PONDICHERRY UNIVERSITY-5643037

B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2014

Third Semester-Electrical and Electronics Engineering

ELECTROMAGNETIC THEORY (2013–2014 Onwards), NOV / DEC 2014, 3rd Sem EEE

Time: Three hours Maximum : 75 marks

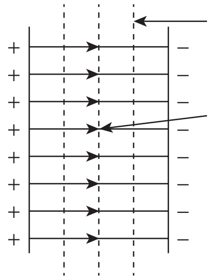
PART A — (10 × 2 = 20 marks)

Answer ALL questions. All questions carry equal marks.

1. State Divergence theorem.
   Ans 1. For answer refer: **Page 30, Topic 1.6.3** take statement and Formula.

2. What are the sources of electromagnetic fields?
   Ans 2. For answer refer: **Page 3, Topic 1.2** → Common sources of man made EM fields.

3. Draw the equipotential lines and electric field lines for a parallel plate capacitor.
   Ans 3.



4. Define dielectric strength. What is the dielectric strength of a co-axial cable?
   Ans 4. For answer refer: **Page 61, Topic 2.3** greyed box.

5. State Stokes’s theorem.
   Ans 5. For answer refer: **Page 28, Topic 1.6.1** greyed box.

6. Distinguish magnetic scalar potential and magnetic vector potential.
   Ans 6. For answer refer: **Page125, Topic 3.9.1**; **Page 126, Topic 3.9.2**.

   (a) Magnetic vector potential is defined as the quantity whose curl gives the magnetic flux density.

$$\vec{B} = \nabla \times \vec{A}$$

   (b) The magnetic scalar potential “V_m” is defined as the closed line Integral of magnetic field Intensity H and it exists if and only if no current is enclosed by H.

$$V_m = \oint H \cdot d\ell = 0.$$

7. Draw the magnetic field pattern in and around a solenoid.
Ans 7. For answer refer: **Page 112, Figure 3.12**.

8. Write point form of Maxwell's equation using Faraday's law.

Ans 8. $\nabla \times E = -\left(\frac{\partial H}{\partial t}\right)$.

9. Define Poynting vector.
Ans 9. For answer refer: **Page 204, First greyed box**.

10. What is the velocity of electromagnetic wave in free space and in lossless dielectric?
Ans 10. For a lossless dielectric,

$$v = \frac{1}{\sqrt{\ }} = \frac{1}{\sqrt{\ _0\ _0\ _r\ _r}} = \frac{3\times 10^8}{\sqrt{\ _r\ _r}}\ \text{m/sec}$$

$$\text{for free space, } v_0 = \frac{1}{\sqrt{\ _0\ _0}} = 3\times 10^8\,\text{m/sec}.$$

PART B – (5 × 11 = 66 marks)

Answer ALL question, One from each Unit. All questions carry equal marks.

UNIT I

11. Using the divergence theory, evaluate $\iint E \cdot ds = 4XZa_x + Y^2 a_y + YZa_z$ over the cube bounded by $x = 0;\ x = 1;\ y = 0;\ y = 1;\ z = 0;\ z = 1$. (11)

Ans 11. Refer "Vector Integration" in "Engineering Mathematics" Vol II by Dr. M. K. Venkataraman.

By divergence theory, we have,

$$\iint_s E \cdot ds = \iiint_v (\nabla \cdot E)\, dv$$

$$E = 4xz\,\hat{a}_x + y^2\hat{a}_y + yz\,\hat{a}_z$$

$$\nabla \cdot E = \left(\hat{a}_x \frac{\partial}{\partial x} + \hat{a}_y \frac{\partial}{\partial y} + \hat{a}_z \frac{\partial}{\partial z}\right) \cdot \left(4xz\,\hat{a}_x + y^2\hat{a}_y + yz\,\hat{a}_z\right)$$

$$= \frac{\partial}{\partial x}(4xz) + \frac{\partial}{\partial y}(y^2) + \frac{\partial}{\partial z}(yz).$$

$$\nabla \cdot E = 4z + 2y + y = 4z + 3y$$

$$\iiint_v (\nabla \cdot E)\, dv = \int_0^1\int_0^1\int_0^1 (4z + 3y)\, dx\, dy\, dz$$

