[OCD016]

UNIVERSITY OF BOLTON

OFF CAMPUS DIVISION

WESTERN INTERNATIONAL COLLEGE

BENG(HONS) ELECTRICAL AND ELECTRONIC ENGINEERING

TRIMESTER ONE EXAMINATION 2021/2022

ENGINEERING ELECTROMAGNETISM

MODULE NO: EEE6012

Date: Thursday 13th January 2022 **Time: 10:00 – 12:30**

INSTRUCTIONS TO CANDIDATES:

There are FIVE questions.

Answer any ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Formula sheets are included in the paper

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Q1

a) Given point $P(-2, 6, 3)$ and vector A = $y\mathbf{a}_x + (x + z)\,\mathbf{a}_y$:

(i) Express *P* and **A** in cylindrical and spherical coordinates.

(4 marks)

(ii) Evaluate **A** at P in the Cartesian, cylindrical, and spherical systems.

(5 marks)

Two point charges 4 nC and -3 nC are located at (1, 0, 4) and (-3, 0, 2), respectively.

(i) Determine the force on a 1 nC point charge located at (1, 2, -6).

(7 marks)

(ii) Find the electric field E at (1, 2, -6).

(1 mark)

b) A point charge of 30 nC is located at the origin, while plane *y* = 3 carries charge

10 nC/m^2. Find D at (0, 4, 3) and at (1,3,2).

(8 marks)

Total 25 marks

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Q2

a) Find H at (-3, 4, 0) due to the current filament shown in Figure 1.

(10 marks)

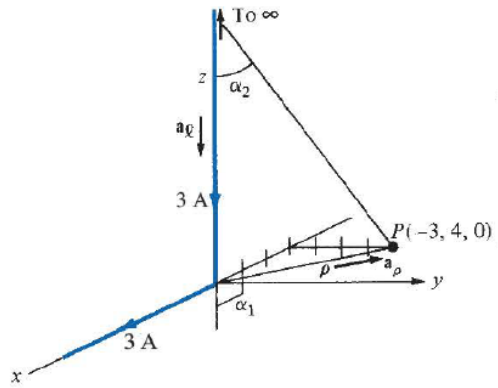

Figure 1

Q2 continues over the page….

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Q2 continued…

b) The solenoid shown in Figure 2 has 2000 turns, a length of 75 cm, and a radius of 5 cm. If it carries a current of 50 mA along at a_φ, find **H** at

i) (0,0,0)

(3 marks)

ii) (0, 0, 75 cm)

(2 marks)

iii) (0, 0, 50 cm)

(2 marks)

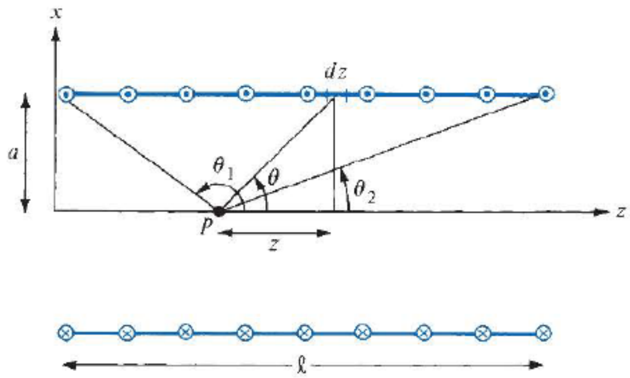

Figure 2

c) A circular loop located on $x^2 + y^2 = 9$, z = 0 carries a direct current of 10 A along a_ϕ. Determine magnetic field intensity H at (0, 0, 4) and (0, 0,-4).

(8 marks)

Total 25 marks

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Q3.

a) The electric field (E) and magnetic field (H) in free space are given by the following expressions

$$E = \frac{50}{\rho} cos(10^6 t + \beta z) a_\phi V/m \qquad H = \frac{H_0}{\rho} cos(10^6 t + \beta z) a_\rho A/m$$

By expressing them in phasor form, determine and analyse

i) Value of constant β such that the fields satsify Maxwell's equations.

(5 marks)

ii) Value of constant H_0 in the given field H to satisfy Maxwell's equations

(5 marks)

b) In a medium characterized by σ=0, $\mu=\mu_0$,$\varepsilon=4\varepsilon_0$, and E= 20 sin($10^8$t- βz)$a_y$ V/m Calculate β and **H**.

(10 marks)

c) Given that A=10 cos(10^8t-10x+60^o)a_z and B_s=(20/j)a_x+10 $e^{j2\pi x/3}a_y$, express A in phasor for, and Bs in instantaneous form.

(5 marks)

Total 25 marks

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Q4.

a) An electric field in free space, **E** = $50\cos(10^8 t + \beta x)\mathbf{a}_y \mathrm{V/m}$

(i) Find the direction of wave propagation.

(1 mark)

(ii) Calculate β and the time it takes to travel a distance of λ/2.

