MACHAKOS UNIVERSITY

University Examinations for 2021/2022

SCHOOL OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

FOURTH YEAR SECOND SEMESTER EXAMINATION FOR

BACHELOR OF SCIENCE (ELECTRICAL AND ELECTRONICS ENGINEERING)

EEE 415: ELECTRODYNAMICS AND INSULATING MATERIALS

DATE: 17/12/2021 **TIME: 11.00-1.00 PM**

INSTRUCTIONS

- *This paper consists of* ***Five*** *Questions*
- ***Question 1*** *is* **Compulsory**.
- *Attempt* ***Any Other Two Questions***

Important Physical Constants

Conductivity of copper $\sigma = 5.8x10^{7}S/m$

$\mu_0 = 4\pi x10^{-7}H/m$

$\epsilon_0 = 8.854x10^{-12}F/m$

QUESTION ONE (COMPULSORY) (30 MARKS)

a) State and explain the three *Sub Regions* of the electromagnetic spectrum (6 marks)

b) Show that the two "Divergence" Maxwell's Equations are implied by the two "Curl" Equations and the Equation of Continuity (4 marks)

c) The current density in a certain region can be approximated in spherical coordinates as

$$J = J_0 \frac{\exp -t/\tau}{r} U_r$$

i. Determine the total current that leaves a spherical surface whose radius is a at the time $t = \tau$ (2 marks)

ii. Derive the expression of the charge density $\rho(r, t)$ (3 marks)

d) The current through a gap filled with a gaseous insulating medium can be expressed by

$$I = \frac{I_0 exp\ (\alpha_0 d)}{\{1 - \alpha_s(exp\ (\alpha_0 d) - 1)\}}$$

All the symbols carry their usual meaning

Given that $\alpha_0 d = K$ as the general form of Townsend Criterion, and that

$$\frac{\alpha_0}{p} = A \exp\left(-\frac{Bp}{E}\right)$$

Show that the point of minimum potential V_B can be given by

$$V_B = \left(\frac{E}{p}\right) pd + \sqrt{\frac{K}{C}}\sqrt{pd}$$

Where A,B,C and E are empirical constants while K defines the relationship between the Townsends and the Panchen's Law (5 marks)

e) For the conducting material, we may assume that the conducting current density is much larger than the displacement current density.

i. Show that the Maxwell's Equations can be cast in the form of a *Diffusion Equation* in this material (6 marks)

ii. A magnetic flux density $B_x\ (z, t)$ occurs near a planar vacuum-copper interface assuming that copper has $\mu = \mu_0$ and that a 60Hz time-harmonic electromagnetic signal is applied. Determine the skin depth (4 marks)

QUESTION TWO (20 MARKS)

a) Define the following terms as used in the study of dielectrics (4 marks)

i. Propagation Constant

ii. Loss Tangent

iii. Intrinsic Impedance

iv. Phase Velocity

b) Beginning from the Maxwell's Equations, show that (3 marks)

$$\nabla^2 E - \gamma^2 E = 0$$

Where

$$\gamma = \alpha + j\beta = j\omega\sqrt{\mu\epsilon}\left[1 + \frac{\sigma}{j\omega\epsilon}\right]^{1/2}$$

All the symbols carry their usual meaning

c) Given that $\epsilon = \epsilon' - j\epsilon''$, show that for a low loss dielectric (9 marks)

$$\alpha = \frac{\omega\epsilon''}{2}\sqrt{\frac{\mu}{\epsilon'}}$$

$$\beta = \omega\sqrt{\mu\epsilon'}\left[1 + \frac{1}{8}(Tan\ \delta)^2\right]$$

$$\eta = \sqrt{\frac{\mu}{\epsilon'}}\left[1 + j\frac{\text{Tan}\ \delta}{2}\right]$$

$$\upsilon_P = \frac{1}{\sqrt{\mu\epsilon'}}\left[1 - \frac{1}{8}(Tan\ \delta)^2\right]$$

d) A narrow-band signal propagates in a lossy dielectric medium with a loss tangent of 0.2 and 550 kHz is the carrier frequency of the signal. If the dielectric constant of the medium is 2.5, determine the (4 marks)

i. Propagation Constant

ii. Group Velocity.

