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ESE 2019 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electronics & Telecommunication Engineering

Test-4: Electronic Devices & Circuits + Advanced Electronics Topics
Analog and Digital Communication Systems-1
Network Theory-2 + Microprocessors and Microcontroller-2

Name : .....

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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. Answer must be written in English only.
3. Use only black/blue pen.
4. 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.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

Good writing skills

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	24
Q.2	40
Q.3	—
Q.4	31
Section-B	
Q.5	29
Q.6	47
Q.7	—
Q.8	—
Total Marks Obtained	171

Signature of Evaluator ..... Cross Checked by .....

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Section A : Electronic Devices & Circuits + Advanced Electronics Topics

(a) Calculate the flat-band voltage for a MOS capacitor with a p-type semiconductor substrate having doping concentration $N_a = 10^{16}$ cm^{-3}, a SiO_2 insulator layer with a thickness of $t_{ox} = 500$ Å with a n^+ polysilicon gate with an equivalent trapped charge per unit area $Q'_{ss} = 10^{11}$ electronic charges per cm^2.

(Assume $\varepsilon_{ox} = 3.9\varepsilon_o$ and the work function difference $\phi_{ms} = -1.1$ V)

[12 marks]

$N_a = 10^{16}/cm^3$, $t_{ox} = 500\ Å$, $Q'_{ss} = 10^{11}$

formula of FLat band voltage $V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}}$

C_{ox} = oxide capacitance per unit area.

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.9 \times 8.856 \times 10^{-14}}{(500 \times 10^{-8})} = 6.90768 \times 10^{-8}\ F/cm^2$$

$$\frac{Q'_{ss}}{C_{ox}} = \frac{10^{11} \times 1.6 \times 10^{-19}}{(6.90768 \times 10^{-8})} = 0.2316\ V.$$

$$V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}} = -(1.1 + 0.2316)\ V$$

$$V_{FB} = -1.3316\ V$$

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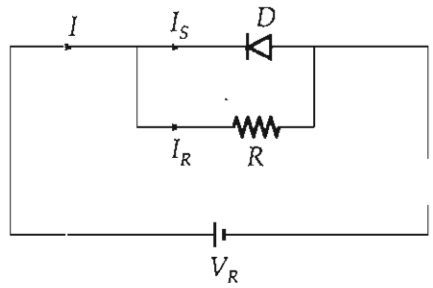
Q.1 (b) It is predicted that, for silicon, the reverse saturation current (I_S) increases by 11% for every 1°C rise in temperature. It is found experimentally in a particular diode circuit, which is shown below, that at reverse biasing voltage (V_R) of 10 V, the reverse saturation current (I_S) is 5 μA and the circuit current (I) increases by 7% for every 1° C rise in temperature. Calculate the value of shunt resistance (R).
(Assume the temperature effect on the resistor R is negligible.)



[12 marks]

→ $V_R = 10V$, $I_S = 5 \times 10^{-6} A$

$\frac{\partial I}{\partial T} = 0.07$, and $\frac{\partial I_S}{\partial T} = 0.11$

$I_D = I_S \left[e^{\frac{Vq}{\eta KT}} - 1 \right]$

$\frac{\partial I_D}{\partial T} = \frac{\partial I_S}{\partial T} \left[e^{\frac{Vq}{\eta KT}} - 1 \right]$ ~~$+ I_S \frac{V \cdot q}{\eta KT}$~~

$\Rightarrow 0.07 = 0.11 \left[e^{V/\eta V_T} - 1 \right]$

$\Rightarrow 0.07 = 0.11 \left[e^{V/\eta V_T} - 1 \right]$

$= 0.636 + 1 = e^{V/\eta V_T}$

$\Rightarrow \frac{V}{\eta V_T} = 1.636$

$\Rightarrow V_D = \eta V_T = (1.636)^{-1} \times 10 = 6.11$ V

$I_D \Rightarrow 5 \times 10^{-6} = I_0 \left[\frac{0.07}{0.11} \right]$

$I_0 = \left[\frac{5 \times 10^{-6} \times 0.11}{0.07} \right] = 7.85 \times 10^{-6} A$

$I_D = I_0 \left(e^{V/\eta V_T} - 1 \right)$

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$$\frac{\partial I_D}{\partial V} = \frac{I_0\left(e^{V/\eta V_T}-1\right)}{(\eta V_T)} = \frac{7.85\times10^{-7}\times\left(\frac{0.07}{0.11}\right)}{0.11}$$

$$\frac{\partial I_D}{\partial V} = 8.17\times10^{-7}\ \mho$$

$$R = 1223111.92\ \Omega.$$

(c) To scale a MOSFET, combined voltage and dimension scaling model with two scaling factors ($1/\alpha$ and $1/\beta$) is used. $1/\beta$ is chosen as the scaling factor for supply voltage (V_{DD}) and gate oxide thickness (t_{ox}), and $1/\alpha$ is used for all other linear dimensions, both vertical and horizontal to the chip surface. Determine the effect of the scaling on the maximum operating frequency.

Assume that there is no effect of scaling on the carrier mobility (μ) in the channel.

[12 marks]

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1 (d) Phosphorus is implanted in a p-type silicon sample with a uniform doping concentration of 10^{16} atoms per cm^3. If the beam current density is 2 μA per cm^2 and the implantation is carried out for 10 minutes, calculate the implantation dose. Also find the peak impurity concentration. Assume R_p = 1.1 μm and ΔR_p = 0.3 μm.

[12 marks]

R_p = Average distance travelled = 1.1 μm

ΔR_p = standard deviation = 0.3 μm

j = current density = 2×10^{-6} A/cm^2 ↓ $j = 2 \times 10^{-6}$ /cm^2

$N_A = 10^{16}$ /cm^3 P type

n = total charge.

A = unit area

As we know $j = \frac{nq}{t} = \frac{Sq}{t}$

$S = \left(\frac{t\,j}{q}\right) = \frac{10 \times 60 \times 2 \times 10^{-6}}{(1.6 \times 10^{-19})}$

Implantation dose $S = 9.5 \times 10^{15}$ /cm^2

As we $N(x) = N_p\, e^{-\frac{(x - R_p)}{2\Delta R_p^2}}$

$\int_{-\infty}^{\infty} N(x)\,dx = \frac{\Delta R N_p \sqrt{2\pi}}{\sqrt{2\pi}\,\Delta R} \int_{-\infty}^{\infty} e^{-\frac{x - R_p}{2\Delta R_p}}$ $\left[\int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}\Delta R} e^{-\frac{(x-R_p)}{2\Delta R_p}} = 1\right]$

$\Rightarrow S = N_p (\Delta R) \sqrt{2\pi}$

$\Rightarrow N_p = \frac{S}{(\Delta R)(\sqrt{2\pi})} = \left(\frac{9.5 \times 10^{15}}{0.3 \times 10^{-6} \times \sqrt{2\pi}}\right)$

$N_p = 9.97 \times 10^{21}$ /cm^2

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Q.2 (a) The total current in a semiconductor is constant and is composed of electron drift current and hole diffusion current. The electron concentration is constant and is equal to 10^{16} cm^{-3}.

The hole concentration is given by $p(x) = 10^{15} \exp(-x / L_p)$ cm^{-3}, where $L_p = 12$ μm and $x \geq 0$. The hole diffusion coefficient $D_p = 12$ cm^2/s and the electron mobility $\mu_n = 1000$ cm^2/V-s. If the total current density is 4.8 A/cm^2, then

(i) Calculate the hole diffusion current density versus x.

(ii) Calculate the electron drift current density versus x.

(iii) Plot the electron drift current density and hole diffusion current density on a single graph.

(iv) Calculate the applied electric field versus x.

(v) Plot the graph of electric field versus x.

[20 marks]

→ N_D = electron concentration = 10^{16}/cm^3

$p(x) = 10^{15} e^{-x/L_p}$ /cm^3

$L_p = 12\ \mu m = 12 \times 10^{-4}$ cm

$D_p = 12$ cm^2/s

$\mu_n = 1000$ cm^2/V s

J = total current density = 4.8 A/cm^2

(i) $I_p = -A q D_p \frac{\partial p}{\partial x}$ (we know)

$\frac{I_p}{A} = J_p = -q D_p \frac{\partial p}{\partial x} = -q D_p 10^{15} \frac{\partial}{\partial x} e^{-(x/L_p)}$

$J_p = +\frac{q D_p \times 10^{15}}{L_p} e^{-x/L_p}$

$= \frac{1.6 \times 10^{-19} \times 12 \times 10^{15}}{(12 \times 10^{-4})} e^{-x/12\times10^{-4}}$ A/cm^2

$J_p = 1.6 e^{-x/12\times10^{-4}}$ A/cm^2 eq (1)

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(ii) $I_{n\,drift} = A q \mu_n n E(x)$; $J_{n\,drift}$ = electron current density

$J_{Total} = J_{p\,drift} + J_{n\,drift}$ [given]

$\Rightarrow 4.8 = 1.6 \times 10^{-15} e^{-x/L_p} + J_{n\,drift}$

$\therefore J_{n\,drift} = 4.8 - 1.6 \times e^{-x/L_p}$ A/cm²

(iii)