(3 marks)

(iii) Sketch the wave at time t= 0, T/4/T/2.

(6 marks)

b) In free space **H**=0.2 cos(ωt-βx) a_z A/m. Find the total power passing through:

(i) A square plate of side 0.1m on plane x+y=1

(2 marks)

(ii) A circular disk of radius 0.05 m on plane x=1.

(2 marks)

c) A certain transmission line 2m long operating at ω = 10^6 rad/s has α = 8 dB/m, β = 1 rad/m, and Z_0 = 60 + j40 Ω. If the line is connected to a source of 10 ∟ 0^0 V, Z_g = 40 Ω and terminated by a load of 20 + j50 Ω.

Determine

(i) The input impedance **(4 marks)**

(ii) The sending-end current **(2 marks)**

(iii) The current at the middle of the line **(5 marks)**

Total 25 marks

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Q5.

a) Assume that a rectangular waveguide is operating in an isotropic, homogeneous dielectric with negligible magnetic properties in-- TM_{13} mode for which a=0.015 m, b= 0.008 m, $\sigma = 0$, $\mu = \mu_0$ and $\varepsilon = 4\varepsilon_0$, $H_x = 2 \, Sin(\pi x/a) \, Cos(3\pi y/b) \, Sin(10^{11}\pi t - \beta z)$ A/m. Determine

(i) Cut off frequency and phase constant, β

(6 marks)

(ii) Propagation constant γ and intrinsic wave impedance η

(4 marks)

b) A standard air-filled rectangular waveguide with dimensions *a* = 8.636 cm, *b* = 4.318 cm is fed by a 4 GHz carrier from a coaxial cable. Determine whether a TE10 mode will be propagated. If so, calculate the phase velocity and the group velocity.

(5 marks)

(c) A brass waveguide ($\sigma_C = 1.1 \times 10^7$ S/m) of dimensions a = 0.042 m, b = 0.015 m is filled with Teflon ($\varepsilon_r = 2.6$, $\sigma = 10^{-15}$ S/m). The operating frequency is 9 GHz. For the TE10 mode:

(i) Calculate α_d and α_c

(5 marks)

(ii) Find the loss in decibels in the guide if it is 0.40 m long.

(5 marks)

Total 25 marks

END OF QUESTIONS

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EQUATION SHEET

Constants: $\varepsilon_0 = 8.852 * 10^{-12}$ F/m, $\mu_0 = 4\pi * 10^{-7}$ H/m

Co-ordinate systems:

$r = \sqrt{(\rho 2 + z^2)}$

$\theta = \tan^{-1}(\rho/z)$

$\sin\theta = \rho / \sqrt{(\rho 2 + z^2)}$

$\cos\theta = z / \sqrt{(\rho 2 + z^2)}$

$$\begin{bmatrix} A_\rho \\ A_\phi \\ A_z \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \\ \cos\theta & -\sin\theta & 0 \end{bmatrix} \begin{bmatrix} A_r \\ A_\theta \\ A_\phi \end{bmatrix}$$

Capacitors:

$C_1 = \alpha\varepsilon_0\varepsilon_{r1} l \, / \, 2.303 \log_{10}(r/r_1)$

$C_2 = \alpha\varepsilon_0\varepsilon_{r2} l \, / \, 2.303 \log_{10}(r_2/r)$

$V_1 = VC_2 / (C_1 + C_2)$

$V_2 = VC_1 / (C_1 + C_2)$

Electrostatics:

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

$$Q = CV$$

$$D = \frac{Q}{A}$$

$$E = \frac{D}{\epsilon_0 \epsilon_r}$$

$$V(\mathbf{r}) = \frac{\mathbf{p} \cdot (\mathbf{r} - \mathbf{r}')}{4\pi\varepsilon_0 |\mathbf{r} - \mathbf{r}'|^3}$$

$$V = E \times d$$

$$Q = \oint_S \mathbf{D} \cdot d\mathbf{S} = \int_y \rho_v \, dv$$

$$\vec{\mathbf{F}} = \frac{Q}{4\pi\varepsilon_o} \sum_{k=1}^{N} \frac{Q_k(\mathbf{r} - \mathbf{r}_k)}{|\mathbf{r} - \mathbf{r}_k|^3}$$

$$\vec{\mathrm{E}} = \frac{\vec{\mathrm{F}}}{\mathrm{q}}$$

$$Q = \int_S \rho_S \, dS$$

$$V(\mathbf{r}) = \frac{Q}{4\pi\varepsilon_0 |\mathbf{r} - \mathbf{r}'|}$$

$$W = -Q \int_L \mathbf{E} \cdot d\mathbf{l}$$

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Magnetostatics:

$$\mathbf{H} = \frac{I}{4\pi\rho}(\cos\alpha_2 - \cos\alpha_1)\mathbf{a}_\phi$$

Ampere circuital law :

