2507/305
ELECTROMAGNETIC FIELD THEORY
Oct./Nov. 2017
Time: 3 hours

THE KENYA NATIONAL EXAMINATIONS COUNCIL

DIPLOMA IN AERONAUTICAL ENGINEERING (AVIONICS OPTION)

MODULE III

ELECTROMAGNETIC FIELD THEORY

3 hours

INSTRUCTIONS TO CANDIDATES

You should have the following for this examination:
Scientific calculator;
Drawing instruments;
Table of electromagnetic field formulae.

*Answer **FIVE** questions of the **EIGHT** questions in the answer booklet provided.*
All questions carry equal marks
Maximum marks for each part of a question are as indicated.
Candidates should answer the questions in English.

Vacuum permittivity, $\varepsilon_o = 8.854 \times 10^{-2}\ F/M$
Vacuum permeability, $\mu_0 = 4\pi \times 10^{-7}\ H/M$
Speed of light in Vacuum, $C = 3.0 \times 10^{8}\ m/s$
Electronic charge, $e = 1.602 \times 10^{-19}\ C$
Electron mass, $m_e = 9.1 \times 10^{-31}\ kg$
Earths gravitational force, $g = 9.8\ N/kg$

This paper consists of 6 printed pages.

Candidates should check the question paper to ascertain that all the pages are printed as indicated and that no questions are missing.

1. (a) State the range of frequencies for each of the following electronic radiation:

   (i) medium frequency (mf) band;
   (ii) visible light;
   (iii) microwaves. (6 marks)

   (b) State the industrial applications of each of the following electromagnetic waves:

   (i) visible light;
   (ii) microwaves. (4 marks)

   (c) With the aid of a diagram, explain the operation of each of the following radiation detectors:

   (i) Geiger Muller (GM) tube;
   (ii) semi conductor detector. (10 marks)

2. (a) Define the following with respect to electrodynamics:

   (i) electric field intensity;
   (ii) electric flux. (3 marks)

   (b) With the aid of a sketch, explain Gauss's law of electrostatics. (5 marks)

   (c) A charge Q_1 $2\,\mu C$, is located at Cartesian co-ordinates A(2,-4,4) metres. Determine the:

   (i) electric field intensity at the origin (0,0,0) due to Q_1;
   (ii) force on another charge Q_1, $-1\,\mu C$, located at B(-1,5,2) metres, due to Q_1. (8 marks)

   (d) Obtain an expression for the electric field intensity, $\tilde{E}$, required to balance the earth's gravitational force on a charge, q coulombs having a mass m kilograms. (4 marks)

3. (a) Differentiate between magnetic field strength and magnetic flux density. (2 marks)

   (b) With the aid of a sketch, explain Biot-Savart law with respect to magnetostatics. (6 marks)

   (c) An infinitely long straight wire carries current I, along the Z-axis in cylindrical co-ordinates. Derive an expression for the magnetic field strength, $\tilde{H}$, along a radius r. (6 marks)

(d) Figure 1 shows a diagram of a square coil 0.6 metres on each side. The coil rotates about the X-axis at $\omega = 25\pi$ rad/s in a magnetic field, $\hat{B} = 0.2\ \tilde{a}_z$. Teslas. Derive an expression for the induced voltage. (6 marks)

