MACHAKOS UNIVERSITY

University Examinations for 2019/2020Academic Year

SCHOOL OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

FOURTH YEAR SECOND SEMESTER EXAMINATION FOR

BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONICS ENGINEERING

EEE 415: ELECTRODYNAMICS AND INSULATING MATERIALS

DATE: 9/11/2020 **TIME: 2.00-4.00 PM**

INSTRUCTIONS

Answer Question One and Any Other Two Questions

Important Physical Constants

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

$\mu_0 = 4\pi x 10^{-7} H/m$

$\epsilon_0 = 8.854 x 10^{-12} F/m$

QUESTION ONE (30 MARKS) (COMPULSORY)

a) 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

(5 marks)

b) Given that $\epsilon = \epsilon' - j\epsilon''$, show that (6 marks)

$$\alpha = \omega \sqrt{\frac{\mu\epsilon'}{2}} \left[\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} - 1 \right]^{1/2}$$

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

All symbols carry their usual meaning

c) Charges are introduced into the interior of a copper conductor during the time $t < 0$.

i) Show that

$$\rho = \rho_0 \exp(-t/\tau)$$

Where τ is the time constant, ρ is the charge density (4 marks)

ii) Determine the time it takes these charges to move to the surface of the conductor so that both the interior charge density and the interior electric field are zero (2 marks)

d) 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

i) Derive and solve the *Diffusion Equation* for this case (4 marks)

ii) Plot the solution for the spatial profile of the magnetic field (2 marks)

e) A y-polarized uniform plane wave $\left(\vec{E}_i, \vec{H}_i\right)$ of frequency 100MHz propagates in air in the +z direction and impinges normally on a perfectly conducting plane at $z = 0$. Assuming the amplitude of $\vec{E}_i$ to be 6mV/m, determine the phasor and instantaneous expressions for

(i) $\vec{E}_i \ and \ \vec{H}_i$

(ii) $\vec{E}_r \ and \ \vec{H}_r$

(iii) $\vec{E}_1 \ and \ \vec{H}_1$ in air (7 marks)

QUESTION TWO (20 MARKS)

a) State *Helmholtz* Theorem (2 marks)

b) The magnetic flux density in a medium can be defined by $\vec{B} = \vec{\nabla}\, x\vec{A}$ where $\vec{A}$ is a vector potential function. A scalar potential function ϕ can also be defined for the same field. Show that the Electric Field for the same medium can be completely defined in terms of the vector and scalar potential functions (3 marks)

c) Beginning from the Maxwell's Equation derived from the Amperes' Law, show that the Inhomogeneous Helmholtz Relationship for a wave propagating in the medium in Q 2b) above can be expressed as (8 marks)

$$\nabla^2\vec{A} + K^2\vec{A} - j\omega\sigma\mu\vec{A} = \sigma\mu\vec{\nabla}\,\phi$$

d) Figure Q 2d) shows two similar parallel wire loops with a radius $R = 50cm$. Their centers are separated by a distance $h = 2\,R$(Helmholtz Coils). Determine the normalized mutual inductance for the system, M/μ_0 (7 marks)

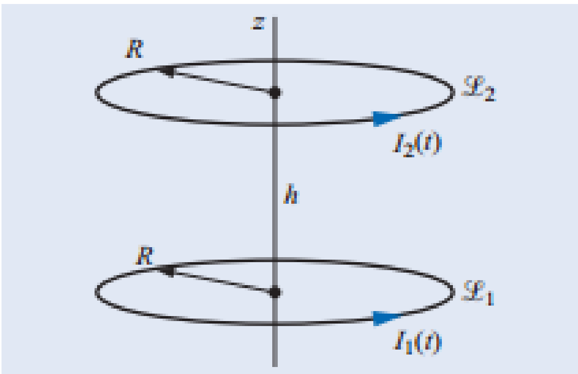

Figure Q 2d)

QUESTION THREE (20 MARKS)

a) For a conducting material, show that

$$\vec{E} = \frac{\vec{\nabla}\, x\vec{B}}{\mu[\sigma + j\omega\epsilon_0(1 + X_e)]}$$

All symbols carry their usual meaning (6marks)

b) Show that the Wave Equation for a good conductor can be defined as

$$\nabla^2\vec{H} + \gamma^2\vec{H} = 0$$

Define the expression of γ completely. All symbols carry their usual meaning (5 marks)

c) In a perfect conductor interface, the electromagnetic field can only penetrate the good conductor to a small distance at microwave frequencies. Show that the *depth of penetration* is proportional to resistivity of the conductor (4 marks)

d) State the boundary conditions for an *Electric Wall* in terms of $\vec{H}$ and $\vec{E}$ (5 marks)

QUESTION FOUR (20 MARKS)

a) State the Boundary Conditions for a *Dielectric-Dielectric Interface* in terms of $\vec{E}$ and $\vec{H}$ (4 marks)

b) A plane wave is propagating in a *dielectric lossy* media. Beginning from the Maxwell's Equations, derive the expression of dielectric *losses* in such a material (6 marks)

c) A harmonic time-dependent vector potential field $\vec{F}$ is defined in a charge-free, current-free region of space filled with homogeneous *dielectric medium* such that

$$\vec{E} = -\frac{1}{\epsilon}\vec{\nabla}x\vec{F}$$

$$(\nabla^2 + \omega^2\mu\epsilon)\vec{F} = 0$$

Where all the symbols carry their usual meaning.

(i) Show that the magnetic field intensity can be given by (2 marks)

$$\vec{H} = j\omega\vec{F}$$

(ii) Obtain the expressions of the fields of a Transverse Electric wave (TE) from the axial component F_z, giving the boundary conditions $\vec{F}$ must satisfy (*Hint: Assume $\vec{F}$ is an axial vector field*) (8 marks)

QUESTION FIVE (20 MARKS)

a) Discuss the classification of *solid-state* insulators, giving the limiting temperature for their operation and the specific examples in each case (6 marks)

b) State the properties of *Liquid* insulators (2 marks)

c) 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

i. Derive the *Townsend Breakdown Criterion* (TBC) (1.5 marks)

ii. Explain the three cases for the TBC (1.5 marks)

iii. Derive the *Panchen's Law* from Q 5 ci) above (2.5 marks)

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

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

Given that A=12, B=365 and $\alpha_s = 0.02$, show that the minimum potential for Air insulation is approximately *261V* (4 marks)

d) Show that the point of minimum potential V_B can be given by the *Schuman's Relationship*

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

A, B, C and E are empirical constants while K defines the relationship between the Townsends and the Panchen's Law (2.5 marks)