MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electronics & Telecommunication Engineering

Test-6 : Electromagnetics + Basic Electrical Engineering [All topics]

Computer Organization and Architecture-1 + Materials Science-1 [Part Syllabus]

Electronic Devices & Circuits-2 + Advanced Communications-2 [Part Syllabus]

Name : ....

Roll No :

Test Centres

Delhi ☑ Bhopal ☐ Jaipur ☐

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Student's Signature

Instructions for Candidates

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

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	8
Q.2	38
Q.3	40
Q.4	
Section-B	
Q.5	33
Q.6	23
Q.7	
Q.8	
Total Marks Obtained	142

Signature of Evaluator ....

Cross Checked by ....

• Dear students, brush up your notes,

• Your accuracy is good.

IMPORTANT INSTRUCTIONS

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

DONT'S

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

DO'S

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

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Section A : Electromagnetics + Basic Electrical Engineering

Q.1 (a) An L-band pulse radar with a common transmitting and receiving antenna having a directive gain of 2500 operates at 1300 MHz and transmits 150 kW. If the object is 100 km from the radar and its scattering cross section is 6 m^2, find:

(i) The magnitude of the incident electric field intensity at the object.

(ii) The magnitude of scattered electric field intensity at the radar.

(iii) The amount of power captured by the object.

(iv) The power absorbed by the antenna from the scattered wave.

[12 marks]

Q.1 (b) What are the methods of starting of synchronous motors?

[12 marks]

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Q.1 (c) A rectangular waveguide with $a = 2b = 2.4$ cm is filled with teflon ($\varepsilon_r = 2.11$, loss tangent of 3×10^{-4}). Assume that the walls of the waveguide are coated with gold ($\sigma_c = 4.1 \times 10^7$ S/m) and that a TE_{10} wave at 5 GHz propagates down the waveguide. Find :

(i) Dielectric attenuation coefficient, α_d.

(ii) Conductor attenuation coefficient, α_c.

[12 marks]

$a = 2.4 > b$

$$f_c\big|_{TE_{10}} = \frac{\frac{c}{\sqrt{\varepsilon_r}}}{2a} = \frac{3 \times 10^{10}}{\sqrt{2.11} \times 2 \times 2.4}$$

$$\boxed{f_c\big|_{TE_{10}} = 4.3 \text{ GHz}}$$

$$\alpha = \beta_{TEM} \sqrt{\left(\frac{f_c}{f}\right)^2 - 1}$$

$$\alpha = \frac{\omega}{c} \sqrt{\varepsilon_r} \sqrt{\left(\frac{4.3}{5}\right)^2 - 1}$$

$$\alpha = \frac{2\pi \times 50}{3} \sqrt{2.11} \sqrt{\left(\frac{4.3}{5}\right)^2 - 1}$$

$$\boxed{\alpha = 90.2592}$$

(i) $\alpha_d =$

Q.1 (d) The short-circuited tests on two single-phase transformer gave the following results:

200 kVA : 3% rated voltage ; rated current at 0.25 power factor lagging

500 kVA : 4% rated voltage ; rated current at 0.3 power factor lagging

These two transformers are connected in parallel. How do they share a load of 560 kW at 0.8 power factor lagging?

[12 marks]

Q.1 (e) The interface $x + y = 8$ between two media carries no current. If medium 1 ($x + y \geq 8$) is non-magnetic with magnetic field intensity $\vec{H}_1 = -3\hat{a}_x + 2\hat{a}_y - \hat{a}_z$ A/m. Find :

(i) The magnetic energy density in medium 1.

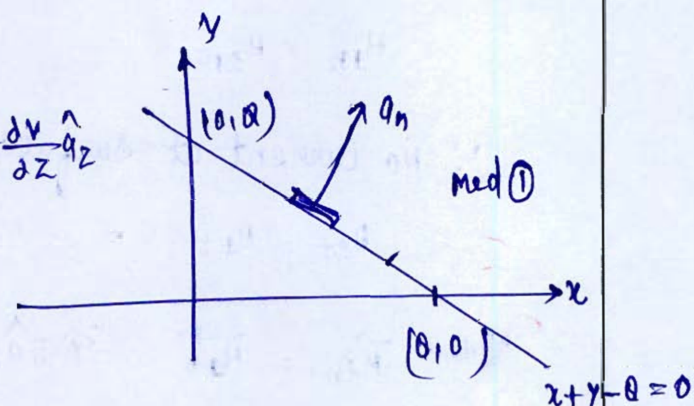
(ii) Magnetization, $\vec{M}_2$ and Magnetic Flux density, $\vec{B}_2$ in medium $2(x + y \leq 8)$ with $\mu_2 = 5\mu_0$.

(iii) The angles $\vec{H}_1$ and $\vec{H}_2$ make with the normal to the interface.

[12 marks]

$V = x + y - 8$

gradient, $\nabla V = \frac{\partial V}{\partial x}\hat{a}_x + \frac{\partial V}{\partial y}\hat{a}_y + \frac{\partial V}{\partial z}\hat{a}_z$



$\nabla V = \hat{a}_x + \hat{a}_y$

$\hat{a}_n = \frac{\nabla V}{|\nabla V|} = \frac{\hat{a}_x + \hat{a}_y}{\sqrt{2}}$

$\boxed{\vec{H}_1 = -3\hat{a}_x + 2\hat{a}_y - \hat{a}_z}$ A/m

$\vec{H}_{1n} = (\vec{H}_1 \cdot \hat{a}_n)\hat{a}_n$

$= \left(-\frac{3}{\sqrt{2}} + \frac{2}{\sqrt{2}}\right)\left(\frac{\hat{a}_x}{\sqrt{2}} + \frac{\hat{a}_y}{\sqrt{2}}\right)$

6

$= -0.5\hat{a}_x - 0.5\hat{a}_y$ A/m

$\boxed{\vec{H}_{1t} = \vec{H}_1 - \vec{H}_{1n} = -2.5\hat{a}_x + 2.5\hat{a}_y - \hat{a}_z \text{ A/m}}$

(i) Magnetic Energy density $= \frac{1}{2}\mu H^2$ Jule/m³

$= \frac{1}{2}\mu_0\mu_r\left(\sqrt{(-3)^2 + 2^2 + (-1)^2}\right)^2$

∵ Non Magnetic ($\mu_r = 1$)

$= \frac{1}{2} \times 4\pi \times 10^{-7} \times (9 + 4 + 1)$

$\boxed{W = 87.964 \text{ Jule/m}^3}$

$B_1 = \mu_1 H_1 = \mu_0 H_1$

$B_{1n} = \mu_0 H_{1n} = -0.5\mu_0 \hat{a}_x - 0.5\hat{a}_y$ T

$B_{1t} = -2.5\mu_0 \hat{a}_x + 2.5\mu_0 \hat{a}_y - \hat{a}_z$

(ii) $\because$ Normal component of magnetic is continu

$H_{1n} = H_{2n}$

$\because$ No current at surface.

