Electromagnetic Waves IA-4

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Q1] Silver is a good conductor,

- Intrinsic impedance $\Rightarrow \eta = \sqrt{\frac{\mu\omega}{\sigma}} \angle 45^\circ$ $\rightarrow$ phase

$$= \sqrt{\frac{\overbrace{(\mu_0\mu_r)}^{\mu}\overbrace{(2\pi f)}^{\omega}}{\sigma}} \angle 45^\circ$$

★ given : $\mu_r = 1$, $\mu_0 = 4\pi \times 10^{-7}$ $\sigma = 61.7 \times 10^6$

$$\Rightarrow \eta = 1.385 \times 10^{-3} \angle 45^\circ \ \Omega$$

let's call this η_2 as silver is medium 2.
medium 1 is free space.

$$\therefore \eta_1 = 377 \angle 0^\circ \Omega \quad \eta_2 = 1.385 \times 10^{-3} \angle 45^\circ \Omega$$

★ given : $E_i = 100$ V/m

$$\frac{E_r}{E_i} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \Rightarrow E_r = 100 \angle -180^\circ = \underline{-100}$$

$E_i \rightarrow 100$

Transmission coefficient $= \frac{E_t}{E_i} = \frac{2\eta_2}{\eta_1 + \eta_2} \Rightarrow E_t = 7.35 \times 10^{-4} \angle 45^\circ$

$E_i \rightarrow 100$

$$\boxed{\begin{aligned} \therefore E_0^r &= 100 \angle -180^\circ \text{ or } -100 \\ E_0^t &= 7.35 \times 10^{-4} \angle 45^\circ \end{aligned}}$$

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given ⇒
- $J = \sin(377t - 117.1z)\, a_x \; mA/m^2$
- $\sigma = 5.8 \times 10^{7}\ S/m$
- $\varepsilon = \varepsilon_0 ,\ \mu = \mu_0$

Q2]

$$J = \sigma E$$

$$E = \frac{J}{\sigma} = \frac{10^{-3}\sin(377t - 117.1z)\vec{x}}{5.8 \times 10^{7}}$$

★ $E = 0.17241 \times 10^{-10} \times \sin(377t - 117.1z)\vec{x}$ Volt/m

$$D = \varepsilon_0 E$$

$$= 8.854 \times 10^{-12} \times 0.17241 \times 10^{-10} \times \sin(377t - 117.1z)\vec{x}\ V/m$$

★ $D = 1.52651 \times 10^{-22} \times \sin(377t - 117.1z)\vec{x}\ C/m^2$

$$J_d = \frac{\partial D}{\partial t} = 1.52651 \times 10^{-22} \times 377 \cos(377t - 117.1z)\vec{x}$$

$$J_d = (5.75494 \times 10^{-19}) \cos[377t - 117.1z]\vec{x}\ A/m^2$$

★ amplitude is :

$5.75494 \times 10^{-19}\ A/m^2$

Q3] $E = (40 - j30)e^{-j20z}\, a_x\ V/m$ (given)

↳ $\beta = 20$ rad/m

a) Angular Frequency (ω):

$\omega = c\beta = 3 \times 10^{8} \times 20 = 6.0 \times 10^{9}$ rad/s

b) Phase constant (β):

$\beta = 20$ rad/m (from given expression)

c) Frequency (f):

$f = \omega / 2\pi = 956$ MHz

d) Wavelength (λ): $\lambda = 2\pi/\beta = 0.314$ m

e) $H_s = \frac{40 - j30}{377} e^{-j20z} a_y = (0.11 - j0.08) e^{-j20z} a_y$ A/m

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$\alpha = 0 \rightarrow$ perfect dielectric

Q4] i) phase constant (β):

$$\beta = 2\pi \times 10^6 \sqrt{(\underbrace{4\pi \times 10^{-7}}_{\mu_0 \mu_r \, 1} \times \underbrace{8.854 \times 10^{-12} \times 81}_{\varepsilon_0 \varepsilon_r \, 81})}$$

