ECE 540 Final Exam – Take Home
Winter Quarter, 1998

Name: ___________________________________________ Date: _______________________

Time picked up: __________________________
Time returned: __________________________

You may use any books, notes, computer, calculator, etc. Show complete solutions including your work. PLEASE do NOT consult with any person (other students, instructors, etc.) about this exam.
1. Design a single stub tuner to match an antenna with $Z_L = 25 + j25\Omega$ to a $50\Omega$ microstrip line.

Specify: Parallel or series stub

Open or short circuit stub

Justify your choice of the type of tuner you choose.

Distance from load to stub $d = 0.0433\lambda$

Length of stub $L = 0.0898\lambda$

Using T-line software:

Rotate $TWG$ $0.0433\lambda = d$ to matching circle

Read $Z_{LSN} = 1 + j1.58$

Plot on Smith Chart

Rotate $TWL$ $0.0898\lambda = L$

$Z_{LN} = \frac{Z_L}{Z_0} = \frac{25 + j25}{50} = \frac{1}{2} + j\frac{1}{2}$

Plot on Smith Chart (I used T-line software)

Rotate $TWG$ $0.0898\lambda = L$ to matching circle

Read $Z_n = 1 + j$

Stub needs to have $Z_S = -j1.58$

Plot on Smith chart, Rotate $TWL$ to $Z_{open}$

$L = 0.125\lambda$
2. Design a double stub tuner to match the same antenna to a 50 Ω w-waxial line.

Distance from load to first stub = 0.1λ
Distance between stubs = 0.3λ

Specify:  [ ] Parallel or series stub  [ ] Open or short circuit stub

Justify your choice of tuner.

Length of first stub (nearest load) ________
Length of second stub (nearest source) ________

Plot $\theta = \frac{1}{2} + j\frac{1}{2}$. Convert to admittance.

Rotate 0.1λ TWL

Rotate matching circle 0.3λ TWL

Move along constant R circle to rotated matching circle

Option 1

Length of Stub 1 = \(0.173λ\)
\(L_1 = 0.173λ\)
\(L_2 = 0.0905λ\)

Option 2
\(L_1 = 0.33λ\)
\(L_2 = 0.366λ\)

Series Short
\(L_1 = \text{No Solution} \quad L_1 = \)
\(L_2 = \quad L_2 = \)
(a) Choose a circular waveguide (see attached table) for use transmitting a signal at 9GHz.

\[ f_{cmn} = \frac{\sqrt{\frac{\pi}{2}}}{\pi a} \left( \frac{m}{a} \right) \left( \frac{c}{\lambda} \right) \left( \frac{r}{a} \right) \]

\[ r = \frac{a}{2} \]

\[ \text{radius} = \frac{1,094}{2} \]

(b) Specify the first four modes of this waveguide and their frequencies.

\[ p_0 = 2.405 \quad p_0 = 3.832 \quad TE_{11} \quad f_{c11} = 6.32 \text{ GHz} \]

\[ \rho'_{11} = 1.841 \quad TM_{01} \quad f_{c01} = 8.256 \text{ GHz} \]

\[ \rho'_{01} = 3.051 \quad TE_{21} \quad f_{c21} = 10.486 \text{ GHz} \]

(c) What range of frequencies do you recommend using this waveguide for?

Range of TE_{11} mode is 6.32 GHz - 10.486 GHz

Need to stay in this range. Manufacturer chooses above TE_{11} and below TE_{21} ... 7.27 - 9.97 GHz

TM_{01} mode is suppressed by not exciting it (feed system)

(d) Why?

(e) How far can you propagate the 9GHz signal on this waveguide before it is attenuated to 50% of its original magnitude?

\[ R_s = \sqrt{\frac{\omega \mu}{2\pi c}} \]

\[ 0_{Cu} = 5.813 \times 10^7 \text{ S/m} \]

\[ \lambda = \lambda c + \lambda d \]

\[ \lambda c = \frac{\lambda}{\text{dielectric loss}} \]

\[ \lambda c = \frac{R_s}{\alpha k \lambda B} \left( k c + \frac{k c}{\rho_0^2 - 1} \right) = 0.00447 \text{ m} \]

\[ k = \frac{2\pi}{\lambda} \]

\[ k c = \beta \sqrt{k c^2 - k_0^2} \]

\[ e^{-d} = 0.5 \]

