MADE EASY
India's Best Institute for IES, GATE & PSUs

Detailed Solutions

ESE-2024 Mains Test Series

E & T Engineering Test No : 7

Section A : Advanced Electronics + Electronic Measurements and Instrumentation

Q.1 (a) Solution:

(i) The segregation coefficient K_0 for boron is given as 0.8. We assume that $C_s = K_0 C_l$ throughout the growth. Thus, the initial concentration of boron in the melt should be

$$C_l = \frac{C_s}{K_0}$$

$$C_l = \frac{10^{16}}{0.8} = 1.25 \times 10^{16} \text{ boron atoms/cm}^3$$

Since the amount of boron concentration is so small, the volume of melt can be calculated from the weight of silicon. Therefore, the volume of 60 kg of silicon is

$$\frac{60 \times 10^3}{2.53} = 2.37 \times 10^4 \text{ cm}^3$$

The total number of boron atoms in the melt is

$$1.25 \times 10^{16} \frac{\text{atoms}}{\text{cm}^3} \times 2.37 \times 10^4 \text{cm}^3 = 2.96 \times 10^{20} \text{ boron atoms}$$

So that,

$$\text{Weight of boron to be added} = \frac{\text{weight/mole}}{\text{atoms/mole}} \times \text{Total number of atoms}$$

$$= \frac{2.96 \times 10^{20} \text{ atoms} \times 10.8 \text{ g/mol}}{6.02 \times 10^{23} \text{ atoms/mol}}$$

$= 5.31 \times 10^{-3}$ g of boron

$=$ 5.31 mg of boron

(ii) Silane (SiH_4) is preferred over silicon chloride ($SiCl_4$) for polysilicon deposition for several reasons, which can be elaborated as:

1. **Safety and Handling:**

   Silane is safer to handle compared to silicon chloride. Silane is a gas at room temperature, while silicon chloride is a liquid that requires careful handling due to its toxicity and corrosiveness. This safety aspect ensures a better working environment in semiconductor fabrication facilities.

2. **Control over deposition conditions:**

   Silane offers better control over deposition conditions. As a gas, it can be more precisely metered into the deposition chamber allowing for finer control over the deposition rate and film thickness. This control is crucial for achieving desired film properties and uniformity across the substrate.

3. **Reduced Impurities:**

   Silane typically produces fewer impurities compared to silicon chloride during deposition. This is important for ensuring the purity and quality of the polysilicon film, which is crucial for semiconductor device performance and reliability. Fewer impurities mean better electrical properties and lower defect densities in the film.

4. **Film Quality:**

   Silane deposition often results in higher quality polysilicon films. The ability to control deposition conditions more precisely, along with the reduced impurity levels, contributes to the superior film quality achieved with silane. High quality polysilicon films are essential for the fabrication of advanced semiconductor devices with tight specifications.

5. **Process compatibility:**

   Silane is compatible with a wider range of deposition processes and equipment compared to silicon chloride. Its gaseous nature allows it to be easily integrated into various deposition systems, including chemical vapor deposition (CVD) and plasma enhanced chemical vapor deposition (PECVD), commonly used in semiconductor fabrication.

Q.1 (b) Solution:

The diffusion coefficient of boron at 1000°C, is given as 2 × 10[14] cm[2]/s, so the diffusion length is

$$\sqrt{Dt} = \sqrt{2 \times 10^{-14} \times 3600}$$
$$= 8.48 \times 10^{-6} \text{ cm}$$

The total number of atoms per unit area of the semiconductor is given by

$$Q(t) = \frac{2}{\sqrt{\pi}} C_s \sqrt{Dt}$$
$$= 1.128 C_s \sqrt{Dt}$$
$$= 1.128 \times 10^{19} \times 8.48 \times 10^{-6}$$
$$= 9.56 \times 10^{13} \text{ atoms/cm}^2$$

The diffusion profile is given by

$$C(x, t) = C_s erfc\left(\frac{x}{2\sqrt{(Dt)}}\right)$$

Thus, the gradient of diffusion profile is obtained as

$$\frac{dC}{dx} = \frac{-Cs}{\sqrt{(\pi Dt)}} \exp\left(\frac{-x^2}{4Dt}\right)$$
$$\left.\frac{dC}{dx}\right|_{x=0} = -\frac{C_s}{\sqrt{\pi Dt}}$$
$$= \frac{-10^{19}}{\sqrt{\pi} \times 8.48 \times 10^{-6}}$$
$$= -6.653 \times 10^{23} \text{ cm}^{-4}$$

When $C = 10^{15}$ cm^3, the corresponding distance x_j is calculated as

$$C(x, t) = C_s erfc\left(\frac{x_j}{2\sqrt{Dt}}\right)$$
$$x_j = 2\sqrt{Dt}\, erfc^{-1}\left(\frac{10^{15}}{10^{19}}\right)$$
$$x_j = 2 \times \sqrt{Dt} \times (2.75)$$
$$x_j = 4.66 \times 10^{-5} \text{ cm} = 0.466\ \mu\text{m}$$

$$\left.\frac{dC}{dx}\right|_{x = 0.466\ \mu m} = \frac{-C_s}{\sqrt{\pi D t}} e^{\frac{-x_j^2}{4Dt}}$$

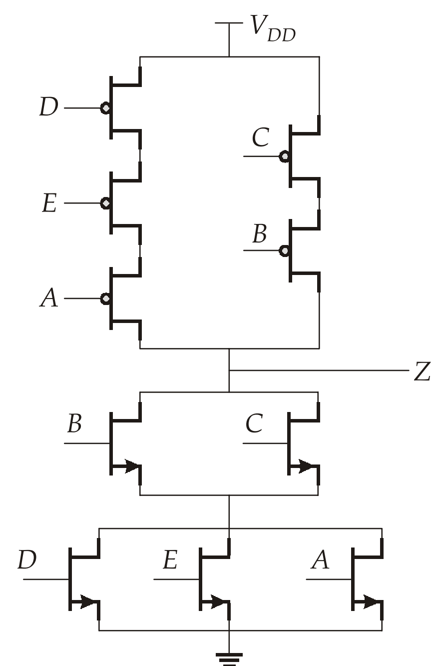
$$= -3.5 \times 10^{20}\ \text{cm}^{-4}$$

Q.1 (c) Solution:

(i) For the given Boolean function

$$Z = \overline{(D + E + A)(B + C)}$$

the equivalent $\left(\frac{W}{L}\right)$ ratios of the nMOS network and the PMOS network are determined as:



For a number of MOSFETs connected in series,

$$\frac{1}{(W/L)_{eq}} = \frac{1}{(W/L)_1} + \frac{1}{(W/L)_2} + \ldots.$$

For a number of MOSFETs connected in parallel,

$$(W/L)_{eq} = (W/L)_1 + (W/L)_2 + \ldots..$$

Thus, we get

$$\left(\frac{W}{L}\right)_{n,eq} = \frac{1}{\dfrac{1}{\left(\frac{W}{L}\right)_D + \left(\frac{W}{L}\right)_E + \left(\frac{W}{L}\right)_A} + \dfrac{1}{\left(\frac{W}{L}\right)_B + \left(\frac{W}{L}\right)_C}}$$

$$= \frac{1}{\dfrac{1}{10+10+10} + \dfrac{1}{10+10}} = \frac{1}{\dfrac{1}{30} + \dfrac{1}{20}}$$

$$= \frac{600}{50} = 12$$

$$\left(\frac{W}{L}\right)_{p,eq} = \frac{1}{\dfrac{1}{\left(\frac{W}{L}\right)_D} + \dfrac{1}{\left(\frac{W}{L}\right)_E} + \dfrac{1}{\left(\frac{W}{L}\right)_A}} + \frac{1}{\dfrac{1}{\left(\frac{W}{L}\right)_B} + \dfrac{1}{\left(\frac{W}{L}\right)_C}}$$

$$= \frac{1}{\dfrac{1}{15} + \dfrac{1}{15} + \dfrac{1}{15}} + \frac{1}{\dfrac{1}{15} + \dfrac{1}{15}}$$

$$= \frac{1}{\dfrac{3}{15}} + \frac{1}{\dfrac{2}{15}} = \frac{15}{3} + \frac{15}{2}$$

$$= \frac{15 \times 2 + 15 \times 3}{6} = \frac{15 \times 5}{6} = \frac{75}{6} = 12.5$$

(ii)

	Moore Machine	**Mealy Machine**
Output dependency	Output depend only on the current state.	Output depends on both the current state and the current input.
Output Assignment	Each state directly corresponds to an output value.	Output values are associated with state transitions.
Number of states	A moore machine requires more states to generate identical output sequence compared to a Mealy machine.	It generally has fewer states than Moore's machine.
Implementation Complexity	Simpler to implement due to output dependence only on states.	Complex due to output dependence on both states and inputs.
Output Timing	Outputs are synchronized with state changes.	Outputs can change asynchronously with inputs.
Response	More logic is required to decode the output resulting in more circuit delays. Therefore, slower response than Mealy machine.	Mealy machine react faster to inputs.

Q.1 (d) Solution:

(i) Given,

$$\text{Area, } A = 5 \times 10^{-4} \text{ m}^2$$
$$C = 950 \text{ pF}$$
$$\epsilon_r = 81$$

1. We know that,

Capacitance measured by the capacitive transducer,

$$C = \frac{\epsilon A}{d} = \frac{\epsilon_0 \epsilon_r A}{d}$$

$$950 \times 10^{-12} = \frac{8.85 \times 10^{-12} \times 81 \times 5 \times 10^{-4}}{d}$$

$$\therefore \quad d = \frac{8.85 \times 10^{-12} \times 81 \times 5 \times 10^{-4}}{950 \times 10^{-12}}$$

$$\therefore \quad d = 3.77 \times 10^{-4} \text{ m}$$

2. Sensitivity with respect to distance,

$$S = \frac{\partial C}{\partial d}$$

but,

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

$$S = \frac{\partial C}{\partial d} = -\epsilon_0 \epsilon_r A \left(\frac{1}{d^2}\right)$$

$$= -81 \times 8.85 \times 10^{-12} \times 5 \times 10^{-4} \left(\frac{1}{\left(3.77 \times 10^{-4}\right)^2}\right)$$

$$\therefore \quad S = -2.5 \times 10^{-6} \text{ F/m}$$

(ii) Given, $3\frac{1}{2}$ digit DVM,

Accuracy specification = ±1% of full scale

Reading = 100 mV on its 200 mV full scale range

For the given DVM, 100 mV reading on the 200 mV full scale range is represented as 100.0 mV

Total number of counts is from 0 – 1999 = 2000 counts

1 count on this 200 mV full scale corresponds to

$$\frac{200 \text{ mV}}{2000} = 0.1 \text{ mV}$$

$$\text{percentage error in reading} = \left(\frac{+1}{100} \times 200\text{ mA}\right)$$

$$= \pm 2\%$$

Therefore, the worst case error can be calculated as,

$$\text{Error} = \pm\left[\frac{2}{100} \times 100\text{ mV} + 1 \times 0.1\text{ mV}\right]$$

$$= \pm[2\text{ mV} + 0.1\text{ mV}]$$

$$= \pm 2.1\text{ mV}$$

$\therefore$ The worst case error in the reading is ±2.1 mV

Q.1 (e) Solution:

Given,

$$I_m = 1 \times 10^{-3}\text{ A}$$

$$R_m = 50\ \Omega$$

$$I_1 = 1\text{ A}, I_2 = 5\text{ A}, I_3 = 10\text{ A}, I_4 = 20\text{ A}$$

The multiplying factors corresponding to different current ranges are,

$$m_1 = \frac{I_1}{I_m} = \frac{1}{10^{-3}} = 1000$$

$$m_2 = \frac{I_2}{I_m} = \frac{5}{10^{-3}} = 5000$$

$$m_3 = \frac{I_3}{I_m} = \frac{10}{10^{-3}} = 10000$$

$$m_4 = \frac{I_4}{I_m} = \frac{20}{10^{-3}} = 20000$$

Shunt resistance required to extend the range of basic ammeter to the given ranges can be calculated as,

For 0-1 A range:

$$R_{sh1} = \frac{R_m}{m_1 - 1}$$

$$= \frac{50}{1000 - 1} = 0.05\ \Omega$$

For 0-5 A range:

$$R_{sh2} = \frac{R_m + R_{sh1}}{m_2} = \frac{50.05}{5000} = 0.01\ \Omega$$

For 0-10 A range:

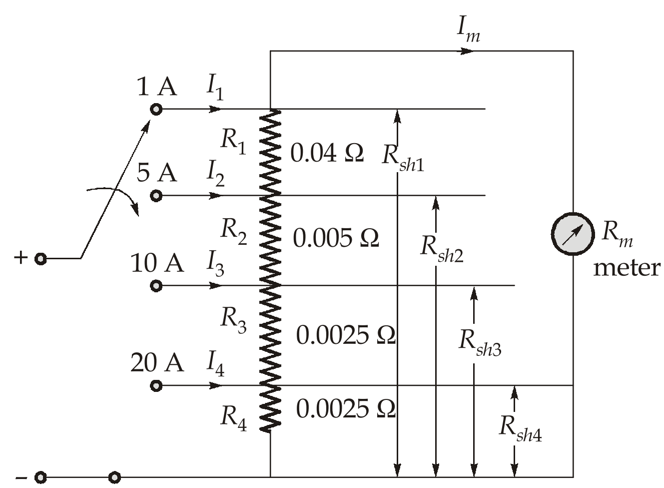
$$R_{sh3} = \frac{R_m + R_{sh1}}{m_3} = \frac{50.05}{10000} = 0.005\ \Omega$$

For 0-20 A range: $R_{sh4} = \frac{R_m + R_{sh1}}{m_4} = \frac{50.05}{20000} = 0.0025\ \Omega$

$\therefore$ The resistances of various sections of the universal shunt are

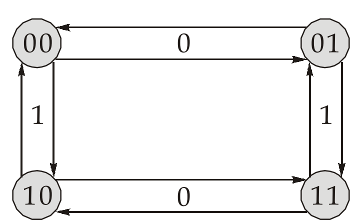
$$R_1 = R_{sh1} - R_{sh2} = 0.05 - 0.01 = 0.04\ \Omega$$
$$R_2 = R_{sh2} - R_{sh3} = 0.01 - 0.005 = 0.005\ \Omega$$
$$R_3 = R_{sh3} - R_{sh4} = 0.005 - 0.0025 = 0.0025\ \Omega$$
$$R_4 = R_{sh4} = 0.0025\ \Omega$$

The universal shunt is,



Q.2 (a) Solution:

(i) The FSM for the above problem statement can be drawn as



Implementation using JK flip-flop:

Excitation table for JK flip-flop is

Q_n	Q_{n+1}	J	K
0	0	0	X
0	1	1	X
1	0	X	1
1	1	X	0

The state table of the given sequential circuit is as below:

Present state		Input	Next state		JK Flip Flop input			
A	B	X	$A(t+1)$	$B(t+1)$	J_A	K_A	J_B	K_B
0	0	0	0	1	0	X	1	X
0	0	1	1	0	1	X	0	X
0	1	0	0	0	0	X	X	1
0	1	1	1	1	1	X	X	0
1	0	0	1	1	X	0	1	X
1	0	1	0	0	X	1	0	X
1	1	0	1	0	X	0	X	1
1	1	1	0	1	X	1	X	0

Simplify using Karnaugh Map for the expressions of flip-flop inputs:

J_A

$AB \backslash x$	$\bar{x}$	x
$\bar{A}\bar{B}$		1
$\bar{A}B$		1
AB	X	X
$A\bar{B}$	X	X

K_A

$AB \backslash x$	$\bar{x}$	x
$\bar{A}\bar{B}$	X	X
$\bar{A}B$	X	X
AB		1
$A\bar{B}$		1

J_B

$AB \backslash x$	$\bar{x}$	x
$\bar{A}\bar{B}$	1	
$\bar{A}B$	X	X
AB	X	X
$A\bar{B}$	1	

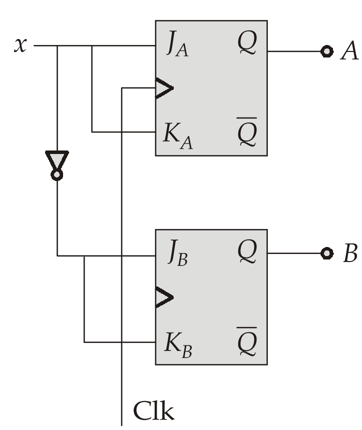
K_B

$AB \backslash x$	$\bar{x}$	x
$\bar{A}\bar{B}$	X	X
$\bar{A}B$	1	
AB	1	
$A\bar{B}$	X	X

$$J_A = x \qquad J_B = \bar{x}$$

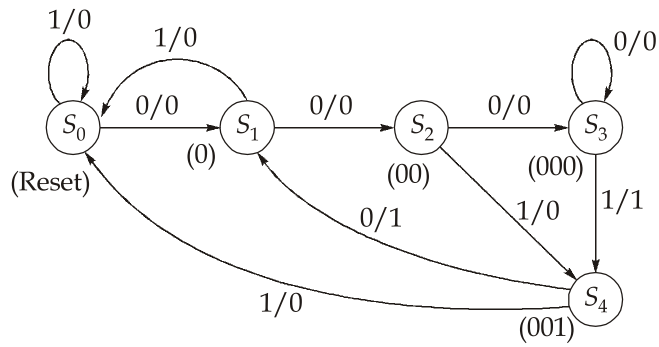
$$K_A = x \qquad K_B = \bar{x}$$

Sequential Circuit:

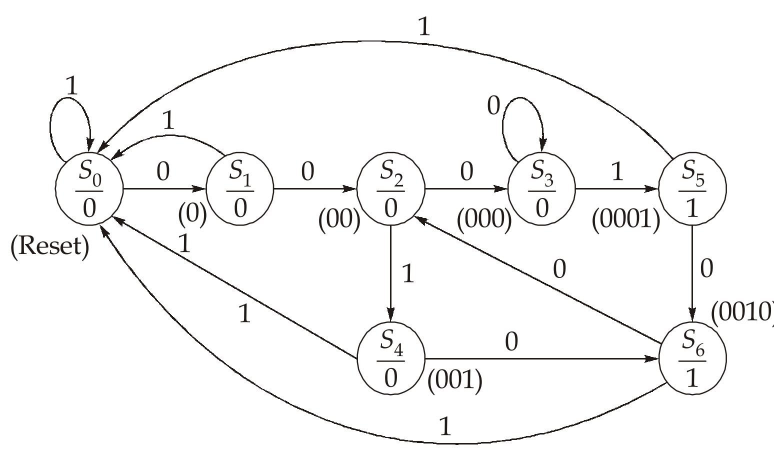


(ii) Mealy Design

Let us consider the states as S_0, S_1, S_2, S_3 and S_4, where S_0 is the initial state.



Moore Design



Q.2 (b) Solution:

(i) Given,

$$V_T = (29 \pm 2) \text{ mV} = (V_T \pm W_{V_T})$$

$$V_D = 0.02 \text{ V}$$

$$W_{V_D} = 1 \text{ mV} = 0.001 \text{ V}$$

Diode current equation,

$$I = I_0 \, e^{V_D / \eta V_T}$$

applying 'log' on both sides,

$$\ln(I) = \ln(I_0) + \frac{V_D}{\eta V_T} \quad \text{...(i)}$$

differentiate w.r.t 'V_T',

$$\frac{\partial I}{I} = 0 + \frac{V_D}{\eta}\left[-\frac{1}{V_T^2}\partial V_T\right]$$

$$\frac{\partial I}{\partial V_T} = -\frac{V_D I}{\eta V_T^2} = \frac{-V_D I}{V_T^2} \text{ for } \eta = 1$$

differentiate eq. (i) w.r.t to V_D

$$\frac{\partial I}{I} = \frac{1}{\eta V_T}\partial V_D$$

$$\Rightarrow \quad \frac{\partial I}{\partial V_D} = \frac{I}{\eta V_T}$$

$$\frac{\partial I}{\partial V_D} = \frac{I}{V_T} \text{ for } \eta = 1$$

$$\text{Uncertainty}, W_r = \sqrt{\left(\frac{\partial I}{\partial V_T}\right)^2 W_{V_T}^2 + \left(\frac{\partial I}{\partial V_D}\right)^2 W_{V_D}^2}$$

$$= \sqrt{\left(-\frac{V_D I}{V_T^2}\right)^2 W_{V_T}^2 + \left(\frac{I}{V_T}\right)^2 W_{V_D}^2}$$

$$= \sqrt{\frac{V_D^2 I^2}{V_T^4} \times W_{V_T}^2 + \left(\frac{I}{V_T}\right)^2 \times W_{V_D}^2}$$

$$= \sqrt{\frac{I^2 \times (0.02)^2}{(0.029)^4} \times (0.002)^2 + \frac{I^2}{(0.029)^2} \times (0.001)^2}$$

$$= I\sqrt{2.262 \times 10^{-3} + 1.189 \times 10^{-3}}$$

$$= 0.0587 \times I$$

$$\% \frac{W_r}{I} = \pm 0.0587 \times 100$$

$$\therefore \quad \% \frac{W_r}{I} = \pm 5.87\%$$

(ii) Given data:

Anode voltage, $E_a = 2000$ V

Length of deflecting plates,

$$l_d = 1.5 \text{ cm} = 1.5 \times 10^{-2} \text{ m}$$

Distance between deflecting plates,

$$d = 5 \text{ mm} = 5 \times 10^{-3} \text{ m}$$

Distance between screen and the center of the deflecting plates,

$$L = 50 \text{ cm} = 0.5 \text{ m}$$

1. Velocity of beam, $V_{ox} = \sqrt{\dfrac{2eE_a}{m}} = \sqrt{\dfrac{2\times1.6\times10^{-19}\times2000}{9.1\times10^{-31}}} = 26.5 \times 10^6$ m/sec

2. Deflection sensitivity, $S = \dfrac{Ll_d}{2dE_a} = \dfrac{0.5\times1.5\times10^{-2}}{2\times5\times10^{-3}\times2000} = 0.375$ mm/V

3. Deflection factor, $G = \dfrac{1}{S} = \dfrac{1}{0.375} = 2.66$ V/mm

Q.2 (c) Solution:

(i) Given,

nominal resistance of each gauge, $R = 100\ \Omega$

gauge factor, G.F = 2.0

Supply voltage, V_s = 6 V

diameter of cylinder, d = 50 mm = 50×10^{-3} m

modulus of elasticity, E = 200 GN/m^2

Poisson's ratio, μ = 0.3

load or force, F = 1 kN

Sensitivity of gauge, S = Output voltage/F

The output voltage of the bridge is

$$dV_0 = 2(1+\mu)\left[\frac{dR/R}{4+2(dR/R)}\right]V_s \approx 2(1+\mu)\left(\frac{dR}{R}\cdot\frac{V_s}{4}\right)$$

[for 4 identical strain gauges mounted on a cylinder and connected as wheatstone arrangement]

Fractional change in resistance,

$$\frac{dR}{R} = \text{G.F.} \times \text{strain}$$

where, strain, $\in = \dfrac{\text{stress}}{\text{Modulus of elasticity}}$

$$\text{stress} = \frac{\text{load}}{\text{cross-sectional area}}$$

$$= \frac{F}{A} = \frac{1\times10^3}{\frac{\pi}{4}d^2} = \frac{1\times10^3}{\frac{\pi}{4}(50\times10^{-3})^2}$$

$\therefore$ stress $= 0.5095 \times 10^{6}\ \text{N/m}^2$

Hence, strain, $\in \; = \dfrac{0.5095 \times 10^6}{200 \times 10^9} = 2.5475 \times 10^{-6}$

$$\therefore \quad \frac{dR}{R} = \text{G.F} \times \in$$

$$= 2 \times 2.5475 \times 10^{-6}$$

$$\therefore \quad \frac{dR}{R} = 5.095 \times 10^{-6}$$

Thus, the output voltage,

$$dV_0 = 2(1+0.3)\left(5.095 \times 10^{-6} \times \frac{6}{4}\right)$$

$$\therefore \quad dV_0 = 19.87 \times 10^{-6} = 19.87\ \mu\text{V}$$

$$\therefore \quad \text{Sensitivity, } S = dV_0/\text{F}$$

$$= 19.87 \times 10^{-6}/1 \times 10^{3}$$

(or) $S = 19.87 \times 10^{-6}\ \mu\text{V/kN}$

(ii) RTD

1. RTD is made up of metals.
2. As metals have positive temperature coefficient hence, RTD also has positive temperature coefficient of resistance.
3. The resistance temperature characteristics of RTD are linear.
4. It is less sensitive to temperature compared to thermistor.
5. RTD has wide operating range of temperature i.e., –200°C to +650°C.
6. RTD's are relatively larger in size.
7. They have low self resistance.
8. RTD's provide high degree of accuracy and long term stability.
9. They are used in laboratory and industrial applications.
10. They are costlier.

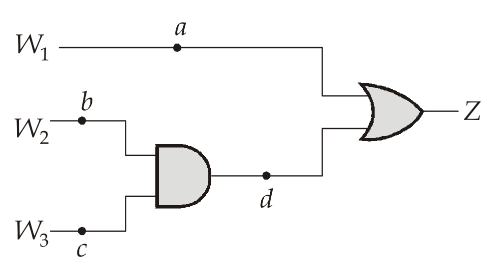
Thermistor

1. Thermistor is made up of semiconductor materials.
2. As semiconductor materials have negative temperature coefficient, hence thermistor also has negative temperature coefficient.
3. The resistance temperature characteristics of thermistor are highly non-linear.

