HERIOT-WATT UNIVERSITY
DEPARTMENT OF COMPUTING AND ELECTRICAL ENGINEERING

22.3MB1 Electromagnetics

Tutorial 5

1. Briefly discuss the effect of conductivity on a plane TEM wave propagating in a lossy medium, and sketch the variation of sinusoidally varying E and H field components for such a wave travelling in the z-direction. [from Question B2, 1993].

   Define the term "skin depth", δ

   Given that the propagation constant γ for a plane TEM wave in a lossy medium is

   $$\gamma = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)} = \alpha + j\beta$$

   derive, for the special case of a "good conductor", expressions for the following:

   (i) attenuation constant: α

   (ii) phase constant: β

   (iii) skin depth: δ

   (iv) intrinsic impedance: η

   The E-field strength of a uniform plane TEM wave in free space is 1 Vm^{-1} and the frequency is 10 kHz. This downward travelling wave is incident on a large flat area of ground with $\sigma = 10^{-2} Sm^{-1}$ and $\varepsilon_r = 5$. Check that the "good conductor" approximation is valid and calculate the E-field, (a) at the surface, and (b) at a depth of 100m.

2. Given the wave equation for an electromagnetic wave propagating in a source-free region, as:

   $$\nabla^2 \underline{E} - \varepsilon\mu \frac{\partial^2 \underline{E}}{\partial t^2} - \sigma\mu \frac{\partial \underline{E}}{\partial t} = 0$$

   show that, for propagation along the z-axis only, and for sinusoidally varying fields, the equation for $\underline{E}$ may be written as: [from Question B1, 1991].

   $$\frac{\partial^2 \underline{E}}{\partial z^2} - \gamma^2 \underline{E} = 0$$

   where

   $$\gamma^2 = j\omega\mu(\sigma + j\omega\varepsilon)$$

The flat side of a metallic object is covered with a 10 mm thick uniform layer of non-conducting material to reduce the amplitude of 3 GHz radar reflections.

If the material has $\mu_r = \varepsilon_r = (5 - j5)$ determine the amplitude of the reflected E-field component relative to the incident value.

3. With reference to suitable diagrams show the instantaneous time and space relationship between electric field and magnetic field for a sinusoidal plane TEM wave propagating in an unbounded region of free space. [from Question B1, 1989].

Indicate the significance of the Poynting Vector for the wave, both graphically and in vector notation.

Briefly, how is the E and H pattern modified for a wave propagating in a conducting medium?

By considering a laser beam as a plane TEM wave, estimate the diameter of the beam of a 1 kW laser that would cause voltage breakdown in air. Assume that air has a dielectric breakdown strength of 3 MVm^{-1}.

[Note: $\eta_\circ$ (free space) = $120\,\pi\Omega$]