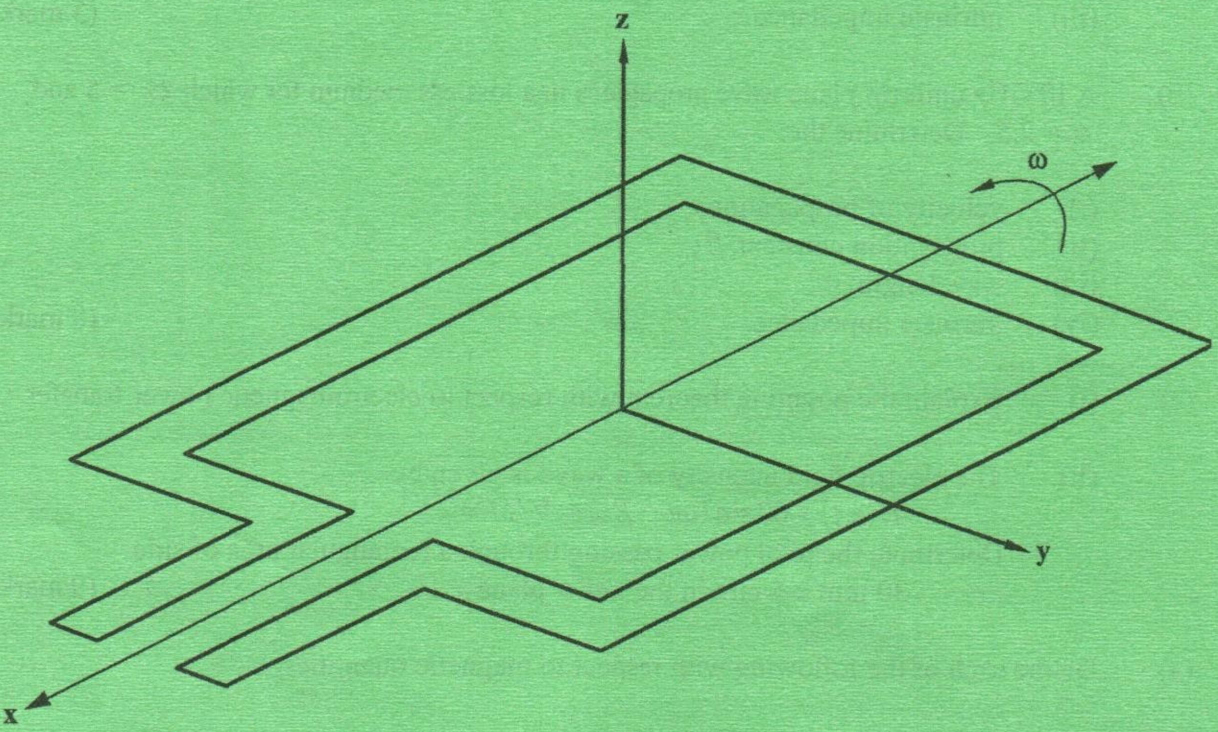

Fig. 1

4. (a) List Maxwell's four equations in point form and explain the significance of each equation. (8 marks)

(b) The electric field intensity, $\tilde{E}$, of an electromagnetic field free space is given by the expression:

$$\tilde{E} = 15\cos(\omega t + 3Z)\ \tilde{a}_y$$

Derive expressions for:

(i) magnetic flux density, $\tilde{B}$;
(ii) magnetic field intensity, $\tilde{H}$;
(iii) electric flux density, $\tilde{D}$. (8 marks)

(c) Explain the relationship between electric fields at the interface of two dielectrics. (4 marks)

5. (a) Define each of the following with respect to electromagnetic waves

(i) TM waves;
(ii) wavelength;
(iii) intrinsic impedance. (3 marks)

(b) A 10 GHz uniform plane wave propagates in a lossless medium for which $\varepsilon_r = 5$ and $\mu_r = 2.5$. Determine the:

(i) velocity of propagation;
(ii) propagation constant, β;
(iii) wavelength;
(iv) intrinsic impedance. (8 marks)

(c) (i) Explain the poynting theorem with respect to electromagnetic power transfer.

(ii) The electric field intensity of a wave is given by

$$\tilde{E}(z,t) = 60 \sin(\omega t - \beta z)\, \tilde{a}_z\ V/M.$$

Determine the total power passing through a rectangular area of side 30 mm x 5 mm in the z = o plane (9 marks)

6. (a) Define each of the following with respect to magnetic quantities:

(i) permeability;
(ii) ferromagnetic material (2 marks)

(b) State the equivalent magnetic quantities corresponding to each of the following electric quantities:

(i) conductance;
(ii) current;
(iii) resistance. (3 marks) ✓

(c) With the aid of a circuit diagram, describe the set-up and the procedure for determining the B-H curve of a magnetic material by the reversal method. (8 marks) X

(d) Figure 2 shows a diagram of a magnetic material made of mild steel. The central limp is wound with 600 turns and has a cross-sectional area of 6 cm^2. Each of the outer limps has a cross-section of 4 cm^2. The air gap length is 1 mm.

(i) Draw an equivalent electrical circuit of the magnetic circuit;
(ii) For a 1.2 mW flux in the central limp, determine the MMF for the air-gap. (7 marks)

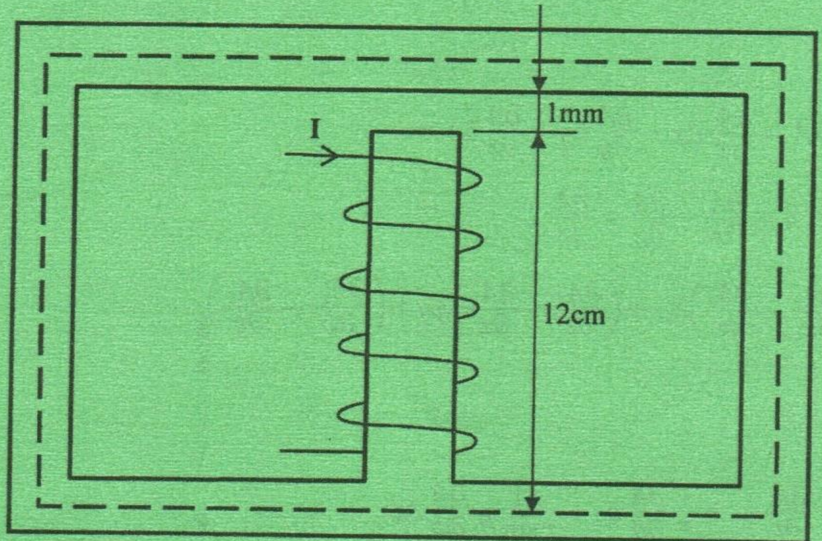

Fig. 2

7. (a) Explain skin depth with respect to electromagnetic wave conduction. (3 marks)