4. Thermistors are highly sensitive to temperature
5. Thermistors has low operating temperature range compared to RTD i.e., –100°C to 300°C.
6. Thermistors are small in size.
7. They have high self resistance.
8. Thermistors also provide an accuracy of ±0.01°C.
9. They are widely used in dynamic temperature measurement.
10. They are available at low cost.

Q.3 (a) Solution:

Test Vector			Output Z Without Fault	Output Z with stuck at 0 fault				Output Z with stuck at 1 fault			
W_1	W_2	W_3		$a/0$	$b/0$	$c/0$	$d/0$	$a/1$	$b/1$	$c/1$	$d/1$
0	0	0	0	0	0	0	0	1	0	0	1
0	0	1	0	0	0	0	0	1	1	0	1
0	1	0	0	0	0	0	0	1	0	1	1
0	1	1	1	1	0	0	0	1	1	1	1
1	0	0	1	0	1	1	1	1	1	1	1
1	0	1	1	0	1	1	1	1	1	1	1
1	1	0	1	0	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1



$$Z = W_1 + W_2W_3$$

Faults detected by the various input vectors has been shown in the below table.

Simplified table for fault detection:

Test			Output Z Without Fault	Output Z with stuck at 0 fault				Output Z with stuck at 1 fault			
W_1	W_2	W_3		$a/0$	$b/0$	$c/0$	$d/0$	$a/1$	$b/1$	$c/1$	$d/1$
0	0	0	0					X			X
0	0	1	0					X	X		X
0	1	0	0					X		X	X
0	1	1	1		X	X	X				
1	0	0	1	X							
1	0	1	1	X							
1	1	0	1	X							
1	1	1	1								

A minimal test set that covers all faults in the circuit can be derived from the table by inspection.

Some faults are covered by only one test vector, which means that these test vectors must be included in the test set. The fault b/1 is covered only by 001. The fault c/1 is covered only by 010. The faults b/0, c/0 and d/0 are covered only by 011. Therefore, these three test vectors are essential. The essential test vector set is {001, 010, 011}.

Q.3 (b) Solution:

Given, $I_m = 1$ mA; $R_m = 25\ \Omega$; $I = 100$ mA

(i) For moving coil instrument,

$$I = I_m\left(1 + \frac{R_m}{R_{sh}}\right)$$

where, R_{sh} is shunt resistance,

$$\Rightarrow \qquad 100 = 1\left(1 + \frac{25}{R_{sh}}\right)$$

$$\Rightarrow \qquad R_{sh} = \frac{25}{99} = 0.2525\ \Omega$$

Instrument resistance with 10°C rise in temperature,

$$R'_m = R_m(1 + \rho_1 \times \Delta T)$$

where, ρ_1 : temperature coefficient of copper

$$= 25(1 + 0.004 \times 10)$$

$$\rho_1 = 26\ \Omega$$

Shunt resistance with 10°C rise in temperature,

$$R'_{sh} = R_{sh}(1 + \rho_2 \Delta T)\ ,$$

where ρ_2 is the temperature coefficient of Manganin

$$R'_{sh} = 0.2525\ (1 + 0.00015 \times 10) = 0.2529\ \Omega$$

The new current through the meter for 100 mA in the main circuit with 10°C rise in temperature,

$$I = I'_m\left(1 + \frac{R'_m}{R'_{sh}}\right)$$

$$100 = I'_m\left(1 + \frac{26}{0.2529}\right)$$

$$I'_m = \frac{100}{1 + \dfrac{26}{0.2529}} = 0.963\ \text{mA}$$

But normal meter current, $I_m = 1$ mA

Error due to rise in temperature = (0.963 – 1) ∗ 100 = –3.7%

(ii) Given,

Manganin resistance used in series with the instrument, $R_s = 75\ \Omega$

Total resistance in the meter,

$$R_{Tm} = R_m + R_{sh}$$

$$R_{Tm} = 25 + 75 = 100\ \Omega$$

$$I = I_m\left(1 + \frac{R_{Tm}}{R_{sh}}\right)$$

$$100 = 1\left(1 + \frac{100}{R_{sh}}\right)$$

$$\therefore \qquad R_{sh} = \frac{100}{99} = 1.01\ \Omega$$

Resistance of the instrument circuit with 10°C rise in temperature,

$$R'_{Tm} = R_m(1 + \rho_1 \times 10) + R_s(1 + \rho_2 \times 10)$$

$$= 25(1 + 0.004 \times 10) + 75(1 + 0.00015 \times 10)$$

$$R'_{Tm} = 101.11\ \Omega$$

Shunt resistance with 10°C rise in temperature,

$$R'_{sh} = R_{sh}(1 + \rho_2 \times 10)$$
$$= 1.01\,(1 + 0.00015 \times 10)$$
$$R'_{sh} = 1.0115\ \Omega$$

The new meter current with 10°C rise in temperature is given by

$$\text{Current, } I = I'_m\left(1 + \frac{R'_{Tm}}{R'_{sh}}\right)$$
$$100 = I'_m\left(1 + \frac{101.11}{1.0115}\right)$$
$$I'_m = \frac{100}{1 + \frac{101.11}{1.0115}} = 0.9905 \text{ mA}$$
$$\therefore \quad \text{Error} = (0.9905 - 1) * 100 = -0.95\%$$

Q.3 (c) Solution:

(i) Given, At ice point, $T_1 = 0°\text{C}$ and Resistance, $R_1 = 5\ \Omega$

At steam point, $T_2 = 100°\text{C}$ and $R_2 = 5.23\ \Omega$

At hot bath,

$$R_3 = 5.795\ \Omega \text{ and } T_3 = ?$$

We know that, for platinum RTD,

$$R_f = R_i[1 + \alpha(\Delta T)]$$
$$R_2 = R_1[1 + \alpha(T_2 - T_1)]$$
$$= R_1 + R_1\alpha(T_2 - T_1)$$
$$R_2 - R_1 = R_1\,\alpha(T_2 - T_1)$$
$$\therefore \quad \alpha = \frac{R_2 - R_1}{R_1(T_2 - T_1)}$$

Substituting the values of R_1 and R_2, we get

$$\alpha = \frac{5.23 - 5}{5(100 - 0)} = 4.6 \times 10^{-4}\,°\text{C}^{-1}$$

We have,

$$R_3 = R_1[1 + \alpha(T_3 - T_1)]$$
$$R_3 = R_1 + R_1\,\alpha(T_3 - T_1)$$
$$\frac{R_3 - R_1}{\alpha R_1} = T_3 - T_1$$

$$\frac{5.795 - 5}{5 \times 4.6 \times 10^{-4}} = T_3 - 0$$

$$\therefore \quad T_3 = 345.65°\text{C}$$

(ii) Given,

$$S = 10 \text{ kVA} = \sqrt{3}\, VI$$

$$\text{P.f} = 0.342 = \cos\phi$$

$$\Rightarrow \quad \phi = \cos^{-1}(0.342) = 70°$$

$$\text{Active power, } P = S\cos\phi = \sqrt{3}VI\cos\phi$$

$$= 10 \text{ kVA} \times 0.342$$

$$\therefore \quad P = 3.42 \text{ kW} = W_1 + W_2 \quad \text{...(i)}$$

1. When P.f is leading,

$$\phi = -70°$$

$$\therefore \quad \tan(-70°) = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$$

$$-2.74 = \frac{\sqrt{3}(W_1 - W_2)}{3.42 \text{ kW}}$$

$$\therefore \quad W_1 - W_2 = -5.42 \text{ kW} \quad \text{...(ii)}$$

On solving equation (i) and (ii),

$$W_1 = -1 \text{ kW}$$

$$W_2 = 4.42 \text{ kW}$$

2. When P.f is lagging,

$$\phi = 70°$$

$$\therefore \quad \tan(70°) = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$$

$$2.74 = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$$

$$2.74 = \frac{\sqrt{3}(W_1 - W_2)}{3.42 \text{ kW}}$$

$$\therefore \quad W_1 - W_2 = 5.42 \quad \text{...(iii)}$$

On solving equation (i) and (iii),

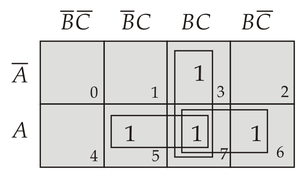
$$W_1 = 4.42 \text{ kW}$$

$$W_2 = -1 \text{ kW}$$

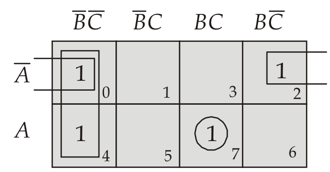
Q.4 (a) Solution:

(i) A total of seven minterms are present in the two functions above whereas the number of AND gates is four in the specified PLA. So, simplification of the above functions is necessary. Simplification is carried out for both the true form as well as the complement form for each of the functions.

Karnaugh maps are drawn for F_1 and F_2 as below:

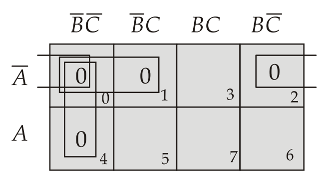


$F_1 = BC + AC + AB$

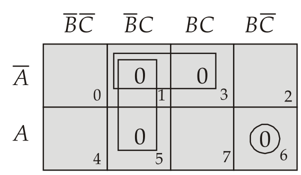


$F_2 = \overline{A}\overline{C} + \overline{B}\overline{C} + ABC$

K-map for F_1' and F_2' where F_1' and F_2' are complement functions of F_1 and F_2.



$F_1' = \overline{A}\overline{B} + \overline{A}\overline{C} + \overline{B}\overline{C}$



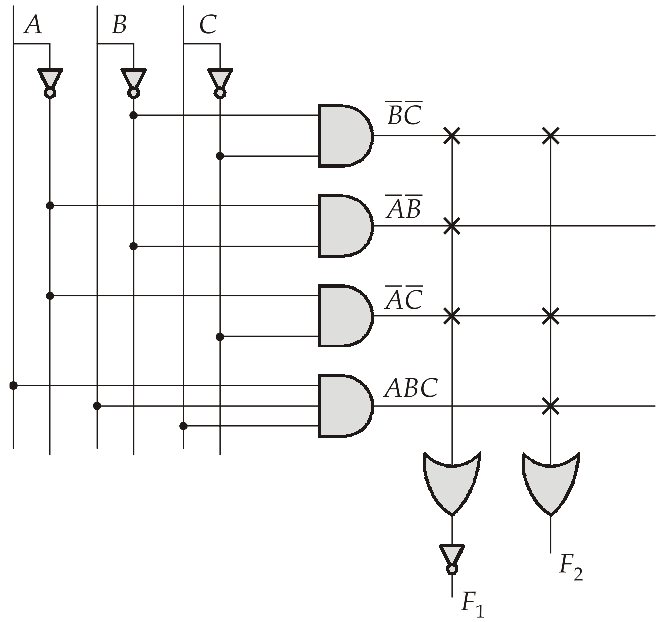
$F_2' = \overline{A}C + \overline{B}C + AB\overline{C}$

From the Boolean expression, it can be observed that if both the true forms of F_1 and F_2 are selected for implementation, the total number of distinct product terms needed to be realized is six, which is not possible by the specified 3 × 4 × 2 PLA. However, if F_1' and F_2 are selected, then the total number of distinct product terms reduces to four, which is now possible to be implemented by the specified PLA.

F_1' can be complemented by the output inverter to obtain the true form of F_1. The PLA program table for these expressions is prepared as below:

	Product term	Inputs			Outputs	
		A	B	C	F_1'	F_2
$\overline{B}\overline{C}$	1	–	0	0	1	1
$\overline{A}\overline{B}$	2	0	0	–	1	–
$\overline{A}\overline{C}$	3	0	–	0	1	1
ABC	4	1	1	1	–	1

Logic Diagram of PLA (3 × 4 × 2):



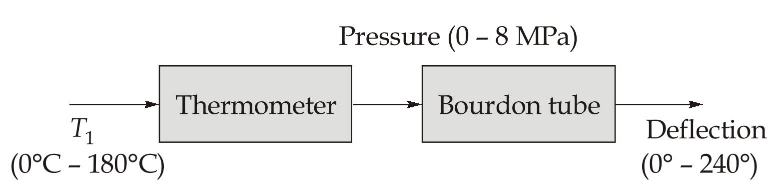
(ii) Lithography is a key process in semiconductor manufacturing that is used to create patterns and features on the surface of the semiconductor material. There are several types of lithography techniques used:

1. **Optical lithography:**
   - Uses UV light with wavelengths in the visible spectrum.
   - Relies on lenses and mirrors to focus and project patterns onto the substrate.
2. **Deep Ultraviolet (DUV) lithography:**
   - Utilizes shorter wavelength of UV light to achieve higher resolution compared to optical lithography.
   - Enhances resolution and enables fabrication of small features.
   - Widely used in semiconductor manufacturing for nodes down to around 14 nm.
3. **Extreme Ultraviolet (EUV) Lithography:**
   - Utilizes extreme ultraviolet light with wavelength around 13.5 nm.
   - Enables much higher resolution and smaller feature sizes compared to DUV lithography.
   - Complex optical systems are required due to the absorption of EUV light by the most materials.

