K.RAMAKRISHNAN COLLEGE OF TECHNOLOGY
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EC8451-ELECTROMAGNETIC FIELDS
TWO MARKS

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

UNIT-1

1. State Stoke's Theorem.(K1/CO1)

The line integral of a vector around a closed path is equal to the integral of curl of a vector over the open surface "S" enclosed by the closed path "L"

$$\oint_L F.dl = \iint_S (\nabla X F).ds$$

2. State Divergence Theorem. (K1/CO1)

The integral of divergence of a vector field over a volume "V" is equal to the surface integral of normal components of the vector over the closed surface

$$\iiint_V (\nabla.F)dv = \oiint_S F.ds$$

3. Explain the scalar & vector components.(K2/CO1)

a. **Scalar Components:**
   It is a component which explains only the magnitude
   Eg. Speed, Weight
b. **Vector Components**:
   It is a components which explains both magnitude & direction.
   Eg. Force

4. Define Unit Vector.(K1/CO1)

It is defined as the ratio of the vector to the magnitude of the vector. It is magnitude is 1.

$$\overline{a_{OA}} = \frac{\overline{OA}}{|\overline{OA}|}$$

5. Define Gradient. (K1/CO1)

It is defined as the rate at which the quantity varies with respect to distance.

6. Mention the criteria for choosing on appropriate co-ordinate system for solving a field problem easily. Explain with example.(K2/CO1)

A Proper co-ordinate system selection is important for easily solving the field problem. Depend on nature of field & the charge.

Point charges are located at points & the force exerted on each other is along a line	Cartesian Coordinate systems
cylindrical conductors & cylindrical surface , cable	Cylindrical Coordinate systems
Antenna, spherical conductors	Spherical Coordinate systems

7. **What are the types of charge distribution? (K1/CO1)**

1.	Point Charge	The dimension of the surface carrying charge is very small when compared to region surrounding.
2.	Line Charge	The charge spread along the line
3.	Surface Charge	The charge distributed over the two dimensional surface
4.	Volume Charge	The charge distributed uniformly over the volume

8. **Explain the types charge densities in detail. (K2/CO1)**

S.No.	Charge Density	Definition	Formula	Unit
1.	Line Charge Density	Total number of charges per total length in meter	$\rho_L = \frac{Q}{L}$	C/m
2.	Surface Charge Density	Total number of charges per total area in square meter	$\rho_S = \frac{Q}{A}$	C/m^3
3.	Volume Charge Density	Total number of charges per total volume in cubic meter	$\rho_V = \frac{Q}{V}$	C/m^3

UNIT-2

1. State Coulomb's Law.

It states that force between two point charges Q1 and Q2 is directly proportional to the product of two charges & inversely proportional to the square of the distance between them.

$$F \alpha \frac{Q_1 Q_2}{R^2} \qquad \text{Q1 \& Q2 are the charges}$$

$$F = \frac{kQ_1 Q_2}{R^2}$$

$$k = \frac{1}{4\pi\varepsilon} \quad \varepsilon = \varepsilon_o \varepsilon_r$$

$$\varepsilon = Permittivity\ of\ the\ medium$$

$$\varepsilon_o = (8.854x10^{-6} F/m) Permittivity\ of\ free\ space$$

$$\varepsilon_r = \text{Re}lative\ Permittivity$$

2. State the principle of Superposition.

If the system consists of n point charge namely $Q_1, Q_2, Q_3 \ldots Q_n$, then the force on any other charge Q is given by the vector sum of all the individual forces produced by n charges on the charge Q.

$$F_{Q_1Q} = \frac{Q_1 Q}{4\pi\varepsilon_o R_{1Q}^2} \overline{a_{1Q}} \qquad F_{Q_2Q} = \frac{Q_2 Q}{4\pi\varepsilon_o R_{2Q}^2} \overline{a_{2Q}}$$

The total force is given as $F_Q = F_{Q_1Q} + F_{Q_2Q}$

$$F_Q = \frac{Q_1 Q}{4\pi\varepsilon_o R_{1Q}^2} \overline{a_{2Q}} + \frac{Q_2 Q}{4\pi\varepsilon_o R_{2Q}^2} \overline{a_{2Q}} + \ldots\ldots\ldots$$

$$F_Q = \frac{Q}{4\pi\varepsilon_o} \sum_{i=1}^{n} \frac{Q_i}{R_{iQ}^2} \overline{a_{iQ}}$$

3. Define Electric fields Intensity.

There exists a region around a change in which it exerts a forces on any other charge is called electric field of that charge.

It is also defined as the force exerted /unit charge.

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_o R_{12}^2} \overline{a_{12}}$$

$$E = \frac{F}{Q_2} = \frac{Q_1}{4\pi\varepsilon_o R_{12}^2} \overline{a_{12}}$$

4. Define Electric Flux.

It is defined as the total number electric field lines originate in the isolated points. It starts from the positive charge & terminates at the negative charges.

It is denoted by $\phi = \psi$

5. Define the Electric Flux Density

It is defined as the total number electric flux per unit area
It is also defined as the product of the electric field intensity and the permittivity of the Point.

$$D = \varepsilon \overline{E}$$
$$D = \varepsilon_o \varepsilon_r \overline{E}$$

6. Mention any two sources of electromagnetic field.

The signal transmitted & the received by antenna
The signal used in optical fiber communication.

