**NANYANG TECHNOLOGICAL UNIVERSITY**

**SEMESTER 1 EXAMINATION 2018-2019**

**EE3001 – ENGINEERING ELECTROMAGNETICS**

November / December 2018 Time Allowed: 2½ hours

**INSTRUCTIONS**

1. This paper contains 4 questions and comprises 7 pages.
2. Answer ALL questions.
3. All questions carry equal marks.
4. This is a closed book examination.
5. Unless specifically stated, all symbols have their usual meanings.
6. A list of formulae and physical constants is provided in Appendix A on pages 5 to 7.
7. The Smith Chart may be used in the solution of Question 4. Please put the Smith Chart inside the answer script and tie it with a thread.

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1. (a) Figure 1 (on page 2) shows a semi-square loop formed by three straight conducting wires in free space. The loop lies in the $z = 0$ plane and carries a uniform line charge density of $\rho_l$.

   (i) What is the direction of the overall electric field intensity at the origin (0, 0, 0) due to the loop? Explain your answer qualitatively.

   (ii) Determine the expression for the overall electric field intensity at (0, 0, 0).

   It is given that $\int \frac{dz}{(b+z^2)^{1.5}} = \frac{z}{b\sqrt{b+z^2}}$ and $\int \frac{zdz}{(b+z^2)^{1.5}} = \frac{-1}{\sqrt{b+z^2}}$

(13 Marks)

Note: Question No. 1 continues on page 2.

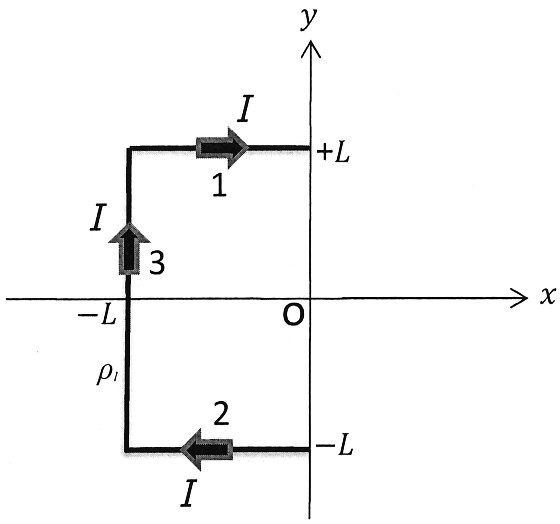


**Figure 1**

(b) Assume that the charges in the semi-square loop in Figure 1 move in the clockwise direction so as to constitute a DC current $I$ in the loop.

(i) Determine an expression for the overall magnetic field intensity at the origin (0, 0, 0) due to the loop.

It is given that $\int \frac{dz}{(a+z^2)^{1.5}} = \frac{z}{a\sqrt{a+z^2}}$

(ii) What major change is expected in the magnetic field intensity if the field point is shifted to (0, $d$, 0), where $d > L$?

(12 Marks)

2. (a) A 5-turn loop with 0.5 m$^2$ area for each turn is situated in air and lies in a uniform magnetic flux density normal to the plane of the loop. If the induced voltage at the loop terminals is 150 mV, calculate the rate of change of the magnetic flux density.

(10 Marks)

(b) Normal breast tissue has a relative permittivity $\varepsilon_r = 7.5$, conductivity $\sigma = 0.5$ S/m, and a relative permeability $\mu_r = 1$ at 2.5 GHz. On the other hand, breast cancer tissue is observed to have a relative permittivity $\varepsilon_r = 66.0$, conductivity $\sigma = 4.4$ S/m, and a relative permeability $\mu_r = 1$ at the same frequency.

Note: Question No. 2 continues on page 3.

(i) Determine the complex permittivity $\varepsilon_c$, attenuation constant $\alpha$, and skin depth $\delta$ for the normal tissue at 2.5 GHz.
(ii) Determine the complex permittivity $\varepsilon_c$, attenuation constant $\alpha$, and skin depth $\delta$ for the cancer tissue at 2.5 GHz.
(iii) If the thickness of the normal and cancer tissues is 2 cm, determine which tissue causes a higher attenuation for the 2.5 GHz signal.
(iv) Based on the result in part (iii), propose a method of treatment for breast cancer.