(b) A parallel plate capacitor has a plate area of 16 cm² and is separated by a distance of 4 mm. A voltage $\theta = V_o \sin \omega t$ is applied across the plates of the capacitor. Obtain an expression for the:

(i) conduction current;
(ii) displacement current density. (8 marks)

(c) A cube defied by, $0 \leq x \leq 1, 0 \leq y \leq 2$ and $0 \leq z \leq 3$ metres contains a volume charge of density, $p = 2xyz$ $\mu c/m^3$. Determine the total electric flux flowing outward from the cube. (9 marks)

8. (a) For the vector field: $\tilde{p} = x^2yz\tilde{a}_x + xz\tilde{a}_z$, determine its:

(i) divergence, $\nabla . \tilde{p}$;
(ii) Curl $\nabla X \, \tilde{p}$. (8 marks)

(b) Given the vectors, $\tilde{A} = 2\tilde{a}_x + 3\tilde{a}_y + 5\tilde{a}_z$ and $B = 6\tilde{a}_x + \tilde{a}_y - 2\tilde{a}_z$ determine:

(i) $|\tilde{A} + \tilde{B}|$;

(ii) component of $\tilde{A}$ along $\tilde{a}_y$;

(iii) a unit vector parallel to $3\tilde{A} - \tilde{B}$. (8 marks)

(c) On the same axis sketch the following functions for two waves travelling in free space:

$\upsilon_1(z,t) = \sin(\omega t)$;

$\upsilon_1(z,t) = \sin(\omega t + a)$. (4 marks)

Table of electromagnetic field formulas

1. Cartesian

Gradient : $\nabla\tilde{A} = \frac{\partial A}{\partial x}\tilde{a}x + \frac{\partial A}{\partial y}\tilde{a}y + \frac{\partial A}{\partial z}\tilde{a}z$

Divergence: $\nabla.\tilde{A} = \frac{\partial A}{\partial x} + \frac{\partial A}{\partial y} + \frac{\partial A}{2z}$

Curl: $\nabla\times\tilde{A} = \left(\frac{\partial A_z}{\partial x} - \frac{\partial A_y}{\partial z}\right)\tilde{a}x + \left(\frac{\partial A_z}{\partial z} - \frac{\partial A_z}{\partial x}\right)\tilde{a}y + \left(\frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y}\right)$

2. Spherical

Gradient: $\nabla A = \frac{\partial A}{\partial r}a_r + \frac{1}{r}\frac{\partial A}{\partial \theta}\tilde{a}_\theta + \frac{1}{r\sin\theta}\frac{\partial A}{\partial \phi}\tilde{a}\phi$

Divergence: $\nabla.\tilde{A} = \frac{1}{r^2}\frac{\partial}{\partial_r}(r^2A_r) + \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta A_\theta) + \frac{1}{r\sin\theta}\frac{\partial A_\phi}{\partial\phi}$

Curl: $\nabla\times\tilde{A} = \frac{1}{r\sin\theta}\left[\left(\frac{\partial}{\partial\theta}(\sin\theta A_\phi) - \frac{\partial A_\theta}{\partial\phi}\right)\tilde{a}r + \frac{1}{r}\left(\frac{1}{\sin\theta}\frac{\partial A_r}{\partial\phi} - \frac{\partial}{\partial r}(rA_\phi)\right)\right]\tilde{a}_\theta$
$+\frac{1}{r}\left(\frac{\partial}{\partial r}(rA_\theta) - \frac{\partial Ar}{\partial\theta}\right)\tilde{a}_\phi$

3. Cylindrical

Gradient: $\nabla A = \frac{\partial A}{\partial r}\tilde{a}r + \frac{1}{r}\frac{\partial A}{\partial\phi}\tilde{\phi} + \frac{\partial A}{\partial z}\tilde{a}_z$

Divergence: $\nabla.\tilde{A} = \frac{1}{r}\frac{\partial}{\partial r}(rA_r) + \frac{1}{r}\frac{\partial A\phi}{\partial\phi} + \frac{\partial A_z}{\partial z}$

Curl: $\nabla\times\tilde{A} = \left(\frac{1}{r}\frac{\partial Az}{\partial\phi} - \frac{\partial A\phi}{\partial z}\right)a\tilde{r} + \left(\frac{\partial A_r}{\partial z} - \frac{\partial A_z}{\partial r}\right)\tilde{a}_\phi$
$+\frac{1}{r}\left(\frac{\partial}{\partial r}(rA_\phi) - \frac{\partial Ar}{\partial\phi}\right)\tilde{a}_z$

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