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*Ollscoil na hÉireann, Gaillimh*
*National University of Ireland, Galway*

# Summer Examinations 2004 / 2005

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| **Exam Code(s)** | 4BN121<br>4BP121 |
| **Exam(s)** | B.E. Degree in Electronic Engineering<br>B.E. Degree in Electronic & Computer Engineering |
| **Module Code(s)** | EE431 |
| **Module(s)** | Electromagnetics and Instrumentation |
| Paper No. | 1 |
| Repeat Paper | |
| External Examiner(s) | Prof. S. McLaughlin |
| Internal Examiner(s) | Prof. D. J. Wilcox<br>Dr. P. Corcoran |
| **Instructions:** | Answer any **three** questions |
| **Duration** | 2 hrs |
| **No. of Pages** | 5 (including cover page) |
| **Department(s)** | Electronic Engineering |
| **Course Co-ordinator(s)** | |

**Requirements**:

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| MCQ | |
| Handout | Yes |
| Statistical Tables | |
| Graph Paper | |
| Log Graph Paper | |
| Other Material | |

**Q 1 (a)** Write down the differential and integral Maxwell's equations in time-harmonic form. If the instantaneous magnetic field is $\mathbf{H} = 2\ cos(\omega t - 3y)\mathbf{a}_z$ A/m in a medium which is characterized by $\sigma = 0$; $\mu = 2\mu_0$ and $\varepsilon = 5\varepsilon_0$ calculate $\omega$ and $\mathbf{E}$.

[9 marks]

**(b)** Using Maxwell's equations as a starting point, determine an expression for the net power flow out of a volume, $V$, in terms of (i) the decrease in the stored electric and magnetic energy within the volume and (ii) the ohmic losses within the volume.

[8 marks]

**(c)** Explain what is meant by the *time-averaged* and *phasor* forms of the Poynting vector. Derive the relationship between these two forms of the Poynting vector.

[7 marks]

**(d)** Assuming a DC current flow in a resistor as illustrated in Figure 1 below, determine the instantaneous Poynting vector, the time averaged power flow and the total power dissipated by the resistor.

[9 marks]

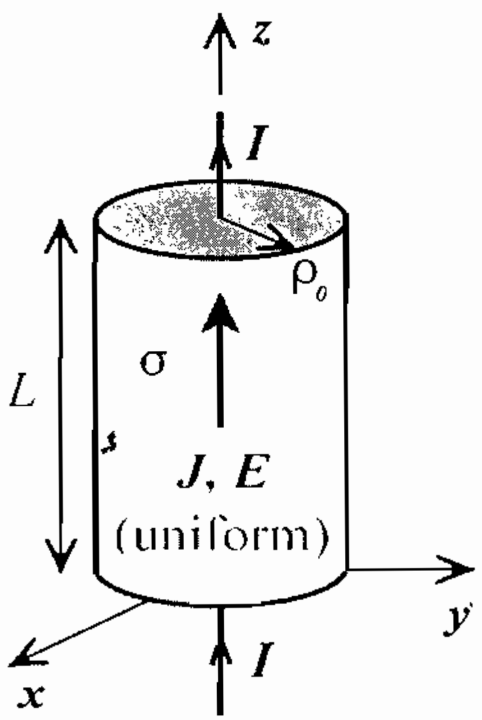


*Figure 1: Energy Flow within the Volume of a Resistor*

**Q 2. (a)** A z-directed uniform plane wave is incident on a planar media interface which lies in the x-y plane. The two regions are characterized by conductivities of $\sigma_1$, $\sigma_2$, magnetic permeabilities of $\mu_1$, $\mu_2$ and electric permittivities of $\varepsilon_1$, $\varepsilon_2$. The incident electric and magnetic phasor fields are:

$$\boldsymbol{E}^i_s = \boldsymbol{E}_{so} e^{-\gamma_1 z}\, \boldsymbol{a}_x; \qquad \boldsymbol{H}^i_s = (\boldsymbol{E}_{so}/\eta_1)\, e^{-\gamma_1 z}\, \boldsymbol{a}_y$$

Write down expressions for the reflected and transmitted fields at the interface and determine expressions for the total electric and magnetic fields in both regions. Derive expressions for the *reflection* and *transmission* coefficients at the interface.