$B_{2t} = B_{1t} = -2.5\mu_0 \hat{a}_x + 2.5\mu_0 \hat{a}_y - \hat{a}_z$

$\vec{H_{2n}} = \vec{H_{1n}} = -0.5\hat{a}_x - 0.5\hat{a}_y$

$\vec{H_{2t}} = \frac{B_{2t}}{\mu_2} = \frac{B_{2t}}{5\mu_0} = -0.5\hat{a}_x + 0.5\hat{a}_y - 0.2\hat{a}_z$

$\boxed{\vec{H_2} = \vec{H_{2n}} + \vec{H_{2t}} = -\hat{a}_x - 0.2\hat{a}_z}$

$\vec{M_2} = (\mu_{r_2} - 1)\vec{H}$ $\left[\because \chi_m = \frac{M}{H}\right.$

$\vec{M_2} = 4 \times \vec{H_2}$

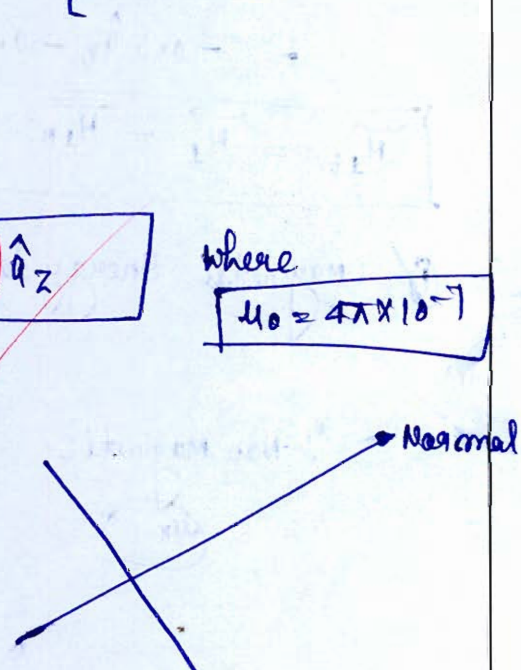
$\boxed{\vec{M_2} = -4\hat{a}_x - 0.8\hat{a}_z}$

$\boxed{\vec{B_2} = \mu \vec{H_2} = -5\mu_0 \hat{a}_x - \mu_0 \hat{a}_z}$

where $\boxed{\mu_0 = 4\pi \times 10^{-7}}$

Angle H_1 with Normal:

$\theta = \cos^{-1}\left[\frac{\hat{a}_n \cdot \vec{H_1}}{|a_n| \cdot |H_1|}\right]$



$$\theta_1 = \cos^{-1}\left[\frac{\frac{-3+2}{\sqrt{2}}}{1 \times \sqrt{14}}\right] \Rightarrow \boxed{\theta_1 = 100.09^\circ}$$

Angle H_2 with Nasional:

$$\theta_2 = \cos^{-1}\left[\frac{\hat{a}_n \cdot \vec{H_2}}{|a_n| \times |H_2|}\right] = \cos^{-1}\left[\frac{\frac{-1-0}{\sqrt{2}}}{1 \times \sqrt{1^2 + (0.2)^2}}\right]$$

$$\theta_2 = \cos^{-1}\left(\frac{-1}{\sqrt{2} \times \sqrt{1+0.04}}\right)$$

$$\boxed{\theta_2 = 133.89^\circ}$$

Q.2 (a) A 150 kVA, 2500/250 V, single-phase two winding transformer is to be used as an auto transformer for stepping up the voltage from 2500 V to 2750 V. At rated load, the two winding transformer has 2.5% loss, 3% voltage regulation and 4% impedance. For the auto transformer, determine the following:

(i) Voltage and current rating.

(ii) kVA rating.

(iii) Efficiency.

(iv) Percentage impedance.

(v) Regulation.

(vi) Short circuit current on each side.

[20 marks]

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Q.2 (b) **(i)** A 50 Ω lossless line has $V_L = 20e^{j20°}$ V and $Z_L = 50e^{j25°}$ Ω. Find the current at $\lambda/8$ distance from the load.

(ii) A uniform plane wave in air with $\vec{E} = 8\cos(wt - 4x - 3z)\hat{a}_y$ V/m is incident on a dielectric slab ($z \geq 0$) with $\mu_r = 1$, $\varepsilon_r = 0.2$, $\sigma = 0$. Determine the reflected E field and H field.

[10 + 10 marks]

(i) $Z_0 = 50$,

we know current equation, for lossless line

$$I(z) = \frac{V_0^+}{Z_0} e^{+j\beta z} - \frac{V^-}{Z_0} e^{-j\beta z} \quad \text{--- (I)}$$ (Reference From Load end)

$$I_L = \frac{V_L}{Z_L} = \frac{20e^{j20°}}{50e^{j25°}} = \frac{2}{5} e^{-j5°} = 0.4e^{-j5°}$$

Put $z = 0$ in Eq (I) then $I(0) = I_L$

$$I_L = \frac{V^+}{Z_0} - \frac{V^-}{Z_0}$$

$$0.4\angle -5° = \frac{V^+ - V^-}{50} \Rightarrow V^+ - V^- = 20\angle -5° \quad \text{--- (I)}$$

As we know, $V(z) = V^+ e^{j\beta z} + V^- e^{-j\beta z}$

at $z = 0$, $V(0) = V_L$

$$V_L = V^+ + V^-$$

$$V^+ + V^- = 20\angle 20° \quad \text{--- (2)}$$

By solving (I) & (II)

$$V^+ = \frac{20\angle -5° + 20\angle 20°}{2}, \quad V^- = \frac{20\angle 20° - 20\angle 5°}{2}$$

$$\boxed{V^+ = 19.52\angle 7.5°} \qquad \boxed{V^- = 4.33\angle 97.5°}$$

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Now from Eq ① $\beta = \frac{2\pi}{\lambda}$ & $z = \frac{\lambda}{8}$

$$I\left(z=\frac{\lambda}{8}\right) = \frac{19.52\angle 7.5^\circ}{50} e^{j\frac{2\pi}{\lambda}\times\frac{\lambda}{8}} - \frac{4.33\angle 97.5}{50} e^{-j\frac{2\pi}{\lambda}\times\frac{\lambda}{8}}$$

$$I\left(z=\frac{\lambda}{8}\right) = \frac{(19.52\angle 7.5^\circ)(1\angle 45^\circ) - (4.33\angle 97.5)(1\angle -45^\circ)}{50}$$

10

$$\boxed{I\left(z=\frac{\lambda}{8}\right) = 0.3038\angle 52.5^\circ} \text{ A}$$

or $\boxed{I\left(z=\frac{\lambda}{8}\right) = 0.184 + j\,0.241 \text{ A}}$

⑪ $\vec{E} = 8\cos(\omega t - 4x - 3z)\,\hat{a}_y$ V/m

$\vec{E} = E_{i0}\cos(\omega t - \vec{\beta}\cdot\vec{r})\,\hat{a}_y$ V/m

By comparison.

