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Detailed Solutions

ESE-2023 Mains Test Series

E & T Engineering Test No : 6

Section A : Electromagnetics + Basic Electrical Engineering

Q.1 (a) Solution:

The satisfactory and successful operation of transformers connected in parallel on both sides requires that they fulfill the following conditions:

(i) Single-phase transformers:

1. The transformers must be connected properly as far as their polarity are concerned so that the net voltage around the loop is zero. A wrong polarity connection results in a dead short circuit.
2. The voltage ratings and the voltage ratio of the transformers should be same to avoid no-load circulating current as even a small voltage difference can give rise to considerable no-load circulating current and extra I^2R loss.
3. There should exist only a limited disparity in the per-unit impedances (on their own bases) of the transformers.
4. The ratio $\frac{X}{R}$ should be same for all the transformers to avoid operation at different power factors.

(ii) 3-phase transformers:

1. Three phase transformer must have zero relative phase displacement on the secondary sides and must be connected in a proper phase sequence.

2. Only the transformers of the same phase group can be paralleled. For example, Y/Y and Y/Δ transformer cannot be paralleled, as their secondary voltages will have a phase difference of 30°.

Q.1 (b) Solution:

For a lossless line:
$$L = 0.1\ \mu\text{H/m}$$
$$C = 160\ \text{pF/m}$$

The characteristic impedance $(z_0) = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.1\times10^{-6}}{160\times10^{-12}}} = 25\ \Omega$

$$\text{Phase velocity } (V_p) = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.1\times10^{-6}\times160\times10^{-12}}}$$
$$= 2.5\times10^{8}\ \text{m/s}$$

Now,
$$\lambda = \frac{V_p}{f} = \frac{2.5\times10^8}{10\times10^6} = 25\ \text{m}$$
$$\beta = \frac{2\pi}{\lambda} = \frac{2\pi}{25} = 0.25\ \text{rad/m}$$

We know,
$$z_{in}(l) = z_0\left[\frac{z_L + jz_0\tan\beta l}{z_0 + jz_L\tan\beta l}\right]$$

For open circuit;
$$z_L \to \infty$$
$$z_{oc}(l) = -jz_0\cot(\beta l) = \frac{-jz_0}{\tan\beta l} \qquad \text{...(1)}$$

$\because$
$$z_{oc} = -jX_C = \frac{-j}{\omega C} = \frac{-j}{2\pi f\cdot C} = \frac{-j}{2\pi\times10^7\times150\times10^{-12}}$$

Here, $C = 150$ pF

$$z_{oc}(l) = \frac{-j}{9.424\times10^{-3}} = -j106.11\ \Omega$$

From (1),
$$-j106.11 = \frac{-j25}{\tan\left(\frac{l}{4}\right)};\quad \beta l = 0.25l = \frac{l}{4}$$
$$\tan\left(\frac{l}{4}\right) = \frac{25}{106.11}$$
$$l = 4\tan^{-1}\left(\frac{25}{106.11}\right) = 0.925\ \text{m}$$

Q.1 (c) Solution:

Given data: VA ratings = 1500 kVA, V_t = 6.6 kV

$$R_a + jX_s = Z_s = 0.093 + j8.5\ \Omega$$

$$PF = 0.8 \text{ lag}$$

Now, Voltage regulation is given as

$$\%\ V\text{ Reg.} = \frac{E_f - V_t}{V_t} \times 100\%$$

For alternator, $$E_f = I_a Z_s + V_{ph} \quad \text{... (i)}$$

$$I_a = I_{ph} = \frac{1500 \times 10^3}{\sqrt{3} \times 6.6 \times 10^3} = 131.2A$$

From equation (i),

$$\therefore \quad E_{f/ph} = I_a Z_s + V_{ph}$$

$$= \left[131.2\angle -\cos^{-1}(0.8)\right] \times \left[0.093 + j8.5\right] + \frac{6.6 \times 10^3}{\sqrt{3}}$$

$$= 4575.76\ \angle 11.149°$$

$$\left|E_f\right| = 4575.76 \text{ Volt}$$

$$\therefore \quad \text{Voltage regulation} = \frac{4575.76 - \dfrac{6.6 \times 10^3}{\sqrt{3}}}{\left(\dfrac{6.6 \times 10^3}{\sqrt{3}}\right)}$$

$$\%\ \text{V. Reg} = 20.08\%$$

Q.1 (d) Solution:

The major characteristics of the sodium sulfur cell are:

1. High open circuit and operating voltage : 1.8-2.1 V
2. High specific energy : 200-300 Wh/kg
3. High energy density : 150 to 250 kWh/m^3
4. High power density or discharge rate : 1 to 3 hour rate.
5. Hermetically sealed construction.
6. No gas evolution.
7. Zero-self discharge or excellent charge retention.
8. High recharge efficiency, 85% at three hour rate.

9. Liquid reactants: No aging of active materials.
10. Potentially five to ten year life.

Limitations of the sodium-sulfur cell are:

1. Operating temperatures 300 - 400°C.
2. Possible aging of solid electrolyte deterioration of mechanical and electrical properties on cycling.
3. High reactive components safety consideration, corrosion.
4. No overcharge capability: Need for voltage control when charging.

Q.1 (e) Solution:

Stator copper losses = 2 kW, Core losses = 1800 W, Rotor copper losses = $P_{r(cu)}$ = 700 W, P_{fw} = 600 W

Now,
$$P_{input} = P_{in} = \sqrt{3}V_L I_L \cos\theta = 480 \times 60 \times 0.85 \times \sqrt{3}$$
$$= 42.4 \text{ kW}$$

(i)
$$P_{ag} = P_{in} - \text{Stator copper losses} - \text{Core losses}$$
$$= 42.4 - 2 - 1.8 = 38.6 \text{ kW}$$

(ii)
$$\text{Power converted} = P_{mech} = P_a - P_{rcu}$$
$$P_{mech} = 38.6 - 0.7 = 37.9 \text{ kW}$$

(iii)
$$\text{The output power} = P_{shaft} = P_{mech} - P_{fw}$$
$$= 37.9 - 0.6 = 37.3 \text{ kW}$$

(iv)
$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100 = \frac{37.3 \times 10^3}{42.4 \times 10^3} \times 100$$
$$= 87.9716\%$$

Q.2 (a) Solution:

Given data: S = 5 kVA, V_1 = 220 V, V_2 = 110 V,

η_{max} = 96.97% at 0.8 pf lag, core loss = 50 W = Iron loss = P_I, Full load regulation = 5% at 0.8 pf lag.