QUESTION THREE (20 MARKS)

a) Define *Complex Poynting Vector* and the *Average Poynting Vector* (2 marks)

b) A plane wave is propagating in a lossy media. Beginning from the Maxwell's Equations, show that the average of the complex pointing vector, includes the complex power (P_S)delivered by the source $\vec{J_s}$, the conduction losses, dielectric losses and the net reactive energy stored in the fields. (8 marks)

c) An *Elliptically Polarized* wave propagating in the +z direction is represented by the x and y components of the electric field vector given by

$$E_x(z,t) = E_1 \sin(\omega t - \beta z)$$

$$E_y(z,t) = E_2 \sin(\omega t + \delta - \beta z)$$

i. Show that the *Poynting Vector* of the Elliptical Polarization is given by (7 marks)

$$\vec{S}_{ave} = \hat{z}\frac{\eta_0}{2}H^2 = \hat{z}\frac{1}{2\eta_0}E^2$$

All the symbols carry their useful meaning

ii. Given that

$$\vec{E} = 10\,\mathrm{Cos}\left(\omega t + \frac{4\pi}{3} z\right) U_x V/m$$

And that

$$\vec{H} = \frac{U_z x \vec{E}}{\mu_0} \; A/m$$

Determine the *average power per unit area* transported by the wave at a frequency of 500MHz from *First Principles* (3 marks)

QUESTION FOUR (20 MARKS)

a) Define TEM Wave (2 marks)

b) State the reduced maxwell's equations for the TEM waves (3 marks)

c) For the TEM waves propagating in a Lossy Medium in +Z direction, derive expressions of $\vec{E}(z,t)$ and $\vec{H}(z,t)$. Explain all the symbols used (8 marks)

d) The Electric Field intensity of a linearly polarized uniform wave propagating in the +z direction in sea water at the surface $z = 0$ is

$$\vec{E} = \hat{x}100\cos(\pi x 10^7) V/m$$

Sea water has $\epsilon_r = 72$, $\mu_r = 1$ and $\sigma = 4S/m$.

Determine the expression for $\vec{E}(z,t)$ and $\vec{H}(z,t)$ at $z = 0.8m$ as a function of time (7 marks)

QUESTION FIVE (20 MARKS)

a) A parallel polarized wave at an oblique incidence on a dielectric interface is as shown in Figure Q 5a). Derive the expressions for the *Brewster and Transmission Angles*. All symbols carry their usual meaning (7 marks)

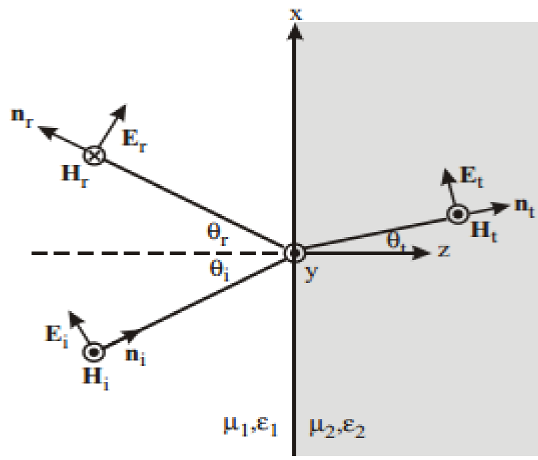

Figure Q 5a)

b) The same wave in Question 5a) is perpendicularly polarized. Derive the expressions for the Fresnel's Coefficients of Reflection and Transmission. All symbols carry their usual meaning. (7 marks)

c) The dielectric constant of pure water is 80. Determine the following

(i) Brewster Angle and Angle of Transmission for Question 5a) above (3 marks)

(ii) Reflection and Transmission coefficients at $\theta_i = \theta_{Bp}$ (3 marks)