4. **Electron Beam lithography (EBL):**
   - Uses a focused beam of electrons to directly write patterns onto a substrate.
   - Commonly used for prototyping, low volume production, and specialized applications such as nanotechnology and research.
5. **Maskless lithography:**
   - Directly writes patterns onto the substrate without the need for a physical mask.
   - There are various means to achieve the desired patterns and they can be broadly classified into additive and subtractive techniques. Additive techniques such as ink jet printing, dip pen nano-lithography (DPN), and micropens add material to a substrate based on a CAD layout. Subtractive techniques such as focused-ion beam (FIB), and laser micromachining selectively remove material from a substrate using ion beam and laser source, respectively.
   - Offers flexibility and rapid prototyping capabilities but may have intentions in throughput for high volume production.
6. **X-Ray lithography:**
   - Lithography using X-ray photons with extremely short wavelengths in the range of 0.4 nm to 2 nm.
   - Overcome the diffraction effects associated with imaging features with sizes comparable to the exposure wavelengths of UV lithographies.
   - High resolutions of ~ 0.5 μm.
7. **Ion lithography:**
   - Uses focused ion beams to pattern a resist.
   - The technique has many similarities to electron beam lithography, but the ions are significantly higher mass than the electrons.
   - It can achieve higher resolution than optical, X-ray, or electron beam lithographic techniques because ions undergo no diffraction and scatter much less than electrons.

Q.4 (b) Solution:

(i)



1.

$$\text{Sensitivity} = \frac{\text{Change in output deflection}}{\text{Change in input temperature}}$$

$$= \frac{240° - 0°}{180°C - 0°C}$$

$$= \frac{240°}{180°C} = 1.33 \text{ degree/°C}$$

2. The pressure exerted by a 50 cm column of mercury,

$$p = \rho g h$$

$$= 13600 \times 9.8 \times 50 \times 10^{-2}$$

$$= 66.64 \text{ kPa}$$

$$\text{Deflection for 8 MPa} = 270°$$

$$\text{Deflection for 1 MPa} = \frac{270°}{8}$$

$$\text{Deflection for } 10^3 \times 1 \text{ kPa} = \frac{270°}{8}$$

$$\text{Deflection for 1 kPa} = \frac{270°}{8 \times 10^3}$$

$$\text{Similarly, deflection for 66.64 kPa} = \frac{66.64 \times 270°}{8 \times 10^3} = 2.24°$$

Error due to elevation effect in measurement

$$= \frac{\text{Angular movement due to elevation}}{\text{Sensitivity of Thermometer}}$$

$$= \frac{2.24°}{1.33°/C} = 1.68°C$$

1.33° rotation is equal to 1°C

$$1° \text{ rotation is equal to } \left(\frac{1}{1.33}\right)°C$$

$$(2.24)° \text{ rotation is equal to } \frac{2.24 \times 1}{1.33} = 169°C$$

∴ Error in temperature value = 169°C – 180°C

$$= -11°C$$

(ii) Given, inductance of a moving iron instrument,

$$L = (24 + 10\theta - \theta^2)\ \mu H$$

The rate of change of inductance with deflection is,

$$\frac{dL}{d\theta} = \frac{d}{d\theta}(24 + 10\theta - \theta^2)$$
$$= 10 - 2\theta\ \mu H/rad$$
$$= (10 - 2\theta) \times 10^{-6}\ H/rad$$

For moving iron instruments, deflection is given as

$$\theta = \frac{1}{2}\frac{I^2}{K}\frac{dL}{d\theta}$$

where, K is spring constant,

$$\theta = \frac{1}{2} \times \frac{(10)^2}{24 \times 10^{-6}}[10 - 2\theta] \times 10^{-6}$$

$$0.48\theta = 10 - 2\theta$$

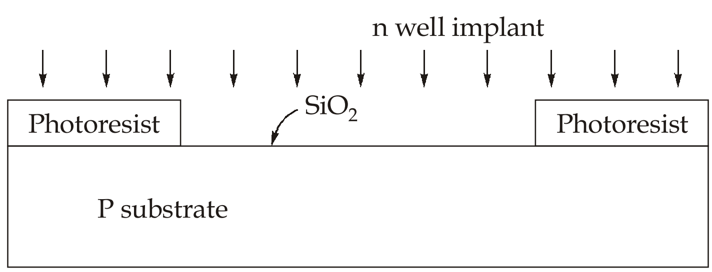
$$\Rightarrow \quad 2.48\theta = 10 \quad \Rightarrow \quad \theta = 4.032\ rad = 231°$$

Q.4 (c) Solution:

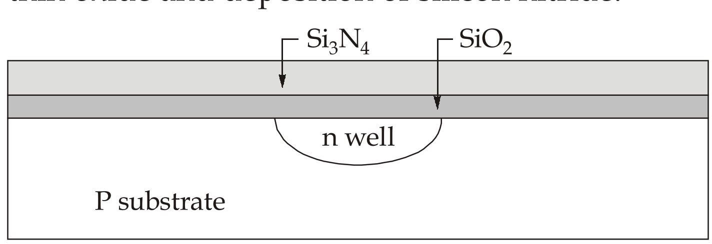
CMOS process steps:

Step 1: Implantation and diffusion of the n-well.

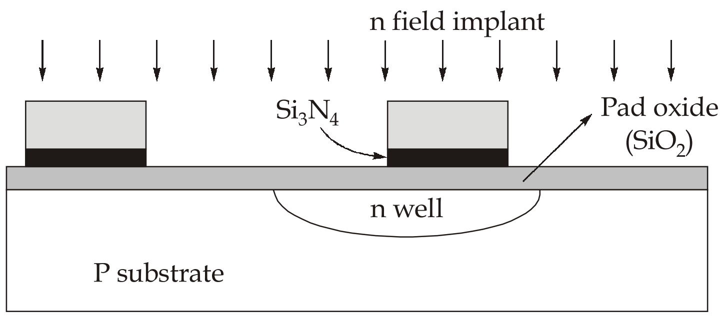
A p-substrate is chosen. The selective diffusion of n-type impurities to create n-well is accomplished using the photolithography.



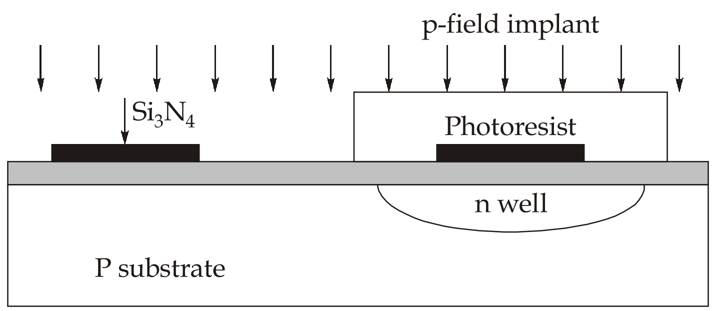
Step 2: Growth of thin oxide and deposition of silicon nitride.



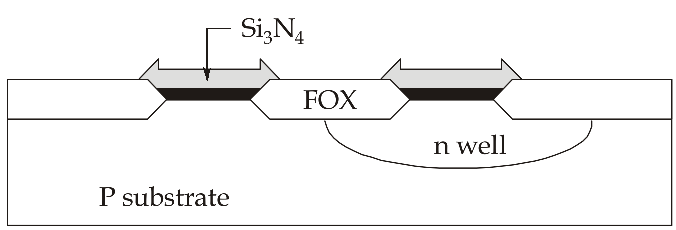
Step 3: Implantation of the n-type field channel stop:



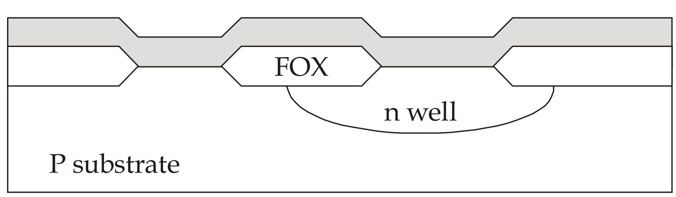
Step 4: Implantation of the p-type field channel stop.



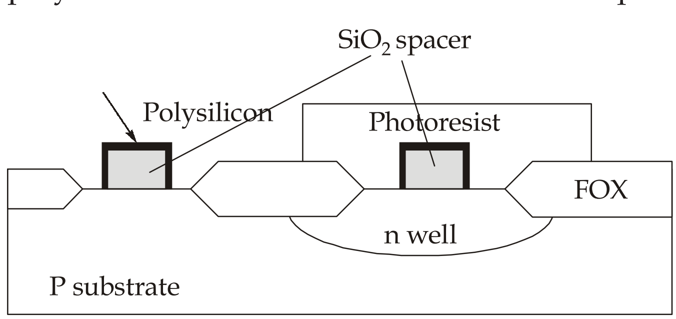
Step 5: Growth of the thick field oxide (LOCOS-localized oxidation of silicon)



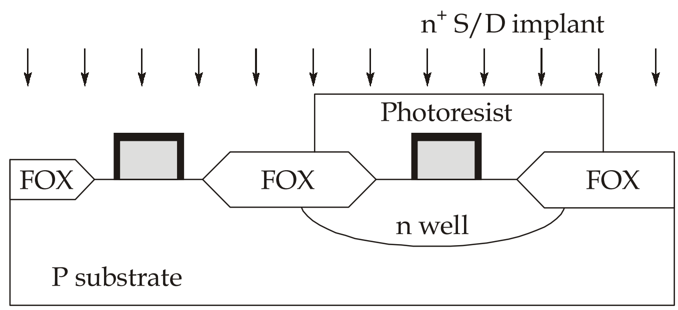
Step 6: Growth of the gate thin oxide and deposition of polysilicon.



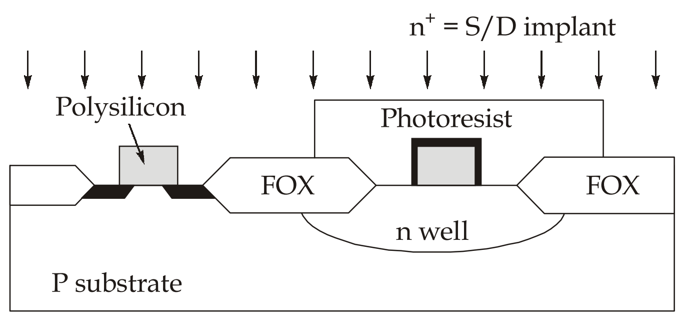
Step 7: Removal of polysilicon and formation of the sidewall spacers.



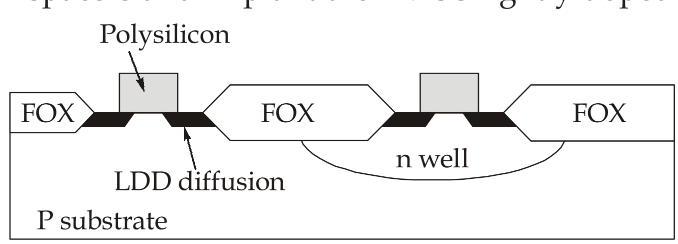
Step 8: Implantation of NMOS source and drain and contact to n well (not shown).



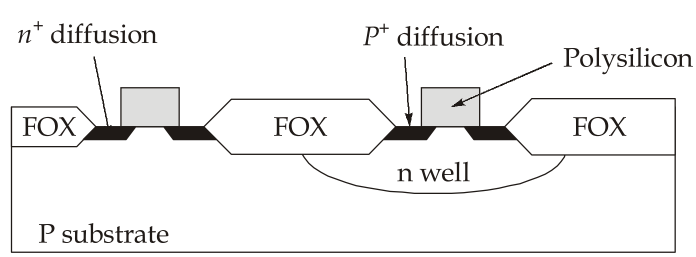
Step 9: Remove sidewall spacers and implant the NMOS lightly doped source/drains.



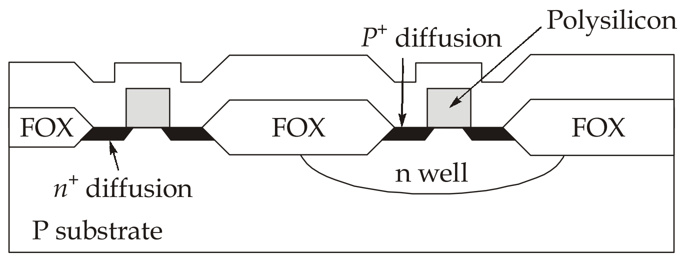
Step 10: Implant the PMOS source/drains and contacts to the P substrate (not shown) remove the sidewall spacers and implant the PMOS lightly doped source/drains.