At maximum efficiency, copper loss is equal to iron loss. Let maximum efficiency is at 'x' times of full load.

$$\eta = \frac{x\,(\text{kVA})\cos\theta}{x\,(\text{kVA})\cos\theta + \text{Iron Loss} + \text{Copper Loss}}$$

$$\therefore \quad \eta_{max} = \frac{x \times 5 \times 10^3 \times 0.8}{x \times 5 \times 10^3 \times 0.8 + 2P_I} = 96.97\%$$

$$x \times 4 \times 10^3 = 0.9697\,[x \times 4 \times 10^3 + 100]$$

$$x = 0.8$$

$\therefore$ $x^2 W_{CuFL} = P_I$ at maximum efficiency, where W_{CuFL} is the full load copper loss

$$(0.8)^2 \times W_{CuFL} = 50$$

$$W_{CufL} = 78.125\ \text{W}$$

Now efficiency at full load at 0.9 pf lagging is given as

$$\%\eta = \frac{5\times10^3\times0.9}{5\times10^3\times0.9+50+78.125}\times100 = 97.232\%$$

Voltage Regulation:

$$\text{Full load regulation} = 5\% \text{ at } 0.8 \text{ pf lagging}$$

$$5\% = \%R\cos\theta + \%X\sin\theta$$

$$\frac{5}{100} = \%R \times 0.8 + \%X \times 0.6 \qquad \text{... (i)}$$

Also $$W_{CuFL} = I_2^2 R_{o2}$$

$$78.125 = \left(\frac{5\times10^3}{110}\right)^2 \times R_{o2}, \quad I_2 = \frac{5\times10^3}{110} = 45.45A$$

$$R_{o2} = 0.0378\ \Omega$$

Put in equation (i), $$\frac{5}{100} = \frac{I_2R_2}{E_2}\times0.8+\frac{I_2X_2}{E_2}\times0.6$$

$$\frac{5}{100} = \frac{45.45\times0.0378\times0.8}{110}+\frac{45.45\times0.6}{110}\times X_2$$

$$X_2 = 0.15128\ \Omega$$

Now voltage regulation at 0.9 pf is given as

$$\%\ \text{Voltage regulation} = \frac{45.45\times0.0378\times0.9+45.45\times0.15128\times0.44}{110}$$

$$= 4.15\%$$

Q.2 (b) Solution:

(i) For the given waveguide, $b > a$. So, TE_{01} is the dominant mode.

For TE_{mn} mode,

$$E_{zs} = 0,$$

$$E_{xs} = \frac{j\mu\omega H_0 n\pi}{h^2 b}\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)e^{-j\beta z},$$

$$E_{ys} = \frac{j\mu\omega H_0 m\pi}{h^2 a}\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)e^{-j\beta z}$$

For TE_{01} mode,

$$E_{ys} = E_{zs} = 0 \text{ and } E_{xs} = \frac{j\omega\mu H_0\pi}{h^2 b}\sin\left(\frac{\pi y}{b}\right)e^{-j\beta z}$$

$$h^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 = \left(\frac{\pi}{b}\right)^2 \quad \because \text{For } TE_{01},\ m = 0 \text{ and } n = 1$$

So,

$$E_{xs} = \frac{j\omega\mu b H_0}{\pi}\sin\left(\frac{\pi y}{b}\right)e^{-j\beta z} = jE_0\sin\left(\frac{\pi y}{b}\right)e^{-j\beta z}$$

The average power transmitted through the waveguide is,

$$P_{avg} = \int_{x=0}^{a}\int_{y=0}^{b}\frac{|E_{xs}|^2 + |E_{ys}|^2}{2\eta}dy\,dx = \frac{E_0^2}{2\eta}\int_{x=0}^{a}\int_{y=0}^{b}\sin^2\left(\frac{\pi y}{b}\right)dy\,dx$$

$$\frac{E_0^2 ab}{4\eta} = 2\text{ mW}$$

$$E_0^2 = \frac{2\times10^{-3}\times4\eta}{2\times10^{-2}\times4\times10^{-2}} = 10\eta$$

For TE_{01} mode,

$$\eta = \eta_{TE} = \frac{\eta_0}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

$$f_c = \frac{c}{2b} = \frac{3\times10^8}{2\times4\times10^{-2}} = 3.75\text{ GHz}$$

So,

$$\eta = \frac{120\pi}{\sqrt{1-\left(\frac{3.75}{10}\right)^2}} = 406.7\ \Omega$$

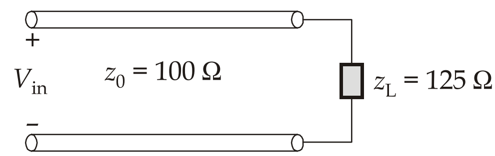
$$E_0 = \sqrt{10\times406.7} = 63.77\text{ V/m}$$

Hence,

$$H_0 = \frac{\pi E_0}{\omega\mu b} = \frac{\pi\times63.77}{2\pi\times10^{10}\times4\pi\times10^{-7}\times4\times10^{-2}} = 63.43\text{ mA/m}$$

So, the peak magnetic field in the waveguide is H_0 = 63.43 mA/m.

(ii) The reflection coefficient at load is given by;



$$\Gamma = \frac{z_L - z_0}{z_L + z_0} = \frac{125-100}{125+100} = \frac{1}{9}$$

We know; $$\text{VSWR} = \text{ISWR} = \text{SWR}$$

$$= \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+\frac{1}{9}}{1-\frac{1}{9}} = \frac{10}{8} = 1.25$$

Q.2 (c) Solution:

(i) From the positive sign in $(\omega x + \beta x)$, we infer that the wave is propagating along $-a_x$.

(ii) In free space, $v = c$;

$$\beta = \frac{\omega}{c} = \frac{10^8}{3\times 10^8} = \frac{1}{3}$$

$$\beta = 0.3333 \text{ rad/m}$$

If T is the period of the wave, it takes T seconds to travel a distance λ at speed c. Hence, to travel a distance of $\lambda/2$, it will take

$$t_1 = \frac{T}{2} = \frac{1}{2}\frac{2\pi}{\omega} = \frac{\pi}{10^8} = 31.42 \text{ ns}$$

(iii) At $t = 0$, $$E_y = 50 \cos \beta x$$

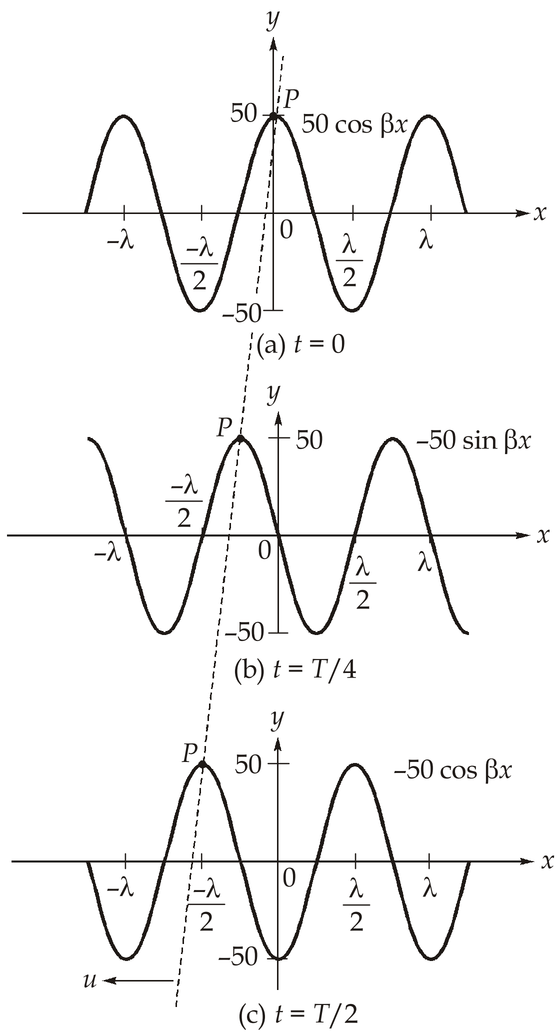
At $t = T/4$, $$E_y = 50\cos\left(\omega\cdot\frac{2\pi}{4\omega} + \beta x\right) = 50\cos(\beta x + \pi/2)$$

$$= -50 \sin \beta x$$

At $t = T/2$, $$E_y = 50\cos\left(\omega\cdot\frac{2\pi}{2\omega} + \beta x\right) = 50\cos(\beta x + \pi)$$

$$= -50 \cos \beta x$$

E_y at $t = 0, T/4, T/2$ is plotted against x as shown below. Notice that a point P (arbitrarily selected) on the wave moves along $-a_x$ as t increases with time. This shows that the wave travels along $-a_x$.