7. State Gauss Law.

The electric flux passing through any closed. Surface is equal to the total charge enclosed by the surface.

$$\iint D.ds = Q$$

The integral form of Gauss Law: $\oiint_S D.ds = \oiiint_V \rho_V dv$

The Point form of Gauss Law: $\nabla.D = \rho_V$

8. State the applications of Gauss Law.

a. Alternative statement for the Coulomb's Law.
b. Used to find E & D.
c. Used to find the charge enclosed (or) flux passing through the closed surface.

9. Define Potential.

The potential at any point in on electric field is defined as the work done in moving a unit test charge from infinity to the point under consideration against the direction of field.

10. State the principle of superposition as applied to on electric potential.

Consider the various point charges Q1 Q2.....Qn The potential due to all there points charges at point A is to be determined As Potential is scalar According to principle of superposition the net potential at point A is algebraic sum of potential at A due to individual point charges.

$$VA= VA1+ VA2+\ldots..\ Van =Q1/4\pi\Sigma_0R_1+ Q1/4\pi\Sigma_0R_2 + Q1/4\pi\Sigma_0R_n$$
$$= \Sigma\ Qm/4\pi\Sigma_0R_m$$

11. Distinguish between potential & potential difference.

The potential at any point in on electric field is defined as the work done in moving a unit test charge from the infinity to the point under consideration against the direction of field .

While work done per unit charge in moving unit charge point B to A in the field E is called as the potential difference between the points B to A.

It is the difference between the absolute potential of points B to A.

12. Give the relation b/w electric field & potential.

The electric field is the negative gradient potential. $E = -\nabla V$

13. What is an electric dipole?

The two point charges of equal magnitude but opposite sign separated by a very small distance give rise to an electric dipole.

14. Define Conductors.

The distance between the conduction & valance band is minimum, the free electrons move easily and initiate the flow of current.
Eg. Copper, Iron.

15. Explain the dielectric materials.

The dielectric materials are not having the free charges, they are having only the bounded charges, which is similar to the insulator, but due to application of electric field electron moves from the original position, which can able to produce the dipole. Such a material is called as dielectric material.

16. Define Polarization.

The separation of bound charges results to produce the electric dipole under the influence of electric field. It is also defined as the total dipole moment per unit volume.

$$P_{Total} = Q_1 d_1 + Q_2 d_2 + \ldots\ldots\ldots\ldots + Q_n d_n$$

$$P_{Total} = \sum_{i=1,2,\ldots} Q_i d_i$$

17. List out the properties of Dielectric materials.

a. It does not have any free charges, it has only bound charges.
b. Due to polarization, dielectric store energy.
c. When external E applied bound charges shift to relative positions.
d. Polarization occur volume charge density is formed inside dielectric surface charge density is formed over the surface of dielectric.

18. Explain Dielectric Strength.

The minimum value of applied electric field at which the dielectric breaks down is called dielectric strength of that dielectric.
Unit is V/m (or) KV/cm.
Dielectric strength of air is 3 KV/cm.

19. Define Capacitance

It is defined as the ratio of charge on the any one of the two conductors to the potential difference between the conductors.

$$C = \frac{Charge\ in\ the\ any\ one\ of\ the\ conductors}{Potential\ Difference\ between\ the\ conductors} \qquad C = \frac{\iint_s D.ds}{-\int E.dL}$$

20. What are the various combinations of capacitor?

In series: $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$ In Parallel : $C_{eq} = C_1 + C_2 + C_3$

21. State the Law of conservation of energy.

The charge can neither be created nor be destroyed, it may change from one form to another form.

22. State the continuity equation in integral & differential form?

Consider a closed surface "S" with current density "J". The total current "I" crossing the surface "S" is given by $I = \iint_S J.dS$ The current flow outwards from the closed surface;

According to principle, there may decrease of an equal amount of positive charge in closed surface. Rate of decrease of charge inside a closed surface= $-\frac{dQ_i}{dt}$

$$I = \iint_S J.dS = -\frac{dQ_i}{dt} \text{ (Integral form of Continuity Equation)}$$

$$\nabla.J = -\frac{\partial \rho_v}{\partial t} \quad \text{(Point form of Continuity Equation)}$$

23. State the equation to energy stored in the capacitor.

$$W_E = \frac{1}{2}CV^2$$

W_E= Energy stored in the capacitor.
C = Capacitance in Farad
V= Potential difference

24. Define Ohm's law at a point?

The point form of ohm's law is given by for a metallic conductor

J =σE

σ = conductivity of material.

25. What is the difference between homogeneous & non homogeneous medium?

The medium is called homogenous ; when the physical characteristics of the medium do not vary from point to point; but remain same every where through at the medium. If the characteristics vary from point to point then the medium is called as non homogenous (or) heterogeneous.

26. What are the components used in the analysis of boundary conditions?

The electric field components & flux components are resolved into two components, they are of normal component & tangential component.

$$E = E_{\tan} + E_N$$
$$D = D_{\tan} + D_N$$

$$E_{\tan} = Tangential\ \ component\ of\ \ electric\ \ field$$
$$E_N = Normal\ \ component\ of\ \ electric\ \ field$$
$$D_{\tan} = Tangential\ \ component\ of\ \ electric\ \ flux$$
$$D_N = Normal\ \ component\ of\ \ electric\ \ flux$$

27. What are the elements used to analyze the boundary conditions?

Closed Path , which is used to analyze the field intensity of the components.
Gaussian Surface, which is used to analyze the flux density of the components.

28. State the boundary conditions between conductor & free space.

i) The tangential components of electric field intensity & flux density is equal to zero.
$E_{\tan} = D_{\tan} = 0$

ii) The normal component of electric flux density is equal to the surface charge density.

