-region increases by a factor of 2.

[6 + 6 marks]

Ans. i) Ferm $f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}$

acc to Boltzman approximation $f(E) \simeq e^{-(E-E_F)/kT}$

$10^{-6} \simeq e^{-(0.55)/kT}$

$\ln(10^{-6}) \simeq -\frac{0.55}{kT}$

$13.81 = \frac{0.55}{kT}$

6

$kT = \frac{0.55}{13.81}$

$\frac{T}{11600} = \frac{0.55}{13.81}$

Temp = 461.79 K°

Ans.

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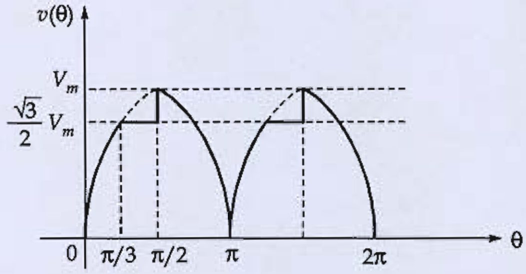
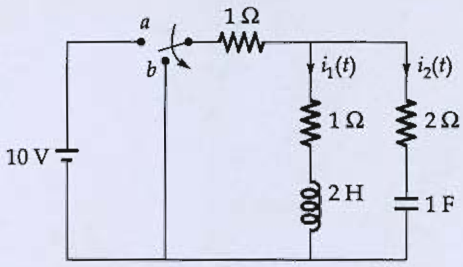
Q.5 (d) (i) The periodic function $v(\theta)$ given below is applied to a resistor of 1 Ω. Calculate the power dissipated in the resistor.
[Given, $V_m = 1$ V]



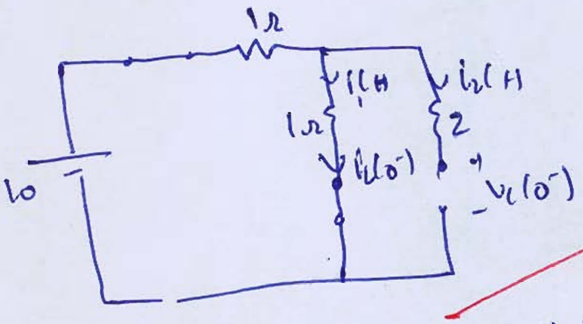
(ii) In the circuit shown below, at $t = 0$, the switch is moved from position 'a' to 'b'.



Determine the value of $\frac{di_1(0^+)}{dt}$.

[6 + 6 Marks]

Ans. ii) at $t = 0^-$ switch at 'a'

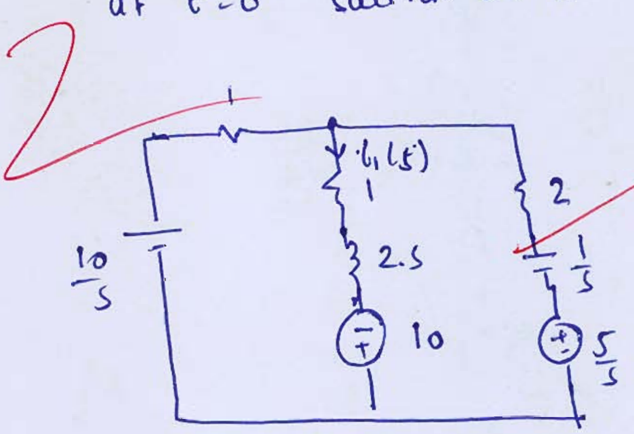


$i_L(0^-) = 5A$

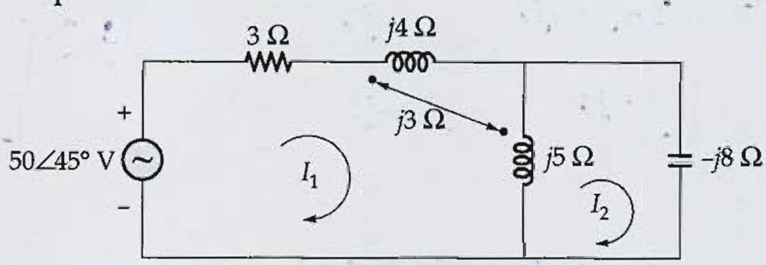
$v_c(0^-) = 5V$

at $t = 0^+$ switch at 'b' $i_L(0^-) = i_L(0^+) = 5A$

$v_c(0^-) = v_c(0^+) = 5V$

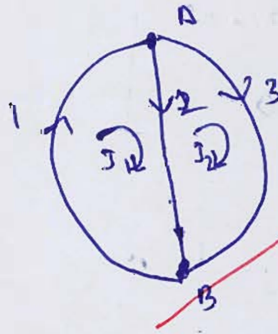


5 (e) For the network shown in figure, write down the tie set matrix and obtain network equilibrium equations in matrix from.