$\vec{\beta}\cdot\vec{r} = 4x + 3z$

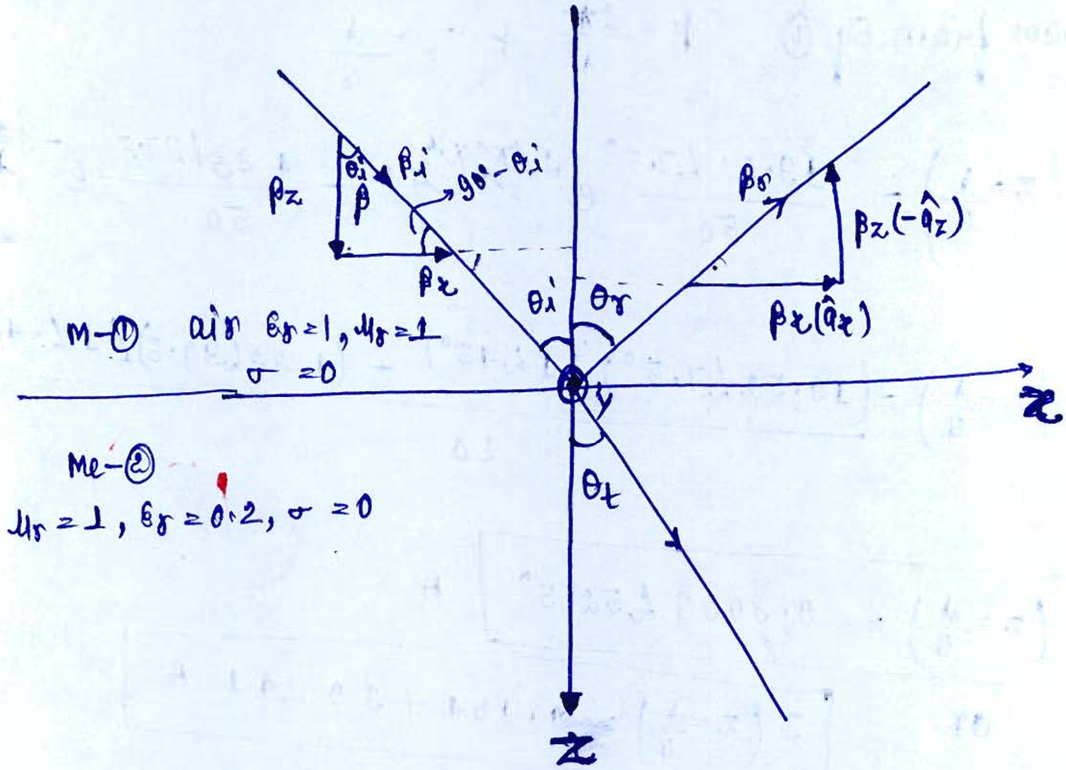
$(\beta_x\hat{a}_x + \beta_y\hat{a}_y + \beta_z\hat{a}_z)\cdot(x\hat{a}_x + y\hat{a}_y + z\hat{a}_z) = 4x + 3z$

By comparison —

$\boxed{\beta_x = 4}$ $\boxed{\beta_z = 3}$ $\beta = \sqrt{\beta_x^2 + \beta_y^2}$

$= \sqrt{16+9}$

$\boxed{\beta = 5}$ rad/m



$\theta_i = \theta_r$ [From Snells law, same medium)

$\eta_1 = 120\pi$ (air) $\quad \eta_2 = 120\pi\sqrt{\frac{\mu_r}{\epsilon_r}}$

$$\eta_2 = \frac{120\pi}{\sqrt{0.2}} = 260.32$$

$\theta_i = \tan^{-1}\left(\frac{\beta_x}{\beta_z}\right)$ | $\vec{\beta_r}\cdot\vec{r} = 4x - 3z$

$\theta_i = \theta_r = 53.13°$

Reflected E field →

$$\vec{E_r} = |\vec{E_{r0}}|\cos(\omega t - \vec{\beta_r}\cdot\vec{r})\,\hat{a}_y$$

we assume, $\vec{E_r}$, $\vec{E_t}$ & $\vec{E_i}$ are in same direction.

$$\Gamma_{\parallel} = \frac{\tan(\theta_t - \theta_i)}{\tan(\theta_t + \theta_i)}$$

$\sqrt{\varepsilon_{r_1}}\sin\theta_i = \sqrt{\varepsilon_{r_2}}\sin\theta_t$

$1 \sin 53.13^\circ = \sqrt{0.2}\sin\theta_t$

$\vec{H}$ field $\Rightarrow$ $\vec{H_r} = \dfrac{\hat{a}_k \times \vec{E_r}}{\eta_1}$

$$\vec{H_r} = \frac{(\hat{a}_x - \hat{a}_z) \times E_{r0}\cos(\omega t - 4x + 3z)\hat{a}_y}{120\pi}$$

Incomplete

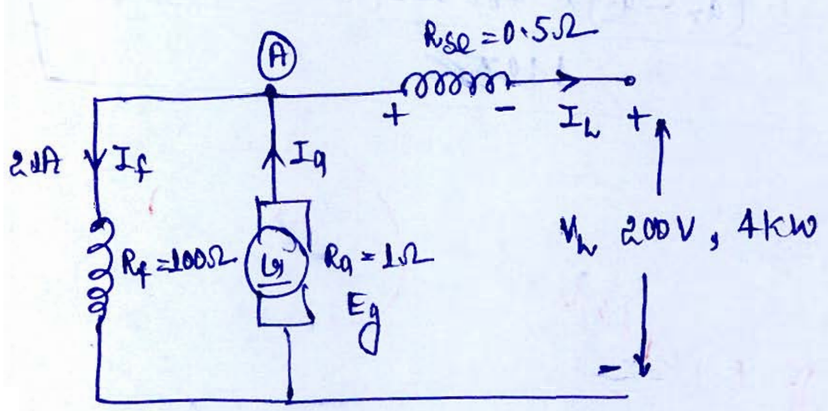
8

Q.2 (c) A 4-pole compound generator has armature, series-field and shunt-field resistance of 1 Ω, 0.5 Ω and 100 Ω respectively. This generator delivers 4 kW at a terminal voltage of 200 V. Allowing 1 V per brush for contact drop, calculate for both short-shunt and long-shunt connections:

(i) the generated emf, and

(ii) the flux per pole if the armature has 200 lap-connected conductors and is driven at 750 rpm.

