SAMPLE FINAL EXAM

Name ______________________________

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UNIVERSITY OF UTAH

ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

MICROWAVE ENGINEERING I

ECE 5320

FINAL EXAM

December 13, 2004

ECE 5320: 2004 Final Exam – Solutions

1. a. $z_L = \frac{Z_L}{Z_0'} = 0.4 - j\,0.4$ The normalized value of z_L is shown as point L in the attached Smith Chart.

Shown also in the Smith chart is the transmission line circle T for section AB of the matching circuit of Fig. 1 of the Exam.

Also from the Smith Chart we can determine y_L at point A as the diametrically opposite point on the transmission line circle T.

$$y_L\Big|_{\text{point A}} = 1.25 + j\,1.25$$

From point A we can move to point B on the circle T such that for

$$y_B = 2.0 - j\,1.3$$

$\frac{l}{\lambda_g} \rightarrow \frac{\text{length } l \text{ between points A and B}}{\lambda_g} = 0.29 - 0.181 = \boxed{0.109}$

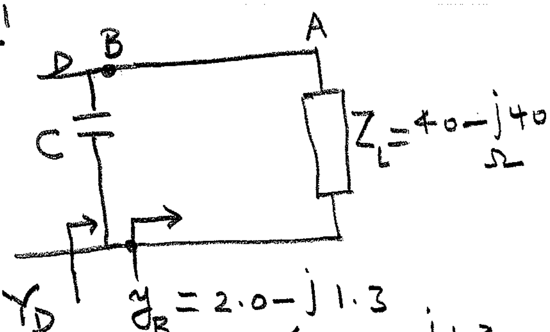


Fig. 1

$y_B = 2.0 - j\,1.3$

$Y_B = y_B Y_0' = \frac{2.0 - j\,1.3}{100} = \frac{1}{50} - j\frac{1.3}{100}$

b. Add capacitance C such that

$$j\omega C = +j\frac{1.3}{100}$$

$$C = \frac{1.3}{100 \times 2\pi \times 3\times10^{8}} = \boxed{0.69\ \text{pF}}$$

$$Y_D = \frac{1}{50} - j\frac{1.3}{100} + j\omega C = \frac{1}{50} + j\,0$$

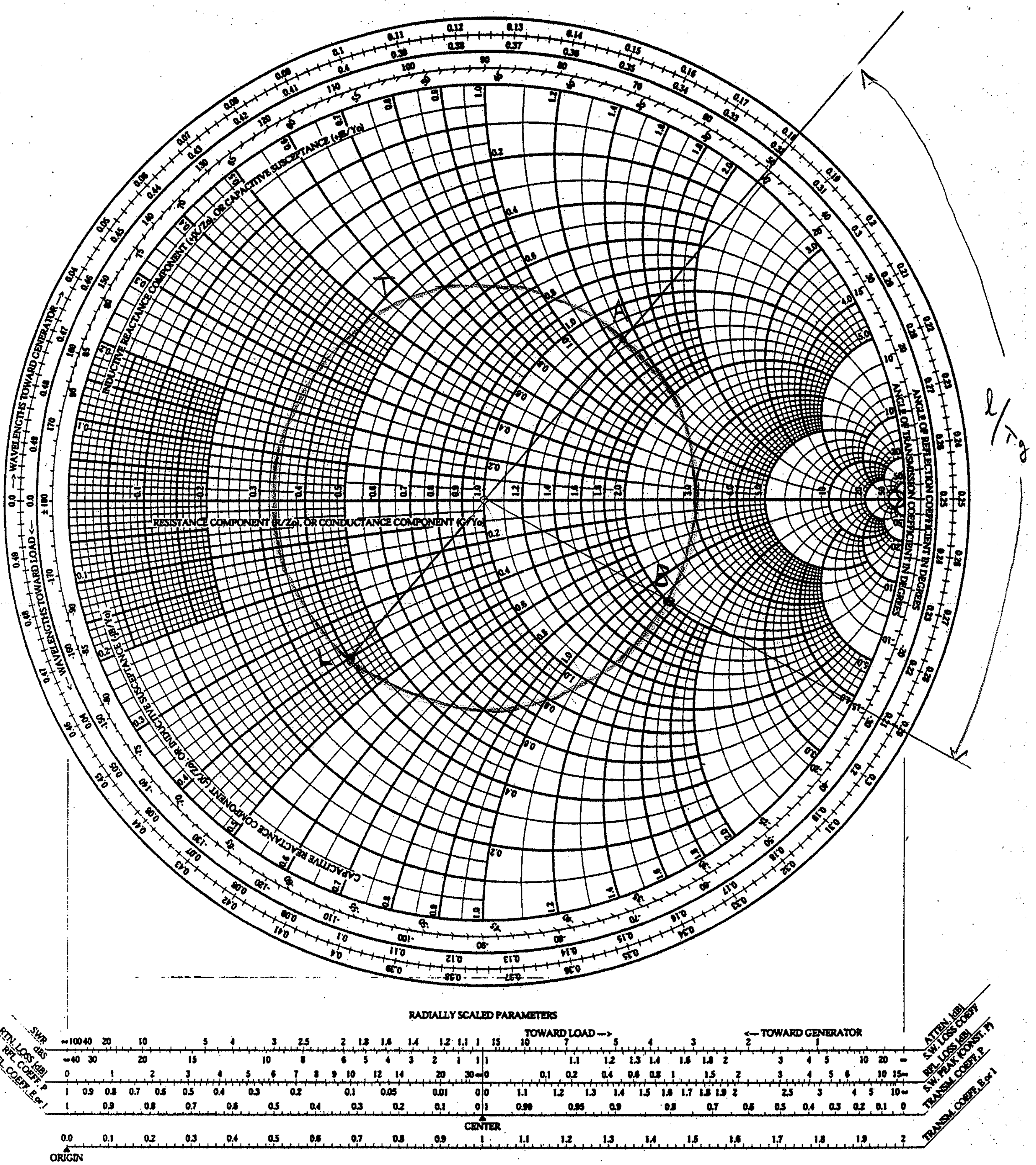
Thus the transmission line is matched for all planes left of point D in Fig. 1