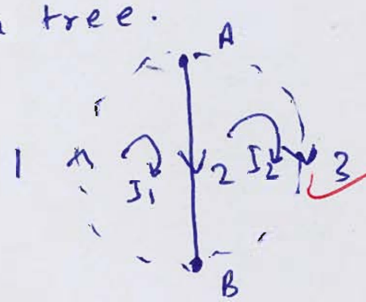
[12 marks]

Ans. Draw Graph ∴ Voltage source replace by short circuit



Fundamental tieset loop
$= l = b - (N-1)$
$= 3 - (2-1)$
$\boxed{= 2}$

• Draw a tree.



tie-set matrix

$B =$

	1	2	3
I_1	1	1	0
I_2	0	-1	1

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$$B = \begin{bmatrix} 1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix}$$

Impedance matrix

$$Z_B = \begin{bmatrix} 3+j4 & j3 & 0 \\ j3 & j5 & 0 \\ 0 & 0 & -j8 \end{bmatrix}$$

$$Z_L = [B][Z_B][B^T]$$

$$= \begin{bmatrix} 1 \end{bmatrix} \begin{bmatrix} 3+j4 & j3 & 0 \\ j3 & j5 & 0 \\ 0 & 0 & -j8 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1 & -1 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 3+j7 & -j3 \\ j8 & -j5 \\ 0 & -j8 \end{bmatrix}$$

$$Z_L = \begin{bmatrix} 1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} 3+j7 & -j3 \\ j8 & -j5 \\ 0 & -j8 \end{bmatrix} =$$

$$= \begin{bmatrix} 3+j7+j8 & -j8 \\ -j8 & -j3 \end{bmatrix} \qquad [I_S] = \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

2

equation

$$[Z_L][I_S] = [B][V_S] + [B][Z_B][I_S]$$

$$\begin{bmatrix} 3+j15 & -j8 \\ -j8 & -j3 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 50\angle 45^\circ \\ 0 \end{bmatrix}$$

$$(3+j15)I_1 - j8 I_2 = 50\angle 45^\circ$$
$$-j8 I_1 - j3 I_2 = 0$$

Ans.

6 (a) (i) A series resonant circuit has its impedance,

$$Z(s) = \frac{20(s+1+j10)(s+1-j10)}{s}$$

Find:

- Resonant frequency
- Q-factor
- Bandwidth
- Impedance of the circuit under resonance condition

(ii) Draw a parallel RLC circuit using the elements of $Z(s)$. And also calculate the extra capacitance (C_{ext}) that must be added in series with capacitor C so that the resonant frequency of parallel RLC circuit is increased by factor of 5.

[10 + 10 marks]

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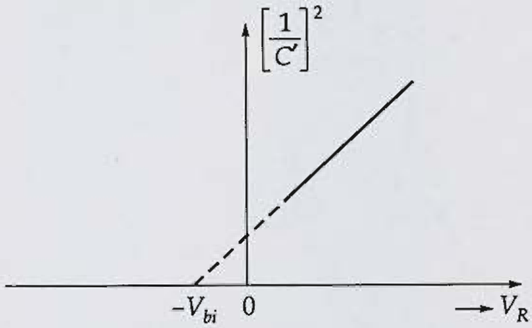
Q.6 (b) (i) A silicon device with n-type material is to be operated at T = 550 K. At this temperature, the intrinsic carrier concentration must contribute no more than 5 percent of the total electron concentration. Determine the minimum donor concentration to meet this specification.
(Given : $n_i = 3.20 \times 10^{14}$ cm^{-3} at T = 550 K)