$D_N = \rho_S$

iii) The normal component of electric field intensity is equal to the ratio of surface charge density to the permittivity of free space. $E_N = \dfrac{\rho_S}{\varepsilon_o}$

29. State the boundary conditions between two perfect dielectrics.

i) The tangential component of field intensity at the boundary in both dielectrics remain same; **E is continuous across the boundary**. $E_{\tan 1} = E_{\tan 2}$

ii) The tangential components of D undergoes some change across the interface; **So D is discontinuous across boundary**. $\dfrac{D_{\tan 1}}{D_{\tan 2}} = \dfrac{\varepsilon_{r1}}{\varepsilon_{r2}}$

iii) The normal components of flux density D is continuous at the boundary between two dielectrics. $D_{N1} = D_{N2}$

iv) The normal component of E are inversely proportional to the relative permittivity of two media. $\dfrac{E_{N1}}{E_{N2}} = \dfrac{\varepsilon_{r2}}{\varepsilon_{r1}}$

30. Write the procedure to calculate the capacitance using Laplace equation.

i) Laplace equation analysis($\nabla^2 v = 0$)

ii) Write the Laplace equation for particular coordinates.

iii) Calculate the potential by taking double integration.

iv) Substitute the boundary conditions & calculate the constant value.

v) Determine the electric field intensity $E = -\nabla V$

vi) Determine the electric flux density. $D = \varepsilon_o E$

vii) Determine the charge value. $Q = \rho_l * L$; $Q = \rho_s * A$; $Q = \rho_v * V$

viii) Determine the capacitance $C = \dfrac{Q}{V}$

31. Explain the electric field distribution inside and outside conductor?

It is known that current must flow when potential exists. When a certain amount of electric charge exists inside a conductor , then mutual reputation between the charge takes place and its gives rise to an electric field E. this produces the current according to ohm's law. But as the charges get distributed uniformly, E vanishes and the current leases.

Thus E is every where zero inside a conductor and all points inside the conductor are equi-potential in nature. When motion of the charges inside the conductor stops. E & D is zero every where inside the conductor . if a gaussion surface is sselected just inside the surface of conductor.

$\int$ D.ds = 0

Thus in the entire volume occupied by the conductor no charge exists . if somehow charge is released inside the conductor , it immediately flows out and reside on the surface of conductor hence electric charge can reside only on the surface of conductor.

UNIT-3

1. Define magnetic field intensity & its unit?

It is a quantitative measure of strongness (or) weakness of the magnetic field.
It is also defined as the force experienced by a unit north pole of one weber strength, when placed at that point. Unit of Magnetic Field Intensity is N/Wb (newton/ weber).

2. Define magnetic flux density & its unit.

It is defined as the flux crossing per unit area, it is denoted as "B". Its unit is Tesla (Wb/m^2)

$$\overline{B} = \mu \overline{H}$$
$$\overline{B} = \mu_o \mu_r \overline{H} \quad \mu_r = 1$$
$$\mu_o = 4\pi X 10^{-7}$$

3. Define Magnetic field & magnetic lines of force?

a) The region around a magnet with in which the influence of magnet can be experienced is called as magnetic field.
b) Such a field represented by imaginary lines around the magnet called as magnetic lines of force.
c) Such a lines of force are called as magnetic lines of flux/ magnetic flux lines.

4. What is the relation between magnetic flux density & field intensity?

The magnetic flux density B & magnetic field intensity h are related to each other through the property of region in which current carrying conductor is placed called as the permeability (μ)

$$B = \mu H; \qquad B = \mu_0 \mu_r H$$

5. State right hand thumb rule?

It states that hold the current carrying conductor in right hand such that thumb pointing in the direction of current and parallel to the conductor then, curled fingers point in the direction of magnetic lines of flux around it.

6. State Biot- savart's law?

The magnetic field intensity dH produced at a point p due to a differential current element IdL is

i) Proportional to the product of the current I and differential length dL
ii) Proportional to the sine of the angle between the element and the line joining point "P" to the current element.
iii) Inversely proportional to the square of the distance between point "P" and the element "R".

$$dH \,\alpha\, \frac{IdLSin\theta}{R^2} \qquad dH = \frac{KIdLSin\theta}{R^2}\,;\ K = \frac{1}{4\pi} \qquad dH = \frac{IdLSin\theta}{4\pi R^2}$$

7. State ampere's circuital law?

The line integral of the magnetic field intensity H around a closed path is exactly equal to the direct current enclosed by the path.

$$\oint H.dL = I$$

8. What are the types of magnetic potential?

a. Scalar Magnetic Potential (V_m)
b. Vector Magnetic Potential. (A)

9. State the applications of ampere's circuital law

It is used to obtain H due to

a) Infinitely long straight conductor
b) Co-axial cable
c) Infinite sheet & current
d) Circular conductor carrying current I

10. What is the scalar magnetic potential?

The scalar magnetic potential V_m can be defined for source free region where current density is equal to zero.

$$H = -\nabla V_m; \quad J=0$$

Magnetic scalar potential can be expressed in terms of H

$$V_m = -\int H.dL$$

11. Define vector magnetic potential & state its unit?

The vector magnetic potential A is defined such that curl of vector magnetic potential is flux density. $\overline{B} = \nabla X \overline{A}$ where as $\nabla.\overline{B} = 0$

The vector magnetic potential A serves an intermediate quantity from which magnetic flux density B is obtained & hence H can be obtained.

12. Can a static magnetic field exist in a good conductor, Explain?

A static magnetic field can exist in good conductor, when conductor carries current , it produces the flux which can exist inside the conductor. Due to this flux, magnetic fields intensity exists at a point inside a good conductor.