c. From the Smith chart

SWR for section AB of the cct = $\boxed{3.02}$

The Complete Smith Chart

Black Magic Design



2. (25 points)

The S-matrix of a three-port circuit is given as follows:

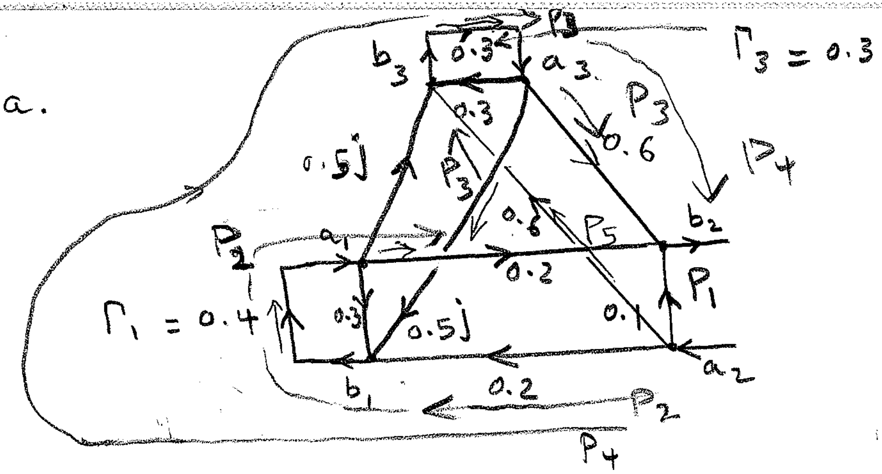
$$S = \begin{bmatrix} 0.3 & 0.2 & 0.5j \\ 0.2 & 0.1 & 0.6 \\ 0.5j & 0.6 & 0.3 \end{bmatrix}$$

<u>Pts</u>

10 a. Draw the flow graph for the above circuit given that ports 1 and 3 are connected to mismatched loads with reflection coefficients $\Gamma_1 = 0.4$ and $\Gamma_3 = 0.3$, respectively.

15 b. Calculate the reflection coefficient b_2 / a_2 at port 2.