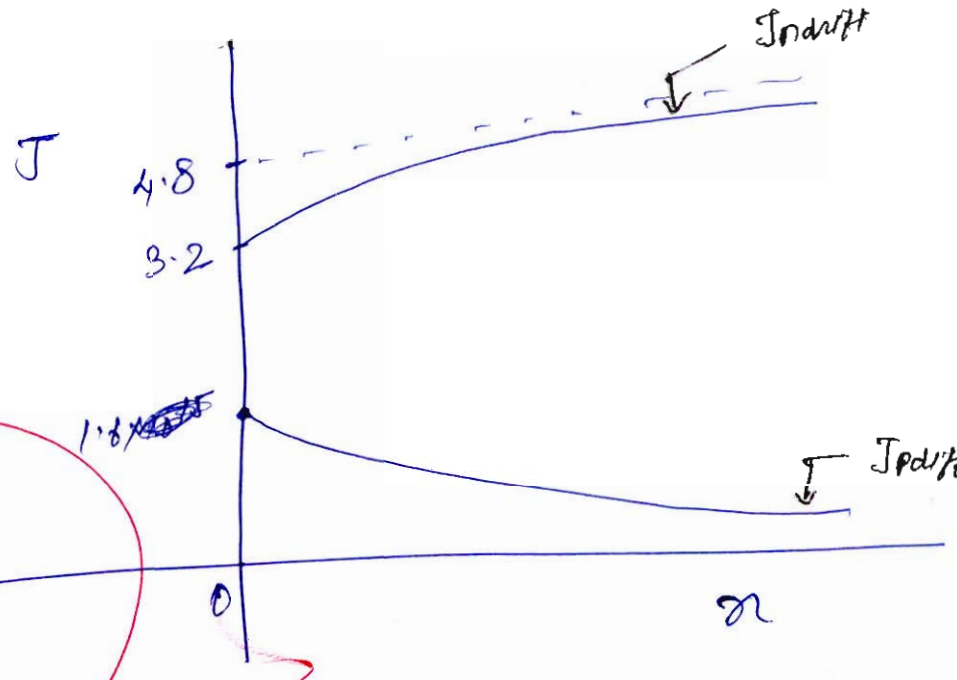


Fig: graph of current density vs x.

(iv) Electric field applied be $E(x)$

$$J_{n\,drift} = q N_D \mu_n E(x)$$

$$J_{n\,drift} = 4.8 - 1.6\, e^{-x/L_p}$$

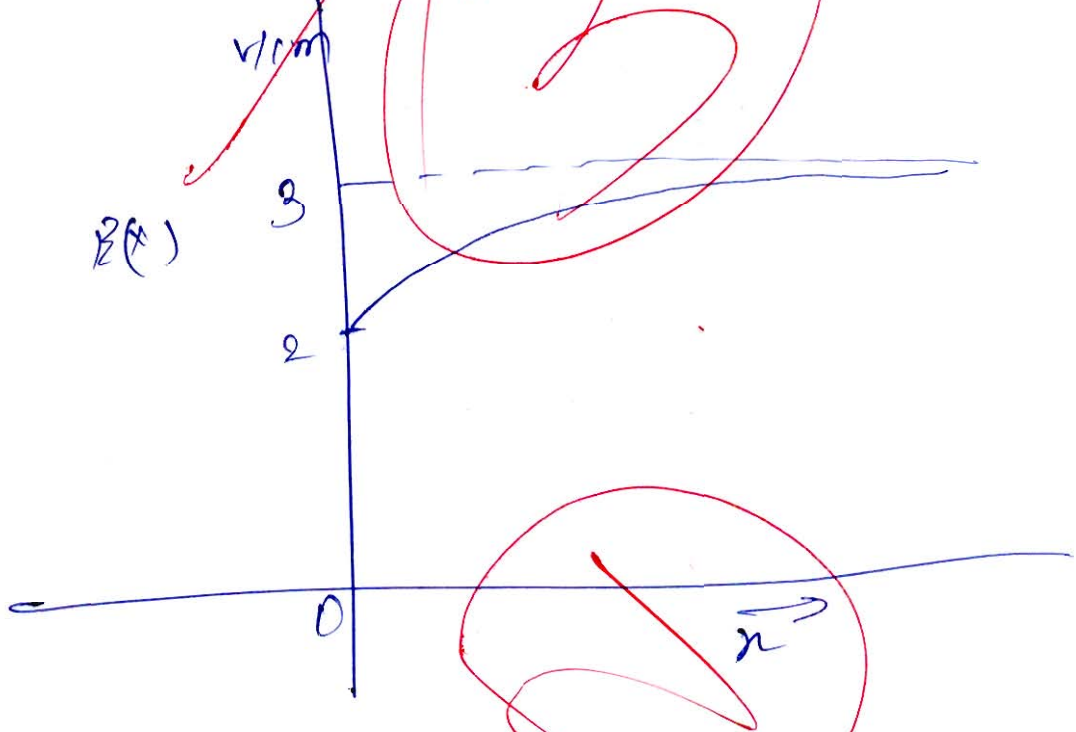
So, $q N_D \mu_n E(x) = 4.8 - 1.6\, e^{-x/L_p}$

$$\Rightarrow E(x) = \frac{[4.8 - 1.6\, e^{-x/L_p}]}{q N_D \mu_n} \text{ V/cm}$$

$$= \frac{4.8 - 1.6\, e^{-x/12\times10^{-4}}}{(1.6\times10^{-19} \times 10^{16} \times 1000)}$$

$$\boxed{E(x) = 3 - e^{-x/12\times10^{-4}} \text{ V/cm}}$$

(v)



graph of electric field vs x.

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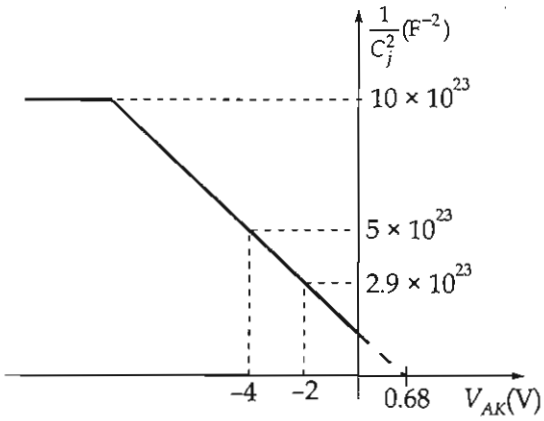
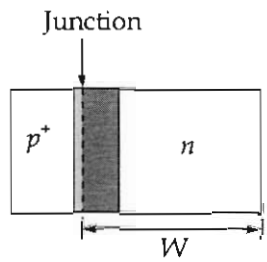
2 (b) Consider a reverse biased p^+-n junction diode. The diode has been biased with a biasing voltage V_{AK}. The graph of V_{AK} versus $\frac{1}{C_j^2}$ is plotted in the figure below, where C_j is the junction capacitance.





The diode has a junction area of 10^{-3} cm^2.

(i) Determine the value of built-in junction potential.

(ii) Calculate the doping concentrations on the two sides of the junction.

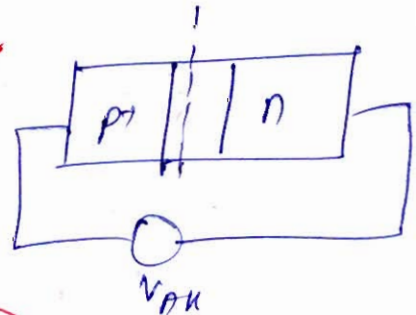
(iii) Calculate the value of width 'W'.

[Assume that $n_i = 1.5 \times 10^{10}$ cm^{-3} and $\varepsilon_{si} = 11.9\varepsilon_0$]

[20 marks]

→ As we know

C_j = transition capacitance



$$C_j' = \left(\frac{A\varepsilon_s}{W}\right) = \frac{A\varepsilon_s}{\sqrt{\frac{2\varepsilon_s}{q}\frac{1}{N_D}(V_R + V_b)}}$$

$$C_j' = \frac{A\varepsilon_s}{\sqrt{\frac{2\varepsilon_s}{q}\frac{V_b}{N_D}\left(\frac{V_R}{V_b} + 1\right)}} = \frac{C_0}{\sqrt{1 + \frac{V_R}{V_b}}}$$

$$C_j^2 = \frac{C_0^2}{\left(1 + \frac{V_R}{V_b}\right)} \Rightarrow$$

$$\Rightarrow \frac{1}{C_j^2} = \frac{1}{C_0^2}\left[1 + \frac{V_R}{V_b}\right] \quad \text{— eq (1)}$$

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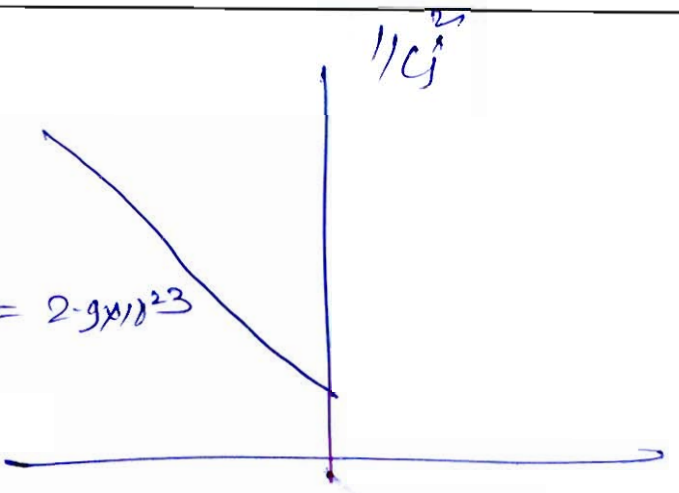

$\left(V_{AK}, \frac{1}{C_j^2}\right)$

If $V_{AK} = -2$ then $\frac{1}{C_j^2} = 2.9 \times 10^{23}$

putting in eqn (1)

$$\Rightarrow 2.9 \times 10^{23} = \frac{1}{C_0^2}\left[1 + \frac{2}{V_b}\right] \quad [V_R = V_{AK}]$$

— eqn (2)

$$\Rightarrow 5 \times 10^{23} = \frac{1}{C_0^2}\left[1 + \frac{4}{V_b}\right] \quad \text{— eqn (3)}$$

Taking ratio of eqn (2) and eqn (3)

$$\Rightarrow \frac{2.9}{5} = \frac{(1 + 2/V_b)}{(1 + 4/V_b)} \; ; \Rightarrow 0.58\left[1 + \frac{4}{V_b}\right] = 1 + \frac{2}{V_b}$$

$$\Rightarrow 0.58 + \frac{0.58 \times 4}{V_b} = 1 + \frac{2}{V_b}$$

$$\Rightarrow 0.58 - 1 = \frac{-0.32}{V_b}$$

$$\Rightarrow V_b = \frac{0.32}{0.42} = 0.761 \text{ V}$$

So, $\boxed{V_b = 0.761 \text{ V}}$

(11) $\frac{1}{C_0^2} = \frac{5\times10^{23}}{\left[1+\frac{V}{V_D}\right]} = \frac{5\times10^{23}}{\left[1+\frac{4}{0.761}\right]} = 7.99\times10^{22}$.