(15 Marks)

3. (a) The electric field of a uniform plane wave (UPW) in free space occupying the region $z \leq 0$ is given by:

$$\vec{E}_i = \left(60\vec{a}_x - j60\vec{a}_y\right)e^{-j(0.25z+\pi/3)} \text{ V/m.}$$

The UPW is incident normally on a planar interface with a lossy medium occupying the region $z > 0$ and having $\mu_r = 1$, $\varepsilon_r = 6$ and $\sigma = 0.2$ S/m. Find the following and state any assumption(s) made:

(i) The time-average Poynting vector of the incident wave, i.e., $\vec{S}_i$.
(ii) The reflection coefficient $\Gamma$ at $z = 0$.
(iii) The average power transmitted into the lossy medium.
(iv) The polarization state (Linear, Left-Handed circular, Right-Handed circular or Elliptical) for the transmitted UPW. Briefly explain your answer.

(13 Marks)

(b) A uniform plane wave in air (occupying the region $z \leq 0$) has a phasor magnetic field given by

$$\vec{H}_i = \vec{a}_y 50e^{-j(2\pi x+3\pi z)} \text{ mA/m.}$$

The UPW is obliquely incident onto a lossless medium (occupying the region $z > 0$) with $\varepsilon = 2.3\varepsilon_0$ and $\mu = \mu_0$.

Determine the following and state any assumption(s) made:

(i) The direction of propagation of the incident UPW, i.e., $\vec{a}_k$.
(ii) The phasor electric field $\vec{E}_i$ of the incident UPW.
(iii) The magnitude of the transmitted electric field at the interface at $z = 0$.

(12 Marks)

4. (a) A 36-cm long lossless transmission line is operating at a frequency of 400 MHz. The line has a characteristic impedance of $Z_0 = 50\ \Omega$ and a phase velocity of $u_p = 2\times10^8$ m/s. The line is connected to a load impedance $Z_L = 30 - j60\ \Omega$ at $z = 0$. Assuming the input end is located at $z = -\ell$ where $\ell$ is the length of the transmission line, find the following:

(i) The reflection coefficient $\Gamma(z)$ at $z = 0$ and $z = -\ell$, respectively.

(ii) The positions $z$ at which $\Gamma(z)$ is a real number.

(iii) The positions $z$ at which the magnitude of voltage is minimum.

(iv) The magnitude of voltage minimum on the line if the magnitude of voltage at $z = 0$ is 50V.

(17 Marks)

(b) When the load in part (a) is replaced by a capacitive impedance of $-j20\Omega$, find the following:

(i) The input impedance at $z = -\ell$.

(ii) The positions of voltage minima on the transmission line.

(8 Marks)

Note: State any assumption made in the above. The Smith chart may be used in the solutions for one or both parts of this question. Please put the Smith chart inside (not outside) the answer script and tie it with a thread.

# Appendix A

## Physical Constants

Permittivity of free space $\varepsilon_0 = \frac{1}{36\pi} \times 10^{-9}$ F/m

Permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ H/m

## ∇ Operator

$$\nabla V = \vec{a}_x \frac{\partial V}{\partial x} + \vec{a}_y \frac{\partial V}{\partial y} + \vec{a}_z \frac{\partial V}{\partial z}$$

$$\nabla \cdot \vec{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}$$

$$\nabla \times \vec{A} = \begin{vmatrix} \vec{a}_x & \vec{a}_y & \vec{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{vmatrix}$$

$$\nabla V = \vec{a}_r \frac{\partial V}{\partial r} + \vec{a}_\phi \frac{\partial V}{r \partial \phi} + \vec{a}_z \frac{\partial V}{\partial z}$$

$$\nabla \cdot \vec{A} = \frac{\partial (r A_r)}{r \partial r} + \frac{\partial A_\phi}{r \partial \phi} + \frac{\partial A_z}{\partial z}$$

$$\nabla \times \vec{A} = \frac{1}{r} \begin{vmatrix} \vec{a}_r & r\vec{a}_\phi & \vec{a}_z \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \phi} & \frac{\partial}{\partial z} \\ A_r & rA_\phi & A_z \end{vmatrix}$$