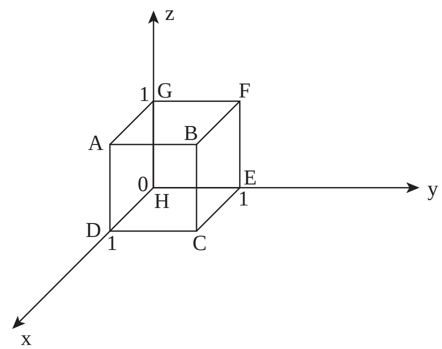
$$= \int_0^1 \int_0^1 [4zx + 3yx]_0^1 \, dy\, dz$$

$$= \int_0^1 \int_0^1 [4z + 3y] dy\, dz = \int \left[4zy + 3\left(\frac{y^2}{2}\right)\right]_0^1 dz$$

$$= \int_0^1 (4z + 1.5)\, dz = \left[4\left(\frac{z^2}{2}\right) + 1.5z\right]_0^1$$

$$= 2 + 1.5 = 3.5$$

With this the answer for the Question is complete.
Just to verify the theorem, let's evaluate the LHS.



The cube has six faces.

At ABCDA, $S_1 = dy\, dz\hat{i}$ at x = 1

$$\vec{E} \cdot ds_1 = \left(4xz\hat{i} + y^2\hat{j} + yz\hat{k}\right) \cdot dy\, dz\, \hat{i}$$

$$= 4xz\, dy\, dz \text{ at } x = 1.$$

$$= 4z\ dy\ dz \text{ at } x = 1$$

$$\int_0^1 \int_0^1 E \cdot ds = \int_0^1 \int_0^1 4z\ dy\ dz = \int_0^1 [4z\, y]_0^1\ dz$$

$$= \int_0^1 4z\ dz = 4\left[\frac{z^2}{2}\right]_0^1 = 2[1 - 0] = 2 \qquad (1)$$

At BFECB, $S_2 = dx\ dz\hat{j}$ at y = 1.

$$\vec{E} \cdot ds_2 = \left(4xz\,\hat{i} + y^2\,\hat{j} + yz\hat{k}\right) \cdot dx\, dz\, \hat{j}$$

$$= y^2\ dx\ dz \text{ at y = 1}$$

$$= dx\ dz \quad \text{at } y = 1$$

$$\int_0^1\int_0^1 E\cdot ds_2 = \int_0^1\int_0^1 dx\ dz = \int_0^1 [x]_0^1\ dz = \int_0^1 dz = [z]_0^1 \qquad (2)$$

$$= 1.$$

At ABFGA, $S_3 = dy\,dx\,\hat{k}$, at z = 1.

$$\vec{E}\cdot ds_3 = \left(4xy\hat{i} + y^2\hat{j} + yz\hat{k}\right)\cdot dy\ dx\ \hat{k}$$

$$= yz\ dy\ dx \quad \text{at } z = 1.$$

$$= y\ dy\ dx \quad \text{at } z = 1$$

$$\int_0^1\int_0^1 E\cdot ds = \int_0^1\int_0^1 y\ dy\ dx = \int_0^1\left[\frac{y^2}{2}\right]_0^1 dx$$

$$= \frac{1}{2}\int_0^1 dx = \frac{1}{2}[x]_0^1 = \frac{1}{2} = 0.5 \qquad (3)$$

At DCEHD, $S_4 = dy\ dx(-\hat{k}) = -dx\ dy\,\hat{k}$. at z = 0

$$\vec{E}\cdot ds_4 = \left(4xz\hat{i} + y^2\hat{j} + yz\hat{k}\right)\cdot\left(-dx\ dy\,\hat{k}\right)$$