$C_0 = 3.53\times10^{-12}$ F/cm^2

$C_0 = \frac{A\varepsilon_0}{\sqrt{\frac{\varepsilon_0 V_d}{q N_D}}} = \varepsilon_0\sqrt{\frac{q N_D}{\varepsilon_0 V_d}} = \sqrt{\frac{\varepsilon_0 q N_D}{2V_d}}$

$\Rightarrow C_0 = \sqrt{\frac{11.9\times8.86\times10^{-14}\times1.6\times10^{-19}\times N_D}{2\times0.761}}$

$\Rightarrow \frac{(3.53\times10^{-12})^2}{(1.108\times10^{-31})} = N_D = 1.124\times10^8$ /cm^3

Answer now $N_d = 0.026\ln\left(\frac{N_A N_D}{n_i^2}\right)$; $\Rightarrow e^{\left(\frac{0.761}{0.026}\right)} \times \frac{(1.5\times10^{10})^2}{N_D} = N_A$

$N_A = 1.030\times10^{25}$ /cm^3

(11) $\frac{1}{C_j^2} = 10\times10^{23}$ (At infinity)

$C_j = \frac{1}{\sqrt{10\times10^{23}}} = 10^{-12}$ F

$C_j = \frac{A\varepsilon_0}{(W)}$

So, $W = \left(\frac{10^{-12}}{11.9\times8.86\times10^{-14}}\right) = 0.94$ cm

Ans

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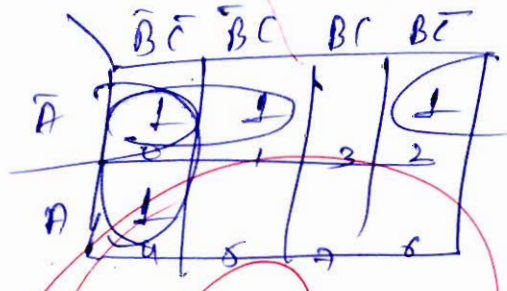
Q.2 (c) Minimise the following Boolean functions using *K*-map and implement them using a (3 × 4 × 2) programmable logic array (PLA).

$F_1(A, B, C) = \Sigma m(0, 1, 2, 4)$

$F_2(A, B, C) = \Sigma m(0, 5, 6, 7)$

[20 marks]

→ $F_1(A, B, C) = \Sigma m(0, 1, 2, 4)$

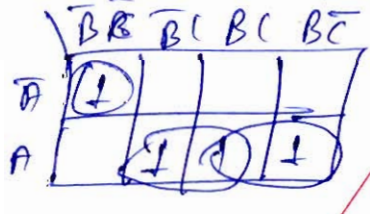


$= \bar{B}\bar{C} + \bar{A}\bar{B} + \bar{A}\bar{C}$

$\bar{F}_1(A, B, C) = \Sigma m(3, 5, 6, 7)$

$= BC + AC + AB$

$\bar{F}_2(A, B, C) = \Sigma m(0, 5, 6, 7)$



$= A\bar{C} + AB + \bar{A}\bar{B}\bar{C}$

$\bar{F}_2(A, B, C) = \Sigma m(1, 2, 3, 4)$

$= \bar{A}C + \bar{A}B + A\bar{B}\bar{C}$

We chose $\bar{F}_1$ and F_2

$\bar{F}_1 = BC + AC + AB$

$F_2 = AC + AB + \bar{A}\bar{B}\bar{C}$

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Product term	Input A	B	C	Function output F_1	F_2
BC	–	1	1	1	–
AC	1	–	1	1	1
AB	1	1	–	1	1
$\bar{A}\bar{B}\bar{C}$	0	0	0	–	1

Table – PLA truth table.

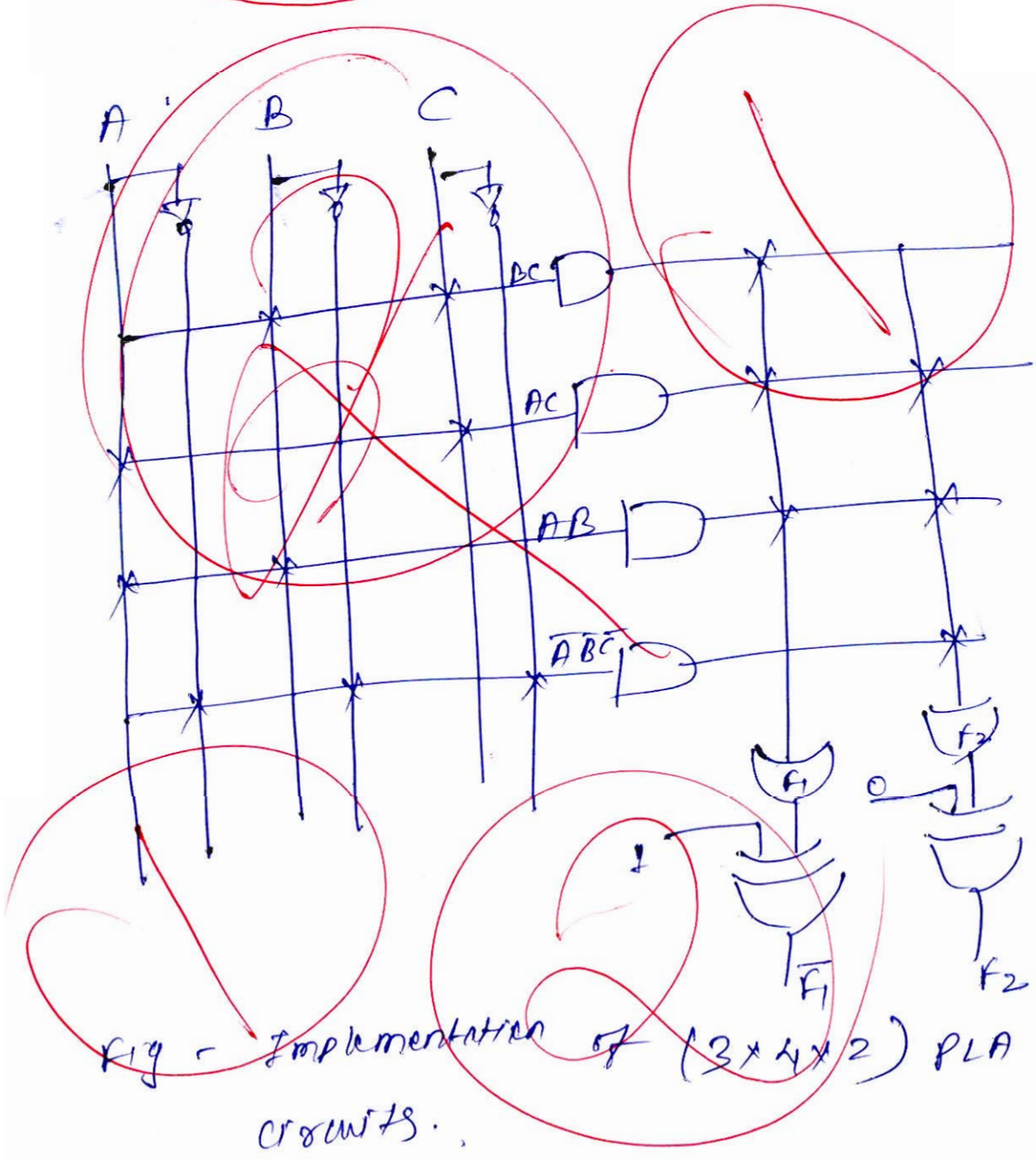

Fig – Implementation of (3×4×2) PLA circuits.

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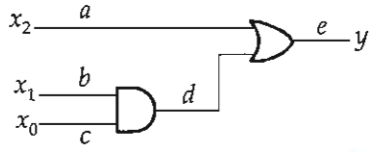
Q.3 (a) Consider the logic circuit shown below:



This circuit consists three inputs (x_2, x_1, x_0), one output (y) and five wires (a, b, c, d, e). Each wire can be stuck either at 0 or 1. Derive a table to show the coverage of the various stuck-at-0 and stuck-at-1 faults by the eight possible tests. Also find all the possible minimal test sets.