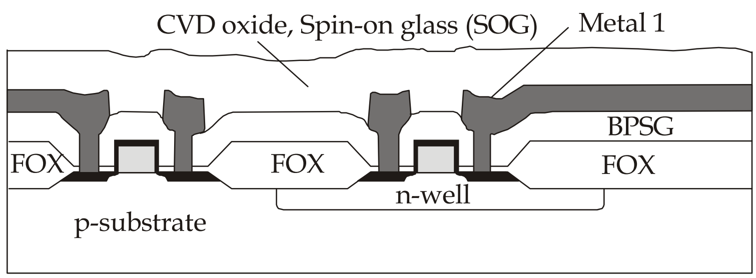
Step 11: Anneal to activate the implanted ions.



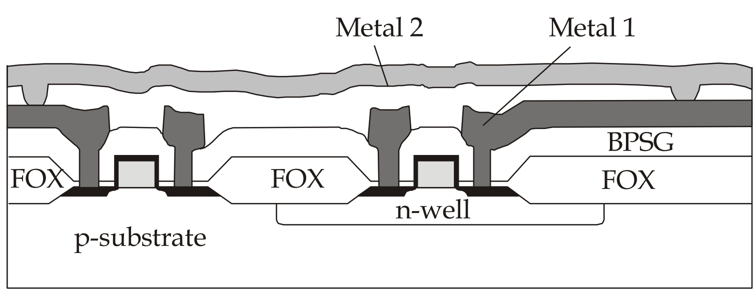
Step 12: Deposit a thick oxide layer.



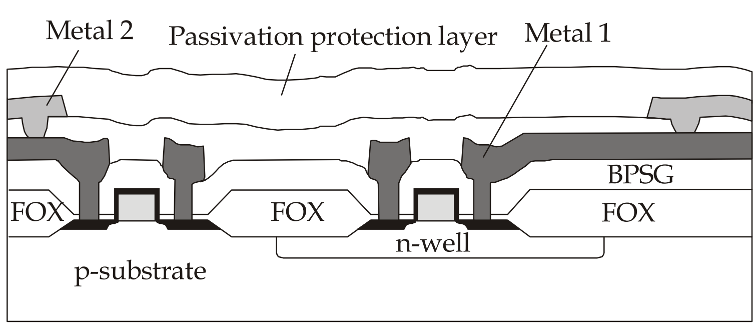
Step 13: Open contacts, deposit first level metal and etch unwanted metal.



Step 14: Deposit another interlayer dielectric (CVD SiO_2), open contacts, deposit second level metal.



Step 15: Etch unwanted metal and deposit a passivation layer and open over bonding pads.



Section B : Electromagnetics-1 + Basic Electrical Engineering-1
Computer Organization and Architecture-2 + Materials Science-2

Q.5 (a) Solution:

Given: $\omega = 2\pi f$

$= 2\pi \times 5 \times 10^6 = 10\pi \times 10^6$ rad/sec

(i) Attenuation constant, $\alpha = \omega\sqrt{\frac{\mu \in}{2}\left(\sqrt{1+\left(\frac{\sigma}{\omega \in}\right)^2} - 1\right)}$

$$= 10\pi \times 10^6 \sqrt{\frac{\mu_0 \times 9 \in_0}{2}\left(\sqrt{1+(0.8)^2} - 1\right)}$$

$$= 10\pi \times 10^6 \sqrt{\frac{4\pi \times 10^{-7} \times 9}{36\pi \times 10^9 \times 2} \times 0.2806}$$

$= 0.1176$ Np/m

Phase constant, $\beta = \omega\sqrt{\frac{\mu \in}{2}\left(\sqrt{1+\left(\frac{\sigma}{\omega \in}\right)^2} + 1\right)}$

$$= 10\pi \times 10^6 \sqrt{\frac{\mu_0 \times 9 \times \in_0}{2}\left(\sqrt{1.64} + 1\right)}$$

$$= 10\pi \times 10^6 \sqrt{\frac{4\pi \times 10^{-7} \times 9}{2 \times 36\pi \times 10^9} \times 2.2806}$$

$$= 10\pi \times 10^6 \sqrt{\frac{2.2806 \times 10^{-16}}{2}}$$

$= 0.3354$ rad/m

Phase velocity $= \frac{\omega}{\beta} = \frac{10\pi \times 10^6}{0.3354} = 9.36 \times 10^7$ m/s

Wave length, $\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{0.3354} = 18.733$ m

Conductivity, $\sigma = 0.8\omega\in = 0.8 \times 2\pi \times 5 \times 10^6 \times \frac{9}{36\pi \times 10^9}$

$= 2 \times 10^{-3}$ S/m

$$\text{Skin depth, } \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \times 5 \times 10^6 \times 4\pi \times 10^{-7} \times 2 \times 10^{-3}}}$$

$$= 5.0329 \text{ m}$$

$$\text{Intrinsic impedance, } \eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega \in}} = \sqrt{\frac{j\mu / \in}{\left(\frac{\sigma}{\omega \in}\right) + j}}$$

$$= \frac{\sqrt{j\mu_0 / 9 \in_0}}{\sqrt{0.8 + j}} = \sqrt{\frac{j4\pi \times 10^{-7} \times 36\pi \times 10^9}{9(0.8 + j)}}$$

$$= \sqrt{\frac{36\pi \times 10^9 \times 4\pi \times 10^{-7}}{9\sqrt{0.64 + 1}} \angle 90° - \tan^{-1}\frac{1}{0.8}}$$

$$= 111.044\angle 19.329° \ \Omega$$

(ii) In complex form:

$$\bar{E}_x = E_{x_0} e^{-\gamma z} \hat{a}_x, \text{ where } \gamma = \text{propagation constant} = \alpha + j\beta$$

$$\bar{E}_x = 120\angle 60° e^{-(\alpha + j\beta)z} \hat{a}_x$$

$$\bar{E}_x = 120 e^{-\alpha z} e^{\left(\frac{j\pi}{3} - j\beta z\right)} \hat{a}_x$$

$$\bar{E}_x = 120 e^{-0.1176z} e^{j\left(\frac{\pi}{3} - 0.3354z\right)} \hat{a}_x$$

We have,

$$\frac{E_{x_0}}{H_{y_0}} = \eta$$

$$H_{y_0} = \frac{E_{x_0}}{\eta} = \frac{120\angle 60°}{111.044\angle 19.329°} = 1.0806\angle 40.671° \text{ A/m}$$

$\therefore$

$$\vec{H}_y = H_{y_0} e^{-\gamma z} \hat{a}_y$$

$$\vec{H}_y = 1.0806 e^{-0.1176z} e^{j(40.671 - 0.3354z)} \hat{a}_y$$

The real instantaneous form for the field components can be obtained as below:

$$\bar{E}_x = 120 e^{-0.1176z} \cos\left(\omega t + \frac{\pi}{3} - 0.3354z\right) \hat{a}_x \text{ V/m}$$

$$\bar{H}_y = 1.0806 e^{-0.1176z} \cos(\omega t + 40.671° - 0.3354z) \hat{a}_y \text{ A/m}$$

Q.5 (b) Solution:

(i) The tangential and normal vector components of $\bar{E}$ in the material-1 are

$$\bar{E}_{1t} = 150\hat{a}_x + 25\hat{a}_y\,;\,\bar{E}_{1n} = -80\hat{a}_z$$

Tangential components of electric field are continuous

$$\bar{E}_{2t} = \bar{E}_{1t} = 150\hat{a}_x + 25\hat{a}_y$$

The normal component of the electric flux density is discontinuous across the surface by an amount equal to the surface-charge density on the boundary i.e.

$$D_{1n} - D_{2n} = \rho_s$$

$$\in_1 E_{1n} - \in_2 E_{2n} = \rho_s$$

$$E_{2n} = \frac{\in_1 E_{1n} - \rho_s}{\in_2} = \frac{5\in_0 (-80) - 2\times 10^{-9}}{2\in_0}$$

$$= \frac{\left(\frac{5(-80)}{36\pi} - 2\right)\times 10^{-9}\times 36\pi\times 10^{9}}{2}$$

$$= \frac{(-400 - 72\pi)}{2} = -313.097 \text{ V/m}$$

Thus, electric field intensity in material-2

$$\bar{E}_2 = \bar{E}_{2t} + \bar{E}_{2n} = 150\hat{a}_x + 25\hat{a}_y - 313.097\hat{a}_z \text{ V/m}$$

(ii) The tangential and normal vector components of the magnetic flux density in material-1 are

$$\bar{B}_{1t} = \mu_1 \bar{H}_{1t} = 3\mu_0 \times 2\times 10^5 \hat{a}_x + 3\mu_0 \times 3\times 10^5 \hat{a}_y$$

$$\bar{B}_{1n} = \mu_1 \bar{H}_{1n} = -(3\mu_0 \times 4 \times 10^5)\hat{a}_z$$

The tangential components of the magnetic field intensity is discontinuous across the interface by an amount equal to the magnitude of the surface current density i.e.

$$\bar{H}_{1t} - \bar{H}_{2t} = \bar{J}_s$$

$$\frac{\bar{B}_{1t}}{\mu_1} - \frac{\bar{B}_{2t}}{\mu_2} = \bar{J}_s$$

$$\bar{B}_{2t} = \frac{\mu_2 \bar{B}_1 t - \mu_1\mu_2 \bar{J}_s}{\mu_1}$$

This gives
$$\bar{B}_{2t} = \frac{3\mu_0 \times 2\times 10^5 \hat{a}_x + 3\mu_0 \times 3\times 10^5 \hat{a}_y - 3\mu_0 \times 3\times 10^5 \hat{a}_x}{3}$$
$$\bar{B}_{2t} = \frac{-3\mu_0 \times 10^5 \hat{a}_x + 9\mu_0 \times 10^5 \hat{a}_y}{3}$$
$$= -\mu_0 \times 10^5 a_x + 3\mu_0 \times 10^5 \hat{a}_y T$$

The normal component of $\bar{B}$ is continuous across the interface i.e.,
$$\bar{B}_{2n} = \bar{B}_{1n} = -(3\mu_0 \times 4\times 10^5)\hat{a}_z T$$

Thus, the magnetic flux in material-2 is
$$\bar{B}_2 = -10^5 \mu_0 \hat{a}_x + 3\mu_0 \times 10^5 \hat{a}_y - 12\mu_0 \times 10^5 \hat{a}_z T$$
$$\bar{H}_2 = \frac{\bar{B}_2}{\mu_2} = \frac{\bar{B}_2}{\mu_0} = -10^5 \hat{a}_x + 3\times 10^5 \hat{a}_y - 12\times 10^5 \hat{a}_z \text{ A/m}$$

Q.5 (c) Solution:

We have,

Critical field, $H_{c1} = 2 \times 10^5$ A/m at $T = -257°$C

$H_{c2} = 4.2 \times 10^5$ A/m at $T = 12$ K

We know that,
$$\frac{C°}{5} = \frac{F-32}{9} = \frac{K-273}{5}$$

Convert all the temperatures into Kelvin,

For –257°C, $$\frac{-257°}{5} = \frac{K-273}{5} \Rightarrow 16 \text{ K}$$

For –450.7°F, $$\frac{-450.7-32}{9} = \frac{K-273}{5} \Rightarrow 4.83 \text{ K}$$

Using, $$H_C = H_0\left[1-\left(\frac{T}{T_c}\right)^2\right]$$

We get, $$2\times 10^5 = H_0\left[1-\left(\frac{16}{T_c}\right)^2\right] \quad ...(i)$$
$$4.2\times 10^5 = H_0\left[1-\left(\frac{12}{T_c}\right)^2\right] \quad ...(ii)$$

Now,
$$\frac{4.2\times10^5}{2\times10^5} = \frac{1-\left(\frac{12}{T_c}\right)^2}{1-\left(\frac{16}{T_c}\right)^2}$$

$$4.2\times10^5-(4.2\times10^5)\left(\frac{16}{T_c}\right)^2 = 2\times10^5-2\times10^5\left(\frac{12}{T_c}\right)^2$$

$$4.2\times10^5-\frac{4.2\times10^5\times16\times16}{T_c^2} = 2\times10^5-\frac{2\times10^5\times12\times12}{T_c^2}$$

$$4.2\times10^5-2\times10^5 = \frac{-2\times10^5\times12\times12}{T_c^2}+\frac{4.2\times10^5\times16\times16}{T_c^2}$$

$$2.2\times10^5 = \frac{3936\times10^5}{T_c^2\times5}$$

$$T_c^2 = \frac{3936\times10^5}{5\times2.2\times10^5} = 357.818$$

$$T_c = 18.92\text{ K}$$

Now, substituting $T_c = 18.92$ K in equation (i), we get

$$\frac{2\times10^5}{1-\left(\frac{16}{18.92}\right)^2} = H_0$$

$$H_0 = 7.02\times10^5\text{ A/m which is the critical field at 0 K.}$$

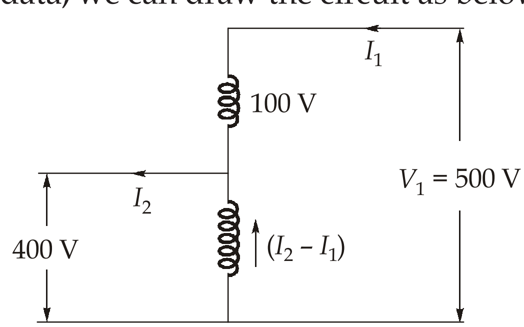
At T = 4.83 K = –450.7 °F,

$$H_c = 7.02\times10^5\left[1-\left(\frac{4.83}{18.92}\right)^2\right]$$

$$H_c = 6.56\times10^5\text{ A/m}$$

Q.5 (d) Solution:

(i) According to given data, we can draw the circuit as below:



As, $I_1 = \frac{10 \times 10^3}{100} = 100$ A

Since, $V_1 I_1 = V_2 I_2$

$500 \times 100 = V_2 I_2$

$I_2 = \frac{500 \times 100}{400} = 125$ A

Now,

kVA rating of auto transformer $= \frac{(V_2 I_2)}{1000}$

$= \frac{125 \times 400}{1000} = 50$ kVA

(ii) Efficiency for 2-winding transformer,

$$\eta = \frac{(\text{kVA})_{\text{rating}} \cdot \cos\theta_0}{(\text{kVA})_{\text{rating}} \cdot \cos\theta_0 + \text{losses}}$$

$$0.97 = \frac{10 \times 1000 \times 0.85}{(1000 \times 10 \times 0.85) + \text{losses}}$$

$$\text{losses} = \frac{10 \times 1000 \times 0.85}{0.97} - (1000 \times 10 \times 0.85)$$

$$\text{losses} = 262.9 \text{ W}$$

Since, Losses for both the transformer are same. Thus, efficiency of auto transformer is given as

$$\eta = \frac{(\text{kVA})_{\text{rating of auto transformer}} \times \cos\theta_0}{(\text{kVA})_{\text{rating of auto transformer}} \cos\theta_0 + \text{losses}}$$

$$\eta = \frac{50 \times 10^3 \times 0.85}{50 \times 10^3 \times 0.85 + 262.9} = 0.9938$$

$$\eta\% = 99.38\%$$

Q.5 (e) Solution:

(i) Given,

Cache access time, $t_c = 18$ ns

Disk (secondary) memory access time,

$t_A = 85$ ns

Hit ratio for cache, $h_c = 0.95$

Hit ratio for main memory, $h_m = 0.91$

The average access time, $t_{av} = 24$ ns

Let, the main memory access time be t_m units.

Now, we know, that average access time of the memory system is given by

$$T_{av} = h_c \times t_c + h_m \times (1 - h_c) \times (t_c + t_m) + (1 - h_c)(1 - h_m)(t_c + t_m + t_A)$$

Substituting the given values,

$$24 = 0.95 \times 18 + 0.91 \times (0.05) \times (18 + t_m) + 0.05 \times 0.09(18 + 85 + t_m)$$

$$6.9 = 0.819 + 0.0455\, t_m + 0.4635 + 0.0045\, t_m$$

$$\Rightarrow \quad 5.6175 = 0.05\, t_m$$

$$t_m = 112.35 \text{ ns}$$

Hence, the main memory access time must be 112.35 ns to achieve the effective access time of 24 ns.

(ii) **1.** The main memory size = 64 K × 16

Therefore, the memory has 2^{16} words and the CPU must generate the address of 16 bit (since 64 K = 2^{16})

The cache memory size = 2 K = 2^{11} words

Therefore, the size of index field of cache

= 11 bits

The tag-field uses 16 – 11 = 5 bits

The size of each cache block = 4 words

Thus, the number of blocks in cache = $\frac{2048}{4}$ = 512

Therefore the number of bits required to select each block = 9 bits (since 512 = 2^9)

The number of bits required to select a word in a block = 2, because there are 4 words in each block.

Thus, the address format is as follows:

5 bits	9 bits	2 bits
Tag	Block	Word

Index

2. The main memory size = 64 K × 16

Therefore, the number of bits in each word of cache = 16

3. From part (a); the number of blocks in cache = 512.

Q.6 (a) Solution:

(i) **1.** The direction of propagation is given by poynting vector. For poynting vector we need to find out magnetic field intensity.

Magnetic field intensity in terms of electric field intensity can be obtained from Maxwell's equation $\vec{\nabla}\times\vec{E} = -j\mu\omega\vec{H}$ as

$$\left(\frac{\partial E_z}{\partial y}-\frac{\partial E_y}{\partial z}\right)\hat{a}_x+\left(\frac{\partial E_x}{\partial z}-\frac{\partial E_z}{\partial x}\right)\hat{a}_y+\left(\frac{\partial E_y}{\partial x}-\frac{\partial E_x}{\partial y}\right)\hat{a}_z = -j\omega\mu(H_x\hat{a}_x+H_y\hat{a}_y+H_z\hat{a}_z)$$

As electric field has only y component and it varies with z only, so

$$-\frac{\partial E_y}{\partial z}\hat{a}_x = -j\omega\mu H_x$$

$$\overline{E} = -E_0e^{-j\beta z}\hat{a}_y$$

$$\overline{H} = \frac{\beta}{\omega\mu_0}E_0e^{-j\beta z}\hat{a}_x = \frac{E_0}{\eta_0}e^{-j\beta z}\hat{a}_x$$

In time domain,

$$\overline{H} = \hat{a}_x\frac{1}{\eta_0}E_0\cos(\omega t-\beta z)\text{ A/m}$$

The pointing vector is,

$$\overline{P} = \overline{E}\times\overline{H} = \left[-\hat{a}_yE_0\cos(\omega t-\beta z)\right]\left[\frac{1}{\eta_0}E_0\cos(\omega t-\beta z)\hat{a}_x\right]$$

$$\overline{P} = \frac{E_0^2}{\eta_0}\cos^2(\omega t-\beta z)\hat{a}_z$$

The direction of power flow in z-direction. This is also the direction of propagation of the wave.

2. The instantaneous power density

$$\overline{P}(z,t) = \overline{E}(z,t)\times\overline{H}(z,t) = \frac{E_0^2}{\eta_0}\cos^2(\omega t-\beta z)\hat{a}_z$$

The time averaged power density is found by integrating the instantaneous power density over one cycle of the wave $\left(T=\frac{1}{f}=\frac{2\pi}{\omega}\right)$

$$\vec{P}_{av}(z) = \frac{1}{T}\int_0^T \frac{E_0^2}{\eta_0}\cos^2(\omega t - \beta z)\hat{a}_z\, dt$$

$$= \frac{1}{T}\frac{E_0^2}{\eta_0}\int_0^T \left[\frac{1}{2} + \frac{1}{2}\cos 2(\omega t - \beta z)\right]\hat{a}_z\, dt$$

$$= \frac{1}{T}\cdot\frac{E_0^2}{\eta_0}\int_0^T \frac{dt}{2}\hat{a}_z + \frac{1}{T}\frac{E_0^2}{\eta_0}\int_0^T \frac{1}{2}\cos 2(\omega t - \beta z)\hat{a}_z dt$$

$$= \frac{E_0^2}{\eta_0}\times\frac{1}{T}\times\frac{T}{2} + \frac{1}{T}\frac{E_0^2}{\eta_0}\times\frac{1}{2}\frac{\sin 2(\omega t - \beta z)}{2\omega}\bigg|_0^T \hat{a}_z$$

$$= \frac{E_0^2}{2\eta_0}\hat{a}_z$$

$$\vec{P}_{av}(z) = \frac{E_0^2}{2\eta_0}\hat{a}_z = \frac{(1200)^2}{2\times 377} = 1909.814\hat{a}_z \text{ W/m}^2$$

3. The power density is uniform throughout space and doesn't depend on the location (except for phase, which varies in z-direction).

   Thus, both the total instantaneous and time averaged power are infinite. This is true of any plane wave.

4. The amount of power received by antenna equals the power density multiplied by the surface area of the antenna (S).

   For 2 m diameter dish, the instantaneous power received is

$$P_t = \left|\vec{P}(z, t)\right|\cdot\vec{S} = \frac{E_0^2\pi d^2}{4\eta_0}\cos^2(\omega t - \beta z),$$

where $S = \pi d^2/4$ in a direction perpendicular to the surface i.e. in +z-direction.

$$P_t = \frac{(1200)^2\times\pi(2)^2}{4\times 377}\cos^2(8\pi\times 10^8 t - \beta z)$$

$$= 11999.717\cos^2(8\pi\times 10^8 t \;\; \beta z)$$

$$P_t \cong 12000\cos^2(8\pi\times 10^8 t - \beta z)$$

The time averaged power received is

$$P_{\text{avg}} = |P_{av}|S = \frac{E_0^2\pi d^2}{8\eta_0} = \frac{(1200)^2\times\pi\times(2)^2}{8\times 377}$$

$$\cong 6000 \text{ W}$$

(ii) According to Maxwell's third equation or Faraday's law, we have

$$\overline{\nabla} \times \overline{E} = -\frac{\partial \overline{B}}{\partial t}$$

We have, $\overline{B} = \overline{\nabla} \times \overline{A}$ ($\overline{A} \rightarrow$ Magnetic vector potential)

$$\overline{\nabla} \times \overline{E} = -\frac{\partial}{\partial t}(\overline{\nabla} \times \overline{A}) \Rightarrow \overline{E} = \frac{-\partial \overline{A}}{\partial t}$$

The static electric field intensity,

$\overline{E_s} = -\overline{\nabla}\,V$ must also be added to this electric field intensity.

$$\overline{E} = \frac{-\partial \overline{A}}{\partial t} - \overline{\nabla}\,V$$

As per Maxwell's first equation

$$\overline{\nabla} \cdot \overline{D} = \rho$$

$$\overline{\nabla} \cdot \overline{D} = \in \overline{\nabla} \cdot \overline{E} = \in \overline{\nabla} \cdot \left(-\frac{\partial \overline{A}}{\partial t} - \overline{\nabla} V \right) = \rho$$

$$-\overline{\nabla} \cdot \frac{\partial \overline{A}}{\partial t} - \nabla^2 V = \frac{\rho}{\in}$$

$$\frac{\partial}{\partial t}(\overline{\nabla} \cdot \overline{A}) + \nabla^2 V = -\frac{\rho}{\in} \quad \text{...(i)}$$

As per Lorentz condition,

$$\overline{\nabla} \cdot \overline{A} = -\mu \in \frac{\partial V}{\partial t}$$

Substituting this in (i),

$$\nabla^2 V + \frac{\partial}{\partial t}\left(-\mu \in \frac{\partial V}{\partial t} \right) = -\frac{\rho}{\in}$$

$$\nabla^2 V - \mu \in \frac{\partial^2 V}{\partial t^2} = -\frac{\rho}{\in}$$

$$\nabla^2 V - \mu \in \frac{\partial^2 V}{\partial t^2} = -\frac{\rho}{\in}$$

Q.6 (b) Solution:

(i) We have,

electrical conductivity, $\sigma = 4 \times 10^7 (\Omega\text{-m})^{-1}$

electron mobility, $\mu_n = 0.0016 \text{ m}^2/\text{V-sec}$

current, $I = 25$ A

magnetic field, $B = 0.4$ T

thickness of aluminium, $d = 15 \times 10^{-3}$ m

We know that,

$$\text{Hall voltage, } V_H = \frac{R_H IB}{d}, \text{ where } R_H = \frac{1}{ne} = \frac{\mu}{\sigma}$$

$$= \frac{\mu_n \times I \times B}{\sigma \times d}$$

$$= \frac{0.0016 \times 25 \times 0.4}{4 \times 10^7 \times 15 \times 10^{-3}}$$

$$= 2.66 \times 10^{-8} \text{ Volt}$$

(ii) Barium Titanate ($BaTiO_3$) belongs to pervoskite family ABO_3. An important transformation occur on heating $BaTiO_3$ above 130°C (Curie temperature) when its dielectric property changes from ferroelectric tetragonal structure with a net dipole moment to paraelectric cubic structure. Below its ferroelectric Curie temperature, the Ti^{4+} ions occupy slightly off-center positions, which means the unit cell has a net electric dipole moment, leading to ferroelectricity. When the temperature of $BaTiO_3$ is raised above its ferroelectric Curie temperature, the off-center displacement of the Ti^{4+} ions becomes thermodynamically unfavorable, and they return to the center of the unit cell. This symmetrical arrangement of the ions results in the loss of the net electric dipole moment, leading to the demise of the ferroelectric behavior of $BaTiO_3$. Hence, the ferroelectric behaviour of $BaTiO_3$ ceases above its ferroelectric curie temperature because the unit cell transforms from tetragonal geometry to cubic.

(iii) The types of polarization are:

1. Electronic polarization: It results from a displacement of the center of negatively charged electron cloud relative to the positive nucleus of an atom by the electric field. This polarization type is found in all dielectric materials and exists only while an electric field is present.
2. Ionic polarization: It occurs only in ionic materials. An applied electric field acts to displace cation in one direction and anions in the opposite direction, which gives rise to net dipole moment.
3. Orientation polarization: It is found only in substances that possess permanent moments. It results due to rotation of the permanent moments into the direction of the applied field.