$$= -yz\ dx\ dy \quad \text{at } z = 0.$$

$$= 0. \qquad (4)$$

At GFEHG, $S_5 = dy\,dz\left(-\hat{i}\right) = -dy\ dz\,\hat{i}$ at x = 0

$$\vec{E}\cdot ds_5 = \left(4xz\hat{i} + y^2\hat{j} + yz\hat{k}\right)\cdot\left(-dy\,dz\,\hat{i}\right)$$

$$= -4xz\ dy\,dz \quad \text{at } x = 0$$

$$= 0 \qquad (5)$$

At AGHDA, $S_6 = dz\,dx(-\hat{j}) = -dx\,dz\,\hat{j}$ at y = 0

$$\vec{E}\cdot ds_6 = \left(4xz\,\hat{i} + y^2\hat{j} + yz\,\hat{k}\right)\cdot\left(-dx\,dz\,\hat{j}\right)$$

$$= -y^2\ dx\,dz \quad \text{at } y = 0$$

$$= 0 \qquad (6)$$

$$\int_s E\cdot ds = ① + ② + ③ + ④ + ⑤ + ⑥$$

$$= 3.5$$

Thus we find, $\oint_s E\cdot ds = \int_v (\nabla\cdot E)\,dv$

Thus divergence theorem is verified.

Or

12. (a) Explain the electric field distribution inside and outside a conductor. (6)
Ans 12. (a) For answer refer: **Topic 2.4 and 2.4.1** in page 61, 62.

12. (b) Explain the principle of electrostatic shielding. (5)
Ans 12. (b) For answer refer: **Topic 1.2.2 and 1.2.3** in page 9.
For answer refer: **Page 9, Topic 1.2.4** "EMI problem can be solved or reduced by ……. (ii) Shielding (iii) Filtering.
For answer refer: **Page 10, Topic 1.2.5**, "Take Only Shielding".

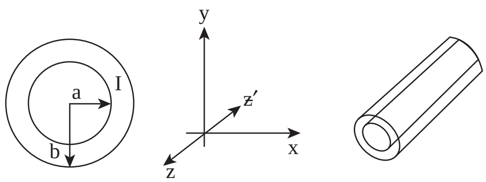
UNIT II

13. State and derive electric boundary conditions for a dielectric to dielectric medium and conductor to dielectric medium. (11)
Ans 13. For answer refer: **Page 80, Topic 2.11** till page 81 before the 1st grey box.

14. Deduce an expression for the capacitance of a parallel plate capacitor having two dielectric media. (11)
Ans 14. For answer refer: **Page 72, Topic 2.8.3**.

UNIT III

15. A hollow conducting cylinder has inner radius 'a' and outer radius 'b' and carries current '*I*' along the positive z direction. Find B and H everywhere.
Ans 15. Similar derivation in **page 114, Topic 3.6.1.3**.



(i) for radius less than "a", $r \le a$
By Ampere's law,

$$\oint H \cdot d\ell = I_{enc}$$

(ie), $H\ell = 0$ ($\because$ no current is enclosed)

$$\Rightarrow H = 0 \ (\because \ell \neq 0).$$

(ie) for any radius less than "a", the magnetic field Intensity "H" and magnetic flux density "B" is zero.

$$\text{for} \left.\begin{matrix} r \le a, & H = 0 \\ r \le a, & B = 0 \end{matrix}\right] \qquad (1)$$