[20 marks]

Q.3 (b) Explain different steps involved in the photolithographic process with diagrams.

[20 marks]

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Q.3 (c) A photoconductor with dimensions $L = 6$ mm, $W = 2$ mm and $D = 1$ mm is placed under uniform radiation. The absorption of the light increases the current by 23.8 mA. A voltage of 10 V is applied across the length of the device. As the radiation is suddenly cut off, the current falls initially at a rate of 23.6 A/s. The electron and hole mobilities are 3600 cm^2/V-s and 1700 cm^2/V-s respectively. Find,

(i) the equilibrium density of electron-hole pairs generated under radiation.

(ii) the minority carrier lifetime.

(iii) the excess density of electron-hole pairs remaining 1 ms after the radiation is cut off.

[20 marks]

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1.4 (a) Assume that p^+n junction is built with a graded n region in which the doping profile is given as,

$$N_d(x) = k_0 x^m \; ; x > 0$$

The device is in equilibrium and the depletion region extends from essentially the junction at $x = 0$ to a point W within n region $(W \equiv x_{n0})$. Assume that m is a positive integer.

(i) Derive an expression for maximum electric field E_0 across the junction.

(ii) Derive the expression for electric field $E(x)$.

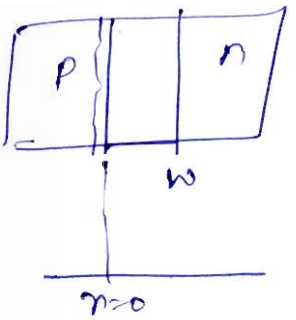
(iii) Find the charge Q due to ionized donors in the depletion region of n-side.

(iv) Derive an expression for junction capacitance C_j of the diode.

[20 marks]

→ given!

$N_d(x) = k_0 x^m \; ; x > 0$



As we know,

$\nabla \cdot D = \rho_v$ [Maxwell equation]

$\Rightarrow \varepsilon_0 \int E \, ds = \int \rho_v \, dv$

$\Rightarrow \varepsilon_0 E(A) = \int_0^x k_0 x^m A \, dx$

$\Rightarrow \varepsilon_0 E A = A k_0 \dfrac{x^{(m+1)}}{(m+1)} \Big|_0^x$

$\Rightarrow \varepsilon_0 E A = \dfrac{k_0 x^{(m+1)}}{(m+1)}$

$\Rightarrow E(x) = \dfrac{k_0 x^{(m+1)}}{\varepsilon_0 (m+1)}$ V/m ← eqn (1)

∇ = gradient function

E = electric field

ρ_v = density

A = Area

As $E(x)$ is the increasing function.

SB

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(i) $E_0 = \left.\dfrac{k_0 x^{(m+1)}}{\varepsilon_0 (m+1)}\right|_{x=w}$

So, $\boxed{E_{0\,max} = \dfrac{k_0 (w)^{(m+1)}}{\varepsilon_0 (m+1)} \text{ V/m}}$

(ii) $\boxed{E(x) = \dfrac{k_0 x^{(m+1)}}{\varepsilon_0 (m+1)} \text{ V/m}}$ [eq (i)]

(iii) As $N_d(x) = k_0 x^m$

So, $\rho/A = \int_0^w N_d(x)\, A\, \partial x$

$\rho/A = \int_0^w k_0 x^m \, \partial x$

$\rho/A = \left[\dfrac{k_0 x^{(m+1)}}{(m+1)}\right]_0^w = \dfrac{k_0 w^{(m+1)}}{(m+1)}$

$\boxed{\text{So, } \rho = \dfrac{k_0 w^{(m+1)}}{(m+1)} \text{ C/m}^2}$

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(iv) As we know $C_j = \frac{\partial \beta}{\partial V} = \frac{\partial \beta}{\partial r} \cdot \frac{\partial r}{\partial V}$

$$\frac{\partial \beta}{\partial r} = \frac{K_0 (m+1) r^{(m+1)}}{(m+1)} = K_0 r^{(m)} \quad \text{— eqn (3)}$$

$$\frac{\partial V}{\partial r} = -E \quad [\text{maxwell eqn}]$$

$$\frac{\partial V}{\partial r} = -\frac{K_0 r^{(m+1)}}{\epsilon_0 (m+1)}$$

$$\frac{\partial r}{\partial V} = \frac{\epsilon_0 (m+1)}{K_0 r^{(m+1)}} \quad \text{— eqn (4)}$$

So, $C_j = \frac{K_0 r^m \times \epsilon_0 (m+1)}{K_0 r^{(m+1)}} = \frac{K_0 \epsilon_0 (m+1)}{K_0 (r)}$

$$C_j = \frac{\epsilon_0 (m+1)}{r}$$

Incomplete

Ans

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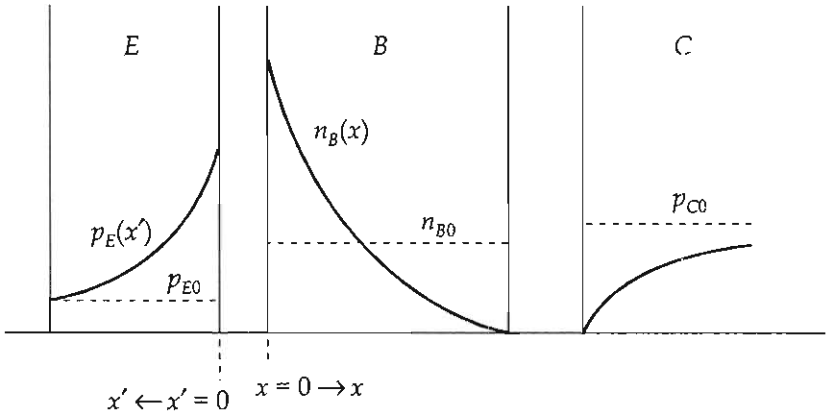
Q.4 (b) A uniformly doped silicon *npn* bipolar transistor is to be biased in forward active mode with the *B*-*C* junction reverse biased by 3 V. The metallurgical base width is 1.1 μm. The doping concentrations in different regions are $N_E = 10^{17}$ cm^{-3}, $N_B = 10^{16}$ cm^{-3} and $N_C = 10^{15}$ cm^{-3}. Assume that $n_i = 1.5 \times 10^{10}$ cm^{-3} at $T = 300$ K.

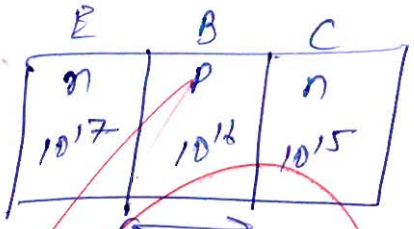
(i) For $T = 300$ K, calculate *B*-*E* voltage (V_{BE}) at which the minority carrier electron concentration at $x = 0$ is 10 percentage of majority carrier hole concentration.

(ii) Determine the minority carrier hole concentration at $x' = 0$ for this bias.

(iii) Determine the neutral base width for this bias.



[20 marks]



(i)

At $x=0$,

n_{Bn} = minority carrier electron in Base

P_B = majority carrier hole in Base

As we know

$$\Rightarrow P_B = n_{Bn}\, e^{V/\eta V_T}$$

[η = 2 for silicon, $V_T = 0.026$ V]

given $n_{Bn} = (0.1)\, P_B$

So, $P_B = 0.1\, P_B\, e^{V/\eta V_T}$

$$\Rightarrow 10 = e^{V/\eta V_T}$$

$$\Rightarrow \ln(10) = \frac{V}{\eta V_T}$$

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$\Rightarrow V = \left[\eta V_T \ln(10)\right] = 2 \times 0.026 \times \ln(10)$

$\boxed{V = 0.1197\ V}$

(ii)

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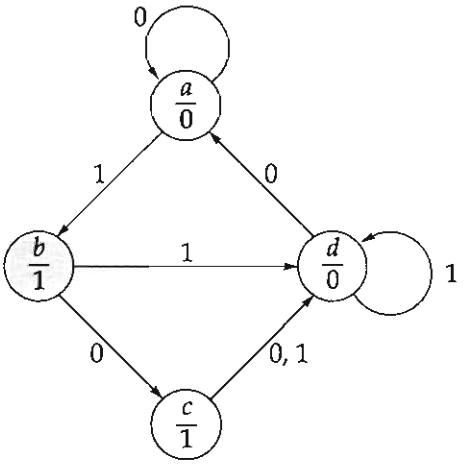
Q.4 (c) Design a synchronous sequential circuit by using *D*-flip flops corresponding to the reduced state diagram shown below.



[20 marks]

→ given state diagram is of moore circuit.

Present state	input next state x=0	x=1	Output
a	a	b	0
b	c	d	1
c	d	d	1
d	a	d	0

Table: State table of state diagram.

