Question 1 (20 marks): A uniform plane wave is propagating in the +z direction in a lossy dielectric medium. Assume that the lossy medium is characterized by σ=2 S/m, $\varepsilon=5\varepsilon_o$ and μ_o. The frequency of the wave is 2.5 GHz. The amplitude of the electric field is 4 V/m at z=0 and the phase is zero. The electric field is oriented in the +y direction.

a) Calculate the attenuation constant (α) and the phase constant (β).

b) Write an expression for the electric field in phasor form ($\mathbf{E}_s(z)$).

c) Calculate the intrinsic impedance of the medium (η).

d) Write an expression for the magnetic field in time-domain form ($\mathbf{H}(z,t)$).

e) Find an expression for the time-averaged Poynting vector ($\mathbf{P}_{avg}(z)$).

f) Assume that a perfectly conducting plate is located at z=0 (i.e. the region z>0 is a perfect electric conductor with $\sigma \rightarrow \infty$). What is the reflection coefficient? Write an expression for the reflected electric field, $\mathbf{E}^r(z,t)$. Is the wave a standing wave or a traveling wave or a combination?

Question 2 (20 marks): A load of impedance Z_L=20+j75 Ω is attached to a transmission line with 50 Ω characteristic impedance (Z_o=50 Ω). The frequency of operation is 900 MHz and the wavelength on the line is 67 cm.

a) Find the reflection coefficient at the load (Γ).

b) Find the standing wave ratio, s.

c) Find the distance from the load to the first voltage minimum.

d) Find the input impedance Z_{in} when a line of length of 45 cm is attached to the load.

e) Design a lumped element network to match the load to the transmission line. Sketch the circuit configuration that you select. Show the steps used to determine the values of the circuit elements on the Smith chart. Calculate the values of the components (capacitors or inductors) that you would use in the network.

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Question 3 (20 marks):

An antenna with unknown impedance (Z_a) is connected to a 50 Ω slotted line. The standing wave ratio is measured, and is found to be 3.8. The location of the first minimum is noted at 8 cm on the scale. When the antenna is replaced with a short, the first minimum is shifted to 5 cm on the scale. The next minimum is located at 20 cm. Assume that the phase velocity on the transmission line is $v_p=3x10^8$ m/s.

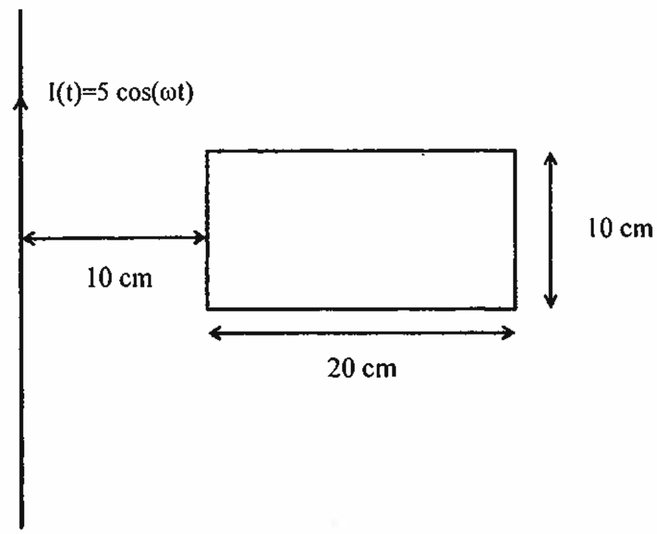
a) Find the frequency of operation.

b) Find the unknown impedance of the antenna, Z_a. Illustrate your steps on the Smith chart.

c) Design shunt (parallel) stub tuners to match the antenna to a 50 W transmission line. Give designs for an open-circuited stub and a short-circuited stub. Show your steps clearly on the Smith chart. State the lengths and locations of the stubs in wavelengths and centimeters. If you cannot solve part b, then use Z_a=75-j45 Ω.

Question 4 (10 marks):

Consider an infinitely long wire placed along the z-axis. This wire carries a current of $I(t)=5\cos\omega t$ mA. A rectangular loop is placed in the xz plane at a distance of 10 cm from the wire. The loop is 20 cm long and 10 cm in height. The loop is located in free space.



a) Find the induced EMF (V_{emf}) in the loop.
b) Sketch the coordinate system orientation (i.e. x, y and z axes) and indicate the direction of current flow during the first quarter period (i.e. t=0 to t=T/4).

Question 5 (20 marks):

Microwave and RF frequency systems have been used industrially for food sterilization and heating. Knowledge of the electromagnetic properties of the food is required in order to analyze the penetration of the microwaves into the product.

For example, mashed potatoes have properties that change with water content, salt content and temperature. At 0.8% salt content, moisture level of 86% and 40°C, the properties of mashed potatoes are ε_r=90 and σ=0.6 S/m at 27 MHz and ε_r=65 and σ=1.2 S/m at 915 MHz.

a) Calculate the attenuation constant (α) and phase constant (β) for both frequencies. Calculate the wavelength (λ).

b) For each frequency, calculate the skin depth. Suggest a maximum sample depth for heating.

c) Consider the case of heating mashed potatoes at 915 MHz. An antenna is placed in air and you decide to model the fields as uniform plane waves. Assume that the incident wave has power of 75 kW/m^2. Write an expression for the incident electric field assuming that the field is oriented in the +x direction and propagates in –z. What fraction of the incident field is reflected and what fraction is transmitted?

Question 6 (10 marks): Indicate the response that best answers the question.

1. A distortionless line has Zo=50 Ω, $\alpha = 40$ mNp/m and v_p=2.5 x 10^8 m/s. The frequency of operation is 250 MHz. The transmission line parameters are:

   a) R=2 Ω/m, L=200 nH/m, G=800 µS/m, C=80 pF/m
   b) R=2 Ω/m, L=200 nH/m, G=800 mS/m, C=80 pF/m
   c) R=2 Ω/m, L=200 nH/m, G=800 µS/m, C=80 nF/m
   d) R=2 Ω/m, L=200 H/m, G=800 S/m, C=80 F/m
   e) None of the above

2. A quarter wavelength transformer is used to match a 50 Ω transmission line to a 75 Ω load. The frequency of operation is 3 GHz and the line has v_p=2 x 10^8 m/s. The impedance of the quarter wavelength line is:

   a) 0.707 Ω
   b) 2 Ω
   c) 70.7 Ω
   d) 140 Ω
   e) None of the above

3. A uniform plane wave is propagating in a lossless dielectric. Consider a dielectric with ε_r=4 and a dielectric with ε_r=16. The frequency of the wave does not change.

   a) In the material with higher permittivity, the wave travels slower and wavelength increases.
   b) In the material with higher permittivity, the wave travels slower and wavelength decreases.
   c) In the material with higher permittivity, the wave travels faster and wavelength increases.
   d) In the material with higher permittivity, the wave travels faster and wavelength decreases.
   e) None of the above

4. An air-filled rectangular waveguide has dimensions a=5 cm, b=3 cm.

   a) At 6 GHz, it is only possible for 1 mode to propagate.
   b) The cutoff frequency for TE10 is 5 GHz
   c) The cutoff frequency for TE01 is 3 GHz
   d) The cutoff frequency for TE10 is 3 GHz.
   e) None of the above

5. Sea water has ε_r=80, σ=4 S/m. The frequency at which the conduction current is 10 times the displacement current is:

   a) Not possible to calculate.
   b) 0.9 GHz
   c) 5.65 GHz
   d) 0.14 GHz
   e) None of the above