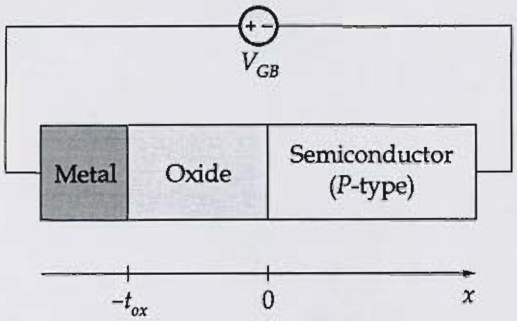
(ii) Assume a silicon p^+n junction at T = 300 K with $n_i = 1.5\times10^{10}\text{cm}^{-3}$. The inverse depletion layer capacitance per unit area squared is a linear function of applied reverse-bias voltage as shown below.



Assume that the intercept of the curve on the voltage axis in above figure gives –0.855 V and that the slope is 1.32×10^{15} (F/cm^2)$^{-2}$V^{-1}.
Determine the impurity doping concentrations 'N_d' and 'N_a'.
[Given : Relative permittivity of Si = 11.7]

[8 + 12 marks]

(c) Consider a MOS structure shown below:



The oxide thickness, t_{ox} = 50 nm and the doping level in the p-type substrate is $N_a = 10^{16}$ cm^{-3}. Assume, intrinsic carrier concentration of semiconductor, $n_i = 10^{10}$/cm^3, thermal voltage, V_T = 26 mV, $\in_{oxide} = 3.45 \times 10^{-13}$ F/cm, $\in_{si} = 1.05 \times 10^{-12}$ F/cm.
Calculate the hole concentration, p at the oxide-semiconductor interface (i.e., $x = 0$) under the following conditions:

(i) At flatband.

(ii) At threshold.

(iii) At a condition in which the potential build up from the quasi-neutral body of semiconductor to $x = 0$ is 0.5 V.

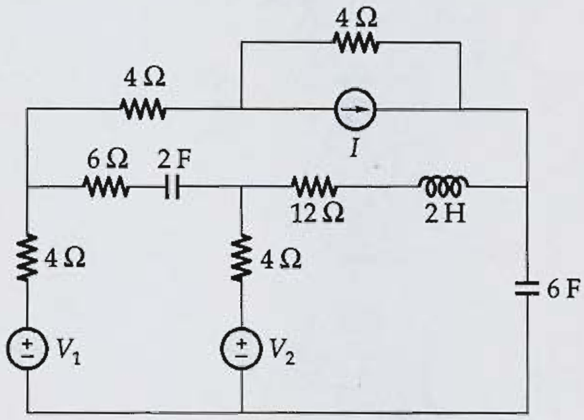
(iv) At a condition when the capacitance per unit area of the MOS structure is 50 nF/cm^2.

[20 marks]

Q.7 (a) Show that the ratio of hole diffusion current to electron diffusion current crossing a p-n junction is given by, $\frac{I_{pn}(0)}{I_{np}(0)} = \left(\frac{\sigma_p}{\sigma_n}\right) \times \left(\frac{L_n}{L_p}\right)$ where σ_p, σ_n are the conductivities and L_n, L_p are diffusion lengths of 'p' and 'n' regions respectively. Assume the junction is located at $x = 0$ and neglect the depletion layer width.

[20 marks]

Q.7 (b) For the network shown in figure, draw the oriented graph and compute.



(i) Complete incidence matrix and reduced incidence matrix.

(ii) Tie set matrix.

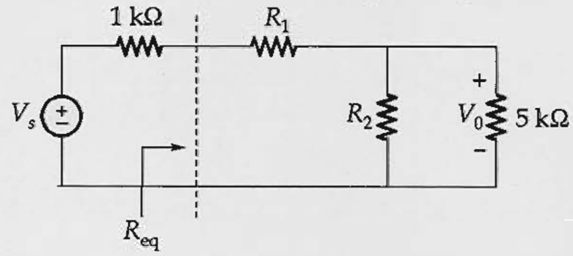
(iii) f-cut set matrix.