[20 marks]



We know, $P_L = V_L I_L$

$$I_L = \frac{P_L}{V_L} = \frac{4\times10^3}{200} = 20A$$

$$I_f = \frac{V_L + I_L R_{se}}{R_f} = \frac{200 + 20\times0.5}{100}$$

$$I_f = \frac{200+10}{100} = 2.1 \text{ Amp.}$$

Then $I_a = I_f + I_L$

$$I_a = 22.1 \text{ Amp}$$

(i) $E_g = V_L + I_a R_a + I_L R_{se} + 2\times \text{Brushdrop}$

$= 200 + 22.1\times1 + 20\times0.5 + 2\times1$

$$E_g = 234.1 \text{ Volt}$$

(ii) $P = 4$, $N = 750$ rpm

$Z = 200$

For lap connected, $A = P$

$\boxed{A = 4}$

So formula of generated emf,

$$\boxed{E_g = \frac{\phi Z N}{60} \cdot \frac{P}{A}}$$ $[\because P = A]$

$$E_g = \frac{\phi Z N}{60}$$

$$234 \cdot 1 = \frac{\phi \times 200 \times 750}{60}$$

$$\phi = \frac{234 \cdot 1 \times 60}{200 \times 750}$$

$$\phi = 0.09364 \text{ Wb}$$

Flux per pole : $\boxed{\phi = 93.64 \text{ mWb}}$

20

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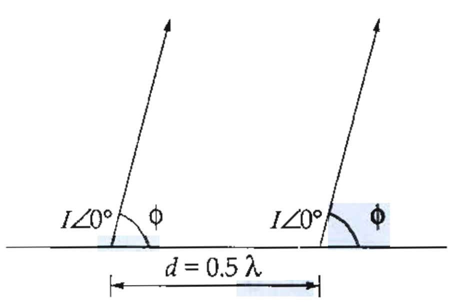
Q.3 (a) (i) Consider an array of two non-directional radiators with spacing $d = 0.5\lambda$. Determine the directions of maximum radiation when the radiators are excited as shown in figure.



(ii) The following S-parameters are obtained for a microwave transistor operating at 2.5 GHz: $S_{11} = 0.85\angle{-30°}$, $S_{12} = 0.07\angle 56°$, $S_{21} = 1.68\angle 120°$, $S_{22} = 0.85\angle{-40°}$. Determine the input reflection coefficient when $Z_L = Z_0 = 75\ \Omega$.

[10 + 10 marks]

(i) Array Factor,

$$A.F. = \frac{\sin\left(\frac{N\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)}$$

For N = 2 (2 Antenna)

$$A.F. = \frac{\sin\psi}{\sin\frac{\psi}{2}} = \cos\left(\frac{\psi}{2}\right)$$

For Max : $\left|\cos\left(\frac{\psi}{2}\right)\right| = \pm 1$

$$\frac{\psi}{2} = \pm n\pi$$

$$\boxed{\psi = \pm 2n\pi}$$

We know, $\psi = \alpha + \beta d \cos\theta$

given, $d = 0.5\lambda$, $\beta = \frac{2\pi}{\lambda}$

$\alpha = 0°$ (Phase difference b/w currents)

$$\psi = 0 + (0.5\lambda)\left(\frac{2\pi}{\lambda}\right)\cos\theta$$

$$\psi = \pi\cos\theta$$

For Max Radiation, $\psi = \pm 2n\pi$

$$\pi\cos\theta = \pm 2n\pi$$

Let $n = 0$, $\cos\theta = 0$

$$\boxed{\theta = \pi/2}$$

So max radiation take place at $\theta = \pi/2$.

(10)

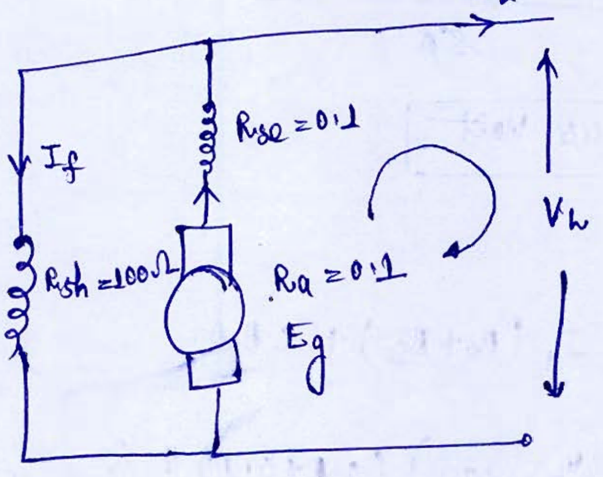
Q.3 (b) A 4-pole long shunt compound d.c. generator has 1200 armature conductors and running at a speed of 500 r.p.m. The diameter of the pole shoe circle is 0.35 m and the ratio of pole arc to pole pitch is 0.7 while the length of the shoe is 0.2 m.

Assume the shunt field, series field and armature resistance are 100 Ω, 0.1 Ω and 0.1 Ω respectively. If the flux density in the air gap is 0.75 T, load current is 100 A and voltage drop per brush is 1 V, then calculate load voltage when

(i) armature winding is lap connected.

(ii) armature winding is wave connected.

[20 marks]



$$I_f = \frac{V_L}{100} \text{ Amp}$$

$$I_a = I_f + I_L$$

$$I_a = \frac{V_L}{100} + 100 \quad \text{--- (1)}$$

10

$B = 0.75$ T (fluxdensity in air)

We know,

$$B = \frac{\phi}{A}$$

$$\phi = B \cdot A$$

$D = 0.35$ m

$l = 0.2$ m

$$\phi = B \times 0.7 \times \text{pole pitch}$$

$$\phi = B \times 0.7 \times (\pi D l)$$

Flux per pole $\phi = B \times 0.7 \times \frac{\pi D l}{P}$ [where $P = 4$]

$$\phi = \frac{0.75 \times 0.7 \times \pi \times 0.35 \times 0.2}{4}$$

$$\boxed{\phi = 0.0288 \text{ Wb}}$$

Given, $P = 4$, $Z = 1200$, $N = 500$ rpm

(i) when winding lap connected

$$\boxed{A = P}$$

$$E_g = \frac{\phi Z N}{60} \times \frac{P}{A}$$

$$E_g = \frac{0.0222 \times 1200 \times 500}{60}$$

$$\boxed{E_g = 222 \text{ Volt}}$$

From KVL :

$$E_g = V_L + I_a (R_a + R_{se}) + 2\,B.D.$$

$$222 = V_L + \left(\frac{V_L}{100} + 100\right)(0.1 + 0.1) + 2$$

$$222 = V_L + \frac{0.2 V_L}{100} + 20 + 2$$

$$266 = \frac{100.2}{100} V_L$$

$$V_L = \frac{266 \times 100}{100.2}$$

$$\boxed{V_L = 265.46 \text{ Volt}}$$

(ii) wave connected, $\boxed{A = 2}$

$$E_g = \frac{\phi Z N}{60} \cdot \frac{P}{A}$$

$$= \frac{0.0222 \times 1200 \times 500}{60} \times \frac{4}{2}$$

$$\boxed{E_g = 576 \text{ Volt}}$$

From KVL :

$$E_g = V_L + I_a(R_a + R_{se}) + 2\times 1.0$$

$$576 = V_L + \left(\frac{V_L}{100} + 100\right)(0.1+0.1) + 2$$

$$576 = V_L + \frac{0.2V_L}{100} + 20 + 2$$

$$\frac{100.2V_L}{100} = 554$$

$$V_L = 552.89\ V$$

10

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Q.3 (c) A plane wave with $\vec{E} = 30\, e^{-\alpha z} \sin(\omega t - z)\, \hat{a}_x$ V/m is propagating through a lossy dielectric medium having an intrinsic impedance of $300\angle 30°\Omega$ and $\mu_r = 1$. Establish the phasor and instantaneous field expressions for $\overline{H}$, and find the loss tangent, propagation constant, wave polarization and the dielectric constant of the medium at 15 MHz. Also determine the skin depth and the depth at which the amplitude of the field is 1% of the value at $z = 0$.

