MERU UNIVERSITY OF SCIENCE AND TECHNOLOGY

P.O. Box 972-60200 – Meru-Kenya.
Tel: +254(0) 799 529 958, +254(0) 799 529 959, +254 (0)712 524 293
Website: www.must.ac.ke Email: info@mucst.ac.ke

UNIVERSITY EXAMINATIONS 2024/2025

THIRD YEAR, FIRST SEMESTER EXAMINATION FOR THE DEGREE OF BACHELOR OF TECHNOLOGY IN ELECTRICAL AND ELECTRONIC ENGINEERING
AND
THIRD YEAR, FIRST TRIMESTER EXAMINATION FOR THE DEGREE OF BACHELOR OF TECHNOLOGY IN ELECTRICAL AND ELECTRONIC ENGINEERING

EET 3312: ELECTROMAGNETIC WAVES

DATE: JANUARY 2025 **TIME: 2 HOURS**

INSTRUCTIONS: Answer Question ONE and any other TWO questions.
Use the following values where applicable

$$\varepsilon_0 = 8.854 \times 10^{-12}\ \text{F/m}$$
$$\mu_0 = 4\pi \times 10^{-7}\ \text{H/m}$$

QUESTION ONE (30 MARKS)

a) State the Faraday's law of electromagnetic induction. (1 Mark)

b) Distinguish between transformer and motional electromotive forces. (2 Marks)

c) With aid of a curve, define the term loss tangent of a medium. (1 Mark)

d) Write the phasor form of Maxwell's equations for a linear, homogeneous medium and state where each law is derived from. (4 Marks)

e) An EM wave in free space is described by

$$\mathbf{H} = 0.4 \cos (10^8 t + \beta y)\, \mathbf{a}_x \text{ A/m}$$

Determine:

i. The angular frequency

ii. The wave number
iii. The wavelength
iv. The direction of wave propagation. (4 Marks)

f) Assuming that sea water has $\mu = \mu_0$, $\varepsilon = 81\varepsilon_0, \sigma = 20$ S/m, determine the frequency at which the conduction current density is 10 times the displacement current density in magnitude (3 Marks)

g) A conducting bar can slide freely over two conducting rails as shown in Fig. Q1(g). If the bar slides at a velocity $U = 20a_y\ m/s$ and
$B = 4\cos(10^6 - y)a_z$ mWb / m^2. Determine the induced voltage in the bar.
(5 Marks)

h) At f =100 MHz, show that silver ($\sigma = 6.1 \times 10^7 S/m, \varepsilon_r = 1, and\ \mu_r = 1$) is a good conductor, while rubber ($\sigma = 10^{-15} S/m, \varepsilon_r = 3.1, and\ \mu_r = 1$) is a good insulator.
(3 Marks)

i) State any two applications of skin effect in electrical engineering.
(2 Marks)

j) Human exposure to the electromagnetic radiation in air is regarded as safe if the power density is less than 10 mW/m^2. Determine the corresponding electric field intensity.
(2 Marks)

k) A parallel polarized wave in free space impinges on a dielectric medium ($\sigma = 0, \varepsilon = \varepsilon_o\varepsilon_r, and\ \mu = \mu_o$). If the Brewster angle is 68^0, find ε_r. (3 Marks)

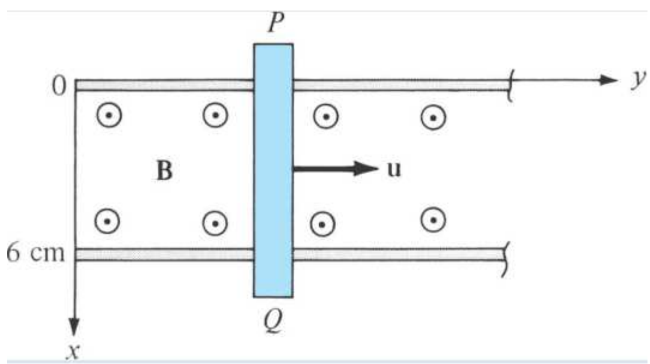

Fig. Q1(g)