[20 marks]

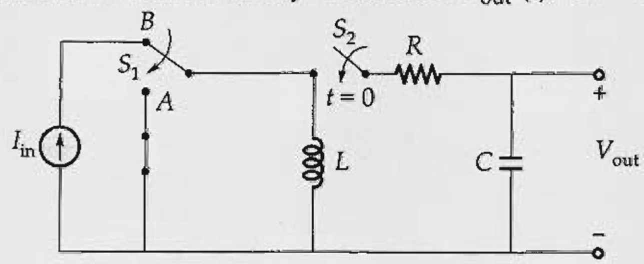
(c) (i) In a certain application, the circuit shown below must be designed to meet these two criteria:

1. $\frac{V_0}{V_s} = 0.05$ 2. $R_{eq} = 39\ k\Omega$

If the load resistor 5 kΩ is fixed, find R_1 and R_2 to meet the criteria.



(ii) In the circuit shown below, $L = 0.5$ H, $C = 0.75$ F, $R = 3\ \Omega$ and $I_{in}(t) = 12$A (DC) for all time. Suppose that switch S_1 has been in position B for a very long time and switch S_2 has been open for all time. At time $t = 0$ switch S_1 moves to position A and switch S_2 closes instantaneously. Calculate $V_{out}(t)$ at $t = 1.5$ seconds if $V_{out}(0^-) = 0$



[10 + 10 marks]

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Q.8 (a) (i) In a very long p-type Si bar with cross-sectional area = 1 cm^2 and $N_A = 10^{17}$ cm^{-3}, we inject holes such that the steady state excess hole concentration is 3×10^{16} cm^{-3} at $x = 0$. What is the steady state separation between E_i and E_{F_p} at $x = 500Å$?
[Assume that $\mu_p = 500$ cm^2/V-s and $\tau_p = 10^{-10}$ s, $n_i = 1.5 \times 10^{10}$ cm^{-3}]

(ii) Assume that an n-type semiconductor is uniformly illuminated, producing a uniform excess generation rate g'.
Show that in steady state the change in the semiconductor conductivity is given by,
$\Delta\sigma = q(\mu_n + \mu_p)\tau_{p_0} g'$

[12 + 8 marks]

Ans. i) Given p-type Si bar. Area 'A' = 1 cm^2

$p_0 = N_A = 10^{17}$ cm^{-3}

$\Delta p = 3 \times 10^{16}$ cm^{-3} → $x = 0$

steady state separation $E_i - E_{F_p} = kT \ln\left(\frac{N_A}{n_i}\right)$ at $x = 500Å$

$p(x) = p_0 + \Delta p\, e^{-x/L_p}$

& $x = 500Å$

$L_p = \sqrt{D_p \tau_p} = \sqrt{\mu_p V_t \tau_p}$

$L_p = \sqrt{500 \times 0.0254 \times 10^{-10}}$

$L_p = 3.59 \times 10^{-5} = 3.6 \times 10^{-5}$.

$= 10^{17} + 3 \times 10^{16}\, e^{-\frac{500 \times 10^{-8}}{3.6 \times 10^{-5}}}$

$= 10^{17} + 2.61 \times 10^{16}$

$p(500Å) = 12.61 \times 10^{16}$ /cm^3

$E_i - E_F = kT \ln\left(\frac{12.61 \times 10^{16}}{1.5 \times 10^{10}}\right)$

$E_i - E_F = 1.6057$

7

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Ans. ii) n-type semiconductor

Generation Rate $= g' = \frac{\text{excess electron}}{\text{minority carrier}} = \frac{\Delta n}{\tau_n} = \frac{\Delta p}{\tau_p}$

$p = p_o + \Delta p$ | $n = n_o + \Delta n$

$\boxed{\Delta p = g'\tau_{po}}$ $\boxed{\Delta n = g'\tau_{no}}$

$\therefore p \gg \Delta p$ $n \gg ..$

at steady state $\Rightarrow \frac{\text{excess } e^-}{e^- \text{ minority carrier}} = \frac{\text{excess hole}}{\text{hole minority carrier lifetime}}$