[15 marks]

**(b)** A uniform plane wave in air is normally incident on an infinite lossless dielectric material with an electric permittivity of $\varepsilon = 3\varepsilon_0$ and magnetic permeability of $\mu = \mu_0$. If the incident wave is given as $\boldsymbol{E}_i = 10\cos(\omega t - z)\, \boldsymbol{a}_y$ V/m, find:

(i) $\omega$ and $\lambda$ of the waves in both regions; [4 marks]

(ii) $\boldsymbol{H}_i$ the incident magnetic field; [4 marks]

(iii) $\Gamma$ and $\tau$; [3 marks]

(iv) the total electric field and [3 marks]

(v) the time-averaged power in both regions [4 marks]

**Q 3. (a)** Explain, using diagrams, the basic circuit theory model of a two-conductor transmission line. Derive expressions from this model for the instantaneous voltage and current as a function of position along the line. Determine the *wavelength* and *velocity of propagation* of these fields along the line.

[9 marks]

**(b)** Determine an expression for the *impedance* at an arbitrary distance, z, along a transmission line with a characteristic impedance of $\boldsymbol{Z_0}$ which is terminated by a load impedance $\boldsymbol{Z_L}$.

[8 marks]

**(c)** A voltage source $[V_{sg} = 100\angle 0^\circ\ V;\ Z_g = R_g = 50\Omega;\ f = 100\ MHz]$ is connected to a lossless transmission line $[L = 0.25\ \mu H/m,\ C = 100\ pF/m,\ l = 10m]$. For loads of $Z_L = R_L = 0, 25, 50, 100$ and $\infty\ \Omega$, determine:

(i) the reflection coefficient at the load; [4 marks]

(ii) the standing wave ratio; [4 marks]

(iii) the input impedance at the transmission line terminals and [4 marks]

(iv) voltage and current plots along the transmission line. [4 marks]

$$\bar{j}_k = \bar{j}_{kD} + \bar{j}_{ke} = -D_k\left(\nabla c_k + \frac{c_k z_k \mathrm{F}}{\mathrm{R}T}\nabla\Phi\right)$$

Q 4. (a) The total ionic flux for the $k^{th}$ ion, $\bar{j}_k$, is given by the sum of ionic fluxes due to diffusion and electric field contributions. Using the Einstein relationship it can be expressed as the Nernst-Planck equation:

By considering equilibrium conditions show how this equation can be used to derive an expression for the static, or Nernst potential across the cell membrane. Explain the meaning of each of the variables and constants used in this derivation.

[14 marks]

(b) Describe, using an equivalent circuit diagram, the Hodgkin/Huxley *parallel conductance* model for the cell membrane. Use this model to determine an expression for the membrane current per unit surface area.

[10 marks]

(c) What are the factors that affect ion flow through the cell membrane? Explain the differences between the three main ionic species found in the region of the cell membrane. What is the Na-K pump? Provide sketches illustrating (i) the relative ionic flows across the cell membrane during passive and active influxes and effluxes and (ii) the relative potential differences induced across the membrane by such flows.

[9 marks]

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Q 5. (a) Describe the mechanisms of *electric activation* in the heart. In particular describe (i) the bioelectric function of the cardiac muscle cell, differentiating it from that of normal muscle cells; (ii) the conduction system of the heart, sketching the electric waveforms of the different cardiac regions and illustrating how they combined to form the externally observed ECG response and (iii) the mechanisms of depolarization and repolarization as the cardiac wavefront propagates.

*[NB: an attached handout sheet is provided to simplify part (ii) of this question].*

[15 marks]

(b) What are the *forward* and *inverse problems* in Bioelectromagnetics? Explain, by means of simple circuit diagrams the lack of uniqueness of the inverse problem.

[7 marks]

(c) Describe and discuss the relative merits of each of the four main approaches to obtaining a consistent solution to the inverse problem.

[11 marks]