NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OFAPPLIED SCIENCE

DEPARTMENT OF APPLIED PHYSICS

BSc. (Hons) IN APPLIED PHYSICS PART IV

ELECTROMAGNETIC THEORY

SPH4106

Examination Paper

December 2024

This examination paper consists of 4 pages

Time Allowed:	**3 hours**
Total Marks:	**100**
Special Requirements:	**None**
Examiner's Name:	**Dr. P. Baricholo**

<u>INSTRUCTIONS</u>

ANSWER ALL PARTS OF QUESTION 1 IN SECTION A AND ANY THREE QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS.

Important Constants

Permittivity of Free Space	ε_0	$= 8.85 \times 10^{-12}$ F m^{-1}
Permeability of Free space	μ_0	$= 4\pi \times 10^{-7}$ Hm^{-1}
Rest mass of an Electron	m	$= 9.1 \times 10^{-31}$ kg
Charge on an Electron	e	$= 1.6 \times 10^{-19}$ C
Speed of light	c	$= 3 \times 10^{8}$ ms^{-1}

SECTION A

1. a) A 100 M*Hz* uniform plane wave $\vec{E} = \hat{x}E_x$ propagates in the +*z* direction. Suppose ε_r = 4, μ_r = 1, σ = 0, and it has a maximum value of 10^{-4} *V/m* at *t* = 0 and *z* = 0.125*m*.

   i. Write the instantaneous expressions for $\vec{E}$ and $\vec{H}$. [2, 2]

   ii. Determine the location where $\vec{E}$ is a positive maximum when $t = 10^{-8}$ sec. [3]

   b) A plane travelling wave has a peak electric field $E_o = 6\ Vm^{-1}$. If the medium is lossless with ε_r = 3, μ_r = 1, find

   i. peak Poynting vector and [2]

   ii. impedance of the medium. [3]

   c) Show that the impedance of free space is given by $Zo = \sqrt{\frac{\mu_o}{\varepsilon_o}} = 120\,\pi\,\Omega$. [3]

   d) A charged particle moves in a straight line through a particular region of space. Could there be a nonzero magnetic field in this region? If so, give two possible situations. [4]

   e) A lossy dielectric is characterized by ε_R=1.5, μ_R=1 and $\frac{\sigma}{\omega\varepsilon} = 2.5 \times 10^{-4}$. At a frequency of 200 MHz, how far can a uniform plane wave propagate in the material before

   i. it undergoes an attenuation 1 Np and [4]

   ii. its amplitude is halved. [3]

   f) The carrier frequencies of FM broadcasts are much higher than for AM broadcasts. Explain why AM signals can be detected more readily than FM signals behind low hills or buildings. [3]

   g) If the magnetic field phasor of a plane wave travelling in a medium with intrinsic impedance is $\eta = 100\ \Omega$ is given by $\vec{H_s} = (10\hat{y} + 20\hat{z})e^{-j4x}$ mA/m. Find the associated electric field phasor. [5]

   h) Given the volume charge density $\rho = -2 \times 10^7 \varepsilon o\sqrt{x}$ C/m^3 in free space, if V = 0 at *x* = 0 and V = 2 V at *x* = 2.5 mm. For *x* = 1 mm, find V and E_x. [3, 3]

SECTION B

2. a) A time-dependent electric field intensity is given as $\vec{E} = \hat{x}10\pi\cos(10^6 t - 50z)$V/m. The field exists in a material with properties ε_r = 4 and μ_r = 1. Given that $\vec{J} = 0$and ρ

= 0, calculate the magnetic field intensity and the magnetic induction vector in the material. [4, 1]

b) The magnetic vector of a plane electromagnetic wave is described as follows:

$$\vec{B} = \hat{k}B_o cos[(10\ m^{-1})y + (3 \times 10^9 s^{-1})t]$$

where $\hat{k}$ is a unit vector in the z-direction, y is in meters, and t is in seconds. What is the time-dependent Poynting vector associated with this wave? [5]

c) Most microwave ovens operate at 2.45 GHz, assume that $\sigma = 1.2 \times 10^{-6}\ S/m$ and $\mu_r = 500$ for stainless steel interior. If $E_s = 50\angle 0^o$ at the surface, find

i. the penetration depth or skin depth δ_s and [3]

ii. amplitude of the electric field E_s as a function of the angle. [3]

iii. Plot this electric field as it propagates in the stainless steel. [4]