13. Plane y= 0 carriers a uniform current of 30 $\overline{a_z}$ mA/m. Calculate the magnetic field intensity at (1, 10, -2)m in rectangular co- ordinate system.

$$H = \frac{1}{2} K x \overline{a_N}$$

$$H = \frac{1}{2}(30\overline{a_z} x \overline{a_y})$$

$$H = -\frac{1}{2} 30\overline{a_x}$$

$$H = -15\overline{a_x}$$

14. Define magnetic flux & flux density?

The total no. of lines of force existing in a particular magnetic field is called as magnetic flux (φ).The flux per unit area in a plane at right angles to the flux called as magnetic flux density (B).

B= φ /A.

15. State the classification of Magnetic materials

a. Dia-magnetic materials (Lead, Copper, Diamond)
b. Para-magnetic materials(Potassium, Tungsten)
c. Ferro-magnetic materials(Iron, Nickel)
d. Anti-ferro magnetic materials(Oxides, Chlorides)
e. Ferri-magnetic materials(Nickel Ferrite, Nickel Zinc Ferrite)
f. Super-magnetic materials

16. Define Domain.

The region in which large number of magnetic moments lined in parallel.

17. Define Residual Field.

If the external field is applied, the domain size increases. If the field is removed the original dipole moment is not achieved, such a moment remain in small region that is called as Residual field (or) Remnant field.

18. Define Hysteresis.

The effect of retaining residual field after the removal of external field, is called as the Hysteresis.

19. Define Magnetization.

The charges bounds the nucleus is called as the bound charges. The field produced due to the movement of bound charges is called as the Magnetization(M). It is also defined as the magnetic dipole moment per unit volume

$$\overline{M} = \lim_{\Delta v \to 0} \frac{1}{\Delta v} \sum_{a=1}^{n\Delta v} \overline{m_a}$$

20. Write the basic expression used in the analysis of magnetic boundary conditions.

$$\oint H.dL = I$$

$$\oiint B.ds = 0$$

21. State Kirchhoff's Flux Law.

It states that "The total magnetic flux arriving at any junction in a magnetic circuit is equal to the total magnetic flux leaving.

$$\sum \phi = 0$$

22. State Kirchhoff's MMF Law.

The resultant MMF around a closed magnetic circuit is equal to algebraic sum of the product of flux & the reluctance of each part of the closed circuits.

$$\sum (mmf) = \sum \phi \Re$$

23. Define Inductance.

It is defined as the ratio of total flux linkage to the current producing that flux.

$$L \ \alpha \ \frac{\phi}{I} \quad ; \quad L = \frac{N\phi}{I}$$

$N \to Number\ of\ turns$
$\phi \to Flux\ Linkage$
$I \to Current\ flowing$ in $the\ coil$

24. Define the self inductance & mutual inductance.

Self inductance : The flux produced by the current flow through the same coil.
Mutual Inductance: The flux produced in the coil-1 due to flow of current in the coil-2

25. Write the expression for energy stored in the inductor.

$$W_m = \frac{1}{2} L I^2$$

L – Inductance
I – Current flowing in the coil

26. State the Lorentz Force Equation.

According to Newton, he stated that two or more forces that they act independently of each other, but their net resultant effect is sum of the effects of all the forces.

$$F = F_e + F_m$$
$$F = Q\overline{E} + Q(\overline{v}x\overline{B})$$
$$F = Q\left[\overline{E} + (\overline{v}x\overline{B})\right]$$

The electric force is independent of velocity
The magnetic force is dependent on velocity of moving charge.

27. Write the applications of Lorentz Force Equation.

The solution of the equation is useful in determination of

a) Electron orbits in magnetron
b) Proton path in cyclotron
c) Plasma characteristics in magneto-hydro dynamic generator.

28. What is the effect of force between the differential current element?

In parallel conductors

a) If the current flows in the same direction, then there is a force of attraction.
b) If the current flows in the opposite direction, then there is a force of repulsion.

29. Define the Magnetic Torque.

It is defined as the rotational force.
It is also defined as the vector product of moment arm(R) and the force (F)
Its unit is N/m

$$\overline{T} = \overline{R}x\overline{F}$$

30. Define Magnetic Dipole Moment.

It is defined as the product of current through the loop and the area of the loop, it is directed normal to the current loop. $\overline{m} = IS$

31. Define Coefficient of coupling.

It is defined as the total flux produced by one coil linking a second coil $K = \frac{\phi_{12}}{\phi_1} = \frac{\phi_{21}}{\phi_2}$

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

32. Write the expression for inductance in different aiding.

a) Series Aiding : $L = L_1 + L_2 + 2M$
b) Series Opposing : $L = L_1 + L_2 - 2M$
c) Parallel Aiding : $L = \frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}$

d) Parallel Opposing: $L = \dfrac{L_1 L_2 - M^2}{L_1 + L_2 + 2M}$

UNIT-4 & 5

1. State Faraday's law of electromagnetic induction

The electromotive force induced in a closed path is proportional to rate of change of magnetic flux enclosed by the closed path

$$e = -N\frac{d\phi}{dt}$$

2. State Lenz Law

The direction of induced electro-magnetic force is such that it opposes the cause producing it. It is also called as the changes in the magnetic flux.

3. What is the significance of displacement current?

The displacement current is associated with the time varying electric fields. It always exists in all imperfect conductors which carry time varying conduction current.

