ECE 3317

Applied Electromagnetic Waves

Exam 2

Nov. 26, 2024

Name: __________SOLUTION____________________________

General Information:

The exam is open-book and open-notes. You are not allowed to use any device that has communication functionality (laptop, cell phone, ipad, etc.).

Remember, you are bound by the UH Academic Honesty Policy during the exam!

Instructions:

- Show all of your work. No credit will be given if the work required to obtain the solutions is not shown.
- Write neatly. You will not be given credit for work that is not easily legible.
- Leave answers in terms of the parameters given in the problem.
- Show units in all of your final answers.
- Circle your final answers.
- Double-check your answers. For simpler problems, partial credit may not be given.
- If you have any questions, ask the instructor. You will not be given credit for work that is based on a wrong assumption.
- Make sure you sign the academic honesty statement below.

Academic Honesty Statement

By taking this exam, you agree to abide by the UH Academic Honesty Policy during this exam. You understand and agree that the punishment for violating this policy will be most severe, including getting an F in the class and getting expelled from the University.

Signature: ______________________________________

Problem 1 (30 pts)

A coaxial cable has the following parameters:

$a = 8.89 \times 10^{-4}$ [m]

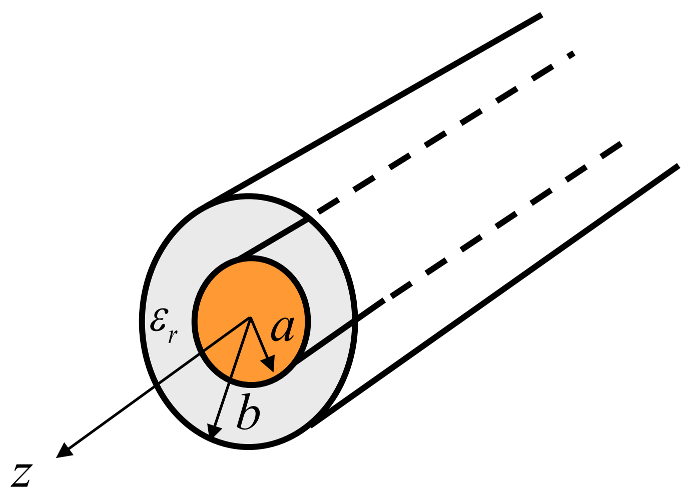
$b = 29.46 \times 10^{-4}$ [m]

$\varepsilon_r = 2.2$

$\sigma = 3.0 \times 10^{7} \left[\text{S/m}\right]$ (conductivity of conductors)

$\tan\delta = 0.001$ (loss tangent of dielectric)

Find the length of the cable at 10 GHz for which the attenuation will be 10 dB.



ROOM FOR WORK

SOLUTION

The formulas for (R, L, G, C) are:

$$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{b}{a}\right)} \quad [\text{F/m}]$$

$$L = \frac{\mu_0}{2\pi}\ln\left(\frac{b}{a}\right) \quad [\text{H/m}]$$

$$G = (\omega C)\tan\delta_d \quad [\text{S/m}]$$

$$R = \left(\frac{1}{2\pi a\,\sigma_{ma}\delta_{ma}} + \frac{1}{2\pi b\,\sigma_{mb}\delta_{mb}}\right) \quad [\Omega/\text{m}]$$

$$\delta_m = \sqrt{\frac{2}{\omega\mu_0\sigma_m}}\,.$$

Using the formulas for (R, L, G, C) we have:

$$C = 1.022\times10^{-10}\ [\text{F}/\text{m}]$$
$$L = 2.396\times10^{-7}\ [\text{H}/\text{m}]$$
$$G = 6.419\times10^{-3}\ [\text{S}/\text{m}]$$
$$R = 8.454\ [\Omega/\text{m}].$$