[20 marks]

Lossy dielectric :

$$\vec{E} = 30 e^{-\alpha z} \sin(\omega t - z)\hat{a}_z$$

→ wave propagation +z dir

$$\eta = 300 \angle 30° \,\Omega, \quad \mu_r = 1$$

$$\theta_\eta = \frac{1}{2}\tan^{-1}\left(\frac{\sigma}{\omega\epsilon}\right)$$

$$30° = \frac{1}{2}\tan^{-1}\left(\frac{\sigma}{\omega\epsilon}\right)$$

10

$$\frac{\sigma}{\omega\epsilon} = \tan 60°$$

$$\frac{\sigma}{\omega\epsilon} = 1.73$$

$$\because 0.01 < \frac{\sigma}{\omega\epsilon} < 100 \quad [\text{Low loss dielectric}]$$

(i) Loss tangent, $\frac{\sigma}{\omega\epsilon} = \tan\theta$

$$\boxed{D = 1.73}$$

Propagation constant, $\beta = \frac{\omega}{c}\sqrt{\frac{\mu_r\epsilon_r}{2}\left[\sqrt{1+\left(\frac{\sigma}{\omega\epsilon}\right)^2}+1\right]}$

$$\therefore \beta = \frac{2\pi \times 15 \times 10^6}{3\times 10^8}\sqrt{\frac{1\times\epsilon_r}{2}\left[\sqrt{1+(1.73)^2}+1\right]} \quad \text{--- (1)}$$

Intrinsic Impedence,

$$\eta = \frac{\sqrt{\frac{\mu}{\epsilon}}}{\left(\sqrt{1+\left(\frac{\sigma}{\omega\epsilon}\right)^2}\right)^{1/2}} \angle \frac{1}{2}\tan^{-1}\frac{\sigma}{\omega\epsilon}$$

Magnitude:

$$300 = \frac{120\pi\sqrt{\frac{\mu_r}{\epsilon_r}}}{\left(1+(1.73)^2\right)^{1/4}} \qquad (\because \mu_r = 1)$$

$$\frac{1}{\sqrt{\epsilon_r}} = \frac{300 \times \left(1+(1.73)^2\right)^{1/4}}{120\pi} = 1.12489$$

$$\epsilon_r = \frac{1}{(1.12489)^2}$$

$$\boxed{\epsilon_r = 0.7902}$$

then From Eq ①

$$\beta = \frac{30\pi}{300}\sqrt{\frac{0.7902}{2}\left[\sqrt{1+(1.73)^2}+1\right]}$$

$$\boxed{\beta = 0.3419 \text{ rad/m}}$$

∵ ~~α = β~~

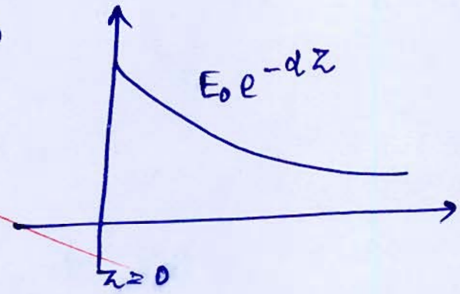
$$\alpha = \frac{\omega}{c}\sqrt{\frac{\mu_r\epsilon_r}{2}\left[\sqrt{1+\left(\frac{\sigma}{\omega\epsilon}\right)^2}-1\right]}$$

$$\boxed{\alpha = 0.1973 \text{ NP/m}}$$

Skin depth, $\delta = \frac{1}{\alpha}$

$$\boxed{\delta = 5.068 \text{ m}}$$

Depth at which, $E = 0.01 E_0$



$$E = E_0 e^{-\alpha z}$$

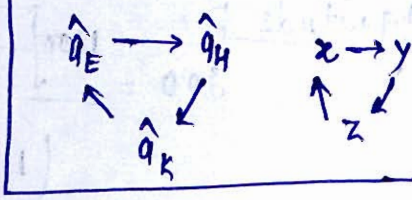
$$0.01 E_0 = E_0 e^{-\alpha z}$$

$$-\alpha z = \ln(0.01)$$

$$z = -\frac{\ln(0.01)}{0.1973}$$

$$\boxed{z = 23.34 \text{ m}}$$

$$\vec{H} = \frac{\hat{a}_K \times \vec{E}}{\eta}$$



$$\vec{H} = \frac{1}{300\angle 30^\circ}\left[\hat{a}_z \times 30 e^{-\alpha z} \sin(\omega t - z)\hat{a}_x\right]$$

$$\vec{H} = \frac{30 e^{-\alpha z}}{300\angle 30^\circ} \sin(\omega t - z)\hat{a}_y$$

$$\boxed{\vec{H} = 0.1 e^{-0.1973 z} \sin(\omega t - z - 30^\circ)\hat{a}_y} \quad A/m$$

Instaneous form :

$$\vec{H} = 0.1 e^{-0.1973 z} \cdot \text{Img}\left\{ e^{-z-30^\circ}\right\} \cdot e^{\omega t}\hat{a}_y$$

By droping $e^{\omega t}$ to get intantaneous to phasor form

$$\vec{H} = 0.1 e^{-0.1973 z} e^{-z-30^\circ} \hat{a}_y$$

$$\boxed{\vec{H} = 0.1\angle -30^\circ \, e^{-1.1973 z} \hat{a}_y} \quad Amp/m$$

Do not write in this margin

Q.4 (a) (i) When a transmission line of finite length is terminated with a load equal to its characteristic impedance, it appears as an "infinite line" to the sending end source. Justify this by applying voltage and current equations.

(ii) An air filled parallel plane waveguide carries the TM_2 mode. The separation between the plates of the waveguide is 20 cm. If the phase velocity of the mode is 1.5c, find the frequency and guided wavelength of mode.

[10 + 10 marks]

Q.4 (b) A series motor, with an unsaturated magnetic circuit and 0.5 Ω total resistance, when running at a certain speed takes 60 A at 500 V. If the load torque varies as the fan load varies with the speed, calculate the resistance required to reduce the speed by 25%.

[20 marks]

Q.4 (c) A 460 V, 25 hp, 60 Hz, 4-pole, Y-connected wound rotor induction motor has the following impedances per phase referred to stator side:

$$R_1 = 0.641\ \Omega,\ R_2 = 0.332\ \Omega;$$
$$X_1 = 1.106\ \Omega,\ X_2 = 0.464\ \Omega, \text{ and } X_m = 26.3\ \Omega$$

(i) What is maximum torque of this motor? At what slip and speed does it occur?

(ii) What is the starting torque of this motor?

(iii) When the rotor resistance is doubled, what is the speed at which the maximum torque now occurs? What is the new starting torque of the motor?

[20 marks]

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

Q.5 (a) A hypothetical 32-bit CPU utilizes a fixed length instruction format that supports four distinct fields: an opcode, a Register Address, a Memory Address, and an Immediate constant field. The following specifications are provided:

- The opcode size is 7 bits.
- The register file contains 32 registers.
- The system supports a 4 kB RAM (assume byte-addressable).
- Each instruction is one word (32 bits) long.