QUESTION TWO (15 MARKS)

a) With aid of a diagram, state the **Poynting's theorem.** (2 Marks)

b) Electromagnetic radiation can be used to heat cancerous tumors. If a plane wave is normally incident on the tissue surface at 1.2 GHz as shown in Fig. Q2(b). At 1.2 GHz, the electrical properties of the tissue are $\mu_r = 1$, $\varepsilon_r = 50, \sigma = 4$ S/m. Determine:
i. The loss tangent of the tissue.
ii. The intrinsic impedance of the tissue.
iii. The refection coefficient. (6 Marks)

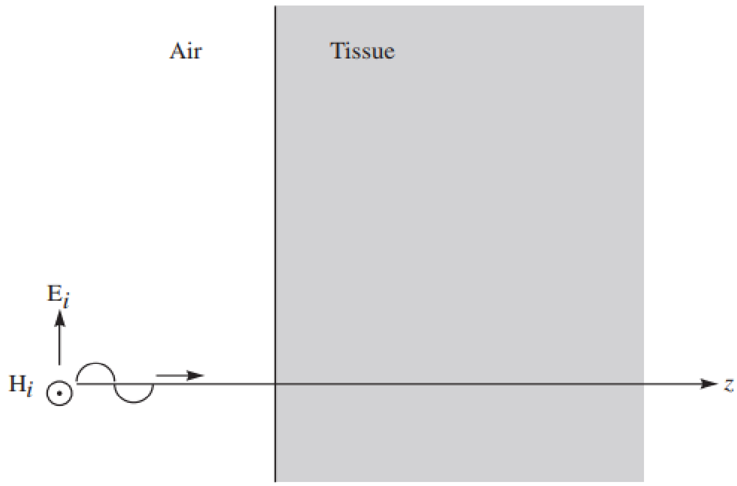

Fig. Q2(b)

c) In a charge-free region for which $\sigma = 0, \varepsilon = \varepsilon_o \varepsilon_r, and\ \mu = \mu_o,$

$$\boldsymbol{H} = 5\cos(10^{11}t - 4y)\, a_z\ A/m$$

Find

i. $\mathbf{J_d}$

ii. **D** and ε_r (7 Marks)

QUESTION THREE (15 MARKS)

a) Explain the term transverse electromagnetic wave. (1 Mark)

b) Consider a linear, isotropic, homogeneous, lossy dielectric medium that is charge free (macroscopic $\rho_v = 0$). Starting with the Maxwell's equations, show:

$$\nabla^2 \mathbf{E_s} + \gamma^2 \mathbf{E_s} = 0$$

$$\nabla^2 \mathbf{H_s} + \gamma^2 \mathbf{H_s} = 0$$

where

$$\gamma^2 = j\omega\mu\sigma - \omega^2\mu\varepsilon$$

(6 Marks)

c) The electric field and magnetic field in free space are given by

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

Express these in phasor form and determine the constants H_0 and β such that the fields satisfy Maxwell's equations. (8 Marks)

QUESTION FOUR (15 MARKS)

a) A plane wave in air has a propagation vector

$$\mathbf{k} = 124\boldsymbol{a}_x + 124\boldsymbol{a}_y + 263\boldsymbol{a}_z$$

Find the:

i. Wavelength

ii. Frequency. (3 Marks)

b) In free space,

$$\mathbf{E} = 40\cos(\omega t - 10z)\boldsymbol{a}_y$$

Find the total average power passing through a circular disk of radius 1.5 m in the *z* = 0 plane. (4 Marks)

c) At 50 MHz, a lossy dielectric material is characterized by $\sigma = 0.08\ S/m, \varepsilon = 3.6\varepsilon_o\ , and\ \mu = 2.1\mu_o$. If:

$$\mathbf{E_s} = 6e^{-\gamma x}\boldsymbol{a}_z$$

Compute:

i. Propagation constant

ii. Intrinsic impedance

iii. $\mathbf{H_s}$ (8 Marks)