We then use

$$\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}\,.$$

This gives us

$$\gamma = 0.24271 + j(310.864)\ \ [1/\text{m}].$$

Hence, we have

$$\alpha = 0.24271\ \ [\text{np}/\text{m}].$$

Multiplying by 8.686, we have

$$\text{Attenuation}_{\text{dB/m}} = 2.1082 \ [\text{dB/m}].$$

We then find the length L of the cable by using

$$(\text{Attenuation}_{\text{dB/m}})L = 10 \ [\text{dB}].$$

This gives us

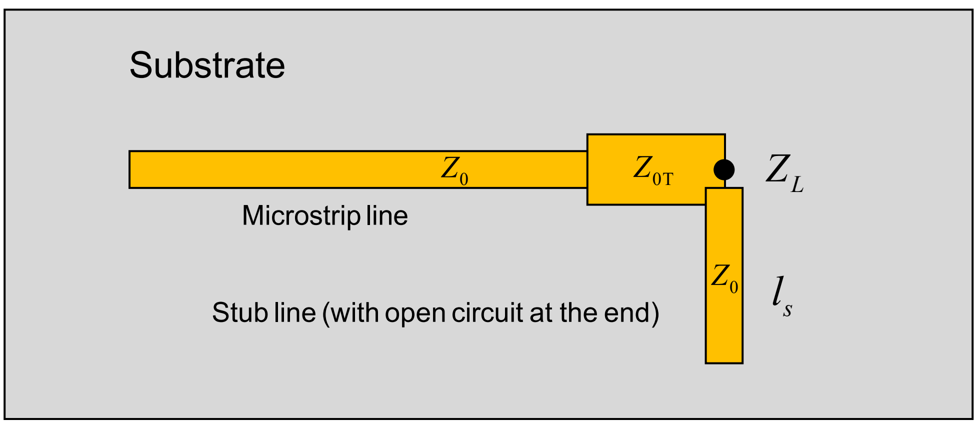
$L = 4.743$ [m].

Problem 2 (35 pts)

A microstrip line on a printed circuit board (PCB) having $Z_0 = 50\,[\Omega]$ is connected to a quarter-wave transformer, which is then connected to a load impedance $Z_L = 75 - j100\,[\Omega]$. The frequency is 3.0 GHz and the effective relative permittivity of the 50 [Ω] line is $\varepsilon_r^{\text{eff}} = 1.5$. An open-circuited microstrip stub line of length l_s is connected in parallel to the load. This stub line also has $Z_0 = 50\,[\Omega]$. The open-circuit stub line and the quarter-wave transformer together ensure that the feed line to the left of the transformer sees a 50 [Ω] load.

a) Find the length of the stub line l_s (in cm) using the Smith chart. (Use the smallest length possible.)

b) Find the value of $Z_{0\mathrm{T}}$.



ROOM FOR WORK

Solution

Part (a)

The first Smith chart below shows the solution for the stub length. Note that after we convert the normalized load impedance into a normalized load admittance, we continue to use the Smith chart as an admittance calculator.

The normalized load admittance is

$$Y_L^N = 0.24 + j\left(0.32\right).$$

Therefore, we want to have

$$Y_{\text{in}}^{\text{stub,N}} = -j\left(0.32\right).$$

The Smith chart also shows the solution for the stub length. The stub length is

$$l_s = 0.451\lambda_g .$$

We also have

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_r^{\text{eff}}}} = 8.159\ \left[\text{cm}\right].$$

Hence, we have

$$l_s = 3.68\ \left[\text{cm}\right].$$

Part (b)

After the stub cancels the imaginary part of the load admittance, we are left with a new load admittance of

$$Y_L^{\text{new,N}} = 0.24 .$$

Hence, taking the reciprocal, we have

$$Z_L^{\text{new,N}} = 4.167 .$$

We then have (multiplying by 50 Ω to unnormalize it) :

