NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF APPLIED PHYSICS

TEE 3201 – ELECTROMAGNETIC THEORY

BSc HONOURS PART III: May 2013 *DURATION: 3 HOURS*

ANSWER **ALL** PARTS OF **QUESTION ONE** FROM SECTION A AND ANY **THREE** FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS.

Planck's Constant	h	$= 6.63 \times 10^{-34}$ Js
Permittivity of Free Space	ε_0	$= 8.85 \times 10^{-12}$ Fm^{-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) i. 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]

ii. Use Ampere's law to show that the magnetic field between the conductors of a coaxial cable is $\boldsymbol{B} = \frac{\mu_0 I}{2\pi r}$, if r is greater than the radius of the inner wire and less than the radius of the outer cylindrical braid. [3]

iii. Show that $\vec{B} = 0$ outside the coaxial cable. [5]

b) What is the difference between magnetic flux and magnetic field? [3]

c) 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. [2]

d) i. Starting from Gauss's law, find the mathematical expressions that constitute the divergence theorem. [4]

ii. In your own words, state the meaning of the divergence theorem. [3]

e) i. Write down Maxwell's equations for conducting media. [4]

ii. Deduce the free space wave equation for the $\vec{E}$ field. [5]

iii. State *two* similarities and *two* differences between the propagation of plane waves in free space and conductive medium. [4]

f) 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]

Section B

2. a) Show that from Maxwell's equation, we can deduce the law of conservation of electric charge i.e. $\nabla \cdot \vec{J} = -\frac{\partial \rho}{\partial t}$. [5]

   b) Demonstrate that $\nabla \cdot \vec{B} = 0$. [5]

   c) i. Consider a plane electromagnetic wave propagating in free space. It the electric field vector is given by $\vec{E}(x, y, z) = E_o \cos kz\, \hat{\imath}$, determine the magnetic field vector $\vec{B}$. [3]

   ii. Explain why for radio and television broadcast, electromagnetic waves are broadcast at high frequency? [4]

   d) The velocity of propagation of a plane wave is given by $v_p = \omega/\beta$. Discuss this velocity in terms of velocity of light, c, for a conductive medium as compared to free space. [3]

3. a) i. Why are the coordinates on a Smith chart normalized? [2]

   ii. How does skin effect affect the loss of a transmission line? [3]

   b) i. For an air-filled waveguide whose inside dimensions are 3.0 in. x 1.5 in., find the cutoff frequency and cutoff wavelength for the TE_{10} mode. [3]

   ii. For the same waveguide, calculate the fields in terms of an arbitrary constant H_{z0} for f = 2.45 GHz operating in the TE_{10} mode. [7]

   c) Highlight the properties of a dielectric and conducting medium. [5]

4. a) Using Maxwell's equations for a non conducting medium, obtain the wave equation. [10]

   b) i. Show that $\vec{E} = \frac{\sqrt{\varepsilon\mu}}{c} \hat{\imath} \times \vec{B}$. [7]

   ii. What is the physical interpretation of the equation in b) i. [3]

5. A 1 MHz plane wave is propagating in a conductive medium of $\varepsilon_r = 8, \sigma = 4.8 \times 10^{-2} S/m, \mu = \mu_0$.

a) Find the ratio between the magnitudes of the conduction to the displacement currents. [3]

b) From the result obtained in question 5a, derive the expression for attenuation constant and its value. [6]

c) If the maximum magnitude of the sinusoidal variation of the x-directed electric field is 100V/m at $t=0, z=0.3\pi$, determine the expression for the electric field in real-time. [6]

d) Determine the corresponding magnetic field. [5]

6. a) i. Define the terms "*relaxation time*" and "*penetration depth*". [4]

ii. Explain what you understand by the voltage standing wave ratio (VSWR), hence show that $VSWR = \frac{1+|\rho_v|}{1-|\rho_v|}$, where ρ_v is the reflection coefficient for voltage. [6]

b) i. In which direction does a constant-phase point move? [2]

ii. Explain what you understand by dispersion as applied to wave propagation? [4]

iii. Assuming that the smaller wave is a reflection of the larger, what is the magnitude of the reflection coefficient? [4]

END OF PAPER