EC341 – ELECTROMAGNETIC WAVES

FINAL EXAM

Closed Book Two single-sided 8½”x11” formula sheets and a calculator are allowed. For full credit: 1)work neatly, 2)give appropriate units on answers, 3)properly use vector notation, 4)use proper notation for time- and frequency-domain quantities, and 5)clearly show all your work. Point values are shown with each problem.

"*NO AID GIVEN, RECEIVED, OR OBSERVED.*" ______________________________

Signature

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Name

constants and material properties

$\varepsilon_o = 8.854(10^{-12})$ F/m $\mu_o = 4\pi(10^{-7})$ H/m $\sigma_{copper} = 5.8\times10^{7}$ /Ωm

1. Use a single susceptance tuner (assume 75Ω lines) to match $\tilde{Z}_L = (300 + j225)\Omega$ to $\tilde{Z}_s = (75\text{-}j150)\Omega$. ***Attach*** Smith Chart.

d_{TL} = ____________________ (9 pts) d_{scs} = ____________________ (9 pts)

Neatly *show physical connections, in detail, for system* (7 pts)

2. An electromagnetic wave, traveling in the $\mathbf{a}_z$ direction, is polarized with its electric vector in the $\mathbf{a}_x$ direction. At z=0, the wave has a time-averaged power flux density $\langle \mathbf{S} \rangle$ = 10 kW/m^2 $\mathbf{a}_z$. The frequency is f=10GHz with material properties μ_r=1, ε_r=16, and σ=10 S/m Take the phase of $\tilde{\mathbf{H}}$ to be 0° at z=0.

i) Can this material be classified as a good conductor or as a good dielectric? (4 pts)
Why or Why not?

ii) Give the appropriate formula for the complex propagation constant, $\tilde{\gamma}$. *Use an approximate formula if appropriate.* DO NOT EVALUATE $\tilde{\gamma} = \left(421 + j938\right)$ m^{-1} (3 pts)

iii) Give the appropriate formula for the complex intrinsic impedance, $\tilde{\eta}$. *Use an approximate formula if appropriate.* DO NOT EVALUATE $\tilde{\eta} = 76.8\angle 24.2°\ \Omega$ (3 pts)

iv) Find the frequency-domain magnetic and electric vectors as functions of position. (6 pts)

v) Find the time-averaged Poynting vector (6 pts)

vi) Find the phase velocity (3 pts)

3. From the TDR experimental results shown below, determine:

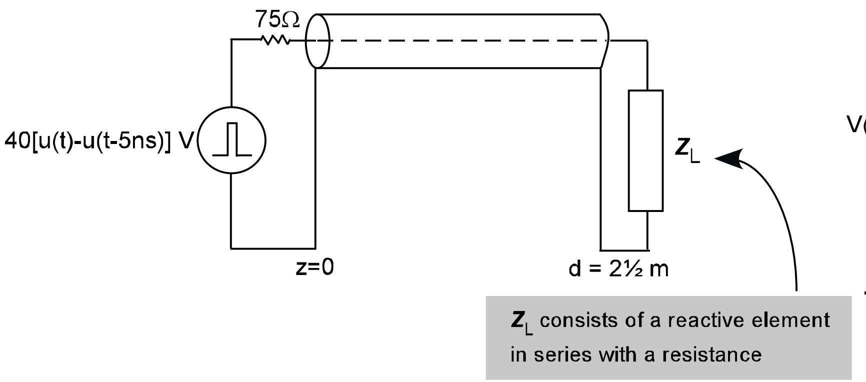
   i) Z_c (5pts)

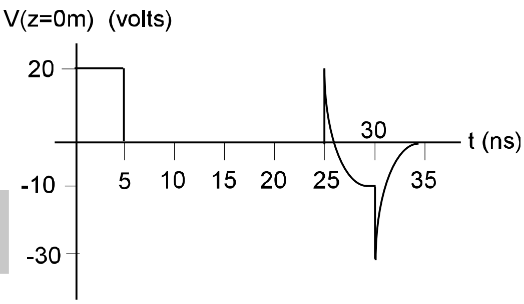
   ii) v_p (5pts)

   iii) $\mathcal{L}$ (5pts)