Let As there's are 4 states

So, we required 2 FF to design this.

let

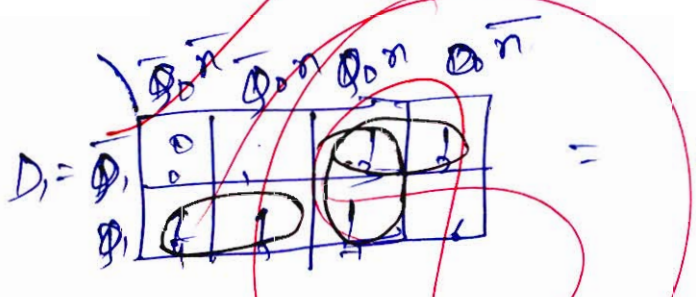
Q_1	Q_0	Assign state
0	0	a
0	1	b
1	0	c
1	1	d

Table :- binary numbers are assign to states

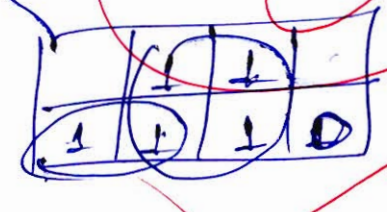
So,

Sn	Q_1	Q_0	x	Q_1^+	Q_0^+	D_1	D_0
0	0	0	0	0	0	0	0
1	0	0	1	0	1	0	1
2	0	1	0	1	0	1	0
3	0	1	1	1	1	1	1
4	1	0	0	1	1	1	1
5	1	0	1	1	1	1	1
6	1	1	0	0	0	0	0
7	1	1	1	1	1	1	1

Table : Truth table of sequential circuits



$= Q_1\bar{Q}_0 + Q_0x + \bar{Q}_1Q_0$



$= x + Q_1\bar{Q}_0$

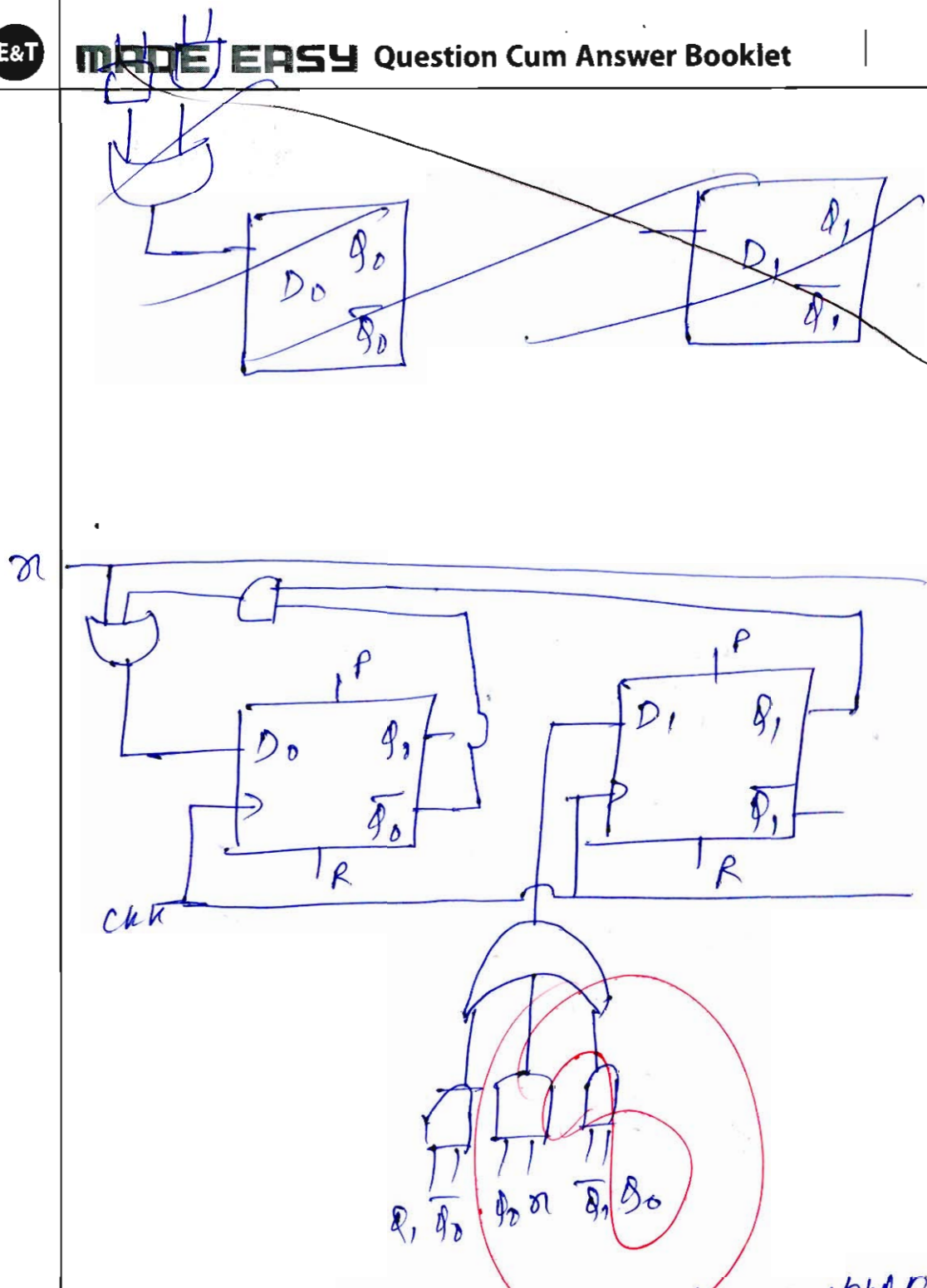


Fig :- implementation of synchronous circuit of given states.

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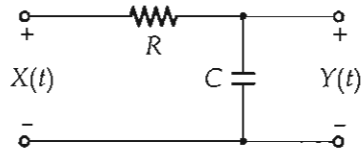
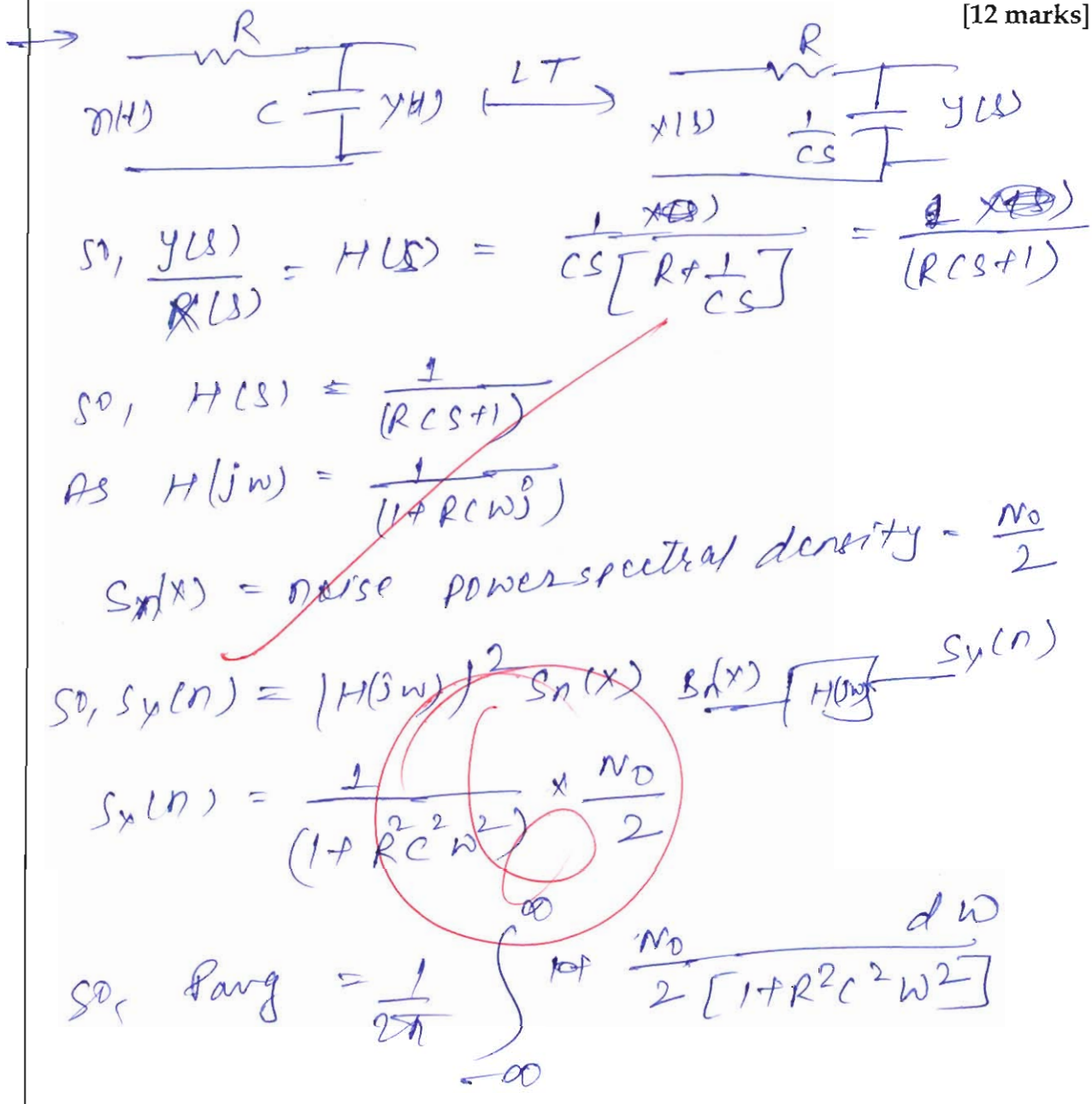
Section B : Analog and Digital Communication Systems-1 + Network Theory-2 + Microprocessors and Microcontroller-2

2.5 (a) A white noise with two sided power spectral density of $N_0/2$ is applied to the RC filter shown in the figure below.



Derive an expression for the average noise power at the output of the filter.