4. Space charge polarization: It occurs due to multiphase defects, vacancies, trapped charges etc. It is also known as interfacial polarization as it ocsurs when there is an accumulation of charge at an interface between two materials or between two regions within a material because of an external field.

   Gaseous Argon-Electronic polarization, because the electron cloud can be polarized by an applied electric field

   Solid LiF - Ionic and electronic polarization, with ionic polarization being the main type due to the presence of lithium cations and fluoride anions.

   Liquid H_2O - Orientational and electronic polarization, with orientational polarization being the main type as water molecules have an inherent dipole moment.

Q.6 (c) Solution:

(i) With respect to given data, we can draw the circuit equivalent of transformer as below:

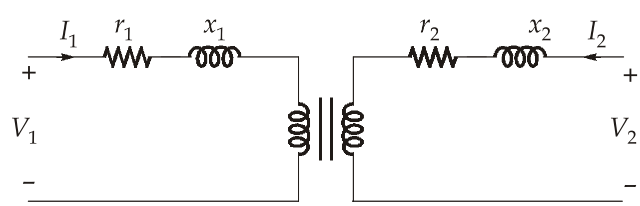


fig. (i)

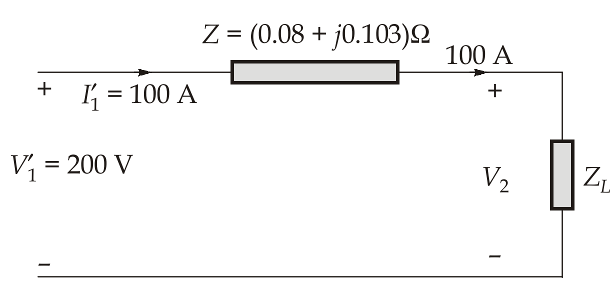
Now, we will refer transformer impedance to the LV side.

$$R_{LV} = 0.05 + \left(\frac{200}{2000}\right)^2 \times 3 \quad \text{and} \quad X_{LV} = 0.05 + \left(\frac{200}{2000}\right)^2 \times 5.3$$

$$R_{LV} = 0.08\ \Omega \qquad\qquad X_{LV} = 0.103\ \Omega$$

Thus,

We can redraw the circuit as



$$\text{Full-load current, } I_2 = \frac{20 \times 1000}{200} = 100\text{A}$$

1. (a) Voltage drop for 0.8 pf lagging load

$$= I_2(R_{LV}\cos\phi + X_{LV}\sin\phi)$$

$$= 100(0.08 \times 0.8 + 0.103 \times 0.6) = 12.58 \text{ V}$$

$$\text{Voltage regulation} = \frac{12.58}{200} \times 100 = 6.29\%$$

(b) Voltage drop for upf = 100(0.08 × 1 + 0.103 × 0) = 8 V

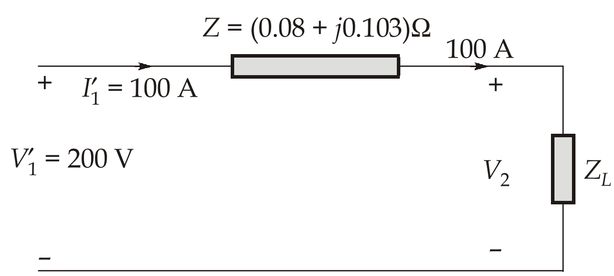
$$\text{Voltage regulation} = \frac{8}{200} \times 100 = 4\%$$

(c) Voltage drop for 0.707 leading load

$$= 100(0.08 \times 0.707 - 0.103 \times 0.707) = -1.63 \text{ V}$$

$$\text{Voltage regulation} = \frac{-1.63}{200} \times 100 = -0.815\%$$

2. Redraw the circuit from fig. (ii)



(a) Voltage drop for 0.8 pf lagging load is 12.58 V

$$\therefore \quad V_2 = 200 - 12.58 = 187.4 \text{ V}$$

(b) Voltage drop for upf is 8 V

$$\therefore \quad V_2 = 200 - 8 = 192 \text{ V}$$

(c) Voltage drop for 0.707 leading load is –1.63 V

$$\therefore \quad V_2 = 200 - (-1.63)$$

$$V_2 = 201.6 \text{ V}$$

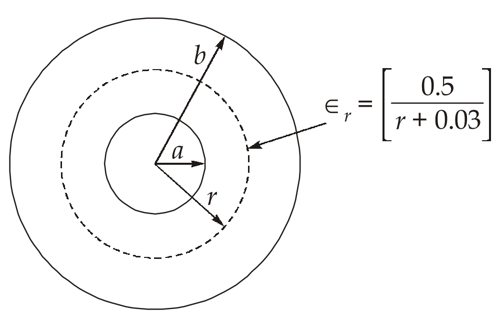
(ii) **Core-Type Transformer:** In the core type transformer, the magnetic circuit of the transformer consists of two sections namely two vertical sections called limbs and two horizontal sections called yokes. Half of each winding (primary and secondary windings) is placed on each limb of the core so that the leakage flux can be minimized.

Shell-Type Transformer: A type of transformer in which the magnetic circuit consists of one central limb and two outer limbs, and both primary and secondary windings are placed on the central limb is called a shell-type transformer.

Core Type Transformer	Shell Type Transformer
1. Easier to construct	1. Complex construction
2. Less mechanical support	2. More mechanical support
3. Lower efficiency due to more leakage flux	3. Higher efficiency due to less leakage flux
4. Easy to repair	4. Difficult to repair
5. Natural cooling is relatively more effective due to distributed windings.	5. Poor natural cooling because the core surrounds the windings.
6. High voltage, high power applications	6. Low voltage, low power applications
7. Less insulation required	7. More insulation required
8. Requires more conductor material for windings.	8. Requires less winding conductor material.
9. Winding surrounds core	9. Core surrounds windings
10. The cross-section may be square, cruciform or three-stepped.	10. The cross-section is rectangular.

Q.7 (a) Solution:

(i) Two concentric spheres have radii $r = a = 0.03$ m and $r = b = 0.08$ m. Relative permittivity of dielectric is $\epsilon_r = \frac{0.5}{r + 0.03}$. The boundary conditions are $V(a) = 150$ V and $V(b) = 0$ V.



If the charge on one of the sphere is Q, the electric flux density for $a < r < b$ is

$$D_r = \frac{Q}{4\pi r^2}\hat{a}_r$$

as the electric field is directed from lower potential to higher potential.

The electric field intensity is

$$E_r = \frac{D_r}{\epsilon_0 \epsilon_r} = \frac{Q}{4\pi \epsilon_0 \times 0.5}\left(\frac{r + 0.03}{r^2}\right)$$

$$= \frac{Q}{2\pi \in_0}\left[\frac{1}{r}+\frac{0.03}{r^2}\right]$$

The potential at $r = b$ is calculated as

$$V = -\int_{0.08}^{0.03} E_r dr = -\frac{Q}{2\pi \in_0}\left[\ln r - \frac{0.03}{r}\right]_{0.08}^{0.03}$$

$$150 = \frac{Q}{2\pi \in_0}\left[\ln\frac{8}{3} + 0.03\left(\frac{1}{0.03}-\frac{1}{0.08}\right)\right]$$

$$150 = \frac{Q}{2\pi \in_0}[1.605]$$

$$Q = \frac{150\times 2\pi}{36\pi\times 10^9\times 1.605} = \frac{150}{18\times 1.605}\times 10^{-9} = 5.192 \text{ nC}$$

1. Electric flux density is,

$$\vec{D} = \frac{Q}{4\pi r^2}\hat{a}_r = \frac{5.192}{4\pi r^2}\hat{a}_r \text{ nC/m}^2$$

$$= \frac{413.167}{r^2}\hat{a}_r \text{ pC/m}^2$$

2. Electric field intensity,

$$\vec{E} = \frac{\vec{D}}{\in_0 \in_r} = \frac{413.167\times 36\pi\times 10^9}{r^2 \in_r}\hat{a}_r \times 10^{-12} \text{ V/m}$$

$$= \frac{46.728}{r^2}\cdot\frac{r+0.03}{0.5}\hat{a}_r \text{ V/m}$$

$$\vec{E} = 93.456\left(\frac{1}{r}+\frac{0.03}{r^2}\right)\hat{a}_r \text{ V/m}$$

(ii) **1.** We need to check if seawater could be treated as a conductor or as a lossy dielectric.

$$\sigma = 5 \text{ S/m}, \omega = 2\pi f = 2\pi(3\times 10^6) \text{ rad/s}$$

$$\in = \frac{81}{36\pi}\times 10^{-9} \text{F/m} = 71.619\times 10^{-11} \text{ F/m}$$

$$\frac{\sigma}{\omega \in} = \frac{5}{2\pi\times 3\times 10^6\times 71.619\times 10^{-11}} = 370.37411 >> 1$$

Hence, we can treat seawater as conductor at 3 MHz.

Attenuation constant,

$$\alpha = \sqrt{\pi f \mu \sigma}$$

$$\alpha = \sqrt{\pi\times 3\times 10^6\times 4\pi\times 10^{-7}\times 5}$$

$$= 7.695 \text{ Np/m}$$

The amplitude of magnetic field decays exponentially with distance '*d*' as

$$H = H_0 e^{-\alpha d}$$

The requisite magnetic field at receiver = 2 μA/m. Hence,

$$2 \times 10^{-6} = H_0 e^{-\alpha d}$$

We have, $H_0 = 15000$ A/m; $\alpha = 7.695$ Np/m

$$2 \times 10^{-6} = 15000\ e^{-7.695d}$$

$$d = \frac{1}{7.695} \ln \frac{15000}{2 \times 10^{-6}} = 2.954 \text{ m}$$

The range of communication should be less than 2.954 m.

2. At 120 Hz,

$$\frac{\sigma}{\omega \in} = \frac{5}{2\pi \times 120 \times 71.619 \times 10^{-11}} = 9.259 \times 10^6 >> 1$$

Hence, it will act as conductor.

$$\alpha = \sqrt{\pi f \mu_0 \sigma} = \sqrt{\pi \times 120 \times 4\pi \times 10^{-7} \times 5}$$

$$= 0.0486 \text{ Np/m}$$

To have a requisite magnetic field strength of 2 μA/m at distance '*d*',

$$2 \times 10^{-6} = H_0 e^{-\alpha d}$$

$$2 \times 10^{-6} = 15000\ e^{-0.0486d}$$

$$d = \frac{1}{0.0486} \ln \frac{15000}{2 \times 10^{-6}} = 467.863 \text{ m}$$

This range is feasible for under water communication. So, communication in seawater is possible at very low frequencies.

3. Wavelength, $\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{\alpha}$ [$\because \alpha = \beta$ for a good conductor]

$$\lambda_1(3 \text{ MHz}) = \frac{2\pi}{7.695} = 0.816 \text{ m}$$

$$\lambda_2(120 \text{ Hz}) = \frac{2\pi}{0.0486} = 129.283 \text{ m}$$

For quarter wavelength antenna, we have

$$\frac{\lambda_1}{4} = 0.204 \text{ m long antenna at 3 MHz}$$

$$\frac{\lambda_2}{4} = \frac{129.283}{4} = 32.32 \text{ m long antenna at 120 Hz}$$

Q.7 (b) Solution:

Concurrency control refers to the management of simultaneous access of shared data in a database by multiple transactions. It ensures that transactions execute correctly and maintain data integrity despite concurrency, preventing problems like lost updates, uncommitted data, or inconsistent reads.

Importance in database systems:

Concurrency control is crucial because:

- It prevents data corruption and maintains consistency by enforcing rules for transaction execution.
- It enables efficient use of system resource by allowing multiple transactions to execute concurrently without interfering with each other.
- It ensures isolation between transactions, meaning that the outcome of each transaction appears as if it occurred in isolation, regardless of other concurrently executing transactions.

Optimistic Vs pessimistic concurrency control:

- **Pessimistic concurrency control:**

  This approach assumes that conflicts between transactions are likely, so it locks data items preemptively to prevent conflicts. It includes techniques like lock-based concurrency control (e.g., read and write locks) and two phase locking. While it ensures strict isolation, it can lead to contention and reduced concurrency.

- **Optimistic concurrency control:**

  This approach assumes that conflicts are rare. So it allows transactions to proceed without acquiring locks initially. It only checks for conflicts at the end of the transaction (during the commit phase). Techniques include time stamp-based concurrency control and validation-based concurrency control. While it offers higher concurrency, it may lead to more roll backs if conflicts occur.

Challenges in distributed databases:

Achieving concurrency control in distributed databases presents additional challenges due to:

- **Network Latency:** Synchronization and communication between distributed nodes can introduce delays, affecting the effectiveness of concurrency control mechanisms.
- **Data Distribution:** Data partitioning and replication across multiple nodes increase the complexity of managing concurrency, as transactions may access distributed data concurrently.