Q.3 (a) Solution:

(i) **1.** Radius of the disc $(r) = 0.2$ m

$$d = 0.06 \text{ m}$$

$$V = 25 \cos 10^4 t \text{ volts}$$

$$E = \frac{V}{d} = \frac{25\cos 10^4 t}{0.06} = 416.67 \cos 10^4 t \text{ V/m}$$

$$J_d(t) = \frac{\partial D(t)}{\partial t} = \varepsilon_0 \frac{\partial}{\partial t} E(t)$$

$$= -\varepsilon_0 \times 416.67 \times 10^4 \sin 10^4 t$$

$$= -3.68 \times 10^{-9} \times 10^4 \sin 10^4 t$$

$$J_d(t) = -36.84 \sin 10^4 t \ \mu\text{A/m}^2$$

$$I_d = J_d \times A$$

$$I_d = -36.84 \sin 10^4 t \times 10^{-6} \times \pi(0.2)^2$$

$$I_d = -4.63 \sin 10^4 t \ \mu A$$

$$|I_d|_{rms} = \frac{4.63}{\sqrt{2}} = 3.27 \ \mu A \qquad ...(1)$$

2. Capacitance, $C = \dfrac{\varepsilon_0 A}{d} = \dfrac{1}{36\pi} \times \dfrac{10^{-9} \times \pi \times (0.2)^2}{0.06}$

$$C = 1.852 \times 10^{-11} \text{ F}$$

$$I_c = C\frac{dV}{dt} = -1.852 \times 10^{-11} \times 25 \times 10^4 \sin 10^4 t$$

$$I_c = -4.63 \sin 10^4 t \ \mu A$$

$\therefore$ $$|I_c|_{rms} = 3.27 \text{ mA} \qquad ...(2)$$

from (1) and (2)

$$|I_d|_{rms} = |I_c|_{rms}$$

(ii) 1.

$$A \times B = \begin{vmatrix} a_x & a_y & a_z \\ 2 & 4 & 0 \\ 0 & 6 & -4 \end{vmatrix}$$

$$A \times B = -16a_x + 8a_y + 12a_z$$

$$|A| = \sqrt{4+16} = \sqrt{20} = 4.47$$

$$|B| = \sqrt{36+16} = \sqrt{52} = 7.21$$

$$|A \times B| = \sqrt{256+64+144} = 21.54$$

Then, since $|A \times B| = |A|\,|B| \sin\theta$

$$\sin\theta = \frac{21.54}{(4.47)(7.21)} = 0.668$$

$$\theta = 41.9°$$

2.

$$A \cdot B = (4)(6) + (0)(-4) = 24$$

$$\cos\theta = \frac{A \cdot B}{|A|\,|B|} = \frac{24}{(4.47)(7.21)}$$

$$\cos\theta = 0.745$$

$$\theta = 41.84°$$

Q.3 (b) Solution:

(i) The radiation efficiency of Hertzian dipole antenna,

$$\eta_{rad} = \frac{P_{rad}}{P_{in}} = \frac{P_{rad}}{P_{rad} + P_{loss}}$$

$$\therefore \quad \eta_{rad} = \frac{R_{rad}}{R_{rad} + R_L}$$

where, R_L is ohmic resistance

R_{rad} is radiation resistance

$$\text{skin depth, } \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \times 10^6 \times 4\pi \times 10^{-7} \times 57 \times 10^6}}$$

$$\therefore \quad \delta = 0.067 \text{ mm}$$

Since radius 'a' is much greater than skin depth, so the current may be assumed to be confined to a cylindrical shell of thickness δ.

$$\therefore \quad \text{Loss resistance, } R_L = \frac{1}{\sigma_c} \cdot \frac{L}{(2\pi a)\delta}$$

$$= \frac{1}{57 \times 10^6} \cdot \frac{2}{2\pi \times 10^{-3} \times 0.067 \times 10^{-3}}$$

$$\therefore \quad R_L = 0.084 \ \Omega$$

$$\text{Radiation resistance, } R_r = 80\pi^2 \left(\frac{L}{\lambda}\right)^2$$

$$= 80\pi^2 \left(\frac{Lf}{c}\right)^2 = 80\pi^2 \left(\frac{2 \times 10^6}{3 \times 10^8}\right)^2$$

$$R_r = 0.035 \ \Omega$$

$$\therefore \quad \eta_{rad} = \frac{0.035}{0.035 + 0.084} = 29.4\%$$

(ii) Given, $i = 100\angle 0° \text{ mA}$

Hence, $I_m = 100 \text{ mA} = 100 \times 10^{-3} \text{ A}$

$r = 100 \text{ m}$

Broadside plane means the maximum radiation for θ = 90°.

The magnitude of electric field $\vec{E}$ is

$$|E_0| = \frac{60 I_m}{r}\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right]$$

$$= \frac{60(100\times10^{-3})}{100}\left[\frac{\cos\left(\frac{\pi}{2}\cos 90^\circ\right)}{\sin 90^\circ}\right]$$

$$|\vec{E}| = 60 \text{ mV/m}$$

We know that, $$|\vec{H}| = \frac{|\vec{E}|}{\eta_0} = \frac{60\times10^{-3}}{120\pi} = 159.15\,\mu\text{ A/m}$$

For half wave dipole,

$$R_{\text{rad}} = 73\ \Omega$$

The average power, $$P_{\text{avg}} = R_{\text{rad}}\times I_{\text{rms}}^2$$

$$= 73\left(\frac{100\times10^{-3}}{\sqrt{2}}\right)^2$$

$$P_{\text{avg}} = 0.365 \text{ W}$$

Q.3 (c) Solution:

$$S_{3\phi} = \sqrt{3}V_L I_L$$

$$50\times10^3 = \sqrt{3}\times440\, I_L$$

Full load output current at u.p.f,

$$I_L = \frac{50\times10^3}{\sqrt{3}\times440} = 65.6 \text{ A} = I_a$$

Let V_p be taken as reference phasor,

$$V_p = \frac{440}{\sqrt{3}}\angle0^\circ = 254\angle0^\circ \text{ V}$$

At unity power factor, $$I_a = I_a\angle0^\circ = 65.6\angle0^\circ = 65.6 \text{ A}$$

(i) Leakage impedance, $$Z_L = R_a + jX_L = 0.25 + j0.5 = 0.559\angle63.4^\circ\Omega$$