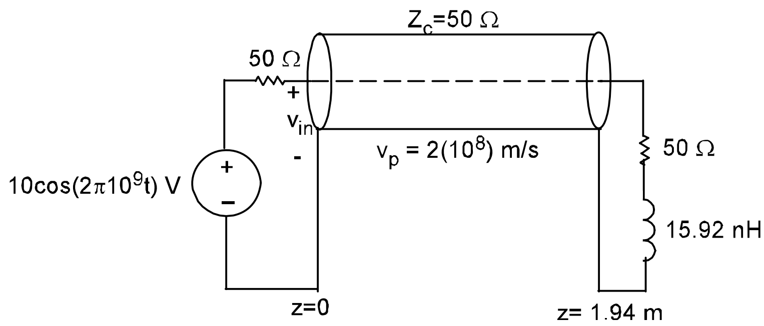
   iv) $\mathcal{C}$ (5pts)

   v) Type of reactive element in series with R_L (clearly explain why) and R_L (5pts)





4. For the system shown below, involving a lossless transmission line, determine:



i) The reflection coefficient at the load, $\tilde{\Gamma}_L$ (6 pts) (Use formula…you may check with Smith Chart)

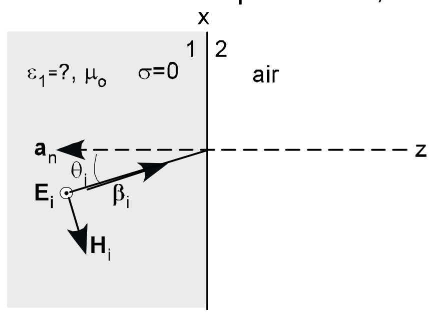
ii) Give the formula which could be used to determine $\tilde{Z}_{in}$, the input impedance of the transmission line. Find $\tilde{Z}_{in}$ using either the formula *or* a Smith chart (Do ***not*** attach Smith Chart). (7 pts)

iii) The phasor voltage input to the transmission line ($\tilde{V}_{in}$). (6 pts)

iv) The average power delivered to the transmission line. (6 pts)

5. In experiment 1, the critical angle for the system shown below is known to be, $\theta_c = 30°$.

In a experiment 2, the magnitude of the ***reflected*** vector, $\tilde{\mathbf{E}}_r$, is measured to be 1 V/m and the angle of ***refraction***, θ_t, is measured to be 60°. For the experiment 2, determine:



i) The incident angle, θ_i. (5 pts)

ii) The incident time-averaged power density, $\langle \underline{S}_i \rangle$. (Give magnitude and a unit vector.) (10 pts)

iii) Find the portion of the incident power that is reflected and transmitted. (10 pts)

6. Check ***T/F*** either ***T*** or ***F*** (2½ pts each)

___ Measurements in a lossless material indicate that for a frequency of 1GHz, λ = 7.5 cm and for an electric field magnitude of 377V/m, the magnetic field magnitude is 2 A/m. Therefore, $\varepsilon \cong 4\varepsilon_o$.
Why or why not? ____

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___ Measurements on a lossless line indicate that Z_c=50Ω and $\mathcal{C}$=100pF/m. Therefore, v_p= 2(10^8) m/s.
Why or why not? ____

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___ A lossy transmission line is terminated with a short circuit. $\tilde{Z}_{in}$ is purely imaginary.

___ A lossless transmission line, d=4.25λ, is terminated with $\tilde{Z}_L = (50 + j50)\Omega$. Since the line is an integral number of ¼ wavelengths, $\tilde{Z}_{in} = \tilde{Z}_L$.

___ If the transmission line parameters, $\mathcal{R}$, $\mathcal{G}$, $\mathcal{L}$, and $\mathcal{C}$, are independent of frequency, distortionless transmission must result.
Why or why not? ____

____

___ The VSWR at the input of a short-circuited length of a lossless transmission line is infinite.

___ For transmission lines, in the low-loss approximation and given that $\mathcal{R}$, $\mathcal{L}$, $\mathcal{G}$ and $\mathcal{C}$ are independent of frequency, the phase velocity is independent of both frequency and loss.

__ In order to obtain distortionless transmission, β and v_p must be independent of frequency.

__ A 20m, 50Ω lossless transmission line fed from a 50V step function source having a 100Ω resistance. The line is connected to a 100Ω load. The phase velocity is 10^8m/s. 0.2μs is required for the system to reach steady-state.

__ If σ for a good conductor is not a function of frequency, the resistance will be independent of frequency.
Why or why not? ____

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7. i) A 1.8λ, 50Ω transmission line, α=0.3neper/λ, is terminated by a (50+j120)Ω load. Use a Smith chart (Do ***not*** attach) and calculator to find $\tilde{\Gamma}_L$ __________, $\tilde{\Gamma}_{in}$ __________, and $\tilde{Z}_{in}$ __________. (7 pts.)

ii) From measurement on a lossless 75Ω transmission line, VSWR = 4. The first voltage minimum occurs 1m and the second occurs 2.5 from the load. Use a Smith chart (Do ***not*** attach) and calculator to determine λ__________, $\tilde{\Gamma}_L$ __________ and $\tilde{Z}_L$ __________. (8 pts.)