- **Consistency Across Nodes:** Ensuring consistency and isolation level across distributed nodes requires coordination and agreement protocols, adding overhead to concurrency control mechanisms.
- **Fault Tolerance:** Distributed systems must handle failures gracefully, ensuring that concurrency control mechanism can recover from failures without compromising data integrity.

Q.7 (c) Solution:

(i) We have,

$$\text{Starting torque, } T_{st} = 1.25\, T_{fl} \quad (T_{fl} = \text{full load torque})$$

$$\text{Maximum torque, } T_{max} = 2.5\, T_{fl}$$

Thus, ratio of $\dfrac{T_{st}}{T_{max}} = \dfrac{1.25\, T_{fl}}{2.5 T_{fl}} = \dfrac{1}{2}$

and we have, $\dfrac{T_{st}}{T_{max}} = \dfrac{2s_{max}}{1+s_{max}^2} = 0.5$

$$2s_{max} = 0.5 + 0.5s_{max}^2$$

$$0.5s_{max}^2 - 2s_{max} + 0.5 = 0$$

$$s_{max} = 3.73, 0.27$$

Since, slip can't be more than 1. Hence, slip at maximum Torque is 0.27.

(ii) As, $T_{max} = 2.5T_{fl}$

We have, $\dfrac{T_{fl}}{T_{max}} = \dfrac{2}{\dfrac{s}{s_{max}} + \dfrac{s_{max}}{s}}$

$$\frac{2}{5} = \frac{2}{\dfrac{s}{0.27} + \dfrac{0.27}{s}}$$

$$\frac{2}{5} = \frac{2 \times 0.27s}{s^2 + (0.27)^2}$$

$$2.7s = 2s2 + 2(0.27)^2$$

$$2s^2 - 2.7s + 2(0.27)^2 = 0$$

$$s = 1.3, 0.06$$

Discard slip values greater than 1. Hence, slip at full load (s_{fl}) is 0.06.

(iii) Since rotor resistance and supply frequency is constant,

$$T \propto \frac{I_2^2}{s}$$

At starting, $s_{st} = 1$. Thus,

$$\frac{T_{st}}{T_{fl}} = 1.25 = \left(\frac{I_{st}}{I_{fl}}\right)^2 \times s_{fl}$$

$$\frac{I_{st}}{I_{fl}} = \sqrt{\frac{1.25}{s_{fl}}} = I_{Pu}$$

$$I_{st} = 4.56 \text{ p.u. of full-load current}$$

Q.8 (a) Solution:

(i) Speed at maximum torque = 980 rpm

$$N_s = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

Slip at maximum torque, $s_{\max} = \dfrac{1500 - 980}{1500} \approx 0.35$

We know that, $$s_{\max} = \frac{R_2}{X_2}$$

$$0.35 = \frac{0.2}{X_2}$$

$$X_2 = 0.57\ \Omega/\text{phase}$$

Now, $$\frac{T_{st}}{T_m} = \frac{2s_m}{1 + s_m^2}$$

$$0.75 = \frac{2s_m}{1 + s_m^2}$$

On solving, we get

$$s_m = 2.22, 0.45$$

As, slip can't be more than 1. Hence, $s_m = 0.45$

Let the total rotor resistance be R_2' to achieve $s_{\max} = 0.45$. We have,

$$s_{\max} = \frac{R_2'}{X_2}$$

$$0.45 = \frac{R_2'}{0.57}$$

$$R_2' = 0.45 \times 0.57$$
$$= 0.2565\ \Omega/\text{phase}$$

If the additional rotor resistance to be added is denoted by R_x', we have

$$R_2' = R_{ex}' + 0.2$$
$$R_{ex}' + 0.2 = 0.2565$$
$$R_{ex}' = 0.0565\ \Omega/\text{phase}$$
$$R_{ex}' = 56.5\ \text{m}\Omega/\text{phase}$$

(ii) The torque of an induction motor is given by

$$T = \frac{3}{\omega_s} \times \frac{sV_2^2 R_2}{R_2^2 + (sX_2)^2}$$

At starting, $s = 1$ and at maximum torque, $s = R_2/X_2$. For $T_{st} = 0.75T_{max}$, we have

$$T_{st} = 0.75\ T_{max} \text{ when } V_s = 360\text{ V}$$
$$\frac{3}{\omega_s} \times \frac{E_2'^2 R_2'}{R_2'^2 + X_2^2} = 0.75 \times \frac{3}{2\omega_s} \frac{E_2^2}{X_2}$$
$$\frac{3}{\omega_s} \times \frac{(360)^2 R_2'}{R_2'^2 + (0.057)^2} = 0.75 \times \frac{3}{2\omega_s} \times \frac{(400)^2}{0.057}$$
$$\frac{R_2'}{R_2'^2 + 0.3249} = 0.81$$
$$R_2' = 0.81R_2'^2 + 0.263$$
$$R_2' = 0.85\ \Omega,\ 0.38\ \Omega$$

For $R_2' = 0.85\,\Omega$, the slip at maximum torque becomes greater than 1, which is not possible. Hence, $R_2' = 0.38\ \Omega/\text{phase}$

The additional rotor resistance required, $R_{ex}' = 0.38 - 0.2 = 0.18\ \Omega/\text{phase}$

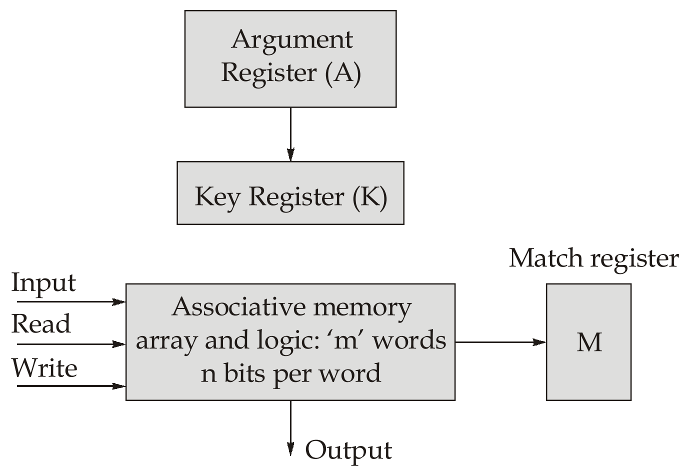
Q.8 (b) Solution:

(i) **Associative memory:** The time required to find an item stored in the memory can be reduced considerably if stored data can be identified for access by the content of data rather than the address. A memory unit accessed by the content or data is called associative memory or content addressable memory.

When a word is written in an associative memory, no address is given. The memory is capable of finding an empty unused location to store a word. When the word is to be read from an associative memory, the content of the word or a part of it is specified. The memory locates all word which match the specified content and mark them for reading.

Associative memory is suited to do parallel searches by data association. Moreover, searches can be done on an entire word or on specific field within a word. Associative memory is costlier, than Random access memory as each cell requires storage capability as well as logic circuit for matching its content with external argument. Associated memory are used where search time is critical and must be short.

The block diagram of associative memory is shown below. It consists of a memory array and logic for *m* words with *n* bits per word.

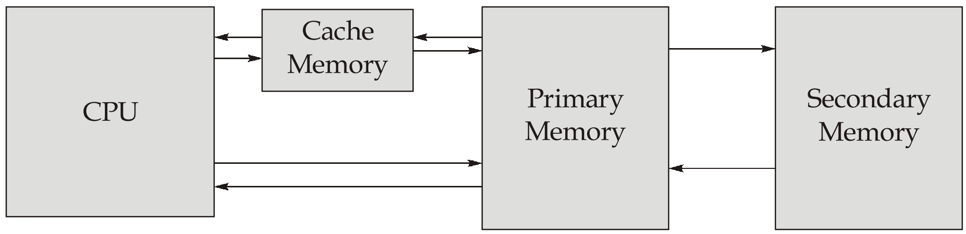


The argument register A and key register are of *n* bits. The match register has M bits each for one memory word. Each word in memory is compared in parallel with content of argument register. The words that match the bits of the argument register set a corresponding bit in the match register. After the matching, those bits in match register that have been set indicate the fact that their corresponding words have been matched.

Reading is accompanied by a sequential access to memory for those words whose corresponding bits in match register have been set.

The key register provides a mask for choosing a particular field or key in the argument word. The entire argument is compared with each memory word if the key register contains all 1's. Otherwise, only those bits in the argument that have 1's in their corresponding position of the key register are compared.

(ii) Cache memory: It has been observed that reference to memory at any given interval of time is confined within few localized area of memory. This property is called the locality of reference. If the active portions of a programme and data are placed in a fast small memory, the average access time can be reduced, thus reducing total time for execution of the programme. Such fast small memory is called cache memory. It is placed between CPU and main memory as shown below:



The cache memory access time is faster than that of main memory by a factor of 5 to 10. The cache is fastest component in memory hierarchy and approaches the speed of CPU components.

Although the cache is only a small fraction of the size of main memory, a large fraction of memory requests will be found in the fast cache memory. When a CPU needs to access memory, the cache is examined. If the word is found in the cache, it is read from the same and if it is not available in cache, then only main memory is accessed to read the word. A block of words containing the one just accessed is then transferred from main memory to cache memory. In this way, some data is transferred to cache for future references to memory.

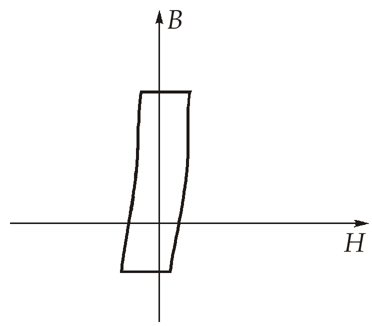
The performance of cache is measured in term of hit ratio. When a word is found in cache it is called hit else miss. The ratio of number of hits divided by total CPU references to memory is called hit ratio. The hit ratio is measured experimentally by running representative programmes in the computer and measuring the number of hits and misses during a given interval of time. Hit ratios of 0.9 and higher have been reported. The average access time is generally closer to access time of cache memory for higher hit ratio.

Q.8 (c) Solution:

The magnetic materials are divided into soft and hard magnetic materials based upon the shape of the hysteresis loop leading to different behavior in the presence of a magnetic field.

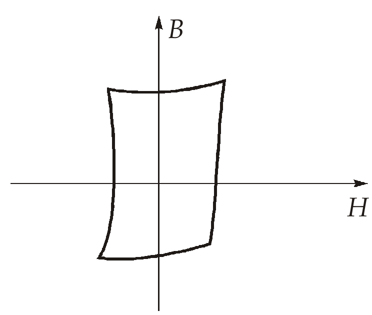
Soft magnetic materials:

If the loop is narrow, as shown in figure below, it is said to be a soft magnetic material. It shows that with a very small magnetic field, the specimen reaches saturation magnetization and with small coercive field, it can be demagnetized. From the relation between magnetization and field strength, we can state that the susceptibility must be large for a soft magnet. Soft magnets are extensively used as transformer cores, memory devices in computers, switching circuit, etc. as they are easy to magnetize and demagnetize. These soft magnetic materials are usually prepared with large ferromagnetic content. Examples include Hipernik (50% Fe, 50% Ni), permalloy (22.1 Fe/78% Ni) and superalloy 16% Fe/79% Ni). These have low hysteresis losses due to the narrow hysteresis loop.



Hard magnetic materials:

These are the materials which retain considerable amount of magnetic energy when magnetic field is removed and it is difficult to demagnetize these materials, once they get magnetized. The hysteresis loop of such materials is wide as shown below. These are characterized by a large coercive field. These are the permanent magnets used in the meters and ammeters, electron tubes, focusing magnets etc. The most important family of hard magnets are the dispersion hardered alloys of Al, Ni and Co, known as Alnico alloys.



Hard Magnetic Material	Soft Magnetic Materials
• Materials retain their magnetism and it is difficult to demagnetise the hard magnetic materials.	• Soft magnetic materials are easy to be magnetised and demagnetised.
• These materials retain their magnetism even after the removal of the applied magnetic field. Hence, these materials are used for making permanent magnets as the domain wall motion is prevented in these materials.	• These materials are suitable for making temporary magnets. These materials are easy to demagnetise as domain wall motion is easier in these materials.
• They are prepared by heating the materials to the required temperature and then quenching them. Impurities increase the strength of hard magnetic materials as domain walls can't move.	• Soft magnetic materials should not possess any void or impurites so that domain wall can move easily.
• These materials have large hysteresis losses.	• These materials have low hysteresis losses.
• Susceptibility and permeability are low.	• Susceptibility and permeability are high.
• Coercive force and retentivity are large.	• Coercive force and retentivity are less..
• Magnetic energy stored is high.	• Magnetic energy stored is very small
• These materials have high value of BH product.	• Magnetic energy stored is very small i.e. small BH product.
• The eddy current loss is high.	• The eddy current loss is small due to high resistivity.