4. Discuss the condition under which conduction current is equal to displacement current

The ratio indicate the nature of a medium : Then the ratio of magnitudes of the conduction current density to the displacement current density is given by

$$\frac{|J_c|}{|J_D|} = \frac{\sigma}{\omega\varepsilon}$$

5. Write the Maxwell's Equation in Point or Differential form

$$\nabla x E = -\partial B/\partial t$$

$$\nabla x H = J + \partial D/\partial t$$

$$\nabla . D = \rho_v$$

$$\nabla . B = 0$$

6. Write the Maxwell's Equation in phasor form

$$\nabla x E = -j\omega\mu H$$

$$\nabla x H = (\sigma + j\omega\varepsilon)E$$

$$\nabla . D = \rho_v$$

$$\nabla . B = 0$$

7. Write the Maxwell's equation derived from Faraday's law

Point Form: $\nabla x E = -\partial B / \partial t$

Integral Form $\int_L E.dl = -\iint_S \partial B / \partial t \, ds$

8. Write the Maxwell's Equation in the integral form

$$\int_L E.dl = -\iint_S \partial B / \partial t \, ds$$

$$\int_L H.dl = I + \iint_S \partial D / \partial t \, ds$$

$$\iint_S D.ds = \iiint_v \rho_v .dv$$

$$\iint_S B.ds = 0$$

9. Write the Maxwell's equation derived from Ampere's law

Point Form: $\nabla x H = J + \partial D / \partial t$

Integral Form $\int_L H.dl = I + \iint_S \partial D / \partial t \, ds$

10. Give the situations when the rate of change of flux results in a non-zero value

i) There exists a relative motion between conductor & flux

ii) Plane of flux & motion of conductors should not be parallel

iii) An alternating flux linking with coils of N-turns

11. Define Poynting Vector ; What is its unit?

If E & H are the time varying electric & magnetic fields respectively then the cross product of E & H is called as the pointing vector

P=EXH

Unit : V.A/m^2 (or) Watts/m^2

12. State Poynting Theorem

It is based on law of conservation of energy in electromagnetism . The pointing theorem states that the net power flowing out of a given volume V is equal to a time rate of decrease in energy stored with in volume V minus Ohmic power dissipated.

13. Define wave.

A wave is defined as the phenomenon which occurs at one place at a given time & gets reproduced at other places a later time where the time delay being proportional to the separation between first & other place in space

14. Define Intrinsic Impedance

It is defined as the ratio of permeability to the permittivity of the medium . it is denoted as η

$$\eta = \sqrt{\frac{\mu}{\varepsilon}}$$

$$\eta = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \sqrt{\frac{4\Pi * 10^{-7}}{8.854 * 10^{-12}}} = 120\Pi = 377\Omega$$

15. Define skin depth

The distance through which the amplitude of the travelling wave decreases t0 37% of its original value is called as the skin depth/ depth of penetration . it is denoted by δ

$$\delta = \frac{1}{\alpha} = \frac{1}{\beta} = \frac{1}{\sqrt{\Pi f \mu\sigma}}$$

16. Write down the expression for velocity , attenuation constant , plane constant , intrinsic impedance , in perfect dielectric .

i) Velocity $V = \frac{c}{\sqrt{\mu_r \varepsilon_r}}$

ii) Attenuation constant $\alpha = 0$

iii) Phase Constant $\beta = \omega\sqrt{\mu\varepsilon}$

iv) Intrinsic impedance $\eta = \eta_0 \sqrt{\frac{\mu_r}{\varepsilon_r}}$

v) Wave length $\lambda = \frac{2\Pi}{\beta}$

17. Determine the wavelength of an electromagnetic wave travelling in free space at 30GHz

$$\lambda = \frac{c}{f} = \frac{3 * 10^8}{30 * 10^9} = 0.1m$$

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EC8451-ELECTROMAGNETIC FIELDS
COURSE HAND OUT

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

Coordinate Systems:

a) Cartesian Coordinate Systems
   i) A constant plane at the value of X
   ii) A constant plane at the value of Y
   iii) A constant plane at the value of Z
b) Cylindrical coordinate Systems
   i) A cylinder with a radius r with z-axis as the axis of cylinder
   ii) A half plane perpendicular to XY plane & at an angle of ϕ with respect to XZ-plane.
   iii) A constant plane at the value of Z.
c) Spherical Coordinate Systems
   i) A sphere of radius r origin as a centre.
   ii) A right circular cone with its apex at the origin & its origin as Z-axis, its half angle is θ.
   iii) A half plane perpendicular to XY-plane; making an angle ϕ with XZ-plane.

Coordinate Systems	Differential Elements	Differential Surface	Differential Volume	Unit Vectors	Limits
Cartesian Coordinate Systems	dx dy dz	$ds_x = dydz\overline{a_x}$ $ds_y = dxdz\overline{a_y}$ $ds_z = dxdz\overline{a_z}$	$dv = dxdydz$	$\overline{a_x}$ $\overline{a_y}$ $\overline{a_z}$	$0 \le x \le \infty$ $0 \le y \le \infty$ $0 \le z \le \infty$
Cylindrical Coordinate Systems	dr $rd\phi$ dz	$ds_r = rd\phi dz\overline{a_r}$ $ds_\phi = drdz\overline{a_\phi}$ $ds_z = rdrd\phi\overline{a_z}$	$dv = rdrd\phi dz$	$\overline{a_r}$ $\overline{a_\phi}$ $\overline{a_z}$	$0 \le r \le \infty$ $0 \le \phi \le 2\pi$ $0 \le z \le \infty$
Spherical Coordinate Systems	dr $rd\theta$ $r\sin\theta d\phi$	$ds_r = r^2 \sin\theta d\theta d\phi\overline{a_r}$ $ds_\theta = r\sin\theta drd\phi\overline{a_\theta}$ $ds_\phi = rdrd\theta\overline{a_\phi}$	$dv = r^2 \sin\theta drd\theta d\phi$	$\overline{a_r}$ $\overline{a_\theta}$ $\overline{a_\phi}$	$0 \le r \le \infty$ $0 \le \theta \le \pi$ $0 \le \phi \le 2\pi$