QUESTION FIVE (15 MARKS)

a) Define the term skin depth. (1 Mark)

b) The electric field intensity of a uniform plane wave in free space is given by

$$\mathbf{E} = 40\cos(\omega t - \beta z)a_x + 60\sin(\omega t - \beta z)a_y\ V/m$$

Determine the magnetic field intensity (6 Marks)

c) A uniform plane wave in air with

$$\mathbf{E} = 8\cos(\omega t - 4x - 3z)\boldsymbol{a}_y\ \text{V/m}$$

is incident on a dielectric slab $(z\ \geq 0)$ with $\varepsilon_r = 2.5, \mu_r = 1, \sigma = 0$

Find:

i. ω and the polarization of the wave

ii. The angle of incidence

iii. The reflected **E** field (8 Marks)

Table 1: Useful Formulas

The gradient of a scalar field V

Cartesian coordinates

$$\nabla V = \frac{\partial V}{\partial x} a_x + \frac{\partial V}{\partial y} a_y + \frac{\partial V}{\partial z} a_z$$

Cylindrical coordinates

$$\nabla V = \frac{\partial V}{\partial \rho} a_\rho + \frac{1}{\rho}\frac{\partial V}{\partial \phi} a_\phi + \frac{\partial V}{\partial z} a_z$$

Spherical coordinates

$$\nabla V = \frac{\partial V}{\partial r} a_r + \frac{1}{\mathrm{r}}\frac{\partial V}{\partial \theta} a_\theta + \frac{1}{r \sin\theta}\frac{\partial V}{\partial \phi} a_\phi$$

The Divergence of a vector A

Cartesian coordinates

$$\nabla \cdot \mathrm{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}$$

Cylindrical coordinates

$$\nabla \cdot \mathrm{A} = \frac{1}{\rho}\frac{\partial}{\partial \rho}(\rho A_\rho) + \frac{1}{\rho}\frac{\partial A_\phi}{\partial \phi} + \frac{\partial A_z}{\partial z}$$

Spherical coordinates

$$\nabla \cdot \mathrm{A} = \frac{1}{r^2}\frac{\partial}{\partial r}(r^2 A_r) + \frac{1}{\mathrm{r}\sin\theta}\frac{\partial}{\partial \theta}(A_\theta \sin\theta) + \frac{1}{r \sin\theta}\frac{\partial A_\phi}{\partial \phi}$$

The curl of a vector A

Cartesian coordinates

$$\nabla \times \mathrm{A} = \left[\frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z}\right] a_x + \left[\frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x}\right] a_y + \left[\frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y}\right] a_z$$

Cylindrical coordinates

$$\nabla \times \mathrm{A} = \left[\frac{1}{\rho}\frac{\partial A_z}{\partial \phi} - \frac{\partial A_\phi}{\partial z}\right] \mathrm{a}_\rho + \left[\frac{\partial A_\rho}{\partial z} - \frac{\partial A_z}{\partial \rho}\right] \mathrm{a}_\phi + \frac{1}{\rho}\left[\frac{\partial(\rho A_\phi)}{\partial \rho} - \frac{\partial A_\rho}{\partial \phi}\right] \mathrm{a}_z$$

Spherical coordinates

$$\nabla \times \mathrm{A} = \frac{1}{r \sin\theta}\left[\frac{\partial(A_\phi \sin\theta)}{\partial \theta} - \frac{\partial A_\theta}{\partial \phi}\right] \mathrm{a}_r + \frac{1}{r}\left[\frac{1}{\sin\theta}\frac{\partial A_r}{\partial \phi} - \frac{\partial(rA_\phi)}{\partial r}\right] \mathrm{a}_\theta + \frac{1}{r}\left[\frac{\partial(rA_\theta)}{\partial r} - \frac{\partial A_r}{\partial \theta}\right] \mathrm{a}_\phi$$