2. a.



b. Reflection coeff. $\frac{b_2}{a_2}$

paths	First order Non-touching Loops $L^{(1)}(1)$	2nd order Non-touching loops $L^{(1)}(2)$
$P_1 \Rightarrow 0.1$	0.3×0.4, 0.3×0.3, $0.4 \times 0.5j \times 0.3 \times 0.5j$ ⇓ 0.12, 0.09, -0.03	$(0.4 \times 0.3)(0.3 \times 0.3) = 0.0108$
$P_2 = 0.2 \times 0.4 \times 0.2 = 0.016$	$0.3 \times 0.3 \Rightarrow 0.09$	0
$P_3 = 0.6 \times 0.3 \times 0.6 = 0.108$	$0.4 \times 0.3 \Rightarrow 0.12$	0
P_4 $0.2 \times 0.4 \times 0.5j \times 0.3 \times 0.6 = 0.0072j$	0	0
P_5 $0.6 \times 0.3 \times 0.5j \times 0.4 \times 0.2 = 0.0072j$	0	0

All first order loops $L(1)$
Touching or nontouching

0.4×0.3, 0.3×0.3

$0.4 \times 0.5j \times 0.3 \times 0.5j$

⇓

0.12, 0.09

-0.03

All second order loops touching or nontouching $L(2)$

$(0.4 \times 0.3)(0.3 \times 0.3)$
$= 0.0108$

$$\frac{b_2}{a_2} = \frac{0.1\left[1 - (\overset{0.18}{\cancel{0.12 + 0.09 - 0.03}}) + 0.0108\right] + 0.016\left[1 - 0.09\right] + 0.108\left[1 - 0.12\right] + 0.0072j + 0.0072j}{1 - (\underset{0.18}{\cancel{0.12 + 0.09 - 0.03}}) + 0.0108}$$

$$= \frac{0.08308 + 0.01456 + 0.09504 + 0.0144j}{0.8308} = \frac{0.19268 + 0.0144j}{0.8308} = 0.23192 + j0.01733$$

$0.2326 \angle 4.273^{\circ}$

3. (30 points)

Pts

11 a. Design a 0.5 dB equal-ripple low-pass filter with a cutoff frequency of 5 GHz and attenuation of 40 dB at twice the cutoff frequency i.e. at 10 GHz. The filter should be matched to a 60Ω microstripline. For this filter, calculate the values of individual inductances and capacitances that are needed **starting with a series element.**

4 b. Sketch the LC equivalent circuit of the designed low-pass filter.

10 c. Using a stepped impedance filter design, calculate the lengths ($\beta_c \ell$) of the sections to use for high impedance sections of characteristic impedance $Z_h = 120\Omega$ and low impedance sections of characteristic impedance $Z_\ell = 15\Omega$.

5 d. Sketch the microstrip layout of the final filter. Find the total length $\beta_c \ell$ of the designed filter.

3. From Fig. 8.27 a for a 0.5 dB ripple filter, an attenuation of 40 dB @ $\frac{\omega}{\omega_c} = 2$ can be obtained for $n = 5$ filter (4

From Table 8.4 the element values for an inductance input prototype are:

$g_1 = \frac{\omega_c L_1}{Z_o} = 1.7058$ $\qquad g_4 = \frac{\omega_c C_4}{Y_o} = 1.2296$

$g_2 = \frac{\omega_c C_2}{Y_o} = 1.2296$ $\qquad g_5 = \frac{\omega_c L_5}{Z_o} = 1.7058$

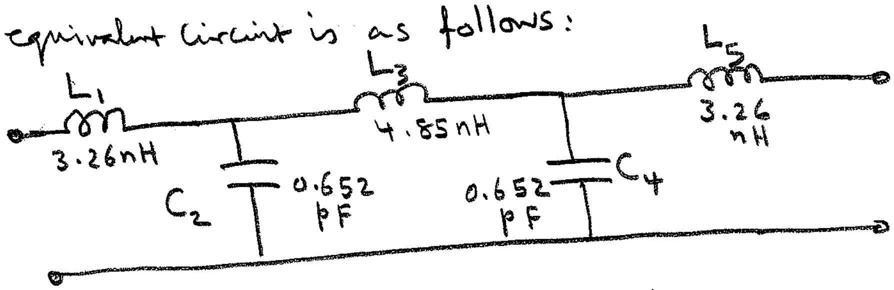
$g_3 = \frac{\omega_c L_3}{Z_o} = 2.5408$

$$L_1 = L_5 = \frac{1.7058 \times 60}{2\pi \times 5 \times 10^9} = 3.26 \text{ nH}$$

$$C_2 = C_4 = \frac{1.2296}{2\pi \times 5 \times 10^9} \times \frac{1}{60} = 0.652 \text{ pF}$$

$$L_3 = \frac{2.5408 \times 60}{2\pi \times 5 \times 10^9} = 4.85 \text{ nH}$$

b. The LC equivalent circuit is as follows:



c. From p. 18-1 of Class Notes, for inductive elements

$$\beta_c l = g \frac{Z_o}{Z_h} = g \frac{60}{120}$$

for inductances L_1, L_5

$$\beta_c l_1 = \beta_c l_5 = 1.7058 \times \frac{60}{120} = 0.8529 \text{ rad} = 48.87^\circ$$