<u>Relation between coordinate systems:</u>

1. Between Cartesian & cylindrical coordinate systems.

$$r = \sqrt{\left(x^2 + y^2\right)} \quad \& \quad \phi = \tan^{-1}\left(\frac{y}{x}\right)$$

2. Between Cartesian & Spherical Coordinate Systems.

$$r = \sqrt{\left(x^2 + y^2 + z^2\right)} \qquad \theta = \cos^{-1}\left(\frac{z}{r}\right) \; \phi = \tan^{-1}\left(\frac{y}{x}\right)$$

Scalar Product	Vector Product
$\overline{A}.\overline{B} = \lvert\overline{A}\rvert\lvert\overline{B}\rvert\cos\theta_{AB}$	$\overline{A}x\overline{B} = \lvert\overline{A}\rvert\lvert\overline{B}\rvert\sin\theta_{AB}$
If two vectors are parallel $\overline{A}.\overline{B} = \lvert\overline{A}\rvert\lvert\overline{B}\rvert$ *If two vectors are perpendicular* $\overline{A}.\overline{B} = 0$	*If two vectors are parallel* $\overline{A}x\overline{B} = 0$ *If two vectors are perpendicular* $\overline{A}x\overline{B} = \lvert\overline{A}\rvert\lvert\overline{B}\rvert$
$\overline{a_x}.\overline{a_x} = 1$ $\overline{a_y}.\overline{a_y} = 1$ $\overline{a_z}.\overline{a_z} = 1$	$\overline{a_x}x\overline{a_y} = \overline{a_z}$ $\overline{a_y}x\overline{a_z} = \overline{a_x}$ $\overline{a_z}x\overline{a_x} = \overline{a_y}$

Parameters	Cartesian	Cylindrical	Spherical
h_1	1	1	1
h_2	1	r	r
h_3	1	1	$r\sin\theta$
u_1	x	r	r
u_2	y	ϕ	θ
u_3	z	z	ϕ

h = Indicates the coefficient of the differential element.

u = Indicates the element.

Gradient: $\nabla v = \frac{1}{h_1}\frac{\partial v}{\partial u_1}\overline{a_{u_1}} + \frac{1}{h_2}\frac{\partial v}{\partial u_2}\overline{a_{u_2}} + \frac{1}{h_3}\frac{\partial v}{\partial u_3}\overline{a_{u_3}}$

Divergence: $\nabla.F = \frac{1}{h_1h_2h_3}\left[\frac{\partial}{\partial u_1}\left[h_2h_3\overline{F_{u_1}}\right] + \frac{\partial}{\partial u_2}\left[h_1h_3\overline{F_{u_2}}\right] + \frac{\partial}{\partial u_3}\left[h_1h_2\overline{F_{u_3}}\right]\right]$

Curl: $\nabla xF = \frac{1}{h_1h_2h_3}\begin{vmatrix} h_1a_{u_1} & h_2a_{u_2} & h_3a_{u_3} \\ \frac{\partial}{\partial u_1} & \frac{\partial}{\partial u_2} & \frac{\partial}{\partial u_3} \\ h_1F_{u_1} & h_2F_{u_2} & h_3F_{u_3} \end{vmatrix}$

Divergence Theorem: $\iiint_v \nabla.F dv = \iint_s F.ds$

Stokes Theorem: $\int_L F.dL = \iint_s (\nabla xF)ds$

Coulomb s Law : $F = \frac{Q_1Q_2}{4\pi\varepsilon R^2}$

Gauss Law: $\oiint D.ds = Q$ & $\nabla.D = \rho_v$

Procedure to find the Electric Field Intensity:

1. Basic equation is $dE = \frac{dQ}{4\pi\varepsilon_o R^2}\overline{a_R}$
2. Determination of dQ based on the type of the charge.
3. Determination of unit vector.
4. Determination of dE & integrate over the particular limits & then we obtain the electric field intensity.

Force between two charges	$F = \frac{Q_1 Q_2}{4\pi\varepsilon_o R^2}$
Electric Field Intensity	$E = \frac{F}{Q_2} = \frac{Q_1}{4\pi\varepsilon_o R^2}$
Electric Flux Density	$D = \varepsilon_o E = \frac{Q_1}{4\pi R^2}$
Electric Potential	$V = -\int E.dL$

Current: $I = \frac{dQ}{dt}$ $(Amphere)$

Relation between the current & current density $I = \int J.ds$

Continuity Equation: $\oint J.ds = I = -\frac{dQ_i}{dt}$ [Integral form]

$$\nabla.J = -\frac{\partial \rho_v}{\partial t} \text{ [Point Form]}$$

$$\nabla^2 v = \left(Divergence\left(Gradient\left(v\right)\right)\right) = \nabla.\left(\nabla v\right)$$