## Electric and Magnetic Fields

$$\vec{E} = \frac{1}{4\pi\varepsilon} \iiint_V \frac{\rho_v \vec{a}_R}{R^2} dv = \frac{1}{4\pi\varepsilon} \iiint_V \frac{\rho_v \vec{R}}{R^3} dv$$

$$V = \frac{1}{4\pi\varepsilon} \iiint_V \frac{\rho_v}{R} dv$$

$$\vec{H} = \frac{1}{4\pi} \int_C \frac{I\vec{dl} \times \vec{a}_R}{R^2} = \frac{1}{4\pi} \int_C \frac{I\vec{dl} \times \vec{R}}{R^3}$$

$$\oint_C \vec{H} \cdot \vec{dl} = I = \iint_S \vec{J} \cdot \vec{ds}$$

$$emf = \oint_C \tilde{E} \cdot \vec{dl} = -\frac{d\Phi_m}{dt} = -\frac{d}{dt} \iint_S \tilde{B} \cdot \vec{ds}$$

## Maxwell's Equations

$$\nabla \times \tilde{E} = -\frac{\partial \tilde{B}}{\partial t}$$

$$\nabla \times \tilde{H} = \frac{\partial \tilde{D}}{\partial t} + \tilde{J}$$

$$\nabla \cdot \tilde{D} = \rho$$

$$\nabla \cdot \tilde{B} = 0$$

## Complex Propagation Constant

$$\gamma = \alpha + j\beta = j\omega\sqrt{\mu\varepsilon_c} = j\omega\sqrt{\mu(\varepsilon - j\sigma/\omega)}$$

## Complex Intrinsic Impedance

$$\eta_c = \sqrt{\frac{\mu}{\varepsilon_c}} = \sqrt{\frac{\mu}{\varepsilon - j\sigma/\omega}}$$

**Reflection and Transmission of Electromagnetic Wave**

$$\frac{\sin\theta_t}{\sin\theta_i} = \sqrt{\frac{\mu_1\varepsilon_1}{\mu_2\varepsilon_2}} \qquad \tan\theta_{B\|} = \sqrt{\frac{\varepsilon_2}{\varepsilon_1}} \qquad \sin\theta_c = \sqrt{\frac{\varepsilon_2}{\varepsilon_1}}$$

$$\Gamma_\perp = \frac{\eta_2\cos(\theta_i) - \eta_1\cos(\theta_t)}{\eta_2\cos(\theta_i) + \eta_1\cos(\theta_t)} \qquad \tau_\perp = \frac{2\eta_2\cos(\theta_i)}{\eta_2\cos(\theta_i) + \eta_1\cos(\theta_t)}$$

$$\Gamma_\| = \frac{\eta_2\cos(\theta_t) - \eta_1\cos(\theta_i)}{\eta_2\cos(\theta_t) + \eta_1\cos(\theta_i)} \qquad \tau_\| = \frac{2\eta_2\cos(\theta_i)}{\eta_2\cos(\theta_t) + \eta_1\cos(\theta_i)}$$

**Transmission Line**

$$V(z) = V_o^+ \ e^{-j\beta z} + V_o^- \ e^{+j\beta z}$$

$$I(z) = \frac{1}{Z_o}\{V_o^+ \ e^{-j\beta z} - V_o^- \ e^{+j\beta z}\}$$

$$\beta = \frac{2\pi}{\lambda}$$

$$\Gamma_L = \frac{V_o^-}{V_o^+} = \frac{Z_L - Z_o}{Z_L + Z_o}$$

$$\Gamma(z) = \Gamma_L \ e^{+j2\beta z} \qquad -\ell \le z \le 0$$

$$Z_{in}(-\ell) = \frac{Z_L + jZ_o\tan(\beta\ell)}{Z_o + jZ_L\tan(\beta\ell)} Z_o$$

END OF PAPER

**EE3001 ENGINEERING ELECTROMAGNETICS**

Please read the following instructions carefully:

1. **Please do not turn over the question paper until you are told to do so. Disciplinary action may be taken against you if you do so.**

2. You are not allowed to leave the examination hall unless accompanied by an invigilator. You may raise your hand if you need to communicate with the invigilator.

3. Please write your Matriculation Number on the front of the answer book.

4. Please indicate clearly in the answer book (at the appropriate place) if you are continuing the answer to a question elsewhere in the book.