Internal emf, $$E_{p\,\text{exc}} = V_p + I_a Z_L$$

$$= 254 + (65.6)(0.559\angle63.4^\circ)$$

$$E_{p\,exc} = 272.4 \angle 6.91° \text{ V}$$

Line value of internal emf,

$$E_{L\,exc} = \sqrt{3} \times 272.4 = 471.8 \text{ V}$$

(ii) Synchronous impedance,

$$Z_s = R_a + jX_s = 0.25 + j3.2$$
$$= 3.21 \angle 85.53° \ \Omega$$

No load emf E_a

$$E_{ap} = V_p + I_a Z_s$$
$$= 254 + [(65.6)(3.21 \angle 85.53°)]$$
$$= 342.37 \angle 37.83° \text{V}$$

Line value of no-load emf,

$$E_{aL} = \sqrt{3}\ E_{ap} = \sqrt{3} \times 324.37 = 593 \text{ V}$$

(iii) Voltage regulation $= \dfrac{E_{ap} - V_p}{V_p} = \dfrac{342.37 - 254}{254}$

$$= 0.3479 \text{ p.u.}$$
$$= 34.79\%$$

(iv)

$$X_S = X_L + X_{AR}$$
$$X_{AR} = X_S - X_L$$
$$= 3.2 - 0.5$$
$$= 2.7 \ \Omega$$

Q.4 (a) Solution:

We need to determine the loss tangent to be able to tell whether the medium is a lossy dielectric or a good conductor.

$$\frac{\sigma}{\omega\varepsilon} = \frac{3}{10^8 \times 1 \times \dfrac{10^{-9}}{36\pi}} = 3393 >> 1$$

showing that the medium may be regarded as a good conductor at the frequency of operation. Hence,

$$\alpha = \beta = \sqrt{\frac{\mu\omega\sigma}{2}} = \left[\frac{4\pi \times 10^{-7} \times 20(10^8)(3)}{2}\right]^{1/2} = 61.4$$

$$\alpha = 61.4 \text{ Np/m}, \quad \beta = 61.4 \text{ rad/m}$$

Also, $|\eta| = \sqrt{\frac{\mu\omega}{\sigma}} = \left[\frac{4\pi\times10^{-7}\times20(10^8)}{3}\right]^{1/2}$

$$= \sqrt{\frac{800\pi}{3}} = 28.94\ \Omega$$

$$\tan 2\theta_\eta = \frac{\sigma}{\omega\varepsilon} = 3393 \to \theta_\eta = 45° = \frac{\pi}{4}$$

Hence, $H = H_0 e^{-\alpha z}\sin\left(\omega t - \beta z - \frac{\pi}{4}\right) a_H$

where, $a_H = a_k \times a_E = a_z \times a_y = -a_x$

and $H_0 = \frac{E_0}{|\eta|} = 2\sqrt{\frac{3}{800\pi}} = 69.1\times10^{-3}$

Thus, $H = -69.1 e^{-61.4z}\sin\left(10^8 t - 61.4z - \frac{\pi}{4}\right) a_x$ mA/m

Q.4 (b) Solution:

(i) For half-wave dipole ($I_0 = I_{max}$), the radiation resistance, $R_{rad} = 73\ \Omega$

For transmitting antenna T_t,

$$\text{Current, } I_{01} = \sqrt{\frac{2P_{max}}{R_{rad}}} = \sqrt{\frac{2\times300}{73}}$$

$\therefore$ $I_{01} = 2.87$ A

At, $f = 300$ MHz,

$$\beta = \frac{2\pi}{\lambda} \text{ where, } \lambda = \frac{c}{f} = \frac{3\times10^8}{3\times10^8} = 1\text{ m}$$

$\therefore$ $\beta = 2\pi$

The far field at angle θ_1 is of magnitude,

$$|E(\theta_1)| = \frac{\eta\beta I_{01}}{4\pi r} h_e(\theta_1)$$

where, $h_e(\theta) = \frac{2}{\beta}\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$

$\therefore$ $|E(\theta_1)| = \frac{\eta I_{01}}{2\pi r}\frac{\cos\left(\frac{\pi}{2}\cos\theta_1\right)}{\sin\theta_1}$

The open-circuit voltage induced at antenna 2,

$$|V_{OC2}| = h_e(\theta_2)\,|E(\theta_1)|$$

$$= \frac{\eta I_{01}}{\beta\pi r}\frac{\cos\left(\frac{\pi}{2}\cos\theta_1\right)\cos\left(\frac{\pi}{2}\cos\theta_2\right)}{\sin\theta_1\sin\theta_2}$$

$$= \frac{377\times 2.87}{2\pi\times\pi\times 100}\times\frac{\cos\left(\frac{\pi}{2}\times\cos 60°\right)\cos\left(\frac{\pi}{2}\cos 90°\right)}{\sin 60°\cdot\sin 90°}$$

$$|V_{OC2}| = 0.45\text{ V}$$

(ii) The effective area of receiving antenna, T_r is

$$A_e(90°) = \frac{\eta}{4\cdot R_{rad}}|h_e(90°)|^2$$

$$h_e(90°) = \frac{2}{\beta}\times\frac{\cos\left(\frac{\pi}{2}\cos 90°\right)}{\sin 90°} = \frac{2}{\beta}$$

$$\therefore\quad A_e(90°) = \frac{120\pi}{4\times 73}\left(\frac{2}{2\pi}\right)^2 = 0.131\text{ m}^2$$

(iii) The available power at receiving antenna (T_r),

$$P_r = \frac{h_e(\theta_2)^2\left|E(\theta_1)^2\right|}{8\,R_{\text{rad}}}$$

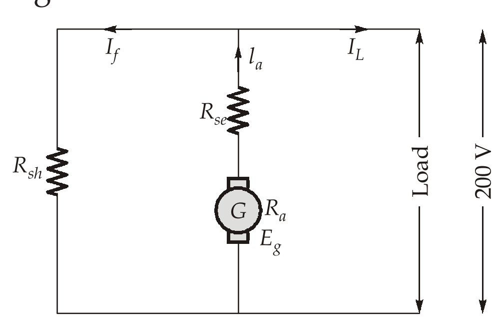
$$= \frac{|V_{OC2}|^2}{8\,R_{\text{rad}}} = \frac{(0.45)^2}{8\times 73}$$

$$\therefore\quad P_r = 344\ \mu\text{W}$$

Q.4 (c) Solution:

Given: V_t = 200 V, R_a = 0.6 Ω, R_{sh} = 150 Ω, R_{se} = 0.3 Ω, Load of 15 kW, 200 V.