Laplace Equation $: \nabla^2 v = 0$

Poisson Equation $: \nabla^2 v = -\frac{\rho_v}{\varepsilon}$

Procedure to Calculate Capacitance using Laplace Equation :

i) Laplace Equation $: \nabla^2 v = 0$
ii) Write the Laplace Equation for the particular coordinate system.
iii) Calculate the potential by taking double integration.
iv) Substitute the boundary conditions & calculate the constant value
v) $E = -\nabla v$
vi) $D = \varepsilon_o E$
vii) $Q = \rho_L x L \quad Q = \rho_S x A \quad Q = \rho_V x V$
viii) $C = \frac{Q}{A}$

Capacitance: $C = \frac{Q}{v} = \frac{\oint \varepsilon E.ds}{-\int E.dl}$

Combination of Capacitance:

Series	$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + ...$
Parallel	$C_{eq} = C_1 + C_2 + ...$

Energy Stored in the Capacitor :

$$W_E = \frac{1}{2} C V^2$$

Various Geometries of Capacitance:

Geometries	Electric Field Intensity	Potential	Capacitance
Parallel Plate Capacitor	$E=\frac{\rho_s}{\varepsilon}\overline{a_z}$	$v=\frac{\rho_s d}{\varepsilon}$	$C=\frac{\varepsilon_o\varepsilon_r A}{d}$
Co-axial cable	$E=\frac{\rho_L}{2\pi\varepsilon r}\overline{a_r}$	$v=\frac{\rho_L}{2\pi\varepsilon}\ln\left(\frac{b}{a}\right)$	$C=\frac{2\pi\varepsilon L}{\ln\left(\frac{b}{a}\right)}$
Spherical capacitor	$E=\frac{Q}{4\pi\varepsilon r^2}\overline{a_r}$	$v=\frac{Q}{4\pi\varepsilon}\left[\frac{1}{a}-\frac{1}{b}\right]$	$C=\frac{4\pi\varepsilon}{\left[\frac{1}{a}-\frac{1}{b}\right]}$
Single isolated Sphere	----	----	$C=4\pi\varepsilon a$
Isolated Sphere coated with dielectric	$E=\frac{Q}{4\pi\varepsilon r^2}\overline{a_r}$	$v=\frac{Q}{4\pi}\left[\frac{1}{\varepsilon_o r_1}+\frac{1}{\varepsilon_1}\left(\frac{1}{a}-\frac{1}{r_1}\right)\right]$	$C=\frac{1}{\left(\frac{4\pi\varepsilon_1}{\left(\frac{1}{a}-\frac{1}{r_1}\right)}\right)}+\frac{1}{4\pi\varepsilon_0 r_1}$
Composite Parallel Plate Capacitor(Boundary Parallel to plates)	-----	$v=\frac{D_1 d_1}{\varepsilon_1}+\frac{D_2 d_2}{\varepsilon_2}+.....$	$C=\frac{A}{\frac{d_1}{\varepsilon_1}+\frac{d_2}{\varepsilon_2}+\frac{d_3}{\varepsilon_3}+\frac{d_4}{\varepsilon_4}+....}$
Dielectric Boundary perpendicular to plates	----	----	$C=\left[\frac{\varepsilon_1 A_1}{d_1}+\frac{\varepsilon_2 A_2}{d_2}+\frac{\varepsilon_3 A_3}{d_3}+...\right]$

Boundary Conditions:

The electric field components are $\overline{E}=\overline{E_{\tan}}+\overline{E_N}$

The electric flux components are $\overline{D}=\overline{D_{\tan}}+\overline{D_N}$

The boundary conditions are studied using following Maxwell's equations

$$\int \overline{E}.dL=0 \quad \& \quad \iint D.ds=Q$$

Right Hand Thumb Rule:

- Thumb indicates the direction of current
- Curled fingers shows the direction magnetic lines of flux.

Magnetic Flux: Total number of magnetic lines of force.

Biot Savart Law:

$$d\overline{H} = \frac{Idl\sin\theta}{4\pi R^2} \quad (Normal \ \ form)$$

$$d\overline{H} = \frac{Idlx\overline{R}}{4\pi R^3} \quad (Vector \ \ form)$$

$$\overline{H} = \oint \frac{Idlx\overline{R}}{4\pi R^3} \quad (Integral \ \ form)$$

Magnetic Field intensity & flux density:

Types of Conductors	Magnetic Field Intensity		Magnetic Flux Density	
Infinite Long Straight Conductor	$\overline{H} = \frac{I}{2\pi r}\overline{a_\phi}$		$\overline{B} = \frac{\mu I}{2\pi r}\overline{a_\phi}$	
Finite Long Straight Conductor	$\overline{H} = \frac{I}{2\pi r}[\sin\alpha_2 - \sin\alpha_1]\overline{a_\phi}$		$\overline{B} = \frac{\mu I}{2\pi r}[\sin\alpha_2 - \sin\alpha_1]\overline{a_\phi}$	
Circular Loop at Z= some value	$\overline{H} = \frac{Ir^2}{2(r^2+z^2)^{3/2}}\overline{a_z}$		$\overline{B} = \frac{\mu Ir^2}{2(r^2+z^2)^{3/2}}\overline{a_z}$	
Circular Loop at Z=0	$\overline{H} = \frac{I}{2r}\overline{a_z}$		$\overline{B} = \frac{\mu I}{2r}\overline{a_z}$	
Infinite Sheet	$\overline{H} = \frac{Ky}{2}\overline{a_x}$		$\overline{B} = \frac{\mu Ky}{2}\overline{a_x}$	
Co-axial cable	r<a	$\overline{H} = \frac{Ir}{2\pi a^2}\overline{a_\phi}$	r<a	$\overline{B} = \frac{\mu Ir}{2\pi a^2}\overline{a_\phi}$
	a<r<b	$\overline{H} = \frac{I}{2\pi r}\overline{a_\phi}$	a<r<b	$\overline{B} = \frac{\mu I}{2\pi r}\overline{a_\phi}$
	b<r<c	$\overline{H} = I\left(\frac{c^2-r^2}{c^2-b^2}\right)\overline{a_\phi}$	b<r<c	$\overline{B} = \mu I\left(\frac{c^2-r^2}{c^2-b^2}\right)\overline{a_\phi}$
	r>c	$\overline{H} = 0$	r>c	$\overline{B} = 0$

