Institute of Engineering,
Jiwaji University

Unit- IV BE IV Sem

WAVE PROPAGATION IN DIELECTRIC

EL-402 ELECTRONICS

EMT

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WAVE PROPAGATION IN DIELECTRIC →

Let uniform plane wave to propagation in dielectric of permittivity ϵ and permeability μ. The medium is isotropic and homogeneous, and the wave equation

$$\nabla^2 E_s = -k^2 E_s \quad — (1)$$

where the wave number is now a function of the material properties:

$$k = \omega\sqrt{\mu\epsilon} = k_0\sqrt{\mu_R \epsilon_R} \quad — (2)$$

From E_{xs} we have

$$\frac{d^2 E_{xs}}{dz^2} = -k^2 E_{xs} \quad — (3)$$

$$E_{xs} = E_{x0} e^{-jkz} = E_{x0} e^{-\alpha z} e^{-j\beta z} \quad - (4)$$

Multiplying (4) by $e^{j\omega t}$

$$E_x = E_{x0} e^{-\alpha z} \cos(\omega t - \beta z) \quad (I)$$

$jk = \alpha + j\beta$

k = complex propagation constant

Complex Permittivity →

The ways in which physical processes in a material can effect the wave electric field are described through a complex permittivity of the form.

$$\boxed{\epsilon = \epsilon' - j\epsilon''} \quad (5)$$

Two important mechanisms that give rise to a complex permittivity are -

i. Bound electron or ion oscillations
ii. Dipole relaxation
iii. Conduction of free electrons or holes

In terms of wave losses in magnetic field,

$$\mu = \mu' - j\mu'' \quad (6)$$

Note - The magnetic response is usually very weak compared to the dielectric response in most materials of interest for wave propagation; in such materials, $\mu \approx \mu_0$.

Loss tangent →

From Eq^n 3, 4 & 5

$$k = \omega\sqrt{\mu(\varepsilon' - j\varepsilon'')}$$

$$= \omega\sqrt{\mu\varepsilon'}\sqrt{1 - j\frac{\epsilon''}{\epsilon'}} \quad -(7)$$

$(\alpha + j\beta)^2 =$

$(\alpha^2 - \beta)^2 + j2\alpha\beta$

$= -\omega^2\mu\epsilon' + j\omega^2\mu\epsilon''$

$\alpha^2 - \beta^2 = -\omega^2\mu\epsilon'$

$2\alpha\beta = \omega^2\mu\varepsilon''$

$\alpha + j\beta =$

$j\omega\sqrt{\mu\epsilon}\left(1 - j\frac{\sigma}{\omega\epsilon}\right)^{1/2}$ (i)

$j\omega\sqrt{\mu\epsilon'}\left(1 - j\frac{\epsilon''}{\epsilon'}\right)^{\frac{1}{2}}$ (ii)

from (1) & (ii)

Solving there two Equations,

$$\alpha = \omega\left\{\frac{\mu\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\varepsilon''}{\varepsilon'}\right)^2} - 1\right)\right\}^{\frac{1}{2}} \text{ Np/m} \quad -(8)$$

$$\beta = \omega\left\{\frac{\mu\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\varepsilon''}{\varepsilon'}\right)^2} + 1\right)\right\}^{\frac{1}{2}} \text{ rad/m} \quad -(9)$$

We see that a non-zero α (and hence loss) resullts if the imaginary part of the permittivity ϵ'', is present.

In Eq^n (8) & (9) the presence of the ratio ϵ''/ϵ', which is called the loss tangent.

$\varepsilon' = \frac{\sigma}{\omega}$

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