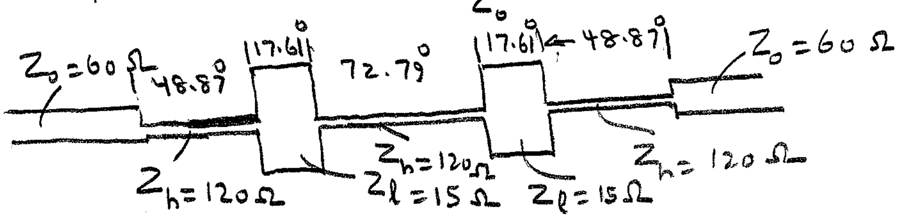
for inductance L_3

$$\beta_c l_3 = 2.5408 \times \frac{60}{120} = 1.2704 \text{ rad} = 72.79^\circ$$

<u>for Capacitive elements C_2, C_4</u>

$$\beta_c l_2 = \beta_c l_4 = g_2 \frac{Z_l}{Z_o} = 1.2296 \times \frac{15}{60} = 0.3074 \text{ rad} = 17.61^\circ$$

d.



Total length = 205.75°
→ 0.57 λ_g

4. (30 points)

For a WR159 air-filled rectangular waveguide, the distance between two consecutive minima (i.e. $\lambda_g / 2$) for the TE_{10} mode has been measured to be 3.8 cm and the reflection coefficient of a particular load is 0.4. Calculate the following:

Pts	
6	a. Frequency of the signal.
6	b. Cutoff frequencies of the TE_{20} and TE_{11} modes of the waveguide.
6	c. SWR in the waveguide.
6	d. Maximum electric field E_{max} for the input power of 10 KW.
6	d. Actual power delivered to the load given that an input power $P_{inc} = 10\ KW$.

5

4. a. $$\lambda_g = \frac{\lambda_0}{\sqrt{1-\frac{f_c^2}{f^2}}} = \frac{c}{\sqrt{f^2-f_c^2}} = 2\times3.8 = 7.6 \text{ cm} \quad (1)$$

For WR 159
$a = 1.59'' = 4.039$ cm
$b = 0.795'' = 2.02$ cm

$$f_c\Big|_{TE_{10}} = \frac{c}{2a} = \frac{30}{2\times4.039} = 3.714 \text{ GHz}$$

From Eq. (1) $$f^2 - f_c^2 = \left(\frac{30}{7.6}\right)^2 = 15.582$$

$$f = (f_c^2 + 15.582)^{1/2} = \left[(3.714)^2 + 15.582\right]^{1/2} = \boxed{5.42 \text{ GHz}}$$

b. $$f_c\Big|_{TE_{20}} = \frac{c}{a} = 2\times3.714 = \boxed{7.428 \text{ GHz}}$$

$$f_c\Big|_{TE_{11}} = c\sqrt{\left(\frac{1}{2a}\right)^2+\left(\frac{1}{2b}\right)^2} = c\sqrt{\frac{1}{4a^2}+\frac{1}{a^2}} = \frac{c}{a}\sqrt{1.25} = \boxed{8.305 \text{ GHz}}$$

c. $$SWR = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+0.4}{1-0.4} = \frac{1.4}{0.6} = \boxed{2.33}$$

e. From Eq. (3.86) $$Z_{TE} = \frac{377}{\sqrt{1-\left(\frac{f_c^2}{f^2}\right)}} = 517.63\ \Omega$$

From Eq. (3.92)
$$P_{10} = 10^4 = \frac{ab}{4Z_{TE}}(E_{max})^2 = \frac{4.039\times2.02}{4\times517.63}(E_{max})^2$$

$$E_{max} = \sqrt{\frac{10^4\times4\times517.63}{4.039\times2.02}} = 1593 \text{ V/cm} \text{ or } \boxed{1.593\times10^5 \text{ V/m}}$$

d. power delivered to the load $= P_{inc}(1-|\Gamma|^2) = 10\times(1-0.16) = \boxed{8.4 \text{ KW}}$

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Score:

Problem 1	________	of a possible 25 points
Problem 2	________	of a possible 30 points
Problem 3	________	of a possible 30 points
Problem 4	________	of a possible 30 points
Total	________	of a possible 115 points