(i) When connected as long shunt.



$$I_L = \frac{15 \times 1000}{200} = 75 \text{ A}$$

$$I_f = \frac{200}{R_{sh}} = \frac{200}{150} = 1.33 \text{ A}$$

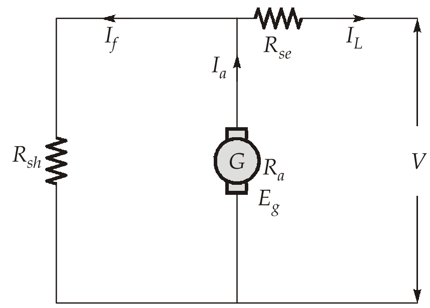
Armature current, $I_a = I_L + I_f = 75 + 1.33 = 76.33$ A

Generated emf, $E_g = I_a (R_a + R_{se}) + V$

$= 76.33 (0.6 + 0.3) + 200$

$= 268.7$ Volt

(ii) When connected as short shunt,



$$I_L = 75 \text{ A}$$

$$I_f = \frac{I_L R_{se} + V}{R_{sh}} = \frac{75 \times 0.3 + 200}{150} = 1.483 A$$

∴ Armature current, $I_a = I_f + I_L = 1.483 + 75$

$= 76.4833$ A

∴ Generated emf, $E_g = I_a R_a + R_{se} I_L + V$

$= 76.4833 \times 0.6 + 75 \times 0.3 + 200$

$= 268.39$ Volt

Section B : Computer Organization and Architecture-1 + Materials Science-1 + Electronic Devices & Circuits-2 + Advanced Communications Topics-2

Q.5 (a) Solution:

Given, $T = 600°C = (600 + 273) = 873$ K

Energy required to form Schottky defect,

$Q_s = 3.6$ eV

Density $\rho = 4.955$ g/cm^3

Atomic weight for potassium,

$A_K = 39.10$ g/mol

Atomic weight for chlorine,

$$A_{cl} = 35.45 \text{ g/mol}$$

The number of lattice sites per cubic meter is given as

$$N = \frac{N_A \rho}{A_K + A_{cl}} \qquad \text{where } N_A = \text{Avagadro's number}$$

$$= 6.023 \times 10^{23} \text{ atoms/mol}$$

$$N = \frac{(6.023\times10^{23}\text{atoms/mol})(4.955\text{ g/cm}^3)(10^6\text{cm}^3/\text{m}^3)}{(39.10\text{ g/mol})+(35.45\text{ g/mol})}$$

$$N = 4 \times 10^{28} \text{ lattice sites/m}^3$$

∴ Now, the number of Schottky defects per cubic meter is given as,

$$N_s = N\exp\left(\frac{-Q_s}{2\text{ kT}}\right)$$

$$N_s = (4 \times 10^{28} \text{ lattice sites/m}^3) \exp\left[\frac{-3.6\ eV}{(2)(8.62\times10^{-5}\text{eV/K})(873\text{ K})}\right]$$

$$N_s = 1.64 \times 10^{18} \text{ defects/m}^3$$

Q.5 (b) Solution:

Given, Memory unit = 512 K words

$$= 2^9 \times 2^{10} = 2^{19} \text{ words}$$

(i) An instruction code is stored in one word of memory.

∴ Instruction size = 32 bits

The instruction has 4 field.

Indirect bit	Opcode	Register code	Address

|← 32 bits →|

There are 64 registers.

∴ Bits required to specify one register = $\log_2 64$ = 6 bits

For address part, bits required = $\log_2(2^{19})$ = 19 bits

For indirect bit, 1 bit is required

∴ Bits required for opcode part = 32 – 1 – 19 – 6

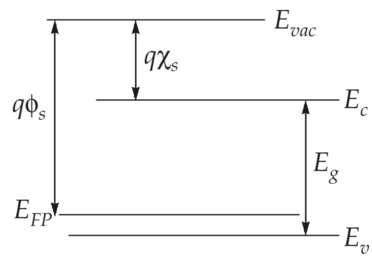
= 6 bits for opcode.

(ii) For register code part, bits required = 6 bits.

For address part, bits required = 19 bits

Q.5 (c) Solution:

(i) For p-type silicon:



$$q\phi_s = q\chi_s + E_g - (E_{FP} - E_v)$$

$$q\phi_s = 4.05 + 1.12 - kT\ln\left(\frac{N_v}{p}\right)$$

$$q\phi_s = 5.17 - 0.0258\ln\left(\frac{1.04\times10^{19}}{10^{17}}\right) \quad ....p \approx N_a$$

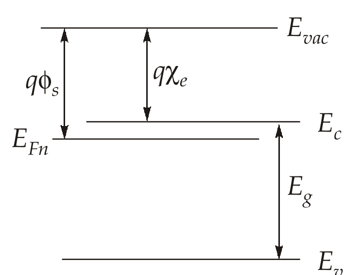
$$= 5.05 \text{ eV}$$

Now, $E_{Vac}(-t_{ox}) - E_{Vac}(\infty) = q\phi_m - q\phi_s$

$$= 4.1 - 5.05$$

$$= -0.95 \text{ eV}$$

(ii) For n-type silicon:



$$q\phi_s = q\chi_e + (E_c - E_{Fn})$$

$$q\phi_s = 4.05 + kT\ln\left(\frac{N_c}{n}\right)$$

$$q\phi_s = 4.05 + 0.0258\ln\left(\frac{2.8\times10^{19}}{5\times10^{15}}\right) \quad ....n \approx N_d$$

$$= 4.27 \text{ eV}$$

Now, $E_{Vac}(-t_{ox}) - E_{Vac}(\infty) = q\phi_m - q\phi_s$

$$= 4.1 - 4.27$$

$$= -0.17 \text{ eV}$$

Q.5 (d) Solution:

We know;

$$f_{\text{muf}} = f_c\sqrt{1+\left(\frac{D}{2h}\right)^2}$$

From secant law, $f_{\text{muf}} = f_c \sec\theta_i$

$$f_c \sec\theta_i = f_c\sqrt{1+\left(\frac{D}{2h}\right)^2}$$

$$\sec 45° = \sqrt{1+\left(\frac{D}{2h}\right)^2}$$

$$\sqrt{2} = \sqrt{1+\left(\frac{D}{2h}\right)^2}$$

$$2 = 1+\left(\frac{D}{2h}\right)^2$$

$$1 = \left(\frac{D}{2h}\right)^2$$

$$\frac{D}{2h} = 1$$

$$D = 2h = 200 \text{ km}$$

Q.5 (e) Solution:

Linear Scattering Losses: Linear scattering mechanisms cause the transfer of some or all of the optical power contained within one propagating mode to be transferred linearly (proportionally to the mode power) into a different mode. This process tends to result in attenuation of the transmitted light as the transfer may be to a leaky or radiation mode which does not continue to propagate within the fiber core, but is radiated from the fiber. It must be noted that as with all linear processes, there is no change of frequency on scattering.

Linear scattering may be categorized into two major types:

(a) Rayleigh scattering

(b) Mie scattering

Both result from the nonideal physical properties of the manufactured fiber which are difficult and, in certain cases, impossible to eradicate at present.

(a) Rayleigh Scattering: Rayleigh scattering is the dominant intrinsic loss mechanism in the low-absorption window between the ultraviolet and infrared absorption tails.

It results from inhomogeneities of a random nature occurring on a small scale compared with the wavelength of the light. These inhomogeneities manifest themselves as refractive index fluctuations and arise from density and compositional variations which are frozen into the glass lattice on cooling. The compositional variations may be reduced by improved fabrication, but the index fluctuations caused by the freezing-in of density inhomogeneities are fundamental and cannot be avoided.

