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# Director's Message

**B. Singh** (Ex. IES)

Engineers and scientists from several disciplines have been involved in shaping the revolutionary growth of technology in India. During the last few decades of engineering academics, India has witnessed geometric growth in engineering pass-out candidates. It is noticeable that the level of engineering knowledge has degraded gradually, while on the other hand competition has increased in each competitive examination including GATE and UPSC examinations. Under such scenario high level efforts are required to take an edge over other competitors.

The objective of MADE EASY books is to introduce a simplified approach to the overall concepts of related stream in a single book with specific presentation. The topic-wise presentation will help the readers to study & practice the concepts and questions simultaneously, which is very useful for Freshers.

The efforts have been made to provide close and illustrative solutions in lucid style to facilitate understanding and quick tricks are introduced to save time.

*Following tips during the study may increase efficiency and may help in order to achieve success.*

- Thorough coverage of syllabus of all subjects
- Adopting right source of knowledge, i.e. standard reading text materials
- Develop speed and accuracy in solving questions
- Balanced preparation of technical and non-technical subjects with focus on key subjects
- Practice online and offline modes of tests
- Appear on self assessment tests
- Good examination management
- Maintain self motivation
- Avoid jumbo and vague approach, which is time consuming in solving the questions
- Good planning and time management of daily routine
- Group study and discussions on a regular basis
- Extra emphasis on solving the questions
- Self introspection to find your weaknesses and strengths
- Study the exam pattern to understand the level of questions
- Apply shortcuts and learn standard results and formulae to save time

**B. Singh** (Ex. IES)
CMD, MADE EASY Group

Contents

# ELECTRICAL ENGINEERING

## Conventional Solved Paper-I

UPSC Engineering Services Examination

# Electromagnetic Theory

**SYLLABUS:** Electric and magnetic fields. Gauss's Law and Ampere's Law, Field in dielectrics, conductors and magnetic materials. Maxwell's equations. Time varying fields. Plane-Wave propagation in dielectric and conducting media, Transmission lines.

# 01

Q.1 State and explain Gauss's law. A spherical volume charge distribution $\rho$ is given by

$$\rho = \rho_0\left(1 - \frac{r^2}{100}\right) \qquad \text{for } r \leq 10 \text{ mm}$$

$$= 0 \qquad \text{for } r > 10 \text{ mm}$$

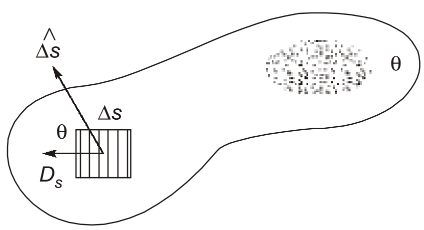
Show that the maximum value of electric field intensity $E$ occurs at $r$ = 7.45 mm. Obtain the value of $E$ at $r$ = 7.45 mm.

[12 marks : 2001]

Solution:

Gauss's Law

Surface integral of the normal component of the electric vector $D$ over any closed surface is equal to the total charge enclosed by the surface.




The total flux through the closed surface

$$\Psi = \int d\Psi = \oint \bar{D}_s \cdot \bar{d}s = \int_{Vol} \rho_v \, dv$$

$$\oint \bar{D} \cdot \bar{d}_s = \int_{Vol} \rho_v dv$$

Applying Gauss's law to the spherical surface at ($r \leq 10$)

$$E'(4\pi r^2) = \frac{Q'}{\epsilon_0} = \frac{1}{\epsilon_0}\left[4\pi\rho_0 \int\left(1 - \frac{r^2}{100}\right) r^2 dr\right] = \frac{4\pi \rho_0 r^2}{\epsilon_0}\left[\frac{r}{3} - \frac{1}{5}\frac{r^3}{100}\right] = \frac{\rho_0}{\epsilon_0}\left[\frac{r}{3} - \frac{1}{5}\frac{r^3}{100}\right]$$

As clearly seen from the above expression, ($E'$) varies with '$r$' and for maximum value of ($E'$)

$$\frac{dE'}{dr} = 0$$

Differentiating with respect to $r$ and equating to zero

$$\frac{\rho_0}{\epsilon_0}\left(\frac{1}{3}-\frac{3}{5}\frac{r^2}{10^2}\right) = 0$$

$$\frac{r^2}{10^2} = \frac{5}{3}\times\frac{1}{3}$$

$\therefore$ $$r = 7.45 \text{ mm}$$

$$\frac{d^2E'}{dr^2} = \frac{\rho_0}{\epsilon_0}\left(\frac{-3}{5}\cdot\frac{2r}{10^2}\right)$$