\[ z = 139.5 \text{ m} \]
<table>
<thead>
<tr>
<th>KIA Designation</th>
<th>Inside Dimensions (Inches)</th>
<th>Recommended Frequency Range</th>
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<tbody>
<tr>
<td></td>
<td>Diameter</td>
<td>Tolerance + or -</td>
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<tr>
<td>WC 992</td>
<td>9.915</td>
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<tr>
<td>WC 647</td>
<td>6.470</td>
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<td>WC 726</td>
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4. A 50Ω lossy microstrip line has $\omega = 0.1$ Np/m, $V_p = 2 \times 10^9$ m/s, $\rho = 0.7$ rad/m and is $\frac{1}{2}$ m long.

(a) Sketch the time domain voltage at the load for the first 30 ns.

$V_{in} = V_s \frac{Z_0}{Z_0 + R_g} = \frac{1}{3} V$

$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{75 - 50}{75 + 50} = 0.2$

$\Gamma_s = \frac{Z_g - Z_0}{Z_g + Z_0} = \frac{100 - 50}{100 + 50} = 0.3$

(b) How long (in seconds) do you expect it to be before the pulses observed at the load are less than 0.01 V in magnitude?

\[
e^{-dz} = e^{-0.1(0.5)} = 0.95 \quad \text{each path}
\]

\[
0.01 \quad e^{-dz} = 0.01 \rightarrow z = 46 \text{ m}
\]

(c) Sketch the voltage on the line as a function of distance at 30 ns.

Pulses:
- 2nd pulse will already be below 0.01 V
- 0.01 V
\[ V_{in} = V_s \frac{Z_0}{Z_0 + R_g} = \frac{1}{3} V \]

\[ P_L = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{75 - 50}{75 + 50} = 0.2 \]

\[ R_g = \frac{Z_0 - Z_L}{Z_0 + Z_L} = \frac{100 - 50}{100 + 50} = 0.3 \]

Attenuation per trip \[ e^{-2z} = e^{-(0.1)(0.5)} = 0.95 \]

Examine first pulse at load \[ V_s e^{-dz} + V_s P_L e^{-dz} = V_s (e^{-dz} + P_L e^{-dz}) \]

\[ V(L) \]

1. \[ V_1 = V_s e^{-dz} + V_s P_L e^{-dz} = V_s e^{-dz} (1 + P_L) \]
2. \[ V_2 = V_s P_L e^{-3dz} (1 + P_L) \]
3. \[ V_3 = V_s P_L^2 e^{-5dz} (1 + P_L) \]
4. \[ V_4 = V_s P_L^3 e^{-7dz} (1 + P_L) \]
5. \[ V_5 = V_s P_L^4 e^{-9dz} (1 + P_L) \]
6. \[ V_6 = V_s P_L^5 e^{-11dz} (1 + P_L) \]

\[ z = 0.5m \]
5. Derive the electric and magnetic fields in the partially-filled WR95 waveguide shown below:

For TE modes \( E_z = 0 \)

For on modes \( \partial / \partial x = 0 \)

\[
\left( \frac{\partial^2}{\partial y^2} + k_y^2 \right) H_z = 0 \quad \text{for teflon} \quad 0 \leq y \leq b/2
\]

\[
\left( \frac{\partial^2}{\partial y^2} + k_y^2 \right) H_z = 0 \quad \text{for air} \quad b/2 \leq y \leq b
\]

Guess \( H_z = \begin{cases} (A_1 \cos k_1 y + B_1 \sin k_1 y)(C_1 \cos k_1 x + D_1 \sin k_1 x) & \text{on} \\ (A_2 \cos k_2 y + B_2 \sin k_2 y)(C_2 \cos k_2 x + D_2 \sin k_2 x) & \text{on} \end{cases} \)

Need \( E_z \) for boundary conditions (remember \( \partial / \partial x = 0 \))

\[
\begin{cases}
E_{x_1} = -\frac{j \mu_0 \omega}{k_1} \frac{\partial H_z}{\partial y} = -\frac{j \mu_0 \omega}{k_2} (-A_1 \sin k_1 y + B_1 \cos k_1 y) \\
E_{x_2} = -\frac{j \mu_0 \omega}{k_2} \left( \Lambda_0 k_2 \sin k_2 y + B_2 \cos k_2 y \right) - \frac{j \mu_0 \omega}{k_2} (C_2 \cos k_2 x + D_2 \sin k_2 x)
\end{cases}
\]