(b) **Mie Scattering:** Linear scattering may also occur at inhomogeneities which are comparable in size with the guided wavelength. These result from the nonperfect cylindrical structure of the waveguide and may be caused by fiber imperfections such as irregularities in the core-cladding interface, core-cladding refractive index differences along the fiber length, diameter fluctuations, strains and bubbles. When the scattering inhomogeneity size is greater than $\lambda/10$, the scattered intensity which has an angular dependence can be very large.

The scattering created by such inhomogeneities is mainly in the forward direction and is called Mie scattering. Depending upon the fiber material, design and manufacture, Mie scattering can cause significant losses. The inhomogeneities may be reduced by:

(i) Removing imperfections due to the glass manufacturing process;

(ii) Carefully controlled extrusion and coating of the fiber;

(iii) Increasing the fiber guidance by increasing the relative refractive index difference.

By these means it is possible to reduce Mie scattering to insignificant levels.

Q.6 (a) Solution:

(i) The $I_D - V_{DS}$ plot shows that for the gate voltage applied, the MOSFET saturates at a V_{DS} of 5 V.

We know that, $$V_{DS,\,sat} = V_{GS} - V_T$$

$$\therefore \quad V_{GS} = V_{DS,\,sat} + V_T$$

$$= 5 + 1$$

$$\therefore \quad V_{GS} = 6 \text{ V}$$

(ii) At near the origin,

$$\text{drain current, } i_D = K\left(V_{GS} - V_T - \frac{V_{DS}}{2}\right)V_{DS}$$

and the slope of the given characteristics is $K(V_{GS} - V_T - V_{DS})$

$$\therefore \quad \left.\frac{\partial I_D}{\partial V_{DS}}\right|_{V_{DS}=0} = K(V_{GS} - V_T) = K \cdot V_{DS,\,sat}$$

where, $(V_{GS} - V_T) = 5\text{ V}$

from the given I_D V_S V_{DS} plot,

$$I_{D,\,sat} = 10\text{ mA at } V_{DS,\,sat} = 5\text{ V}$$

$$\therefore \quad 10 \times 10^{-3} = \frac{K}{2}(V_{GS} - V_T)^2 = \frac{K}{2}(V_{DS,\,sat})^2$$

$$K = \frac{2 \times 10 \times 10^{-3}}{(V_{DS,\,sat})^2} = \frac{2 \times 0.01}{25}$$

$$\therefore \quad K = 0.0008\text{ A/V}^2$$

$$\therefore \quad \text{The slope, } KV_{DS,\,sat} = 0.0008 \times 5 = 4 \times 10^{-3}\text{ S}$$

(iii) At any point in the channel,

the inversion charge,

$$Q_{inv}(x) = -C_{ox}(V_{GS} - V_T - V_x)$$

where, $C_{ox} = \dfrac{\in_{ox}}{t_{ox}}$ and $0 < V_x < V_{DS}$

1. At the source end $(x = 0)$, $V_x = 0$

$$Q_{inv}(0) = \frac{-\in_{ox}}{t_{ox}}(V_{GS} - V_T) = -\left(\frac{3.5 \times 10^{-13}}{10^{-6}}\right)(5)$$

$$= -1.75 \times 10^{-6}\text{ C/cm}^2$$

2. At the drain end $(x = L)$, $V_x = V_{DS} = 2.5\text{ V}$

$$Q_{inv}(x = L) = \frac{-\in_{ox}}{t_{ox}}(V_{GS} - V_{DS} - V_T)$$

$$= -\left(\frac{3.5 \times 10^{-13}}{10^{-6}}\right)(5 - 2.5)$$

$$= -8.75 \times 10^{-7}\text{ C/cm}^2$$

Q.6 (b) Solution:

(i) Given mean speed of conduction electron $u = 3.89 \times 10^8$ cms^{-1}. If τ is the mean scattering time, l is the mean free path then,

$$l = u\tau$$

$$\text{Drift mobility, } \mu_d = \frac{q\tau}{m_e}; \ (m_e = \text{mass of electron})$$

$$\tau = \frac{\mu_d m_e}{q} = \frac{(8\times10^{-4})(9.1\times10^{-31})}{(1.6\times10^{-19})}$$

$$\tau = 4.55 \times 10^{-15} \text{ sec}$$

$$l = u\tau = 3.89 \times 10^{8} \times 10^{-2} \times 4.55 \times 10^{-15}$$

$$l = 17.69 \text{ nm}$$

(ii) According to Wiedemann – Franz – Lorentz law,

Thermal conductivity, $K = \sigma L T$

where L = Lorentz number (or) Wiedemann-Franz-Lorentz coefficient

$$L = \frac{\pi^2 K_B^2}{3q^2} = \frac{\pi^2 \times (1.381\times10^{-23})^2}{3\times(1.6\times10^{-19})^2}$$

$$L = 2.45 \times 10^{-8} \text{ W}\Omega\text{K}^{-2}$$

So, $$K = \frac{300\times2.45\times10^{-8}}{9.21\times10^{-8}}$$

$$K = 79.81 \text{ Wm}^{-1}\text{ K}^{-1}$$

(iii) $\sigma = nq\mu_d$

Concentration of conduction electrons,

$$n = \frac{\sigma}{q\mu_d}$$

$$n = \frac{1}{9.21\times10^{-8}\times1.6\times10^{-19}\times8\times100}$$

$$n = 8.483 \times 10^{22} \text{ cm}^{-3}$$

Atomic concentration $n_{at} = \dfrac{N_A\rho}{A_{\text{In}}}$

where ρ = Density; A_{In} = Atomic mass of Indium

$$n_{at} = \frac{6.023\times10^{23}\times9.22}{204.84}$$

$$n_{at} = 2.71 \times 10^{22} \text{ cm}^{-3}$$

Effective number of conduction electrons donated per In atom (n_{eff}) is,

$$n_{\text{eff}} = \frac{n}{n_{at}} = \frac{8.483\times10^{22}}{2.71\times10^{22}} = 3.13 \approx 3$$

Q.6 (c) Solution:

(i) We have;

$$\text{Noise figure } (F) = 6 \text{ dB} = 10^{0.6} \cong 4$$

$$\text{Receiving Antenna Gain} = 6\left(\frac{D}{\lambda}\right)^2 \text{ ; } D = \text{diameter}$$

$$G = 6\left(\frac{D.f}{c}\right)^2 \text{ ; } c = \text{speed of light}$$

$$= 6\left(\frac{20 \times 4 \times 10^9}{3 \times 10^8}\right)^2 \text{ ; for C-band } f_{\text{downlink}} = 4 \text{ GHz}$$

$$G = 426666.66$$

$$= 56.3 \text{ dB}$$

Now; $$\text{Effective temp } (T_e) = T_0(F - 1)$$

$$T_0 = \text{ambient temperature}$$

$$= 290 \text{ K}$$

$\therefore$ $$T_e = 290\,(4 - 1)$$

$$= 870 \text{ K}$$

Therefore, figure of merit of earth station

$$= \frac{G}{T} = \frac{426666.66}{870} = 490.42 = 26.91 \text{ dB}$$

(ii) $$\text{Apogee } (r_a) = a(1 + e)$$

$$= 42200(1 + 0.3)$$

$$= 54860 \text{ Km}$$

$$\text{Perigee } (r_p) = a(1 - e)$$

$$= 42200(1 - 0.3)$$

$$= 29540 \text{ Km}$$

$\therefore$ $$\frac{r_a}{r_p} = \frac{54860}{29540} = 1.85$$

Q.7 (a) Solution:

(i) **Booting of OS:** Hardware does not know where the operating system resides and how to load it. Hence, it needs a special program to do this job i.e., Boot strap loader.