iii) Use a 1/4-λ transformer (use 50Ω lines) to match $\tilde{Z}_L = (150 + j200)\Omega$ to $\tilde{Z}_s = 50\Omega$.

d_{scs}__________, $Z_{c(1/4\text{-wave})}$__________. (10 pts) (***Attach*** Smith Chart)

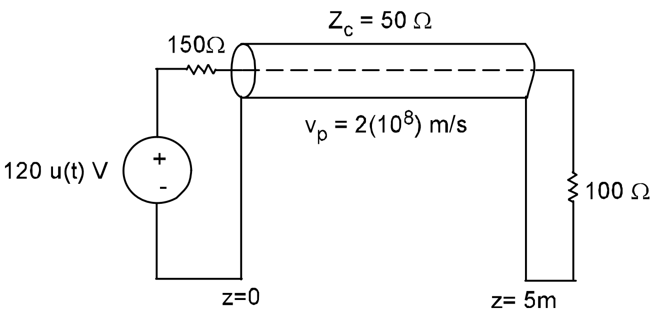
Neatly *show physical connections, in detail, for ¼-λ transformer problem (part iii)*

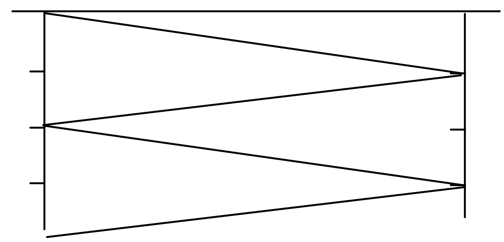
8. Check ***T/F*** either ***T*** or ***F*** (2½ pts each)

___ The quasi-static model for the parallel-plate capacitor predicts $C = \varepsilon A/d$. For this to be valid, the $\lambda^2 >> \ell^2$ must be satisfied.

___ In the quasi-static model for the inductor, 2nd-order effects predict the first corrective term to appear in the model is an capacitance in parallel with the inductance.

Complete bounce diagram and find $v_{in}(z=0, t=60\text{ ns})$ = _____ and $v_{in}(z=0, t \to \infty)$ = _______ (7½ pts)





___ For a plane wave traveling in a lossy medium, the phase of the magnetic field will lag that of the electric field.

___ Given an air-core inductor with dimensions of 1cm, the quasi-static model is valid at 1GHz.
Why or why not? ____

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___ A plane wave travels in a lossy medium. The magnitude of the electric vector is 10 V/m and the intrinsic impedance is $100\angle 60°$ Ω/m. $\left|\langle \underline{S}_i \rangle\right|$ = 0.25 W/m^2.

Why or why not? ____

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___ A study of quasi-statics reveals that the lumped-element model used to model physical circuit elements changes with frequency.

___ Using Faraday's law, one can demonstrate that KVL is not a law of nature, but is only valid for closed loops that are **not** linked by changing magnetic fields.

Answers

1. $d_{TL} = 0.1\lambda$ $d_{scs} = 0.131\lambda$
2. i) neither ii) $(421 + j938)\ m^{-1}$ iii) $76.8\angle 24.2°\ \Omega$

   iv) $16.9\ e^{-421z}\ e^{-j938z}\ \mathbf{a}_y$ A/m $1300e^{-421z}\ e^{-j938z}\ e^{j24.2°}\ \mathbf{a}_x$ V/m

   v) $\mathbf{a}_z\ 10\ e^{-842z}$ KW/m^2
3. i) 75 Ω ii) $2(10^8)$ m/s iii) 0.375 μH/m

   iv) 66.7 pF/m iv) $R_L = 25\ \Omega$, series element is L (not req. here, but $\approx$18.75 nH)
4. i) $0.707\angle 45°$ ii) $43.1\angle -70.3°\ \Omega$ iii) $5.65\angle -38.1°$ V iv) 125 mW
5. i) 25.66° ii) $8.28\ (0.9\ \mathbf{a}_z + 0.433\ \mathbf{a}_x)$ mW/m^2 iii) 0.32 0.68
6. F, T, F, F, F, T, T, F, F, F
7. i) $0.775\angle 40°$ $0.263\angle -176°$ $(28.5 - j0.5)\ \Omega$

   ii) 3 m $0.6\angle 60°$ $(63.75 + 102)\ \Omega$ iii) $d_{scs} = 0.276\lambda$ $Z_c = 144.3\ \Omega$
8. T, T, (45 V, 48 V, $\Gamma_s = 0.5$, $\Gamma_L = 0.333$, $t_d = 25$ ns) T, T, T, T, T