Blast From the Past!

Exam 2

Fall 2022

Problem 2 (35 pts)

A plane wave in air is incident vertically on the ocean at 18 GHz. The plane wave is polarized with the electric field in the x direction. The relative permittivity of the ocean water at this frequency is $\varepsilon_r = 38$. The ocean water has a conductivity of $\sigma = 4$ [S/m], but it also has polarization loss, which gives us an effective conductivity of 42.054 [S/m]. The ocean water is nonmagnetic.

a) Find the complex relative effective permittivity ε_{rc} of the ocean water.

b) Find the loss tangent of the ocean water.

c) Find the attenuation in [dB/m] in the ocean water.

d) Find the percentage of power that gets reflected from the surface of the ocean.

Note: In part (d) it doesn't matter if you take the wave to be TM or TE, since they are the same for vertical incidence.

Note:
The effective conductivity accounts for both the actual conductivity and the polarization loss.

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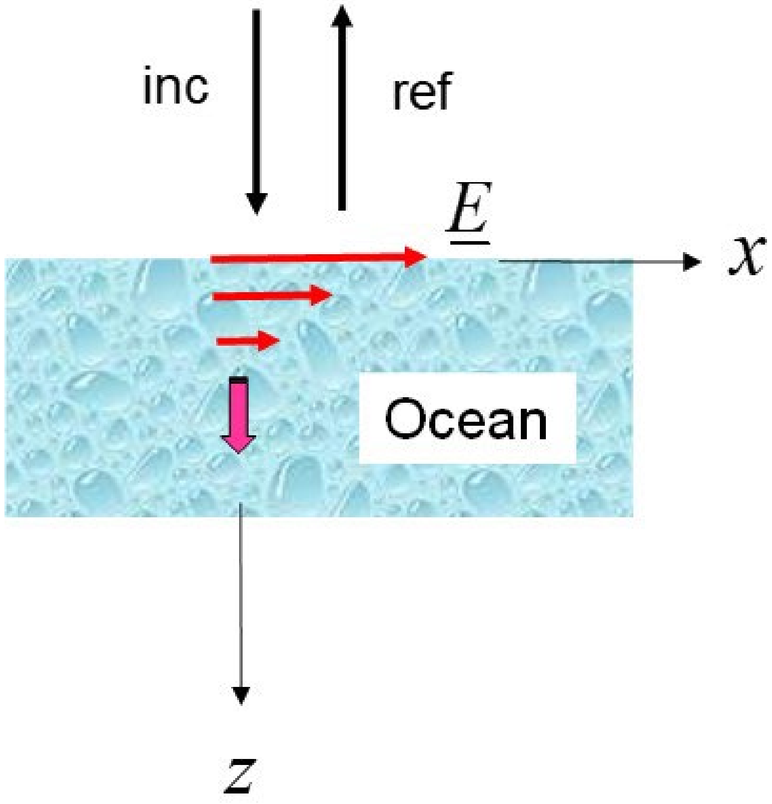

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Part (a)

$$\varepsilon_c = \varepsilon - j\left(\frac{\sigma}{\omega}\right) = \varepsilon_0\left[\varepsilon_r - j\left(\frac{\sigma}{\omega\varepsilon_0}\right)\right]$$

$$\sigma = \sigma_{\text{eff}}$$

so

$$\varepsilon_{rc} = \varepsilon_r - j\left(\frac{\sigma}{\omega\varepsilon_0}\right)$$

Note:
σ_{eff} is called σ_d in the class notes,
when modeling a dielectric material.

This gives us:

$$\varepsilon_{rc} = 38 - j(41.994)$$

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Part (b)

The loss tangent is:

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} = \frac{-\operatorname{Im}(\varepsilon_c)}{\operatorname{Re}(\varepsilon_c)} = \frac{-\operatorname{Im}(\varepsilon_{rc})}{\operatorname{Re}(\varepsilon_{rc})}$$

Hence, we have

$$\tan\delta = 1.105$$

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Part (c)

The wavenumber of the seawater is:

$$k = \omega\sqrt{\mu_0 \varepsilon_c} = \omega\sqrt{\mu_0 \varepsilon_0 \varepsilon_{rc}} = k_0\sqrt{\varepsilon_{rc}} = \frac{2\pi}{\lambda_0}\sqrt{\varepsilon_{rc}}$$

Hence, we have

$$k = 2595.03 - j(1151.55)$$

Therefore,

$$k'' = 1151.55 \ [\text{np/m}]$$

Multiply by 8.686 to convert to dB/m:

$$\text{Attenuation} = 10002.4 \ [\text{dB/m}]$$

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$$\theta_i = \theta_r = \theta_t = 0$$

$$Z^{\text{TM}} = \frac{k_z}{\omega\varepsilon} = \frac{k}{\omega\varepsilon} = \frac{\omega\sqrt{\mu\varepsilon}}{\omega\varepsilon} = \sqrt{\frac{\mu}{\varepsilon}} = \eta$$

$$Z^{\text{TE}} = \frac{\omega\mu}{k_z} = \frac{\omega\mu}{k} = \frac{\omega\mu}{\omega\sqrt{\mu\varepsilon}} = \sqrt{\frac{\mu}{\varepsilon}} = \eta$$

Part (d)

$$Z_1^{\text{TM}} = Z_1^{\text{TE}} = \eta_1 = \eta_0 = 376.7303$$

$$P_r^{\%} = |\Gamma|^2\, 100$$

$$Z_2^{\text{TM}} = Z_2^{\text{TE}} = \eta_2 = \frac{\eta_0}{\sqrt{\varepsilon_{rc}}}$$

$$\Rightarrow \quad P_r^{\%} = 61.46$$

$$\Gamma = \Gamma^{\text{TM}} = \Gamma^{\text{TE}} = \frac{\dfrac{\eta_0}{\sqrt{\varepsilon_{rc}}} - \eta_0}{\dfrac{\eta_0}{\sqrt{\varepsilon_{rc}}} + \eta_0} = \frac{\dfrac{1}{\sqrt{\varepsilon_{rc}}} - 1}{\dfrac{1}{\sqrt{\varepsilon_{rc}}} + 1}$$

$$\Rightarrow \quad \Gamma = -0.779283 + j(0.085512)$$