At $r = 7.45$ mm, $$\frac{d^2E'}{dr^2} < 0$$

Therefore, maximum $E$ occurs at $r = 7.45$ mm

$$E'_{max} = \frac{\rho_0}{\epsilon_0}\left[\frac{7.45}{3}-\frac{1}{5}\times\frac{7.45^3}{10^2}\right] = \frac{\rho_0}{\epsilon_0}\times 1.6563 \text{ V/mm}$$

**Q.2 Define Poynting's vector and Poynting's theorem, Show that ratio of Poynting's vector to energy density is $\leq 3\times10^8$ m/s.**

**[12 marks : 2001]**

**Solution:**

**Poynting's theorem and poynting vector.**

Consider the flow of electromagnetic energy out of a closed surface.

$$\text{div}(E\times H) = H\cdot\text{curl } E - E\cdot\text{curl } H$$

where $$\text{Curl } E = -\frac{\partial B}{\partial t} = -\mu\frac{\partial H}{\partial t}$$

$$\text{Curl } H = J + \in\frac{\partial E}{\partial t}$$

Substituting in equation

$$\text{div}(E\times H) = -H\left(\cdot\mu\frac{\partial H}{\partial t}\right) - E\cdot J - E\left(\cdot\in\frac{\partial E}{\partial t}\right)$$

By divergence theorem

$$\text{div}(E\times H) = \text{div }\rho$$

$$\iiint_{v\Omega}\text{div } s = \iint_{\text{surface}}\cdot\rho\,\hat{n}\,da$$

Thus, $$\iint\rho\cdot\hat{n}\,da + \frac{\partial}{\partial t}\iiint\left(\frac{\mu H^2}{2}+\frac{\varepsilon E^2}{2}\right)dv = \iiint E\cdot J dv$$

The Poynting vector '$(s = \bar{E}\times\bar{H})$' may be regards as the vector representing the amount of energy per unit time crossing unit area at any point. The direction of power flow is in the direction of $(\bar{E}\times\bar{H})$.

$$\frac{\text{Poynting Vector}}{\text{Energy directly}} \leq 3\times10^8 \text{ m/s}$$

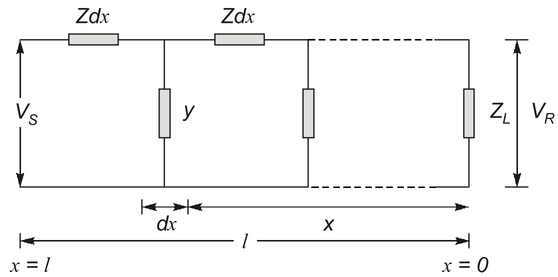
($\therefore$ rate of flow of energy can't be greater than the velocity of light)

Q.3 Explain travelling waves on a transmission line and define Standing Wave Ratio (SWR). A high frequency lossless transmission line has a characteristic impedance of 600 Ω. Calculate the value of current SWR when the load is (500 + $j$ 300)Ω.

[12 marks : 2001]

Solution:

For a long transmission line terminals at load impedance ($Z_L$).




Here $\quad dI = y\,dx\,V$ and $dV = ZI\,dx$

$$\therefore \quad \frac{dV}{dx} = ZI \quad \text{and} \quad \frac{dI}{dx} = yV$$

$$\therefore \quad \frac{d^2V}{dx^2} = z\frac{dI}{dx} = ZyV$$

$$\therefore \quad \frac{d^2V}{dx^2} - yZ\,V = 0$$

Let $\quad yZ = r^2 \qquad$ then $\dfrac{d^2V}{dx^2} - r^2V = 0$

Solution of differential equation,

$$V = V_+ e^{-rx} + V_- e^{rx}$$

$$I = I_+ e^{-rx} + I_- e^{rx}$$

At ($x = 0$)

$$Z_L = \frac{V}{I} = \frac{V_+ + V_-}{I_+ + I_-} = \frac{Z_0(I_+ - I_-)}{I_+ + I_-}$$

$$\therefore \quad \frac{I_-}{I_+} = \frac{Z_0 - Z_L}{Z_0 + Z_L} = \Gamma_R = \frac{V_-}{V_+}$$

Where, $\quad |\Gamma_R|$ = Reflection coefficient

$Z_0$ = Characteristic impedance

Standing ware Retro: (SWR) → Ratio of maximum value of minimum amplitudes of the voltage or current waves.

$$\text{SWR} = \frac{1+|\Gamma_R|}{1-|\Gamma_R|}$$

Where $\quad Z_L = 500 + j\,300\ \Omega$

$Z_0 = 600\ \Omega$

then, $$\Gamma_R = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{-100 + 300j}{1100 + 300j} = 0.277 \angle 93^\circ \qquad (\therefore |\Gamma_R| = 0.277)$$

$$\text{SWR} = \frac{1+|\Gamma_R|}{1-|\Gamma_R|} = \frac{1.27}{0.72} = 1.77$$