Determine the number of bits available for the immediate constant field and calculate the largest unsigned constant that can be represented within this instruction.

[12 marks]

Instruction :

← 32 bit →

Opcode	Reg. Add	Memory Ad	Im. Const
7 bit	$\log_2 32 \Rightarrow 5$ bit	$\log_2 4\times2^{10} \Rightarrow 12$ bit	

Immediate Constant field No. of bits

$= \text{Total} - (7+5+12)$

$= 32 - 24$

$= 8$ bit

Do not write in this margin

Largest unsigned constant $= 2^n - 1$

$= 2^8 - 1$

$= 255$

Good

Do not write in this margin

Q.5 (b) (i) Iron has a density of 7.87 g/cm^3 and the mass of an iron atom is 9.27×10^{-26} kg. If the atoms are spherical and tightly packed (Ignore the spaces between the spheres),

1. What is the volume of an iron atom?
2. What is the distance between the centers of adjacent atoms?

(ii) Silver has FCC structure and its atomic radius is 1.44 Å. Find the spacing between the (220), (200) and (111) planes.

[6 + 6 marks]

Volume of iron atom = $\frac{\text{Mass of Iron Atom}}{\text{density}}$

$= \frac{9.27 \times 10^{-26}}{7.87 \times 10^{-3}} \frac{cm^3}{kg}$

$\boxed{\text{Volume} = 1.177 \times 10^{-23}\ cm^3}$

~~$\because$ 1 cm = 100~~

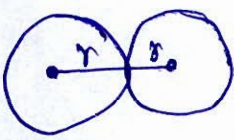
$\because$ Iron form BCC structure,

$a^3 = 1.177 \times 10^{-23}\ cm^3$

$\boxed{a = 2.6 \times 10^{-8}\ cm}$

(6)

For BCC : $4r = \sqrt{3}a$



Distance b/w then $= 2r$

$d = 2r = \frac{\sqrt{3}a}{2}$

$d = \frac{\sqrt{3}a}{2}$

$\boxed{d = 2.26 \times 10^{-8}\ cm}$

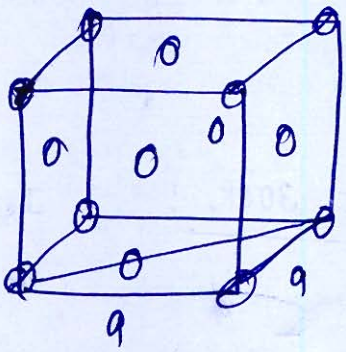
(ii) For FCC :

$(4R)^2 = a^2 + a^2$

$4R = \sqrt{2}a$

$a = \frac{4R}{\sqrt{2}}$

$a = 4.07\,\mathring{A}$



2

space b/w (2, 2, 0) & (2 0 0) $= a\sqrt{(2-2)^2 + (2-0)^2 + 0^2}$

$= 2a$

$= 8.14\,\mathring{A}$

space b/w (2 2 0) (1, 1 1) $= a\sqrt{(2-1)^2 + (2-1)^2 + (0-1)^2}$

$= \sqrt{3}a$

$= 7.04\,\mathring{A}$

space b/w (2 0 0) (1 1 1) $= a\sqrt{(2-1)^2 + (0-1)^2 + (0-1)^2}$

$= a\sqrt{1 + 1 + 1}$

$= \sqrt{3}a$

$= 7.04\,\mathring{A}$

Do not write in this margin

Q.5 (c) At 300 K, an ideal Si p-n junction solar cell has a short-circuit current of 2 A and an open-circuit voltage of 0.5 V. How does the maximum output power of the solar cell change if the temperature raises to 400 K?

[12 marks]

at 300K :

$I_{SC} = 2A$

$V_{OC} = 0.5 V$

$\because V_{OC} = V_T \ln\left[1 + \frac{I_{SC}}{I_S}\right)$

Q.5 (d) Two step index fibers exhibit the following parameters:

(i) A multimode fiber with a core refractive index of 1.5, a relative refractive index difference of 3% and an operating wavelength of 0.82 μm.

(ii) An 8 μm core diameter single-mode fiber with a core refractive index same as in part (i), a relative refractive index difference of 0.3% and an operating wavelength of 1.55 μm.

Estimate the critical radius of curvature at which large bending losses occur in both cases.

[12 marks]

(i) $n_1 = 1.5$, $\Delta = 0.03$ $\lambda = 0.82\,\mu m$

For Multimode:

$$R_C = \frac{20 n_1^2 \lambda}{(NA)^3} = \frac{20 n_1^2 \lambda}{(n_1\sqrt{2\Delta})^3}$$

$$R_C = \frac{20(1.5)^2 \times 0.82}{(1.5\sqrt{2\times 0.03})^3}$$

$$R_C = 743.919\,\mu m$$

6

For Single Mode: $\lambda = 1.55 \mu m$ $\Delta = 0.003$

$$R_C = \frac{20 n_1^2 \lambda}{(n_1 - n_2)^3}\left[2.498 - 0.9\frac{\lambda}{\lambda_c}\right]$$

$$\lambda_c = \frac{2\pi a}{2.405} n_1 \sqrt{2\Delta}$$

$$= \frac{\pi \times 8}{2.405} \times 1.5 \sqrt{2 \times 0.003}$$

$$\lambda_c = 1.214 \mu m$$

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

$$\Delta \times 2n_1^2 = n_1^2 - n_2^2$$

$$n_2 = \sqrt{(1.5)^2 - 0.005 \times 2 \times (1.5)^2}$$

$$n_2 = 1.492$$

$$R_C = \frac{20 (1.5)^2 \times 1.55}{(1.5 - 1.492)^3}\left[2.498 - 0.948 \times \frac{1.55}{1.214}\right]$$

$$R_C = 1.754 \times 10^8 \mu m$$

$$R_C = 175.4 m$$

3

Do not write in this margin

Q.5 (e) (i) Explain how to check conflict serializability and view serializability of the following schedule:

$S : r_1(X); r_3(Y); r_3(X); r_2(Y); r_2(Z); w_3(Y); w_2(Z); r_1(Z); w_1(X); w_1(Z)$

(ii) The transmitting and receiving antennas with respective heights of 49 m and 25 m are installed to establish communication at 100 MHz with a transmitted power of 100 Watts. Determine the LOS distance and the received electrical field signal strength at receiver.

[6 + 6 marks]

(ii) $LOS = 4.123 [\sqrt{h_t} + \sqrt{h_r}]$ km

$= 4.123 [\sqrt{49} + \sqrt{25}]$

$= 4.123 [7 + 5]$

$= 12 \times 4.123$

$LOS = 49.476$ km

3

$f = 100$ MHz, $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{100 \times 10^6} = 3$ m

$P_t = 100$ watt

$E_t =$

$E = \frac{88 \sqrt{P_t}\, \lambda^2}{4\pi d}$

$E =$

Q.6 (a) Consider the following hypothetical format used to represent the floating-point data, to be stored in the memory.