$\beta = \rightarrow$ ~~0.185~~ 0.1886 rad/m

ii) Wavelength (λ):

$$\lambda = 2\pi / \beta = 33.3148 \text{ meters}$$

iii) velocity (v):

$$v = \frac{c}{\sqrt{\varepsilon_r \mu_r}} = \frac{3 \times 10^8}{\sqrt{81}} = \frac{\cancel{3} \times 10^8}{\cancel{9}\,3}$$

$$= 0.3333 \times 10^8 = 3.333 \times 10^7$$

$$v = 3.33 \times 10^7 \text{ m/s}$$

iv) $$\eta = \sqrt{\frac{\mu_0 \mu_r^{\rightarrow 1}}{\varepsilon_0 \varepsilon_{r \rightarrow 81}}} = \sqrt{\frac{4\pi \times 10^{-7}}{8.854 \times 10^{-12} \times 81}} = 41.859\,\Omega$$

$\simeq 42\,\Omega$

OR $\frac{377}{\sqrt{81}} = 41.8889$

$\simeq 42\,\Omega$

v) Electric field:

$$\vec{E} = (\cos(2\pi \times 10^6 t - 0.1886z))\,\hat{a}_z$$

$$\vec{H} = \frac{1}{42}\cos(2\pi \times 10^6 t - 0.1886z)\,\hat{a}_y$$

Magnetic field

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Q5] given :

$\varepsilon_r' = 3.2$

$\sigma = 1.5 \times 10^{-4}$ S/m

$f = 3$ MHz

i) loss tangent : ($\tan\delta$)

$$\tan\delta = \frac{\sigma}{\omega\varepsilon}$$

$\omega = 2\pi f$
$= 2\pi \times 3 \times 10^{6}$
$= 18.8495 \times 10^{6}$ rad/s

$$\tan\delta = \frac{1.5 \times 10^{-4}}{18.8495 \times 10^{6} \times 8.854 \times 10^{-12} \times 3.2}$$

$$\boxed{\tan\delta = 0.28086}$$

ii) attenuation constant (α):

$\omega\varepsilon = 5.3407 \times 10^{-4}$

$\mu\varepsilon = \mu_0 \mu_r \varepsilon_0 \varepsilon_r$
$= 4\pi \times 10^{-7} \times 8.854 \times 10^{-12} \times 3.2$
$= 3.56 \times 10^{-17}$

$$\alpha = \omega \sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1+\left(\frac{\sigma}{\omega\varepsilon}\right)^2} - 1\right]}$$

$$\alpha = 18.849 \times 10^{6} \sqrt{\frac{3.56 \times 10^{-17}}{2}\left(\sqrt{1+\left(\frac{1.5 \times \cancel{10^{-4}}}{5.34 \times \cancel{10^{-4}}}\right)^2} - 1\right)}$$

$$\alpha = 18.85 \times 10^{6} \sqrt{1.78 \times 10^{-17}\left(\sqrt{1 + 0.07884} - 1\right)}$$

$$\alpha = 18.85 \times 10^{6} \sqrt{1.78 \times 10^{-17} (0.03867)}$$

$$= 18.85 \times 10^{6} \times (8.2967 \times 10^{-10})$$

$$= 0.015639$$

$$\boxed{\alpha = 0.015639}$$

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Q5] iii) phase constant (β):

$$\beta = \omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1+\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]}$$

$$= 18.85\times10^{6}\sqrt{1.78\times10^{-17}\left(\sqrt{1+0.0788}+1\right)}$$

$$= \cancel{188.8}\ 18.85\times10^{6}\sqrt{1.78\times10^{-17}\times2.03865}$$

$$= 18.85\times10^{6}\sqrt{3.627\times10^{-17}}$$

$$= 18.85\times10^{6}\left(6.022\times10^{-9}\right)$$

$$\boxed{\beta = 0.1135}$$

$\therefore$ β is 0.1135 rad/m

iv) intrinsic impedance:

$$\eta = \frac{\sqrt{\dfrac{\mu_0\,\cancel{\mu_r}\to 1}{\varepsilon_0\,\cancel{\varepsilon_r}\to 3.2}}}{\sqrt[4]{1+\left(\dfrac{\sigma}{\omega\varepsilon}\right)^2}} = \frac{\dfrac{377\,\Omega}{\sqrt{3.2}}}{\sqrt[4]{1.0788}} = \frac{210.749}{\sqrt[4]{1.0788}}$$

$$= \frac{210.749}{1.01914}$$

$$\eta = 206.791\,\Omega$$

$$\boxed{\eta = 206.8\,\Omega}$$