NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

APPLIED PHSYICS DEPARTMENT

SPH 2105 – ELECTROMAGNETISM

BSc HONOURS PART II: *JANUARY 2003* *DURATION: 3 HOURS*

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

SECTION A

1. (a) (i) What is a "*loaded aerial*"? [1]

(ii) Define the terms for waves travelling on a lossless transmission line
(a) *velocity factor* [1]
(b) *complex reflection co-efficient* [1]

(iii) What is a "*loop*" or "*frame*" aerial? [2]

(b) An elliptically polarised wave travelling in the positive y-direction in air has the z and x components given by: $E_Z = 3\sin(\omega t - \beta y)\ Vm^{-1}$ and $E_X = 6\sin(\omega t - \beta y + 75^\circ)\ Vm^{-1}$. Find the average power per unit area conveyed by the wave. [5]

(c) The transmission co-efficient for a $\perp$ polarised wave is given by the relation

$$\rho_\perp = \frac{\cos\theta_i - \sqrt{(\varepsilon_2/\varepsilon_1) - \sin^2\theta_i}}{\cos\theta_i + \sqrt{(\varepsilon_2/\varepsilon_1) - \sin^2\theta_i}},$$

where the variables have their usual meanings for media 1 and 2.

(i) If $\varepsilon_2 > \varepsilon_1$, comment on the value of this relation. [1]

(ii) What happens if $\varepsilon_2 < \varepsilon_1$ and $\sin^2\theta_i \geq \varepsilon_2/\varepsilon_1$? Give the physical meaning. [3]

(iii) If the wave were parallel polarised, define the Brewster angle, θ_{iB} and give the physical interpretation. [3]

iv) A wave composed of both perpendicular and parallel components is incident at the Brewster angle. Comment on what happens to this wave. What implications are there for a circularly polarised wave incident at the Brewster angle? [3]

(d) (i) From the two Maxwell's equations; one derived from Ampere's law and the other one derived from Faraday's law, show that a constant equal in value to the speed of light $c = 3\times10^8 ms^{-1}$ may be deduced. [5]

(ii) A wave function is given by the relation $E_y = \sin(\beta x + vt)$. Show that the wave is travelling in the negative x-direction. [2]

(iii) Calculate the intrinsic impedance attributed to free space. [1]

(e) Show and explain Heaviside's condition for a distortionless transmission line, given $Z_0 = \sqrt{L/C}\left[1 + j\left(G/2\omega L - R/2\omega L\right)\right]$. [4]

(f) (i) Define the term, "*impedance matching*". Explain its use in *RF* applications. [4]

(ii) Give at least four ways to accomplish impedance matching. [4]

SECTION B

2. (a) (i) Define the terms "*relaxation time*" and "*skin effect*". [4]

(ii) A 3GHz frequency wave (*wavelength of 100mm*) is carried in a conductor A of μ_r and ε_r equal to unity. Determine the intrinsic impedance, Z_c for the conductor A at 100 mm. Assume that $\frac{\varepsilon\omega}{\sigma} = 2.9 \times 10^{-9}$ for conductor A; $\mu_0 = 4\pi \times 10^{-7} Hm^{-1}$ and $\varepsilon_0 = 8.85 \times 10^{-12} Fm^{-1}$. [4]

(iii) Comment on the value of Z_c obtained in the above calculation. [2]

(b) (i) An electromagnetic wave is linearly polarised in the vertical y-direction. Explain what you understand by this statement in terms of the electric field and the magnetic field of the wave. []

(ii) An electromagnetic wave travels from medium 1 of impedance Z_1 into medium 2, of impedance Z_2, where $Z_1 << Z_2$. Write down the relation for the transmitted electric field, E_t. [2]

(iii) Comment on the physics implied in the relation you have just written in (ii) above. [2]

(iv) The energy velocity for a wave is given by the relation $v_{en} = \frac{EH}{\varepsilon E^2}$. Comment on this relation with reference to the phase velocity v_p and the group velocity v_g in both non-dispersive and in a lossless dispersive medium. [5]

3. (a) A dielectric liquid has constants $\varepsilon_r = 81$ and $\mu_r = 1.0$. A wave is incident from the liquid onto the liquid-air interface.

(i) Calculate the critical angle. [2]

(ii) If the incident $E_\perp = 1000 mVm^{-1}$ and the angle of incidence is $45°$, calculate the magnitude of the field strength in air at the interface and at a distance $\frac{\lambda}{4}$ away from the interface. [8]

(iii) Comment on your result. [2]

(b) An aerial has an effective height of 120m and the current at the base is 450 amps (r.m.s.) at 50 kHz.

(i) Calculate the power radiated. [4]

(ii) If the total resistance of the aerial circuit is 1.2Ω, calculate the efficiency of the aerial. [3]

(iii) A feeder of characteristic impedance, 600Ω, is terminated in a resistance load of 60Ω. Calculate the standing wave ratio (swr). [1]

4. (a) If an open-wire feeder has a capacitance per km of $0.03\mu F$ and an inductance per km of $10.8mH$,

(i) find the characteristic impedance of the line, and [4]

(ii) calculate the characteristic impedance suitable for a quarter-wave matching line to match this feeder to a load of 300Ω. [4]

(b) (i) Explain in brief the meanings of the term: *stub matching*. [3]

(ii) Draw a polar diagram for an array of two vertical aerials, separated by a half-wave length, when the currents in the aerials are in phase. Show the calculations from which your diagram has been constructed. [9]

5. (a) (i) If at TM mode of propagation a wave guide has a cutoff frequency of 3GHz, calculate the characteristic impedance of the waveguide at a frequency of 5GHz. [3]

(ii) Determine the waveguide impedance for the TE mode of propagation for the conditions in (i) above. [3]

(iii) Determine the Q of a cavity resonator such that the centre frequency is 500 MHz and the response exceeds 70.7% of maximum from 495MHz to 505 MHz. [3]

(iv) Where must a micro-wave antenna be placed in relation to a parabolic reflector, in order to take advantage of beam-shaping properties of the parabola? [3]

(b) Consider a lossless coaxial line with an inductance, L henries / metre and a capacitance, C farads / metre.

(i) Give expressions for the characteristic impedance in Ohms and the velocity factor for this line. [4]

(ii) Calculate the inductance and capacitance of a 1 metre length of this line, if it has impedance of 50 Ohms and a velocity factor of [4]

6. (a) (i) State the electromagnetic boundary conditions that constrain electromagnetic wave propagation at the interface between air and a perfect conductor. [4]

(ii) Explain what is meant by the term *"transverse electromagnetic wave"* and give a diagram showing the directions of propagation, of electric field and the magnetic field in such a wave. [4]

(iii) State how a stack of metal plates spaced on an arbitrary distance apart, may be introduced into the transverse electromagnetic wave without disturbing it. [3]

(b) (i) Give a qualitative description of how the boundary conditions are satisfied for propagation in a rectangular hollow metal waveguide of cross-sectional dimensions, A metres and B metres. Assume $A > B$. [3]

(ii) If A is 1 cm long, determine the lowest mode cut-off frequency of this guide if it is air filled. [3]

(iii) Comment on the probable sources of attenuation in a waveguide made up of a rectangular metal pipe filled with a substance of relative dielectric constant q. [3]

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