[12 marks]



$$P_{avg} = \frac{1}{2\pi} \cdot \frac{N_0}{2 \times R^2C^2} \int_{-\infty}^{\infty} \frac{1}{\left(\frac{1}{R^2C^2} + \omega^2\right)} d\omega = \frac{1}{2\pi} \times \frac{N_0}{2 \times R^2C^2}$$

$$= \frac{1}{2\pi} \times \frac{N_0 \times RC}{2 R^2C^2} \left[\tan^{-1} \omega RC \right]_{-\infty}^{\infty}$$

$$= \frac{1}{2\pi} \times \frac{N_0}{2} \times \frac{RC}{R^2C^2} \times \frac{2\pi}{2} = \frac{N_0}{4RC} \quad \text{As}$$

$$P_{avg} = \frac{N_0}{4RC} \cdot \omega$$

Q.5 (b) When a carrier signal is amplitude modulated by a sinusoidal message signal $m_1(t)$, the transmission efficiency of the resultant AM signal is 20%. When another sinusoidal message signal $m_2(t)$ is added to $m_1(t)$, without changing any other parameter, the antenna current of the AM transmitter is increased by 5%. If the same AM transmitter with same carrier signal is excited with $m_2(t)$ alone, then determine the transmission efficiency of the resultant AM signal.

[12 marks]

→ initial

let modulation index of $m_1(t)$ = μ_1

modulation index of $m_2(t)$ = μ_2

given η_1 = efficiency = 20%

$$\Rightarrow \eta_1 = \frac{\mu_1^2}{(2+\mu_1^2)} \quad [\text{we know}]$$

$$\Rightarrow \frac{\mu_1^2}{2+\mu_1^2} = 0.2$$

$$\Rightarrow \mu_1^2 = 0.2\left[2 + \mu_1^2\right]$$

$$\Rightarrow \mu_1^2 = 0.4 + \mu_1^2 \times 0.2$$

$$\Rightarrow 0.8\mu_1^2 = 0.4$$

$$\Rightarrow \mu_1^2 = \frac{0.4}{0.8} = \frac{1}{2}$$

$$\mu_1 = \frac{1}{\sqrt{2}}$$

→ Initial current = $I_{in} = I_o\sqrt{\left(1+\frac{\mu_1^2}{2}\right)}$

After addition of $\omega_2(t)$ = $I_{att} = I_o\sqrt{1+\left(\frac{\mu_1^2+\mu_2^2}{2}\right)}$

So, $I_o\sqrt{1+\left(\frac{\mu_1^2+\mu_2^2}{2}\right)} = (1.05)\, I_o\sqrt{1+\frac{\mu_1^2}{2}}$

$\Rightarrow \left[1+\frac{(0.5+\mu_2^2)}{2}\right] = (1.05)^2\left[1+\frac{0.5}{2}\right]$

$\Rightarrow 1+0.25+\frac{\mu_2^2}{2} = (1.05)^2 = 1.378$

$\Rightarrow \frac{\mu_2^2}{2} = (1.375-1.25) = 0.128$

$\Rightarrow \mu_2^2 = 0.25625$

$\Rightarrow \mu_2 = 0.5062$

→ now it is done by $\omega_2(t)$

So, $\eta = \frac{\mu_2^2}{(2+\mu_2^2)} = \frac{(0.5062)^2}{2+(0.5062)^2}$

$= 0.1135$

$\eta\% = 11.35\%$ Ans.

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Q.5 (c) Define the "tree" of a connected graph. What are the properties of a tree? For the reduced incidence matrix of a graph given below, determine the total number of possible trees.

nodes ↓ / branches →

$$A = \begin{array}{c} \\ a \\ b \\ c \\ d \end{array} \begin{bmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ 1 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & -1 & -1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & -1 \end{bmatrix}$$

Also draw the graph from this reduced incidence matrix.

[12 marks]

→ Tree — Tree in a graph is constructed by connecting all the nodes without any loop.

Properties of Tree →

(a) Leaf of tree is called as twigs.

(b) Tree don't contain any loop.

(c) Tree contain all the nodes.

(d) Total number of tree in a graph is $[I][I]^T$ where I = reduce incidence matrix.

So, As

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

$A^T =$

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number of Tree $(N) = [A][A]^T$

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

$$\Rightarrow \begin{matrix} + & -1 & + & -1 \end{matrix}$$

$$\begin{bmatrix} 3 & -1 & -1 & 0 \\ -1 & 3 & 0 & -1 \\ -1 & 0 & 3 & -1 \\ 0 & -1 & -1 & 3 \end{bmatrix}_{4\times 4}$$

$\Rightarrow 3[(9-1)-1[+3]] + 1(-9) - 1[-6]$

$\Rightarrow 3[8-3] - 9 + 6$

$\Rightarrow 3[5] - 9 + 6$

$\Rightarrow 15 - 9 + 6$

$\Rightarrow 12$ Ans

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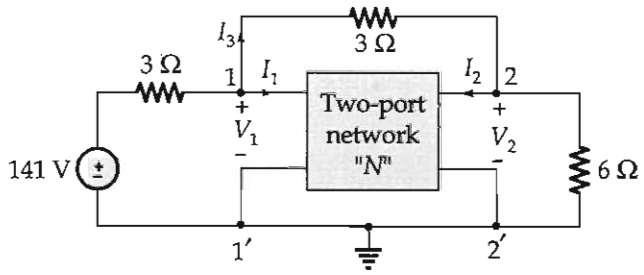
Q.5 (d) The z-parameters of the two port network-N shown in the figure below are given by $z_{11} = 2\ \Omega$, $z_{12} = z_{21} = 1\ \Omega$ and $z_{22} = 4\ \Omega$. Find the values of currents I_1, I_2 and I_3.

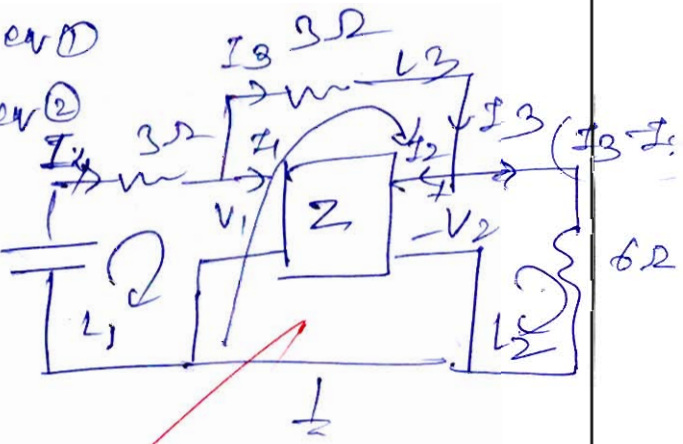


[12 marks]

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

So, $V_1 = 2I_1 + I_2$ — eqn (1)

$V_2 = I_1 + 4I_2$ — eqn (2)



→ Applying KVL in loop L_1

$\Rightarrow -141 + 3I_4 + V_1 = 0$

$\Rightarrow I_4 = 141 - V_1 = 141 - 2I_1 - I_2$ — eqn (3)

$I_4 = I_3 + I_1 = 141 - 2I_1 - I_2$

$\Rightarrow I_3 = 141 - 3I_1 - I_2$ — eqn (4)

→ Applying KVL in loop L_2

$\therefore -V_2 + 6(I_3 - I_2) = 0$

$\Rightarrow 6(I_3 - I_2) = V_2$

$\Rightarrow 6I_3 - 6I_2 = I_1 + 4I_2$

$\Rightarrow I_1 + 10I_2 - 6I_3 = 0$ — eqn (5)

Applying KVL in loop L3

$-V_1 + 3I_3 + V_2 = 0$

$\Rightarrow -[2I_1 + I_2] + 3I_3 + I_1 + 4I_2 = 0$

$\Rightarrow -2I_1 - I_2 + 3I_3 + I_1 + 4I_2 = 0$

$\Rightarrow -I_1 + 3I_2 + 3I_3 = 0$ - eq (6)

$I_1 = 3I_2 + 3I_3$ - eq (8)

Putting eq (8) in eq (5) and eq (3)

$I_3 = 141 - 3[3I_2 + 3I_3] - I_2$

$\Rightarrow I_3 = 141 - 9I_2 - 9I_3 - I_2 = 141 - 10I_2 - 9I_3$

$\Rightarrow 10I_3 + 10I_2 = 141$; $\Rightarrow I_3 + I_2 = 14.10$ - eq (7)

$\Rightarrow 3I_2 + 3I_3 + 10I_2 - 6I_3 = 0$

$\Rightarrow 13I_2 = 3I_3$

$\Rightarrow I_2 = \frac{3}{13} I_3$ - eq (8)

$I_3 + 0.230 I_3 = 14.10$ [eq (8) and eq (7)]

$I_3 = \frac{14.10}{1.230} = 11.463$ A

$I_2 = \frac{3}{13} \times I_3 = 11.463 \times \frac{3}{13} = 2.64$ A

$I_1 = 3[I_2 + I_3] = 3[11.463 + 2.64]$

$= 42.32$ A

Ans.

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Q.5 (e) Explain different transfer modes of an 8237 DMA controller in active cycle.

