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The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Electrical and Computer Engineering

Study Programme	: Bachelor of Technology Honours in Engineering
Name of the Examination	: Final Examination
Course Code and Title	**: EEX7333 /ECX6543 Microwave Devices and Antennas**
Academic Year	: 2020/21
Date	: 2022 – 02 - 23
Time	: 0930-1230 hrs
Duration	**: 3 hours**

General Instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **Eight (8)** questions in **Five (5)** pages.
3. Answer **Five (5)** questions. All questions carry equal marks.
4. Answer for each question should commence on a new page.
5. Important formulas are provided.
6. This is a Close Book Test **(CBT).**
7. Answers should be in clear handwriting.
8. Do not use red color pen.

1. According to Maxwell's equations, $\nabla \times H$ (the curl of magnetic field intensity) is given by

$\nabla \times H = J + \frac{\partial D}{\partial t}$, where H, J and D are the magnetic field intensity, the electric current density and the electric flux density respectively.

(a) Write an expression for the divergence of D in terms of charge density ρ. [2 *marks*]

(b) What is the relationship between J and the electric field intensity E? [2 *marks*]

(c) Take the divergence of the above equation (consider both sides) and show that

$$\frac{\partial \rho}{\partial t} + \rho \frac{\sigma}{\epsilon} = 0$$

, where σ and ε are the conductivity and the permittivity of the medium respectively. [4 *marks*]

(d) Show that $\rho = \rho_0 e^{-\left(\frac{\sigma}{\varepsilon}\right)t}$ is a solution to the differential equation given in (c). [4 *marks*]

(e) If $\sigma = 5\ S/m$ and $\varepsilon_r = 75$ for sea water find the time constant $\tau = \frac{\varepsilon}{\sigma}$ for sea water. The free space permittivity $\varepsilon_0 = 8.854 \times 10^{-12}\ F/m$. Compare this value with the period of a microwave signal whose frequency is 9 GHz. [4 *marks*]

(f) Does the charge density created in sea water due to the microwave signal disappear quickly? Justify your answer. [4 *marks*]

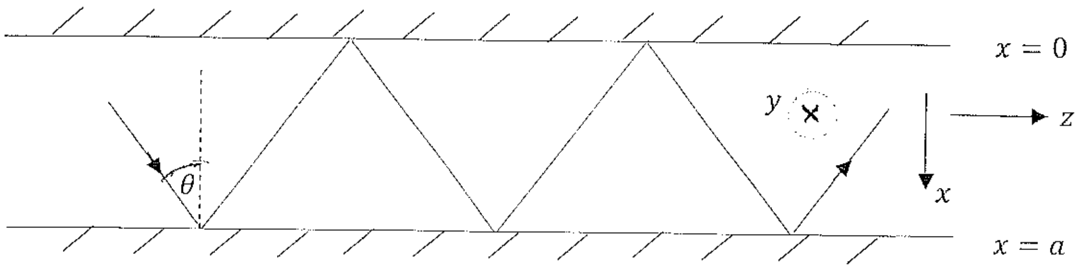
2. (a) The wave equation in free space is given by

$$\nabla^2 E = \mu_0 \varepsilon_0 \frac{\partial^2 E}{\partial t^2}$$

(i) If the above equation represents a plane wave propagating in the *z*-direction rewrite the above equation using the electric field component E_x . [4 *marks*]

(ii) How does the Electric field components E_x and E_y vary with x, y *and* z? [3 *marks*]

(b) A plane wave is reflected between two parallel conducting planes as shown in Fig.2.



The angle of incidence of the wave is θ. The separation between the conducting planes is a.

The electric field component in the y- direction is given by $E_y = A\, sin(\beta x cos\theta) e^{-j\beta z\, sin\theta}$, where A is a constant.

(i) State the boundary conditions for E_y. [3 *marks*]

(ii) Show that $cos\theta = \frac{m\lambda}{2a}$, where m is an integer. [6 *marks*]

(iii) Using b (ii) find the cut-off wavelength λ_c. [4 *marks*]

3. (a) Transverse electric field components inside a rectangular waveguide for TE_{mn} mode is given below:

$$E_x = nA \cos\left(\frac{m\pi x}{a}\right) \sin\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$$

$$E_y = mB \sin\left(\frac{m\pi x}{a}\right) \cos\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$$ where A and B are constants.

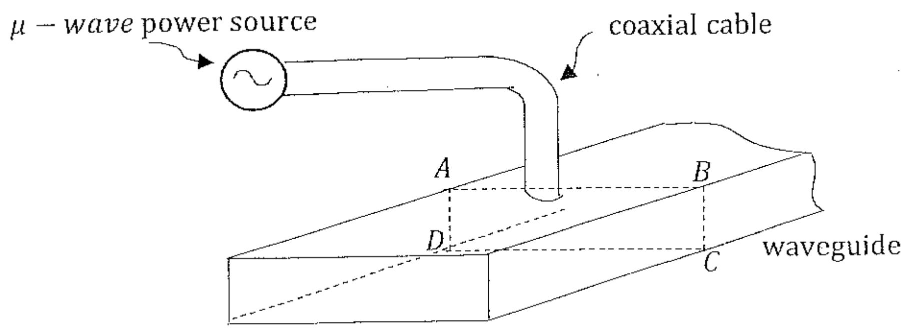
(i) What are the boundary conditions that should be satisfied by E_x and E_y? [3 *marks*]

(ii) Show that E_x and E_y satisfy the boundary conditions mentioned in (ii). [4 *marks*]