Format:

S (Sign)	BE (Bias Exponent)	M (Mantissa)
1 bit	7 bit	12 bit

Data: $(-14.75)*2^{12}$ is to be stored in the memory.

Calculate the hexadecimal equivalent when the data is stored in the Main Memory

(i) Without normalisation.

(ii) With normalisation; and also denormalise the obtained result and bring back to its original form $(-14.75)*2^{12}$.

[8 + 12 marks]

$-14.75 * 2^{12}$

Converting decimal into Binary.

2	14	0
2	7	1
2	3	1
	1	

$(14)_{10} \rightarrow (1110)_2$

0.75 × 2 = (1).50

0.50 × 2 = (1).00

$(0.75)_{10} \rightarrow (0.11)_2$

$(14.75)_{10} \rightarrow (1010.11)_2$

Sign bit → (−) $1110.11 * 2^{12}$

(i) Without Normalisation: S = 1 (−ve sign)

~~M = 1010~~

M = 111000000000

Bias Exponent = Actual Exponent + Bias

$= 12 + (2^{n-1} - 1)$

$= 12 + (2^6 - 1)$

$= 75$

$(75)_{10} \longrightarrow (1001011)_2$

Format:

1	1001011	11000000000

(ii) With Normalisation:

$-1.1011 * 2^{12+3}$

S = 1 , M = 110110000000

3

B.E. = Actual exp. + Bias

= $15 + (2^6 - 1)$

= 78

$(79)_{10} \longrightarrow (1001110)$

Format:

S	B.E.	M
1	1001110	110110000000

Now denormalisation:

$(-1)^S * 1.M * 2^{B.E - Bias}$

$(-1)^1 * 1.110110000000 * 2^{78-(2^{7-1}-1)}$

$-1.11011 * 2^{78-(64-1)}$

$-1.11011 * 2^{78-63}$

~~$-1.11011 * 2^{15}$~~

$-1110.11 * 2^{12}$

Binary to decimal Conversion

Hexadecimal ???

6

$(1110)_2 \longrightarrow (0\times 2^0 + 1\times 2^1 + 1\times 2^2 + 1\times 2^3)$

$\longrightarrow (0+2+4+8)_{10}$

$\longrightarrow (14)_{10}$

$(0.11)_2 \longrightarrow \left(.\frac{1}{2}\times 1 + \frac{1}{2^2}\times 1\right)$

$\longrightarrow \left(0.\left(.\frac{1}{2}+\frac{1}{4}\right)\right)$

$= (0.75)_2$

Then together $\longrightarrow (1110.11)_2 \longrightarrow (14.75)_2$

$$-14.75 * 2^{12}$$

Q.6 (b) Consider an MOS capacitor fabricated on P-type Si substrate with a doping of 5×10^{16} cm^{-3}, oxide thickness of 10 nm and N^+ poly-gate.

(i) Find C_{ox} (Oxide capacitance), V_{fb} (Flatband voltage) and V_t (Threshold voltage) of the MOS capacitor.

(ii) Find the accumulation charge (C/cm^2) at $V_g = V_{fb} - 1$ V.

(iii) Find the depletion and inversion charge at $V_g = 2$ V.

(Assume, $\chi = 4.05$ eV, $E_g = 1.12$ eV, $n_i = 10^{10}$ cm^{-3}, $\varepsilon_{ox} = 3.45 \times 10^{-13}$ F/cm, $\varepsilon_s = 1.04 \times 10^{-12}$ F/cm, $q = 1.6 \times 10^{-19}$ C, $V_T = 0.026$ V)

[12 + 4 + 4 marks]

N – MOS:

$$N_D = 5 \times 10^{16} \text{ cm}^{-3}$$

(1)

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.45 \times 10^{-13}}{10 \times 10^{-7}}$$

$$C_{ox} = 3.45 \times 10^{-13+6}$$

$$\boxed{C_{ox} = 0.345 \mu F}$$

$$V_{fb} = \phi_{ms} + \frac{Q_{dep}}{C_{ox}}$$

Do not write in this margin

Q.6 (c) A digital satellite communication link, with uplink frequency of 30 GHz transmits data at 1 Mbps. The downlink provides $\frac{E_b}{N_0}$ of 30 dB. The net uplink losses work out to 211.5 dB. Determine the antenna diameter for the transmitting earth station to get overall $\frac{E_b}{N_0}$ of 17 dB, in optimal configuration assuming following parameters.

(i) Transponder amplifier output of 200 mW.

(ii) Antenna efficiency of 60%.

(iii) Satellite receive antenna gain of 45 dB.

(iv) Satellite receive noise power density of –169 dBm/Hz.

[20 marks]

$f = 30\text{ GHz}$, $R_b = 1\text{ Mbps}$

$\left(\frac{E_b}{N_0}\right)_{downlink} = 30\text{ dB} = 10^3$ $\left\{ \because \left(\frac{E_b}{N_0}\right)_{dB} = 10\log_{10}\left(\frac{E_b}{N_0}\right) \right.$

~~$\left(\frac{E_b}{N_0}\right)_{Net} = 211.5\text{ dB} = 10^{21.15}$~~

Net uplink losses, $(\text{loss})_{uplink} = 211.5\text{ dB}$

3

$\left(\frac{E_b}{N_0}\right)_{net} = 17\text{ dB} = 10^{1.7}$

we know $\frac{1}{\left(\frac{E_b}{N_0}\right)_{net}} = \frac{1}{\left(\frac{E_b}{N_0}\right)_{uplink}} + \frac{1}{\left(\frac{E_b}{N_0}\right)_{downlink}}$

$\frac{1}{\left(\frac{E_b}{N_0}\right)_{uplink}} = \frac{1}{10^{1.7}} - \frac{1}{10^3}$

$\left(\frac{E_b}{N_0}\right)_{uplink} = \frac{1}{\frac{1}{10^{1.7}} - \frac{1}{10^3}}$

$= 52.763$

$$\boxed{\left(\frac{E_b}{N_0}\right)_{uplink} = 17.2233\text{ dB}}$$

Path Loss = $92.5 + 20\log_{10} f + 20\log_{10} d$

$(f \rightarrow GHz)$ & $(d \rightarrow km)$

$$\left(\frac{E_b}{N_0}\right)_{uplink} = (EIRP) + G_r|_{dB} + \text{path loss (dB)} - 10\log_{10}(N_0 B)$$

$(G_t + P_t)|_{dB}$ − other losses ——— (1)

~~path loss = 92.5 + 20 log₁₀ 30×8 + 20~~

∵ Net uplink losses = 211.5 dB (path + other losses)