3. a) Two infinite length, concentric and conducting cylinders of radii a and b are located on the z axis. If the region between cylinders is charged free and $\varepsilon = 3\varepsilon_o$, $V = V_o$ at a, $V = 0$ at b and $b > a$. Find the capacitance per meter length. [10]

b) Show that the ratio of the amplitudes of the conduction current density and the displacement current density is $\frac{\sigma}{\omega\varepsilon}$ for the applied field $E = E_m \cos \omega t$. [5]

c) Find the displacement current density associated with the magnetic field

$$\vec{H} = A_1 \sin(4x) \cos(\omega t - \beta z)\, \widehat{\boldsymbol{a}}_x + A_2 \cos(4x) \sin(\omega t - \beta z)\, \widehat{\boldsymbol{a}}_z. \quad [5]$$

4. a) A 3 GHz frequency wave (wavelength of 100 mm) is carried in a conductor A of μ_r and ε_r equal to unity. Determine the intrinsic impedance, Z_c for the conductor at 100 mm. Assume that $\frac{\varepsilon\omega}{\sigma} = 2.9 \times 10^{-9}$ for conductor A; $\mu_o = 4\pi \times 10^{-7}\ Hm^{-1}$ and $\varepsilon_o = 8.85 \times 10^{-12}\ Fm^{-1}$. [5]

b) An open wire (parallel wire) telephone line has the following line parameters: R = 4.11 Ωkm^{-1}; L = 0.00337 H km^{-1}; G = 0.29 $\mu S\ km^{-1}$ and C = 9.15 nF km^{-1}. Find

i. Z_o, [3]

ii. γ and [3]

iii. iii. the input impedance 20 km from a load of ZL = (50 +50j) Ω at a frequency of 1000 Hz. [4]

c) A lossless line whose Z_o is 50 Ω is connected to a load $Z_L = 50/\underline{25.99^o}\ \Omega$. Find Z_{in} at $l = \lambda/8$. [5]

5. a) A slab of perfect dielectric material ($\varepsilon_r = 2$) is placed in a microwave oven. The oven produces an electric field (as well as a magnetic field). Assume that the electric field intensity is uniform in the slab and sinusoidal in form and that it is perpendicular to the surface of the slab. The microwave oven operates at a frequency of 2.45 GHz and produces an electric filed intensity with amplitude 500 V/m inside the dielectric.

   i. Calculate the displacement current density in the dielectric. [3]

   ii. Is there a displacement current in air? If so, calculate it. [2]

b) At a frequency of 4 MHz a parallel wire transmission line has the following parameters: R = 0.025 Ω /m, L = 2 μH/m, G = 0, C = 5.56 pF/m. The line is 100 meters long, terminated in a resistance of 300 Ω. Find

   i. the standing wave ratio and [5]

   ii. voltage reflection coefficient of the load. [3]

c) Distinguish a lossless transmission line from a distortionless transmission line. [2]

d) Explain the difference between phase velocity and group velocity. [2]

e) What do you understand by the term "standing wave"? [3]

6. a) A plane polarized electromagnetic wave in the Y-direction is incident on a conducting medium whose conductivity $\sigma = 5.8 \times 10^7$ (Wm^{-1}) and frequency 100 MHz. Obtain an expression for:

   i. penetration depth, [2]

   ii. phase velocity, [2]

   iii. attenuation constant and [3]

   iv. intrinsic impedance of the medium. [3]

b) Discuss "gain" as applied to antennas. [4]

c) Suggest the factors that influence the design structure of a waveguide. [3]

d) State 2 similarities and 2 differences between the propagation of plane waves in free space and conductive medium. [3]

END OF EXAMINATION