$$d\mathbf{H} = \frac{I d\mathbf{l} \times \mathbf{a}_R}{4\pi R^2}$$

$$L = \frac{\lambda}{I} = \frac{N\Psi}{I}$$

$$B_1 = \mu I\rho/2\pi a^2 \text{ (for } 0 <= \rho <= a\text{)}$$
$$B_2 = \mu I/2\pi\rho\text{(for } a <= \rho <= b\text{)}$$

$$\mathbf{H} = \begin{cases} \frac{I\rho}{2\pi a^2}\mathbf{a}_\phi, & 0 \le \rho \le a \\ \frac{I}{2\pi\rho}\mathbf{a}_\phi, & a \le \rho \le b \\ \frac{I}{2\pi\rho}\left[1 - \frac{\rho^2 - b^2}{t^2 + 2bt}\right]\mathbf{a}_{\phi >} & b \le \rho \le b + t \\ 0, & \rho \ge b + t \end{cases}$$

$$\mathbf{a}_\phi = \mathbf{a}_\ell \times \mathbf{a}_\rho$$

Maxwell's Equations

$\nabla . E_s = 0$

$\nabla . H_s = 0$

$\nabla \times H_s = j\omega\varepsilon_0 E_s$

$\nabla \times E_s = -j\omega\mu_0 H_s$

$\omega/\beta = C/\sqrt{(\mu_r\varepsilon_r)}$

$E_0/H_0 = \sqrt{(\mu_0\mu_r/\varepsilon_0\varepsilon_r)}$

$$\text{charge density,}\rho = \nabla \cdot \mathbf{D} = \frac{1}{r}\frac{\partial}{\partial r}(r\mathbf{D}_r) + \frac{1}{r}\frac{\partial \mathbf{D}_\theta}{\partial \theta} + \frac{\partial \mathbf{D}_z}{\partial z}.$$

EM wave propagation and Transmission lines

$\varepsilon_r = \beta^2 / (\omega^2\mu_0\, \mu_r\, \varepsilon_0)$

$\eta = \sqrt{(\mu/\varepsilon)}$

$P_{avg} = E \times H$

$P_{total} = \int P_{avg} .dS$

$\gamma = \alpha + j\beta$

$$Z_{in} = Z_o\left(\frac{Z_L + Z_o \tanh\gamma\ell}{Z_o + Z_L \tanh\gamma\ell}\right)$$

$$I(z = 0) = \frac{V_g}{Z_{in} + Z_g}$$

$$V_o = Z_{in} I_o$$

$$V_o^+ = \frac{1}{2}(V_o + Z_o I_o)$$

$$V_o^- = \frac{1}{2}(V_o - Z_o I_o)$$

$$I_s(z = \ell/2) = \frac{V_o^+}{Z_o}e^{-\gamma z} - \frac{V_o^-}{Z_o}e^{\gamma z}$$

$$\text{phase velocity, } v = \frac{\omega}{\beta} = \frac{1}{\sqrt{\mu\varepsilon}}$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} = -\mu_0\frac{\partial \vec{H}}{\partial t}$$

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Waveguides and Optical Fibres:

$$f_{c_{mn}} = \frac{u'}{2}\sqrt{\frac{m^2}{a^2} + \frac{n^2}{b^2}}$$

$$u' = \frac{1}{\sqrt{\mu\varepsilon}}$$

$$\beta = \omega\sqrt{\mu\varepsilon}\sqrt{1 - \left[\frac{f_c}{f}\right]^2}$$

$$\gamma = j\beta$$

$$\eta_{\mathrm{TM}_{mn}} = \eta'\sqrt{1 - \left[\frac{f_c}{f}\right]^2}$$

For the TE_{10} mode

$$\alpha_d = \frac{\sigma\eta'}{2\sqrt{1 - \left[\frac{f_c}{f}\right]^2}}$$

$$f_c = \frac{u'}{2a}$$

$$\eta' = \sqrt{\frac{\mu}{\varepsilon}}$$

$$R_s = \frac{1}{\sigma_c\delta} = \sqrt{\frac{\pi f\mu}{\sigma_c}}$$

For the TE_{10} mode

$$\alpha_c = \frac{2R_s}{b\eta'\sqrt{1 - \left[\frac{f_c}{f}\right]^2}}\left(0.5 + \frac{b}{a}\left[\frac{f_c}{f}\right]^2\right)$$

$$\alpha = \alpha_d + \alpha_c$$

$$P_a = (P_d + P_a)\,e^{-2\alpha z}$$

Numerical aperture, NA = Sin θ_a = $\sqrt{(n_1^2 - n_2^2)}$

$V = \pi d \sqrt{(n_1^2 - n_2^2)}/\lambda$

No: of modes, $N = V^2/2$

$\alpha\ell = 10 \log_{10}[P(0)/P(\ell)]$

$T=2\pi/\omega$

$\lambda=Nt$

$\beta=2\pi/\lambda$

END OF FORMULA SHEETS

END OF PAPER