Noise power density ⇒ $N_0 B|_{dB} = -169$ dBm/Hz

~~10 log₁₀ N₀B =~~

$$= 10\log_{10}\frac{N_0 B}{10^{-3}} = -169$$

$$N_0 B = 10^{-16.9} \times 10^{-3}$$

$$N_0 B = 1.2589 \times 10^{-20} \text{ watt/Hz}$$

Band width $B = \frac{R_b}{2} = \frac{1\times10^6}{2} = \frac{1}{2}\times10^6$

$$N_0 B = \frac{1.2589}{2} \times 10^6 \times 10^{-20} \text{ watt}$$

$$N_0 B|_{dB} = 10\log_{10}(0.6296 \times 10^{-14})$$

$$N_0 B|_{dB} = -142 \text{ dB}$$

Go through soln

$$\left(\frac{E_b}{N_0}\right)_{uplink} = \frac{P_t G_t G_r}{Losses \times (N_0 B)} \quad \left[\because P_t = 0.2\,watt \right.$$

$$\left(\frac{E_b}{N_0}\right)_{dB} = 10\log_{10} P_t + G_t(dB) + G_r(dB) - Losses - (N_0 B)(dB)$$

$$17.2233 = 10\log_{10} 0.2 + G_t(dB) + 45 - 211.5 + 142$$

$$\boxed{G_t|_{dB} = 48.713\,dB} \quad \text{Gain of Tx Antenna}$$

$$G_t|_{dB} = 10\log_{10} G_t \Rightarrow G_t = 10^{4.8713}$$

$$\boxed{G_t = 74353.25746}$$

We know, in transmission parabolic Antenna, used,

$$G_t = \eta \pi^2 \left(\frac{D}{\lambda}\right)^2$$

$$G_t = \eta \pi^2 \left(\frac{Df}{c}\right)^2$$

$$\left(\frac{Df}{c}\right)^2 = \frac{G_t}{\eta \pi^2}$$

$$\frac{Df}{c} = \frac{1}{\pi}\sqrt{\frac{G_t}{\eta}}$$

$$D = \frac{c}{f} \times \frac{1}{\pi}\sqrt{\frac{G_t}{\eta}}$$

$$D = \frac{3\times10^8}{30\times10^9 \pi}\sqrt{\frac{74353.25746}{0.6}}$$

Diameter: $\boxed{D = 1.1205\ m}$

6

Q.7 (a) (i) In general, ceramic materials used for engineering applications can be divided into two groups: Traditional ceramics and Engineering ceramics. Briefly explain them.

(ii) What are the two methods for preparing ceramic raw materials? What types of ingredients are added to them?

[10 + 10 marks]

Q.7 (b) A multimode parabolic graded index fibre has an acceptance angle of 8°.

(i) Estimate relative refractive index between core axis (n_1) and cladding (n_2) when sum of refractive index (RI) of core and cladding is 3.046.

(ii) Also calculate solid acceptance angle, RI of cladding and number of modes if the diameter of core is 40 μm and wavelength is 1.2 μm.

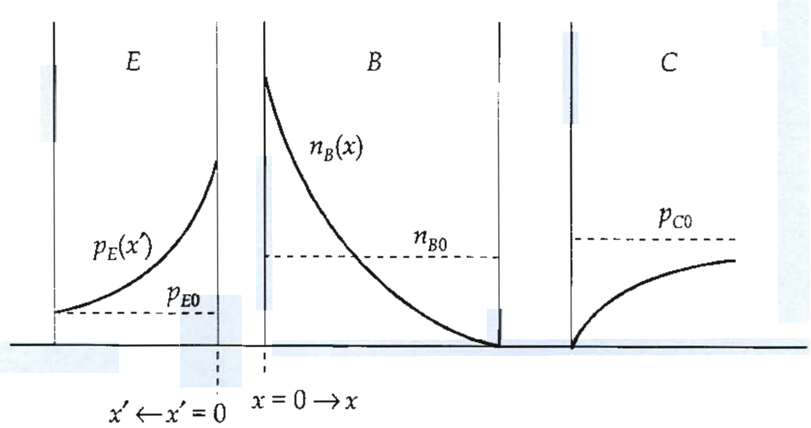
[10 + 10 marks]

Q.7 (c) A uniformly doped silicon *npn* bipolar transistor is to be biased in forward active mode with the *B-C* junction reverse biased by 3 V. The metallurgical base width is 1.1 μm. The doping concentrations in different regions are $N_E = 10^{17}$ cm^{-3}, $N_B = 10^{16}$ cm^{-3} and $N_C = 10^{15}$ cm^{-3}. Assume that $n_i = 1.5 \times 10^{10}$ cm^{-3} at $T = 300$ K.

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

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

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



[20 marks]

Q.8 (a) **(i)** Consider a hypothetical CPU that supports instructions with two register operands, one memory operand, and 7-bit immediate field. The instruction set size is 120. A specific program contains 200 such instructions. If the system supports 64 registers and has a 2 kB memory space (byte-addressable), calculate the total storage space required to store this program in Bytes.

(ii) Explain maximum usable frequency in ionospheric propagation. Derive a relationship between MUF and critical frequency.

[10 + 10 marks]

Q.8 (b) **(i)** The spacing between the principle planes in a crystal of NaCl is 2.82 Å. It is found that the first order Bragg's reflection occurs at 10°.

1. What is the wavelength of X-rays?
2. At what angle, the second order reflection occurs?
3. What is the highest order of reflection seen?

(ii) Consider a MOSFET whose gate width changes as a function of distance along the channel as:

$W(x) = W_0 + x$

where $x = 0$ at the source and $x = L$ at the drain. Except for its gate width, assume that this MOSFET is like the typical MOSFET.

1. Find an expression for drain current, I_D for this device. Ignore the bulk charge effect.
2. Derive an expression for I_{Dsat} for this device.

[10 + 10 marks]

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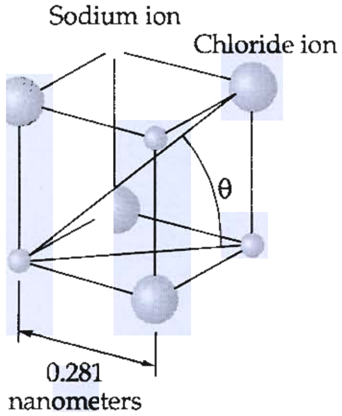
Q.8 (c) (i) The drawing shows sodium and chloride ions positioned at the corners of a cube that is part of the crystal structure of sodium chloride (common table salt). The edge of the cube is 0.281 nm (1 nm = 1 nanometer = 10^{-9} m) in length.

1. Find the distance (in nanometers) between the sodium ion located at one corner of the cube and the chlorine ion located on the diagonal at the opposite corner.
2. What is the value of the angle θ in the drawing?



(ii) Given the following properties of chromium: Density = 7.19 g/cm^3, atomic number = 24, atomic weight = 52 g/mol, melting point = 1907°C, boiling point = 2672°C, number of vacancies = 2.574×10^{22} atoms/m^3. Calculate the activation energy for vacancy formation in chromium at 670°C.

[10 + 10 marks]

OOOO

Space for Rough Work

Space for Rough Work

$\frac{C}{N_0}$ $\frac{G_r G_t P_t * k}{N_0 B}$

$\frac{G_r G_t P_t}{\text{Path loss} \times N_0 B}$

$\sqrt{\frac{j \omega \mu}{\sigma + j \omega \epsilon}}$

$\sqrt{\frac{\mu/\epsilon}{\left(\frac{\sigma}{j\omega\epsilon} + 1\right)}}$ $\sqrt{\mu/\epsilon}$

$Q = CV$

$V =$

Space for Rough Work