$\Rightarrow \frac{\Delta n}{\tau_{no}} = \frac{\Delta p}{\tau_{po}}$

as conductivity of semiconductor

$\sigma = ne\mu_n + pe\mu_p$

$\therefore$ change in conductivity

$\Delta\sigma = q\mu_n(\Delta n) + q\mu_p \Delta p$

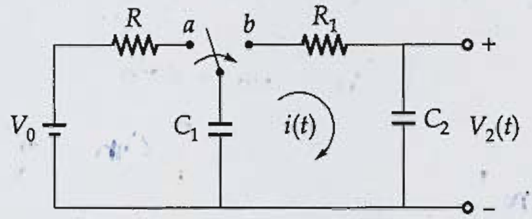
$= q\mu_n(g'\tau_{no}) + q\mu_p(g'\tau_{po})$

as at steady state $\Delta n = \Delta p$

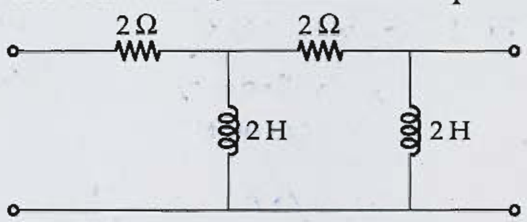
$$\boxed{\Delta\sigma = q.(\mu_n + \mu_p)\tau_{po} g'}$$ Ans.

8

Q.8 (b) (i) The switch is moved from the position *a* to *b* at $t = 0$, having been in the position *a* for a long time before $t = 0$. The capacitor C_2 is uncharged at $t = 0$. Find i(t) and $V_2(t)$ for $t > 0$.

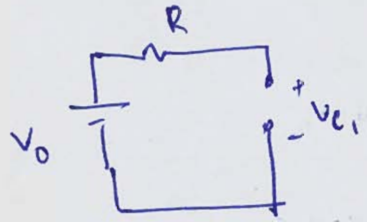


(ii) For the ladder network below, determine the *h* parameters in the *s* domain.



[10 + 10 marks]

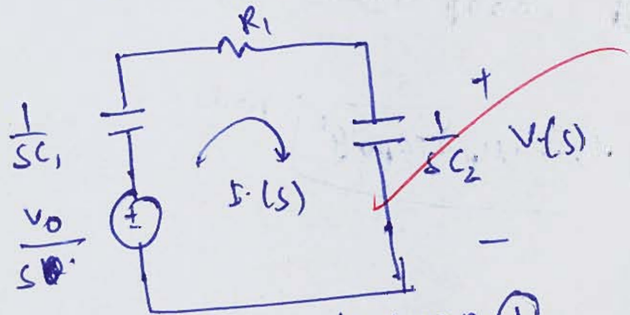
Ans. i) at $t = 0^-$ · switch position (a)



$$V_{C_1}(0^-) = V_0$$

~~at $t = 0^+$ switch position (b) $V_C(0^-) = V_C(0^+) = \frac{V_0}{R}$~~

Redraw circuit in Laplace



apply KVL in loop (1)

$$I(s) = \frac{\frac{V_0}{S}}{\left(R_1 + \frac{1}{SC_1} + \frac{1}{SC_2}\right)} = \frac{V_0}{S\left(\frac{SR_1C_1C_2 + C_2 + C_1}{SC_1C_2}\right)}$$

$$= \frac{V_0 \, (C_1C_2)}{R_1C_1C_2\left[S + \frac{(C_1 + C_2)}{R_1C_1C_2}\right]}$$

$$I(s) = \frac{V_0/R_1}{s + \left(\frac{C_1+C_2}{R_1C_1C_2}\right)} \quad -(1)$$

apply Inverse Laplace tran

$$\Rightarrow \quad i(t) = \frac{V_0}{R_1} e^{-\left(\frac{C_1+C_2}{R_1C_1C_2}\right)t} \text{ Amp}$$

Now V(s) by ohms law

$$V(s) = I(s) \times \frac{1}{sC_2}$$

$$= \left[\frac{V_0/R_1}{s+\left(\frac{C_1+C_2}{R_1C_1C_2}\right)}\right]\frac{1}{sC_2} = \frac{V_0/R_1C_2}{s\left(s+\frac{(C_1+C_2)}{R C_1 C_2}\right)}$$

partial fractn

$$\frac{V_0}{R_1C_2} = \frac{A}{s} + \frac{B}{s+\frac{(C_1+C_2)}{R C_1 C_2}}$$

$$V(s) = \frac{\frac{V_0 C_1}{C_1+C_2}}{s} - \frac{\frac{V_0 C_1}{C_1+C_2}}{s+\frac{(C_1+C_2)}{R C_1 C_2}}$$