Exp: BIOS [Basic Input Output System]

Bootstrap loader locates the kernel, loads it into main memory and starts its execution. In some systems, a simple bootstrap loader fetches a more complex boot program from disk, which in turn loads the kernel.

Booting sequence: There is a standard boot sequence that all personal computer use.

1. The CPU runs an instruction in memory for the BIOS. This instruction contains a jump instruction that transfers to the BIOS start up program.
2. This program runs a power on self test (POST) to check that devices the computer will rely on are functioning properly.
3. The BIOS goes through the configured boot sequence until it finds a device that is bootable.
4. Once BIOS finds a bootable device, BIOS loads the boot sector and transfer execution to the boot sector. If the boot device is a hard drive, it is referred to as Master boot record (MBR).
5. The MBR code checks the partition table for active partition. If one is found, the MBR code loads that partition's boot sector and executes it.
6. The boot sector is often operating system specific, however in most operating system its main function is to load and execute the operating system kernel, which continues startup.
7. If there is no active partition or the active partition's boot sector is invalid, the MBR may load a secondary boot loader which will select a partition and load its boot sector, which usually loads the operating system kernel.

(ii) Comparison among Scheduler:

Long Term Scheduler	Short Term Scheduler	Medium Term Scheduler
1. It is a job scheduler.	It is a CPU scheduler.	It is a process swapping scheduler.
2. Speed is lesser than short term scheduler.	Speed is fastest than the other two.	Speed is in between long and short term scheduler.
3. Controls degree of multiprogramming.	It provides lesser control over degree of multi-programming.	It reduces the degree of multi-programming
4. It is almost absent or minimal in time sharing system.	It is also minimal in time sharing system.	It is a part of time sharing systems.
5. It selects processes from pool and loads them into memory for execution.	It selects processes which are ready to execute.	It can swap-out and re-introduce the processes into memory and execution can be continued.

Q.7 (b) Solution:

(i) For $V_D = 0.2$ V, $I_D - V_D$ curve is in the linear regime,

1. Therefore at $V_G = 4$ V; $V_D = 0.2$ V (given); $I_D = 0.35$ mA

$$\text{drain current, } I_D = K_n\left[(V_G - V_T)V_D - \frac{V_D^2}{2}\right]$$

$$0.35 \times 10^{-3} = K_n\left[(4 - V_T)(0.2) - \frac{(0.2)^2}{2}\right]$$

$$0.35 \times 10^{-3} = K_n[0.8 - 0.2\,V_T - 0.02]$$

$$0.35 \times 10^{-3} \simeq K_n[0.8 - 0.2V_T] \quad \text{...(i)}$$

2. At $V_G = 5$ V; $V_D = 0.2$ (given), $I_D = 0.75$ mA

$$\text{drain current } I_D = K_n\left[(V_G - V_T)V_D - \frac{V_D^2}{2}\right]$$

$$0.75 \times 10^{-3} = K_n\left[(5 - V_T)0.2 - \frac{(0.2)^2}{2}\right]$$

$$0.75 \times 10^{-3} \simeq K_n[1 - 0.2V_T] \quad \text{...(ii)}$$

From equation (i) and (ii),

$$0.35 \times 10^{-3} = K_n[0.8 - 0.2V_T]$$

$$0.75 \times 10^{-3} = K_n[1 - 0.2\,V_T]$$

$$K_n[1 - 0.8] = 0.4 \times 10^{-3}$$

$$\therefore \quad K_n = \frac{0.4 \times 10^{-3}}{0.2} = 2 \times 10^{-3}\,\text{A/V}^2$$

From equation (i),

$$0.35 \times 10^{-3} = 2 \times 10^{-3}[0.8 - 0.2\,V_T]$$

$$\therefore \quad V_T = 3.125\text{ V}$$

(ii) For $V_D = 3$ V, $I_D - V_D$ curve is in the saturation regime,

1. At $V_G = 4$ V; $V_D = 3$ V, $I_D = 0.5$ mA

$$\text{drain current, } I_D = K_n\left[\frac{(V_G - V_T)^2}{2}\right]$$

$$0.5 \times 10^{-3} = K_n\left[\frac{(4 - V_T)^2}{2}\right]$$

$$1 \times 10^{-3} = K_n[(4 - V_T)^2] \quad \text{...(iii)}$$

2. At $V_G = 5$ V; $V_D = 3$ V, $I_D = 1.5$ mA

drain current, $I_D = K_n\left[\frac{(V_G - V_T)^2}{2}\right]$

$$1.5 \times 10^{-3} = K_n\left[\frac{(5 - V_T)^2}{2}\right]$$

$$3 \times 10^{-3} = K_n[5 - V_T)^2] \qquad \text{...(iv)}$$

From equation (iii) and (iv),

$$\frac{3\times10^{-3}}{1\times10^{-3}} = \frac{(5-V_T)^2}{(4-V_T)^2}$$

$$\Rightarrow \quad 1.73(4 - V_T) = 5 - V_T$$

$$\Rightarrow \quad 0.73V_T = 1.92$$

$$\Rightarrow \quad V_T = 2.63 \text{ V}$$

Substituting in equation (iii),

$$K_n = \frac{1\times10^{-3}}{(4-2.63)^2} = 0.53\times10^{-3}\,\text{A/V}^2$$

Q.7 (c) Solution:

(i)

P_{id}	AT	BT	CT	$TAT = CT - AT$	$WT = TAT - BT$
P_1	1	2	18	17	15
P_2	2	4	19	17	13
P_3	3	6	20	17	11
P_4	4	8	21	17	9

Gantt Chart:

		P_1	P_2	P_3	P_4	P_4	P_4	P_3	P_4	P_3	P_4	P_2	P_3	P_4	P_2	P_3	P_4	P_1	P_2	P_3	P_4
Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20, 21

$\therefore$ Average waiting time, $T_{avg} = \frac{15+13+11+9}{4}$

$$T_{avg} = 12 \text{ ns}$$

$\therefore$ Average turnaround time, $T_{avg} = \frac{17+17+17+17}{4}$

$$T_{avg} = 17 \text{ ns}$$

(ii)

P_{id}	AT	BT	CT	$TAT = CT - AT$	$WT = TAT - BT$
P_1	0	4	4	4	0
P_2	1	5	16	15	10
P_3	2	1	5	3	2
P_4	3	2	18	15	13
P_5	4	3	21	17	14
P_6	5	6	11	6	0

Gantt Chart:

P_1	P_3	P_6	P_2	P_4	P_5

0 4 5 11 16 18 21

$\therefore$ Average turnaround time, $T_{avg} = \dfrac{4+15+3+15+17+6}{6} = 10$ ns

$\therefore$ Average waiting time, $T_{avg} = \dfrac{0+10+2+13+14+0}{6} = \dfrac{39}{6} = 6.5$ ns

Q.8 (a) Solution:

(i) 1. Dielectric Constant:

- It is defined as the ratio of the capacitance of a dielectric compared to the capacitance of air under the same conditions.
- A low dielectric constant contributes to low power loss and low loss factor and a high dielectric constant permits small physical size.
- By combining capacitor dielectrics having different temperature coefficient it is possible to reduce effect of the temperature change.
- Capacitance of a capacitor is directly proportional to the dielectric constant of the dielectric material used in the capacitor.
- Dielectric ceramic are used for manufacturing capacitor, insulators and resistors.