(ii) For any radius "r" from a to b, "$a \le r \le b$", we have,

$$\oint H \cdot d\ell = \int J \cdot ds = I_{enc}$$

$$H(2\ \ r) = \frac{I}{(b^2 - a^2)}\left[\ \ (r^2 - a^2)\right]$$

$$H = \frac{I}{(b^2 - a^2)} \frac{(r^2 - a^2)}{(2\ \ r)}$$

$$H = \frac{I}{2\ \ (b^2 - a^2)} \left[r - \frac{a^2}{r} \right]$$

$$B = \ \ H = \frac{I}{2\ \ (b^2 - a^2)} \left[r - \frac{a^2}{r} \right]$$

(iii) for any radius “r”, greater than *b*, we have,
(ie) $r > b$;

$$\oint H \cdot d\ell = I_{enc}$$

$$H(2\ \ r) = I$$

$$H = \frac{I}{(2\ \ r)} \qquad (3)$$

$$B = \ \ H = \frac{I}{(2\ \ r)}$$

Or

16. A small current loop L_1, with magnetic moment $5a_z$ A.m^2 is located at the origin while another small loop current L_2 with magnetic moment $3a_y$A.m^2 is located at (4, –1, 7). Determine the torque on L_2.

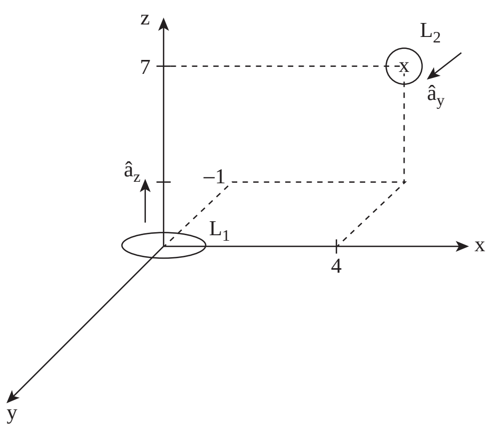
Ans 16. Magnetic moment of the loop, “m”, is defined as the maximum torque on the loop per unit magnetic flux density.

$$m = \left(\frac{T_{\max}}{B} \right) = IA.$$

To find the maximum torque on L_2, we need to multiply the magnetic moment of L_2 with magnetic flux density B at (4, –1, 7).

(ii) $T_2 = B \cdot L_2$

Now, we have to find B at L_2 (4, –1, 7) due to loop L_1.



$$r = \sqrt{(4-0)^2 + (-1-0)^2 + (7-0)^2}$$

$$= \sqrt{16+1+49} = \sqrt{66}$$

$$r = 8.13\,\text{m}.$$

If B = 1 T, then $T_2 = B(3) = 3B = 3(1) = 3\,\text{N-m}$. [The problem seems to have missing information]

UNIT IV

17. (a) A magnetic circuit comprising a toroid of 5000 turns and an area of 6 cm^2 and mean radius of 15 cm carries a current of 4 A. Find the reluctance and flux given $\mu_r = 1$.

Ans 17. (a)

(a) N = 5000
$A = 6$ cm^2 $= 6 \times 10^{-4}$ m^2
$R = 15$ cm $= 15 \times 10^{-2}$ m
$I = 4$ A.
$\mu_r = 1$.
Reluctance, $\mathbb{R} = \dfrac{MMF}{\quad}$

$$H = \frac{NI}{2\ \ r} = \frac{5000\times 4}{2\ \ \times 15\times 10^{-2}}$$

$$= 21.220\times 10^3\ \text{AT/m}.$$

$$B = \ \ \cdot H = \ \ _o \cdot \ \ _r\ H = \ \ (1)H = 26.67\times 10^{-3}\,T$$

$$= B\cdot A = 16\times 10^{-6}\ \text{Wb}.$$

$$MMF = Ni = \oint H\cdot d\ell = H\ell$$

$$MMF = 21.220\times 10^3 \times 2\ \ \times 15\times 10^{-2} = 19.999\times 10^3$$

Reluctance, $\mathbb{R} = \dfrac{19.999\times 10^3}{16\times 10^{-6}} = 1.25\times 10^9$.