[12 marks]

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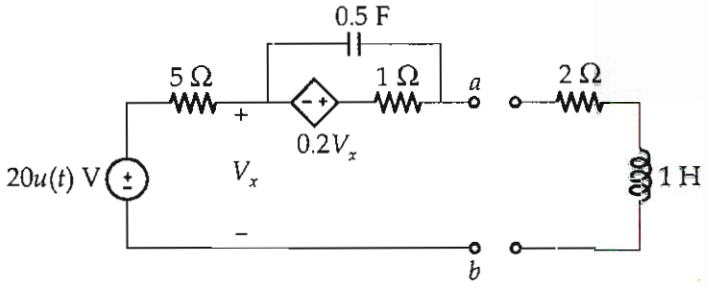
Q.6 (a) Consider the circuit shown in the figure below:



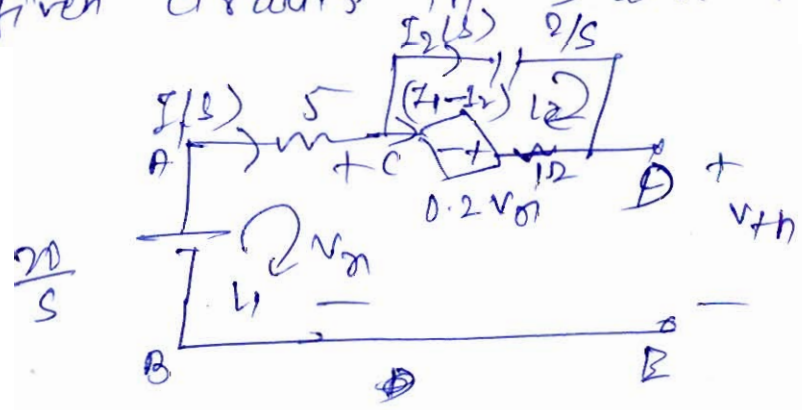
The initial charge on the capacitor in the circuit is zero.

(i) Find the *s*-domain Thevenin's equivalent circuit across the terminals '*a*' and '*b*'.

(ii) Find the *s*-domain expression for the current that the circuit delivers to a load consisting of a 1 H inductor in series with a 2 Ω resistor.

[15 + 5 marks]

→ given circuits in s domain



Applying KVL in loop AC loop 1

$$\Rightarrow -\frac{20}{s} + 5I_1(s) + V_n = 0$$

$$\Rightarrow I_1(s) = \left(\frac{20}{s} - V_n\right)\frac{1}{5} \quad \text{— eqn (1)}$$

Applying KVL in loop 2

$$\Rightarrow \frac{2}{s}I_2(s) - (I_1 - I_2) + 0.2V_n = 0$$

$$\Rightarrow \left(\frac{2}{s} + 1\right)I_2 - I_1 + 0.2V_n = 0$$

$$\Rightarrow$$

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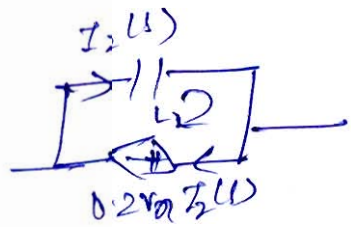
As circuit is open so, $I_1(s) = 0$

$V_{oc} = \frac{20}{s}$ — eq (1)

Applying KVL in loop L_2



$$\left(\frac{2}{s}+1\right)I_2(s) + 0.2V_{oc} = 0$$

$$I_2(s) = \frac{-(0.2V_{oc})}{\left(\frac{2}{s}+1\right)}$$

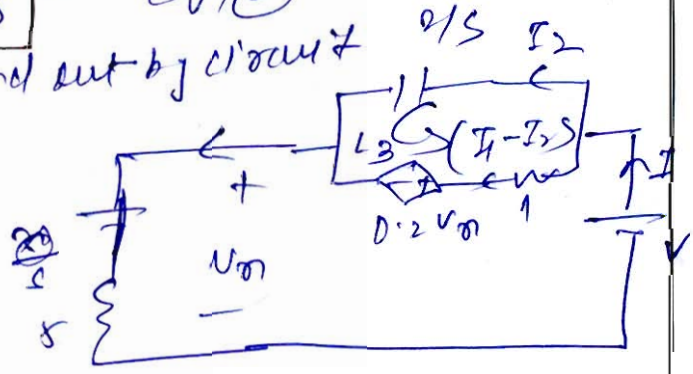
$$I_2(s) = \frac{-0.2 \times 20 \times s}{s[2+s]} = \frac{-2}{(2+s)}$$

$$V_{ab} = V_{Th} + -V_{oc} + \frac{2}{s}\times\left(\frac{-2}{2+s}\right) = 0$$

$$V_{Th} = \frac{20}{s} + \frac{4}{s(2+s)}$$ — eq (2)

Z_{th} → Z_{th} can by found out by circuit

$V_{oc} = 5I_1$ — eq (3)



Applying KVL in loop L_3

$$\frac{2}{s}I_2 - 0.2V_{oc} - (I_1 - I_2) = 0$$

$$\frac{2}{s}I_2 - 0.2 \times 5I_1 - I_1 + I_2 = 0$$

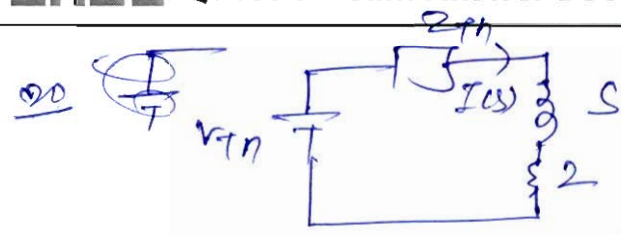
$$\left(\frac{2}{s}+1\right)I_2 = 2I_1$$ — eq (4)

$$-V + \frac{2}{s}I_2 + V_{oc} = 0$$

$$V = \left[\frac{2}{s} \times \frac{2s}{(2+s)} + 5\right] I_1 = \left[\frac{4}{(2+s)} + 5\right] I_1$$

$$\frac{V}{I_1} = Z_{Th} = \frac{4+5}{(2+s)} = \frac{14+5s}{(2+s)} = Z_{th}$$

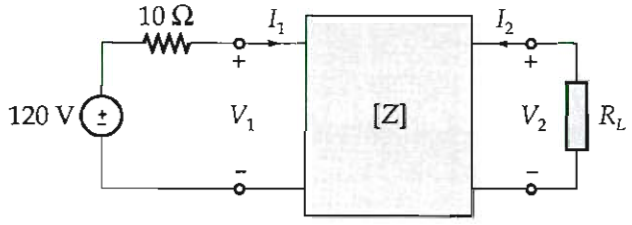
(11)



$$I(s) = \frac{V_{Th}}{(Z_{Th} + 2 + s)} = \frac{\left(\frac{20}{s} + \frac{4}{s(2+s)}\right)}{\left[\frac{14+5s}{(2+s)} + 2 + s\right]} = \frac{\frac{1}{s}\left[\frac{44+20s}{(2+s)}\right]}{\frac{14+5s+(2+s)}{(2+s)}}$$

$$= \frac{(44+20s)}{s[14+5s+4+s^2+4s]} = \frac{(44+20s)(2+s)}{s[s^2+9s+18]} \quad \Omega$$

Q.6 (b) The impedance matrix of the two port network shown below is $[Z] = \begin{bmatrix} 40 & 60 \\ 80 & 120 \end{bmatrix} \Omega$.



(i) Find the value of R_L for which maximum power will be transferred to it.

(ii) Calculate the maximum power that can be delivered to R_L.

[20 marks]

→ Maximum power transferred

when $R_L = |Z_{Th}^{*}|$ As R_L = Real resistance

$V_1 = 40 I_1 + 60 I_2$

$V_2 = 80 I_1 + 120 I_2$

As R_L is open so, $I_2 = 0$

so, $V_1 = 40 I_1$ and $V_2 = 80 I_1$

Applying KVL

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$\Rightarrow -120 + 10I_1 + V_1 = 0$

$\Rightarrow -120 + 10I_1 - 40I_1 = 0$

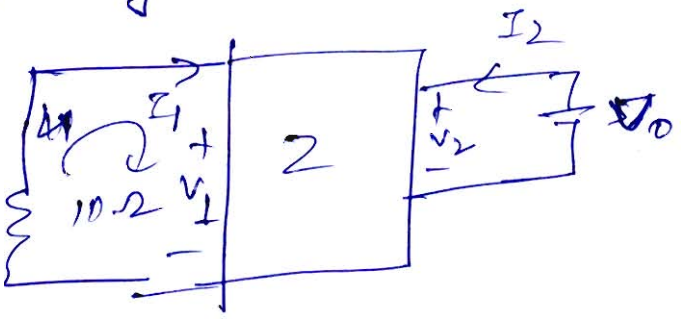
$\Rightarrow -120 - 30I_1 = 0$

$\Rightarrow I_1 = -4\ A.$

So, $V_2 = 80I_1 = -80 \times 4\ V = -320\ V.$

$V_2 = V_{Th} = 320\ V$

Zth is finding



$\frac{V_0}{I_2} = Z_{Th}$

As $V_0 = 80I_1 + 120I_2$

$V_1 = 40I_1 + 60I_2$

Applying KVL in loop 1

$\Rightarrow 10I_1 + V_1 = 0 \Rightarrow 10I_1 + 40I_1 + 60I_2 = 0$

$\Rightarrow 50I_1 = -60I_2 \Rightarrow I_1 = -1.2I_2$

$V_0 = 80I_1 + 120I_2 = 80 \times (-1.2)I_2 + 120I_2$

$V_0 = (-96 + 120)I_2 = -24$

$\frac{V_0}{I_2} = 24\ \Omega$

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So, $R_L = Z_{Th} = 24\ \Omega$ for maximum power transfer

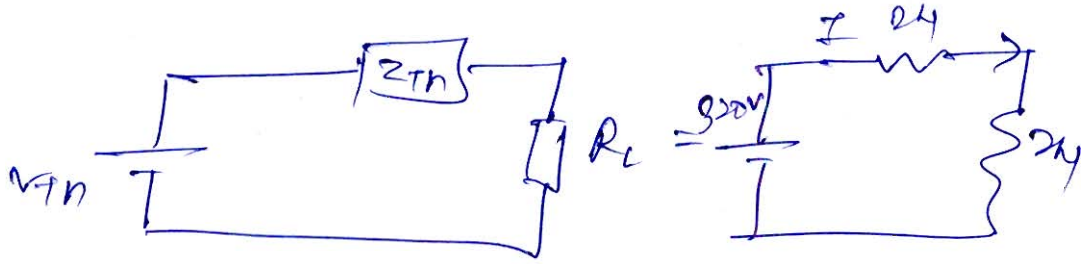

Figure: Thevenin equivalent circuits

$$I = \frac{320}{48} = 6.66\ A$$

P_T = Power transferred $= I^2 R_L = (6.66)^2 \times 24$

$= 1066.66\ W$

Ans.