$$Z_L^{\text{new}} = 208.35 \left[\Omega\right].$$

For the transformer characteristic impedance, we then have

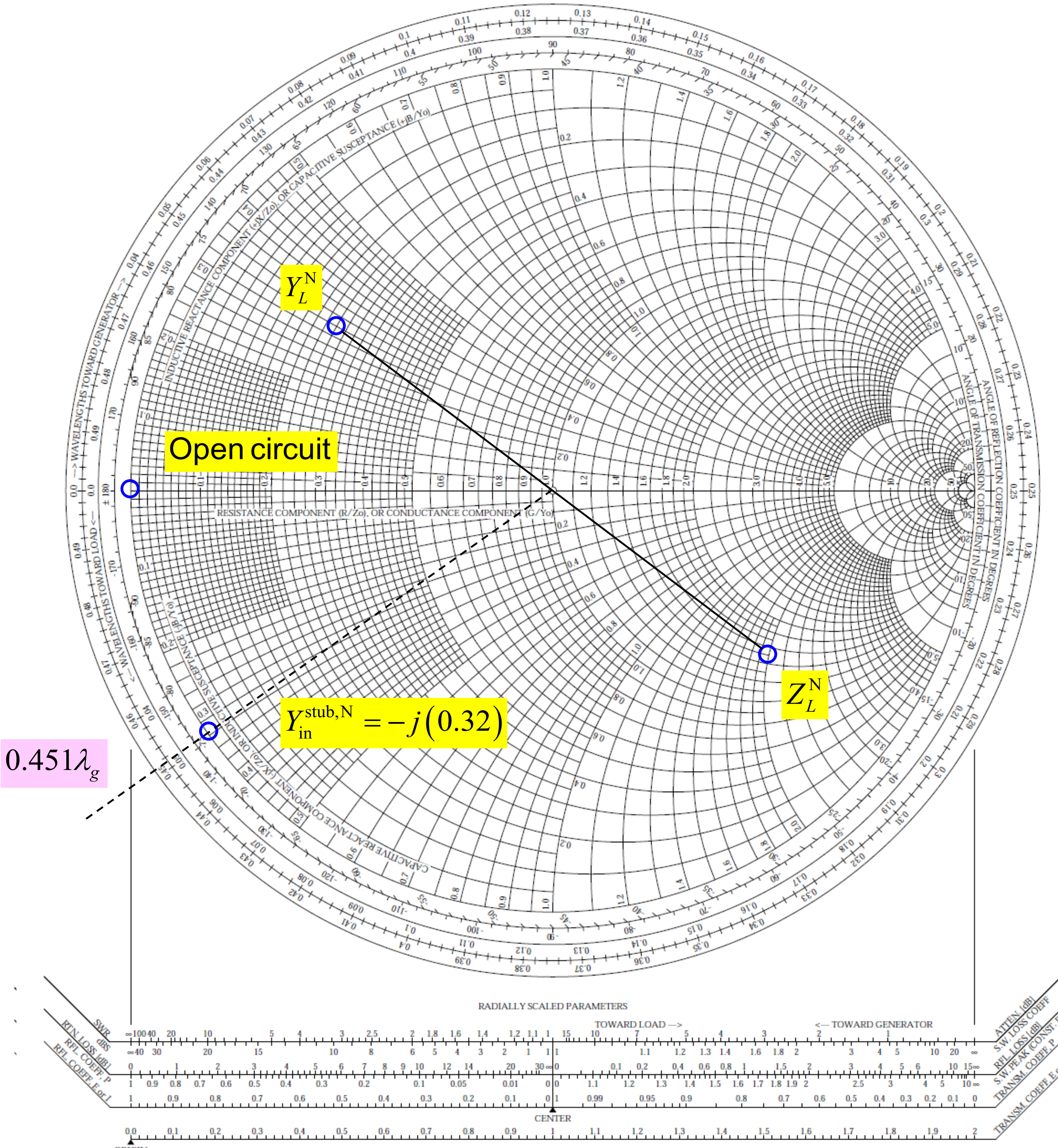
$$Z_0^{\text{T}} = \sqrt{(50)(208.35)}\,.$$

This gives us

$$Z_0^{\text{T}} = 102.1 \left[\Omega\right].$$

The Complete Smith Chart

Black Magic Design



Problem 3 (35 pts)

A plane wave is traveling in the z direction downward in the ocean, as shown below, at 1.0 GHz. The electric field is given by

$$\underline{E} = \left[(1 + j2)\,\underline{\hat{x}} + (1 - j3)\,\underline{\hat{y}} \right] e^{-jkz} .$$

The ocean water has a relative permittivity of $\varepsilon_r = 80$ and a conductivity of $\sigma = 4 \; [\mathrm{S/m}]$.

(a) Classify the polarization of this wave (linear, LHCP, RHCP, LHEP, RHEP).

(b) Find the axial ratio of this wave.

(c) Find how many dB of attenuation there is when the wave travels 1.0 [cm] into the ocean.

ROOM FOR WORK

Solution

Part (a)

The electric field has components along $\hat{x}$ and $\hat{y}$:

$$E_x = 1 + j2$$

$$E_y = 1 - j3 .$$

Hence E_x leads E_y (E_y lags E_x). In time, the wave therefore rotates from the x axis to the y axis. The wave propagates in the $+z$ direction. Hence, the wave is right-handed. Since the magnitude of E_y and E_x are not equal, and the phase difference is also not ±90°, the wave is not circularly polarized.

Hence, we have

RHEP.

Part (b)

We have

$$\frac{E_y}{E_x} = \left(\frac{1 - j3}{1 + j2}\right) = -1 - j = \sqrt{2}e^{j(-3\pi/4)}$$

Hence, we have

$$b = \sqrt{2}$$

$$\beta = -\frac{3\pi}{4}\left[\text{radians}\right] = -135^{\circ} .$$

Using the equations in the table, we then have

$$\xi = -20.905^{\circ} .$$

From this we have

AR = 2.618.

Part (c)

We use

$$k = k' - jk'' = \omega\sqrt{\mu\varepsilon} = \omega\sqrt{\mu_0\varepsilon_0}\sqrt{\varepsilon_{rc}} = k_0\sqrt{\varepsilon_{rc}}$$

where

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

and

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

We then have

$$\varepsilon_{rc} = 80 - j(71.9004).$$

This gives us

$$k = 202.963 - j(77.804) \quad [1/\mathrm{m}].$$

Hence, we have

$$k'' = 77.804 \quad [\mathrm{np/m}].$$

Multiplying by 8.686 we then have

$$\mathrm{Attenuation}_{\mathrm{dB/m}} = 675.806 \quad [\mathrm{dB/m}]$$

Hence, in traveling 1 [cm] we have

$$\mathrm{Attenuation}_{\mathrm{dB}} = 6.758 \quad [\mathrm{dB}]$$