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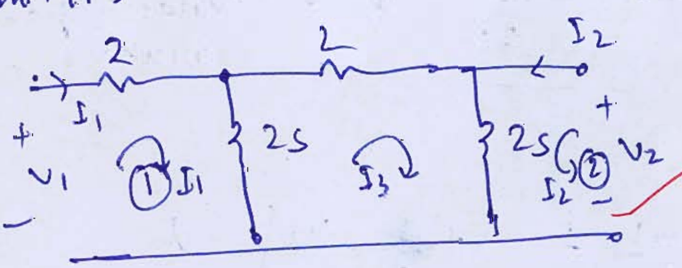
inveverse laplace

$$v(t) = V_0 \frac{C_1}{C_1+C_2}\left[1 - e^{-\left(\frac{C_1+C_2}{R C_1 C_2}\right)t}\right] u(t) \text{ Volt}$$

Ans. (ii)



as h-parameter eqs

$$V_1 = h_{11}I_1 + h_{12}V_2 \quad -(a)$$

$$I_2 = h_{21}I_1 + h_{22}V_2 \quad -(b)$$

a.

apply KVL in loop-1

$v_1 = (2+2s)I_1 - 2sI_3$ — (3)

$v_1 = 2(s+1)I_1 - 2sI_3$ — (3)

apply KVL in loop 2

$(2+4s)I_3 + 2sI_2 - 2sI_1 = 0$

$I_3 = \frac{s}{(2s+1)} I_1 - \frac{s}{(2s+1)} I_2$ — (1)

apply KVL in loop 3

$V_2 = 2sI_2 + 2sI_3$ — (2)

substitute equation (1) in equation (2)

$V_2 = 2sI_2 + 2s\left[\frac{s}{(2s+1)} I_1 - \frac{s}{(2s+1)} I_2\right]$

$V_2 = \frac{2s(s+1)}{(2s+1)} I_2 + \frac{2s^2}{2s+1} I_1$

$I_2 = \left(\frac{-2s^2}{2s+1}\right) \times \frac{(2s+1)}{2s(s+1)} I_1 + \frac{(2s+1)}{2s(s+1)} V_2$

$I_2 = \frac{-s}{s+1} I_1 + \frac{(2s+1)}{2s(s+1)} V_2$ — (c)

compare equation b and c ⇒ $h_{21} = \frac{-s}{s+1}$ | $h_{22} = \frac{2s+1}{2s(s+1)}$

10

substitute equation (1) in equation (3)

$v_1 = 2(s+1) \cdot I_1 - 2s\left[\frac{s}{(2s+1)} I_1 - \frac{s}{(2s+1)} I_2\right]$

$v_1 = \left(\frac{(2s^2+6s+1)}{2s+1}\right) I_1 + \frac{2s^2}{2s+1} I_2$ — substitute value I_2 from equation c

$V_1 = \frac{8s^2+7s+1}{(2s+1)(s+1)} I_1 + \frac{s}{s+1} V_2$ — d

Compare equat (a) & d

$h_{11} = \frac{8s^2+7s+1}{(2s+1)(s+1)}$ | $h_{12} = \frac{s}{s+1}$

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c) (i) Assume the base transit time of a BJT is 100 ps and carriers cross the 1.2 μm base-collector space charge region at a speed of 10^7 cm/s. The emitter-base junction charging time is 25 ps and the collector capacitance and resistance are 0.1 pF and 10 Ω respectively. Determine the cut-off frequency of the BJT.

(ii) An npn silicon transistor is biased in the inverse active mode with $V_{BE} = -3$ V and $V_{BC} = 0.6$ V. The doping concentrations are $N_E = 10^{18}$ cm^{-3}; $N_B = 10^{17}$ cm^{-3}, and $N_C = 10^{16}$ cm^{-3}. Other parameters are $x_B = 1$ μm, $\tau_{E0} = \tau_{B0} = \tau_{C0} = 2 \times 10^{-7}$ s, $D_E = 10$ cm^2/s, $D_B = 20$ cm^2/s, $D_C = 15$ cm^2/s and area $A = 10^{-3}$ cm^2. Calculate the collector and emitter currents (Neglect geometry factors and assume the recombination factor is unity) (Assume, $n_i = 1.5 \times 10^{10}$ cm^{-3}, $V_t = 0.0259$ V, τ = carrier life time and D = diffusion coefficient.)

[10 + 10 marks]

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Space for Rough Work

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