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.6 (c) (i) Two random processes $X(t)$ and $Y(t)$ are related as, $Y(t) = \frac{dX(t)}{dt}$. Two random variables U and V are formed by sampling $X(t)$ and $Y(t)$ respectively at $t = 2$ sec. If $X(t)$ is a real WSS process, then prove that U and V are orthogonal and uncorrelated.

(ii) The auto-correlation function of a stationary process $X(t)$ is given by, $R_X(\tau) = e^{-|\tau|/2}$. Find the value of the expectation, $E[(X(5) - X(3))^2]$.

[15 + 5 marks]

(1) $U(t) = x(t)$

$V(t) = y(t-t) = \dfrac{\partial x(t-t)}{\partial t} = \dfrac{x(t) - x(t-h)}{h}\Big|_{h\to 0}$

for system to be orthogonal.

$R_{UV}(\tau) = 0$

so, $R_{UV}(\tau) =$ $x(t)$

$U(t) = x(t)$ sampled at $t = 2$ sec

$V(t) = \dfrac{\partial x(t)}{\partial t} = \dfrac{x(t) - x(t-h)}{h}\Big|_{h\to 0}$ at $t = 2$ sec

$R_{UV}(\tau) = E[U(t)\, V(t-\tau)] = 0$ for orthogonal

$= E\left[x(t)\left[\dfrac{x(t-\tau) - x(t-h-\tau)}{h}\right]\right]_{h\to 0}$

$R_{UV}(\tau) \lim_{h\to 0} \frac{1}{h}\{E[x(t)\, x(t-\tau)] - E[x(t)\, x(t-h-\tau)]\}$

$=$ zero.

So, U and V are orthogonal.

Uncorrelated function are those which has covariance is zero.

$C_{UV}(X) = 0$.

$C_{UV}(0,1) = R_{UV}(\tau) - E[UV] = 0$

As $R_{UV}(\tau) = 0$ because both are orthogonal

$C_{UV}(U,V) = -E[UV] + E[U]E[V]$

$= -E\left[x(t)\left[\frac{x(t) - x(t-h)}{h}\right]_{h\to 0}\right]$

$= -\lim_{h\to 0}\frac{1}{h}\left\{E[x(t)x(t)] - E[x(t)x(t-h)]\right\}$

As both $x(t)$ is WSS so,

$E[x(t)x(t)] = E[x(t)x(t-h)]$

Hence

$C_{UV}(U,V) =$ zero.

Hence uncorrelated.

(iii) $R_X(\tau) = e^{-|\tau|/2}$

$E[(x(5) - x(3))^2] = E[x^2(5) + x^2(3) - 2x(5)x(3)]$

$= E[x^2(5)] + E[x^2(3)] - 2E[x(5)x(3)]$

$= R_X(0) + R_X(0) - 2R_X(2)$

$= 1 + 1 - 2e^{-2/2}$

$= 2[1 - e^{-1}] = 1.26$ Ans

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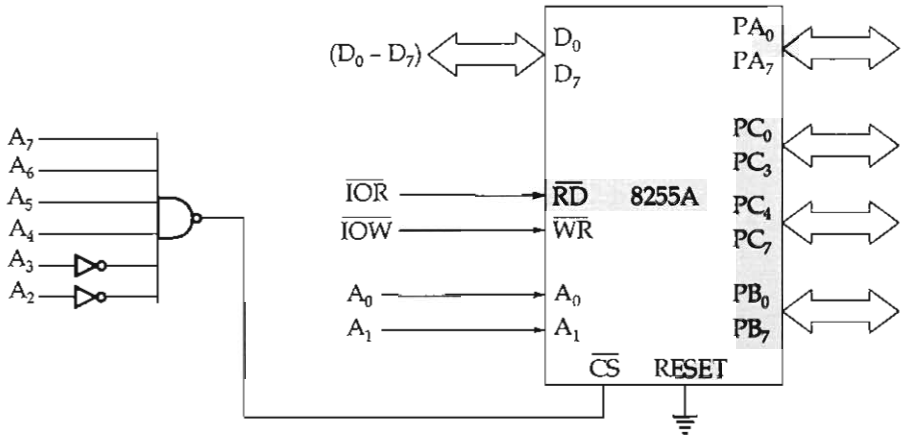
7 (a) Consider the following interface of the programmable peripheral interface (8255A):



(i) Determine the I/O addresses of port A, port B, port C and control register of the interface shown in the above figure.

(ii) The following mode 0 port configuration is desired:
Port A-Input ; Port B-Output ; Port C (upper)-Output ; Port C (lower)-Input
Assuming the interface circuit given in the above figure, write an 8085 program which initializes the 8255A with desired port configuration.

[10 + 10 marks]

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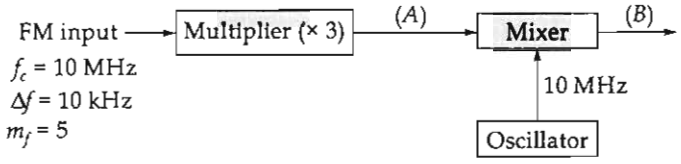
7 (b) **(i)** What are the capture effect and threshold effect in an FM system? List two different methods used for FM threshold improvement.

(ii) In the block diagram shown below, determine the carrier frequency (f_c), maximum frequency deviation (Δf) and modulation index (m_f) at points A and B. Assume that at the output of the mixer, the additive frequency component is being selected.



[12 + 8 marks]

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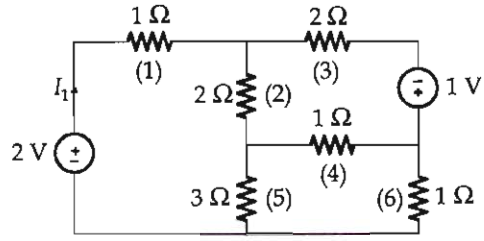
' (c) For the network shown in the figure below, draw the oriented graph and obtain the tie-set matrix by selecting the set of branches {2, 4, 5} as tree. By using this matrix, calculate the current I_1.



[20 marks]

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Q.8 (a) (i) Distinguish between microprocessor and microcontroller.

(ii) Write an 8051 assembly language program to copy the value 55H into RAM memory locations 40H to 45H using,
Direct addressing mode
Register indirect addressing mode without loop
Register indirect addressing mode with loop

[8 + 12 marks]

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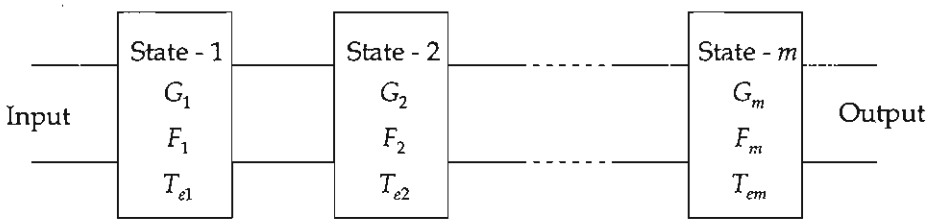
Q.8 (b) Derive an expression for the noise figure of the m-stage cascaded amplifier shown below. Assume that all the stages have same noise-equivalent bandwidth.



G_i = Available power gain of ith stage

F_i = Noise figure of ith stage

T_{ei} = Effective noise temperature of ith stage

[15 marks]

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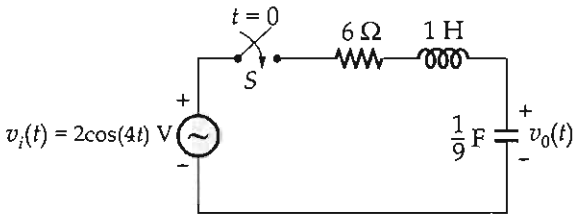
Q.8 (c) Consider the circuit shown below with excitation $v_i(t)$ and response $v_0(t)$.



If $v_0(0) = 2$ V and switch is closed at $t = 0$, then determine,

(i) Zero input response of the circuit.

(ii) Zero state response of the circuit.

(iii) By using the results obtained in part (i) and (ii), compose the overall response of the circuit. Also indicate the transient part and the steady state part of the overall response.

[10 + 10 + 5 marks]

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○○○○

Space for Rough Work

$$\begin{bmatrix} -1 & 0 & -1 \\ -1 & 3 & -1 \\ 0 & -1 & 3 \end{bmatrix}$$

$-1[9-1] - [-1[1]$

$-1[8]-1$

-9

$$\begin{bmatrix} -1 & 3 & 0 \\ -1 & 0 & 3 \\ 0 & -1 & -1 \end{bmatrix}$$

$-1[0+3]-3[1-0]$

$-3-3$

Space for Rough Work