Ampere's Circuital Law: $\int \overline{H}.dL = I$

Scalar Magnetic Potential (V_m) : $\nabla x(\nabla V_m) = 0$; $\nabla V_m = -\overline{H}$; $V_m = -\int_a^b \overline{H}.dL$

Vector Magnetic Potential (A) : $\nabla x(\nabla xA) = 0$; $\nabla.B = 0$; $\nabla xA = B$

Lorentz Force Equation:

$$\overline{F} = \overline{F_e} + \overline{F_m}$$

Force due to electric field : $\overline{F_e} = Q\overline{E}$

Force due to magnetic field: $\overline{F_e} = Q(vx\overline{B})$

Force on a differential current element:

$$dF = dQ(vxB)$$

$dQ = \rho_L dL$; $dF = \rho_L dL(vxB)$; $dF = IxBdL$

$dQ = \rho_S dS$; $dF = \rho_S dS(vxB)$; $dF = KxBdS$

$dQ = \rho_V dV$; $dF = \rho_V dV(vxB)$; $dF = JxBdV$

Force between different current elements:

Two parallel current conductors

i) If the current flow in the same direction= Force of attraction.
ii) If the current flows in the opposite direction= Force of repulsion.

Magnetic Torque: $\overline{T} = \overline{R}x\overline{F}$

Torque of Planar Coil: $\overline{T} = BIS(-\overline{a_y})$

Magnetic Dipole Moment: $\overline{m} = (IS)\overline{a_n}$

Magnetic Boundary Conditions:

The magnetic field components: $\overline{H} = \overline{H_{\tan}} + \overline{H_N}$

The magnetic flux components : $\overline{B} = \overline{B_{\tan}} + \overline{B_N}$

The boundary conditions are studied using the following Maxwell's equations

$$\int H.dL = I \quad \& \quad \iint B.dS = 0$$

Inductance: $L\alpha \dfrac{\phi}{I}$ $L = \dfrac{N\phi}{I}$ [N indicates no. of turns in the coil]

Inductance of Solenoid: $L = \dfrac{\mu N^2 A}{l}$

Inductance of Toroid: $L = \dfrac{\mu N^2 h}{2\pi} \ln\left(\dfrac{r_2}{r_1}\right)$

Inductance of Co-axial cable: $L = \dfrac{\mu d}{2\pi} \ln\left(\dfrac{b}{a}\right)$

Important Laws:

Faraday s Law: $e = -N\dfrac{d\phi}{dt}$

Ampere s Circuital Law: $\oint H.dL = I$

Gauss Law for Electric Field: $\oiint D.dS = Q$

Gauss Law for Magnetic Field: $\oiint B.dS = 0$

Maxwell Equations:

Equation	Point Form	Integral Form
I Equation	$\nabla x E = -\dfrac{\partial B}{\partial t}$	$\oint_L E.dL = -\iint_S \dfrac{\partial B}{\partial t} dS$
II Equation	$\nabla x H = J + \dfrac{\partial D}{\partial t}$	$\int_L H.dL = \iint_S \left(J + \dfrac{\partial D}{\partial t} \right) dS$
III Equation	$\nabla .D = \rho_v$	$\iint_S D.dS = \iiint_V \rho_v dV$
IV Equation	$\nabla .B = 0$	$\iint_S B.dS = 0$

Poynting Theorem:

$$\overline{P} = \overline{E} x \overline{H}$$

$$-\nabla .P = \sigma E^2 + \frac{1}{2}\frac{\partial}{\partial t}\left[\mu H^2 + \varepsilon E^2 \right]$$

Wave equation:

$$\nabla^2 E - \mu\varepsilon \frac{\partial^2 E}{\partial t^2} = 0 \quad \& \quad \nabla^2 H - \mu\varepsilon \frac{\partial^2 H}{\partial t^2} = 0$$

Various Conditions

i) For Static Fields: $\dfrac{\partial}{\partial t} = 0$

ii) For free space: $\rho_v \to 0$; $\sigma \to 0$; $So\ J = 0$

iii) For Good Conductor: σ *value is very high*; $J \gg \dfrac{\partial D}{\partial t}$

Good Conductor, so $\rho_v = 0$

iv) Harmonically Varying Fields: $\overline{D} = \overline{D_o} e^{j\omega t}$ & $\overline{B} = \overline{B_o} e^{j\omega t}$

Conduction Current Density:

$$J = J_c + J_D$$

$$J_c \rightarrow Conduction\ current\ density$$

$$J_D \rightarrow Displacement\ current\ density$$

$$J = \sigma E + \frac{\partial D}{\partial t} = \sigma E + j\omega\varepsilon E$$

$$|J_C| = \sigma E\ ;\ |J_D| = \omega\varepsilon E$$

$$\frac{|J_C|}{|J_D|} = \frac{\sigma}{\omega\varepsilon}$$

i) If the ratio is greater than 1 is CONDUCTOR.
ii) If the ratio is lesser than 1 is DIELECTRIC.