2. Dielectric Strength:

- It is defined as the ability of a material to withstand electrical breakdown at high voltage.
- Dielectric strength is determined as value of electric field strength (expressed in V/m) at which electrical breakdown occurs.
- The specific values of dielectric strength vary from 100 V per mil for low-tension electrical porcelain to 500 V per mil for some special bodies.
- Rutile bodies show higher breakdown strength at higher frequencies.

3. **Volume and Surface Resistivity:**

- The volume resistivity, also known as electrical resistivity or specific electrical resistance, is the measurement of how strongly a material can resist an electric current.
- A material with high volume resistivity is an electrical insulator, and a material with low or no volume resistivity is designated as an electrical conductor.
- A volume resistivity of 10^6 ohms/cm^3 is considered as the lower limit for an insulating material.
- At room temperature, practically all ceramic materials exceeds this lower limit.
- As the temperature of ceramic material is raised, the volume resistivity decreases; the volume resistivity of soda-lime glasses decreases rapidly with temperature, whereas some special bodies are good insulators.
- Surface resistivity for dry, clean surface is 10^{12} ohms/cm^2. At 98% humidity, the surface resistivity may be 10^{11} ohms/cm^2 for a glazed piece or 10^9 ohms/cm^2 for an unglazed piece.
- The presence of dissolved gases and other deposits also tends to decrease the surface resistivity of ceramic material.

(ii) Defects are imperfections which cause disruptions in what otherwise would be a perfect lattice.

Point defects (0-D): An atom is missing or is in an irregular position in the lattice.

- **Vacancy defect:** Absence of an atom in a lattice point where there is supposed to be an atom. It occurs when atoms are removed from their lattice positions (typically to the surface) as a result of thermal fluctuations. It is also known as Schottky defect.
- **Substitutional defect:** When an atom in the lattice is replaced by different atoms, which is not the same size as the other atoms, it causes distortions in the lattice.
- **Interstitial defect:** Atom located in a 'void' (i.e., a position that is not part of the lattice or basis) within the crystal structure.
- **Frenkel defect:** A Frenkel defect is another form of a point defect or an vacancy - interstitial pair which is created when an atom or cation leaves its original place in the lattice structure to create a vacancy while occupying another interstitial position within the solid crystal.

Line defects (1-D): When defect in crystal is centered around a line or the lattice distortion is centered around a line then the type of defect generated is called line defect. Line defects are called dislocations.

- **Dislocation:** Boundary between two regions of a surface which are perfect themselves but are out of registry with each other. The resulting lattice distortion is centered along a line.

  The Line imperfections (Dislocations) in a 2-D lattice are of following types:

  1. **Edge dislocation:** Burger vectors and normal vectors along the dislocation line are perpendicular.
  2. **Screw dislocation:** Burger vectors and normal vectors along the dislocation line are parallel.
  3. **Mixed dislocation:** Burgers vector is at some acute angle to the dislocation line.

  Note: A vector by which the lattice on one side of an internal surface containing the dislocation line is displaced (moved) relative to the lattice on the other side is known as the Burgers vector.

Q.8 (b) Solution:

(i) For a solar cell,

short circuit current, $I_{sc} = I_{op}$

$\therefore$ $I_{sc} = I_{op} = qA\, g_{op} (L_p + L_n + W)$

where, g_{op} = optical generation rate = 10^{18} EHP/cm^{3}s

$W = 1\ \mu\text{m}$

$L_n = L_p = 2\ \mu\text{m}$

$\therefore$ $I_{sc} = I_{op} = 1.6 \times 10^{-19} \times 4 \times 10^{18} (2 + 2 + 1)$

$= 0.32$ mA

Open circuit voltage, $$V_{OC} = \frac{kT}{q}\ln\left[1+\frac{I_{op}}{I_{th}}\right] = 0.0259\ln\left[1+\frac{0.32\ mA}{32\times nA}\right]$$

$V_{OC} = 0.24$ V

(ii) For a MOS transistor,

the threshold voltage,

$$V_T = \phi_{ms} - \frac{Q_f}{C_{ox}} + 2\phi_f + \frac{2\sqrt{\in_s qN_A\phi_f}}{C_{ox}}$$

where, $C_{ox} = \dfrac{\in_{ox}}{t_{ox}}$

given, $\phi_{ms} = -0.98$ V

$Q_f = 10^{11} \times q$ C-cm^{-2}

$\phi_f = kT\ln\left(\dfrac{N_A}{n_i}\right)$

$\therefore$ $\phi_f = 0.026\ln\left(\dfrac{10^{17}}{9.65\times10^9}\right) = 0.42$ V

$$V_T = -0.98 - \frac{1.6\times10^{-19}\times10^{11}}{C_{ox}} + 0.84 + \frac{2\sqrt{11.9\times\in_0\times10^{17}\times0.42\times1.6\times10^{-19}}}{C_{ox}}$$

$$V_T = -0.14 + \frac{15.2\times10^{-8}}{C_{ox}}$$

but, $C_{ox} = \dfrac{\in_{ox}}{t_{ox}} = \dfrac{3.9\times8.85\times10^{-14}}{t_{ox}}$

$= \dfrac{3.45\times10^{-13}}{t_{ox}}$

For sufficient isolation,

$$V_T > 20 \Rightarrow \frac{t_{ox}\times15.2\times10^{-8}}{3.45\times10^{-13}} > 20.14$$

$\therefore$ $t_{ox} > \dfrac{20.14\times3.45\times10^{-13}}{15.2\times10^{-8}}$

$t_{ox} > 45.7\ \mu$ cm

(or) $t_{ox} > 0.457\ \mu$m

Q.8 (c) Solution:

(i) The overall signal attenuation in decibels through the fiber is:

$$\text{signal attenuation} = 10\log_{10}\frac{P_i}{P_0} = 10\log_{10}\frac{120\times10^{-6}}{3\times10^{-6}}$$

$= 16$ dB

(ii) The signal attenuation per kilometer for the fiber is

$$\alpha_{dB}L = 16$$

$$\alpha_{dB} = \frac{16}{L} = \frac{16}{8} = 2\text{ dB km}^{-1}$$

(iii) As $\alpha_{dB} = 2$ dB km^{-1}, the loss incurred along 10 km of the fiber is given by;

$$\alpha_{dB}L = 2 \times 10 = 20 \text{ dB}$$

However, the link also has nine splices (at 1 km intervals) each with an attenuation of 1 dB. Therefore, the loss due to the splices is 9 dB.

Hence, the overall signal attenuation for the link is:

$$\text{signal attenuation} = 20 + 9$$

$$\alpha_T = 29 \text{ dB}$$

(iv) To obtain a numerical value for the input/output power ratio:

$$\frac{P_i}{P_0} = \alpha_T = 10^{2.9} = 794.3$$

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