(b) An electromagnetic wave is propagating in an air-filled lossless waveguide. The frequency of the wave is 12 GHz. The mode of propagation of the wave is TE_{21}. If the wave guide has the inner dimensions $a = 4\ cm$ and $b = 2\ cm$, find

(i) the wave number k. [3 *marks*]
(ii) the cutoff wave number k_c. [3 *marks*]
(iii) the propagation constant β. [4 *marks*]
(iv) the guide wavelength λ_g. [3 *marks*]

4. (a) A waveguide is excited magnetically as shown in the Fig. 4. The mode of excitation is TE_{10}



(i) What is the direction of the resultant transverse electric field? [4 *marks*]
[You may use the equations given in 3(a)]

(ii) Sketch the electric field distribution at the coaxial cable – waveguide junction in the ABCD plane. [5 *marks*]

(b) What are precautions taken in a practical waveguide to minimize the attenuation due to the metallic body? [4 *marks*]

(c) (i) What are the major causes for the attenuation of a signal in a waveguide? [4 *marks*]

(ii) What is *loss tangent*? [3 *marks*]

5. (a) A cylindrical waveguide has following transverse magnetic field components for the TM_{nm} mode:

$$H_\rho = \frac{j\omega\varepsilon n}{{k_c}^2\rho}(A\cos n\phi - B\sin n\phi)\, J_n(k_c\rho)e^{-j\beta z}$$

$$H_\phi = \frac{-j\omega\varepsilon}{k_c}(A\sin n\phi + B\cos n\phi)\, J_n{}'(k_c\rho)e^{-j\beta z}$$

Derive an expression for k_c by applying the boundary conditions to the waveguide. [7 *marks*]

(b) For a cylindrical waveguide, values of ρ_{nm} for different values of n and m for TM_{nm} mode are given in the Table 5.

n	ρ_{n1}	ρ_{n2}	ρ_{n3}
0	2.405	5.520	8.654
1	3.832	7.016	10.174
2	5.135	8.417	11.620

Table 5

(i) Using the values given in the table explain how you would find the dominant TM mode for a cylindrical waveguide. [5 *marks*]

(ii) Find the cutoff frequency for the dominant TM mode for an air-filled waveguide having the breadth $a = 4\ cm$. [4 *marks*]

(iii) What is a linearly polarized wave? [4 *marks*]

6. (a) The electric field vector of a plane wave propagating in the $z - direction$ is given by $\bar{E}(z,t) = E_0(\hat{x}\cos(\omega t - k_0 z) + \hat{y}\sin(\omega t - k_0 z))$ where $\hat{x}$ and $\hat{y}$ are the unit vectors in the direction of $x - direction$ and $y - direction$ respectively.

(i) Find the magnitude and the direction of $\bar{E}(z,t)$ when $z = z_0$. [5 *marks*]

(ii) Show that the wave is *circularly* polarized. [5 *marks*]

(b) For a circular resonant cavity with radius a and the cavity length d the propagation constant for nm^{th} mode satisfies the condition $sin(\beta_{nm} d) = 0$.

(i) Find a general value for β_{nm}. [3 *marks*]

(ii) Substituting the answer to (b)(i) in the expression $\beta_{nm}{}^2 = k^2 - k_c{}^2$, show that the resonance frequency of the cavity for TM_{nm} mode is given by

$$f_{nml} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{p_{nm}}{a}\right)^2 + \left(\frac{l\pi}{d}\right)^2}.$$ [4 *marks*]

(iii) Use the Table 5 to find the resonance frequency of the cavity for TM_{211} mode. The radius a and the cavity length d for the cavity are $4\ cm$ and $6\ cm$ respectively. Assume that the cavity is air-filled. [3 *marks*]
[The velocity of $e.m.$ waves in air is $3 \times 10^8\ m/s$.]

7. (a) Write the scattering matrix for a 3-port junction. [1 *marks*]

(i) If all the ports of the junction are matched and the junction is lossless write the relationship between various elements of the s- matrix. [3 *marks*]

(ii) If $|s_{12}| = 0$, find all the elements of the matrix. [6 *marks*]

(iii) Show that the junction is *a circulator*. [4 *marks*]

(b) Describe the principle of operation of a multi-hole directional coupler. [6 *marks*]

8.

(a) The far-field electric field strength of a Hertzian dipole at a distance R is given by

$$E_\theta = j\frac{Ie^{-j\beta R}dl}{4\pi R}\eta_0\beta sin\theta.$$

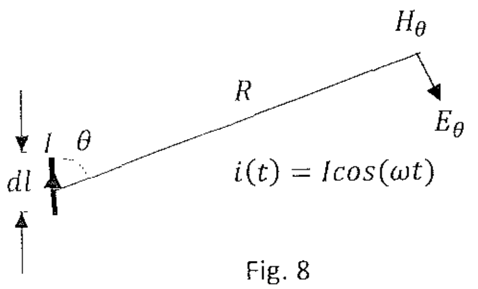


Fig. 8

(i) What is the direction of the magnetic field strength H_θ? [4 *marks*]

(ii) Draw the radiation pattern of the antenna and find the beamwidth. [8 *marks*]

(b) A rectangular waveguide is connected to a rectangular horn whose width and the height are 6 cm and 3 cm respectively. The waveguide is operating in the dominant TE mode and has an internal width of 4 cm. The waveguide is operating at a frequency of 1.2 f_c, where f_c is the cutoff frequency of the waveguide. Find the directivity of the horn antenna. [8 *marks*]

[$Directivity = \frac{7.5\,A}{\lambda^2}$, A *is the aperture of the antenna.* λ *is the wavelength of the signal*]