17. (b) An iron ring with a cross sectional area of 3 cm^2 and a mean circumference of 15 cm is wound with 250 turns wire carrying a current of 0.3 A, the relative permeability of the ring is 1500. Calculate the flux established in the ring. (6)

Ans 17. (b) $A = 3$ cm^2 $= 3 \times 10^{-4}$ m^2

$2\ \ R = 15$ cm $= 15 \times 10^{-2}$ m
$N = 250$
$I = 0.3$ A
$\mu_r = 1500$

$$= B\cdot A \qquad (1)$$

$$H = \frac{NI}{2\ \ r} = \frac{250\times 0.3}{2\ \ r} = \frac{250\times 0.3}{15\times 10^{-2}}$$

$$H = 500\ \text{AT/m}$$

$$B = \quad H = \quad _0 \quad _r H = \quad _0 (1500)\,(500) = 942.5 \times 10^{-3}$$

$$= B \cdot A = 942.5 \times 10^{-3} \times 3 \times 10^{-4} = 282.75 \times 10^{-6} \text{ Wb.}$$

18. Find H in a magnetic material
(a) When μ = 0.000018 H/m and H = 120 A/m. (11)
Ans 18. (a) H is already given.
H = 120 AT/m.

18. (b) When B = 300 μT and magnetic susceptibility = 20
Ans 18. (b) $B = 300 \times 10^{-6}$ T

$$_m = 20$$
$$_r = 1 + \quad _m = 1 + 20 = 21$$
$$= \quad _0 \quad _r$$

$$H = \left(\frac{B}{\quad} \right) = \frac{300 \times 10^{-6}}{21 \times \quad _0} = 11.37 \text{ AT/m}.$$

UNIT V

19. Derive the electromagnetic wave equation in frequency domain and the propagation constant and intrinsic impedance. (11)
Ans 19. For answer refer: **Page 176, Topic 5.3** till Eq (I) in page 177. Refer **Page 179, Topic 5.3.3** till Eq. (4) $\quad = \quad + j$ for propagation constant.

Intrinsic Impedance, $\quad = \sqrt{\frac{j}{\quad + j}}$ (Formula in page 186).

Or

20. A plane travelling wave has a peak electric field intensity E as 6 kV/m. If the medium is lossless with $\mu_r = 1$, $\quad _r = 3$, find the velocity of the EM wave, peak poynting vector, impedance of the medium and the peak value of the magnetic field H.

Ans 20. $E_m = 6 \times 10^3$ V/m

$$_r = 1; \quad _r = 3.$$

(i) Velocity $= \frac{1}{\sqrt{\quad}} = \frac{1}{\sqrt{\quad _0 \quad _r \quad _0 \quad _r}} = \frac{1}{\sqrt{\quad _0 \quad _0}\sqrt{\quad _r \quad _r}}$

$$v_0 = \frac{3 \times 10^8}{\sqrt{\quad _r \quad _r}} = \frac{3 \times 10^8}{\sqrt{1 \times 3}} = \sqrt{3} \times 10^8 \text{ m/sec}$$

$$v_0 = 1.732 \times 10^8 \text{ m/sec.}$$

(ii) $\vec{P} = \left(\frac{E_0^2}{120}\right) = \frac{(6 \times 10^3)^2}{120} = 95.5 \times 10^3$ Watts.

(iii) Impedance of the medium, $= \sqrt{\frac{j}{(\quad + j \quad)}}$

for lossless medium, $= 0$;

$$= \sqrt{\left(\frac{j}{j}\right)} = \sqrt{\left(\frac{}{}\right)} = \sqrt{\left(\frac{_0 \; _r}{_0 \; _r}\right)}$$

$$= \sqrt{\frac{1(\; _0)}{3(\; _0)}} = 217.50$$

(iv) Peak value of magnetic field, H $= \left(\frac{E}{}\right) = \frac{6 \times 10^3}{217.50} = 27.6$ AT/m.