Boundary conditions on \( E_z \)

\[
E_{x_1}(y=0) = 0 \quad \Rightarrow \quad B_1 = 0
\]

\[
E_{x_2}(y=b) = 0
\]

\[
E_{x_1}(y=b/2) = E_{x_2}(y=b/2) \quad \Rightarrow \quad B_2 = 0
\]

\[
\frac{j \mu_0 \omega}{k_1} A_1 \sin k_1 b/2 = \frac{j \mu_0 \omega}{k_2} \left( A_2 \sin k_2 b/2 + B_2 \cos k_2 b/2 \right)
\]

\[
\frac{A_1}{k_1 \sin k_1 b/2} = \frac{A_2}{k_2 \sin k_2 b/2}
\]

Knowing \( k_1 \) and \( k_2 \), we could find \( A_1 / A_2 \).
Need Eq for boundary conditions

\[
\frac{E_y}{k_1} = \frac{\omega}{k_2} \text{A} \sin k_2 y
\]

Apply center BC on Hz also

\[H_z, (b/2) = H_z, (b/2)\]

\[A_1 \cos k_1 b/2 = A_2 \cos k_2 b/2\]

Combine these equations

\[A_1 \cos k_1 b/2k_1 = A_2 \cos k_2 b/2k_2\]

\[\frac{A_1}{k_1} \sin k_1 b/2 = \frac{A_2}{k_2} \sin k_2 b/2\]

\[k_1 \tan k_1 b/2 = k_2 \tan k_2 b/2\]

Solve numerically for \(k_1\) & \(k_2\)
(a) Derive the S-parameters for the circuit below. Line lengths not shown are assumed to have zero length.

\[ C_1 = 1 \text{pF} \quad 0.2\lambda \quad C_2 = 1 \text{pF} \quad F = 1 \text{GHZ} \]

Port 1 \quad \text{Port 2}

\[ L_1 = 1 \text{pH} \quad 1 \text{pH} = L_2 \quad 0.2\lambda \]

(b) If a 75\Omega load is connected to port 2 and a 1V source is input to port 1 (V' = 1V) how much power is delivered to the load?

\[ (a) \quad Z \quad Z_0 \quad Y \]

\[ \text{ABCD matrix} \]

\[
\begin{bmatrix}
1 & \frac{1}{j\omega L} & 0.3 & j47.5 \\
0 & 1 & 0 & 0 \\
0.3 & 0.3 & 1 & j\omega C \\
\end{bmatrix}
\]

Using MATLAB,

\[
\begin{bmatrix}
1 & j\omega C \\
0 & 1 \\
0.3 & 0.3 \\
\end{bmatrix}
\]

\[ \text{ABCD} \]

\[
\begin{bmatrix}
-0.19 & j3.05 \\
-j0.0001 & -0.0192 \\
\end{bmatrix} \times 10^{10}
\]

Convert to S =

\[
\begin{bmatrix}
0.8-j0.57 & 0 \\
0 & 0.8-j0.57 \\
\end{bmatrix}
\]
Using Mason Loop Rule

\[ S_{uv} = \frac{S_{uu} (1 - S_{22} \Gamma_L) + S_{21} \Gamma_L S_{12} (1 - \theta)}{1 - S_{22} \Gamma_L} \approx 0.82 - j.57 \]

\[ S_{12} = \frac{S_{12} (1 - \theta)}{1 - S_{22} \Gamma_L} = 0 \]

\[ S_{21} = \frac{S_{21} (1 - \theta)}{1 - S_{22} \Gamma_L} \approx 0 \]

\[ S_{22} = \frac{S_{22} (1 - \theta)}{1 - S_{22} \Gamma_L} \approx 1.86 - j.80 \]

\[ V_2^+ = 0 \quad V_2^- V_1^+ = S_{21} V_1^+ \approx 0 \]

\[ \rho = \frac{V_2}{Z_L} \approx 0 \]
Grading/Points Possible

Name __________________________

Problem 1 ________________ / 30 points
Problem 2 ________________ / 35 points
Problem 3 ________________ / 35 points
Problem 4 ________________ / 30 points
Problem 5 ________________ / 40 points
Problem 6 ________________ / 30 points

Total __________________________ / 200 points