Microwave Engineering I
Final
April 29, 2002

Name Key

SS# ____________________

You may use your portfolio and a calculator.

Grading:
You will receive the highest of....

Midterm I	OR	Final Problems 1 and 2
Midterm II	OR	Final Problems 3 and 4
Midterm III	OR	Final Problems 5 and 6

Good luck and do well!

Problem 1 (50 points) Smith Charts, Lossy Lines, Double Stub Matching

(a) An antenna has an impedance of 25 + j 10 Ω. It is connected to a 50 Ω line that is 1 meter = 2.125 λ long. The line has a loss factor of α = 2 Np/m. What is the input impedance to this line?

(b) Design a double stub matching network for a load that is ~~10 – j 10 Ω~~ 35+j5Ω. Stubs are parallel, short circuited lines. The distance between the two stubs is 0.125 λ. All lines are 50 Ω.

(a) $Z_L = 25 + j\,10\Omega / 50\Omega = 0.5 + j\,0.2$

$e^{-2\alpha z} = 0.2$ (α = 2, z = 1m)

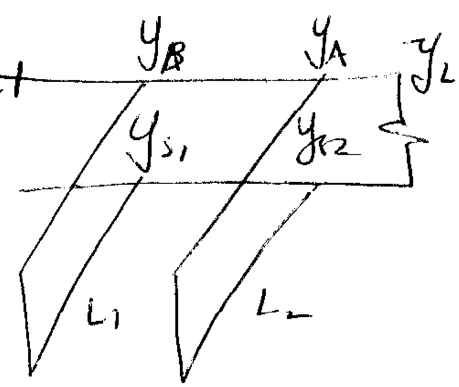
$Z_{in} = (1.05 + j\,0.15)\,50\Omega = 52.5 + j\,7.5\Omega$

(b) $Z_L = \dfrac{35 - j5\,\Omega}{50\,\Omega} = 0.7 - j\,0.1$ Draw circle 0.125 TWG

Convert to $y_L = 1.4 - j\,0.2$

Follow real circle to $y_A = 1.4 + j\,0.1$

Rotate TWG to matching circle $y_B = 1.0 - j\,0.325$



$1 + j0 = y_{s1} + y_B \Rightarrow y_{s1} = j.325$

$y_A = y_{s2} + y_L \Rightarrow y_{s2} = j\,0.3$

Rotate y_{s1} TWL to y_{sc}

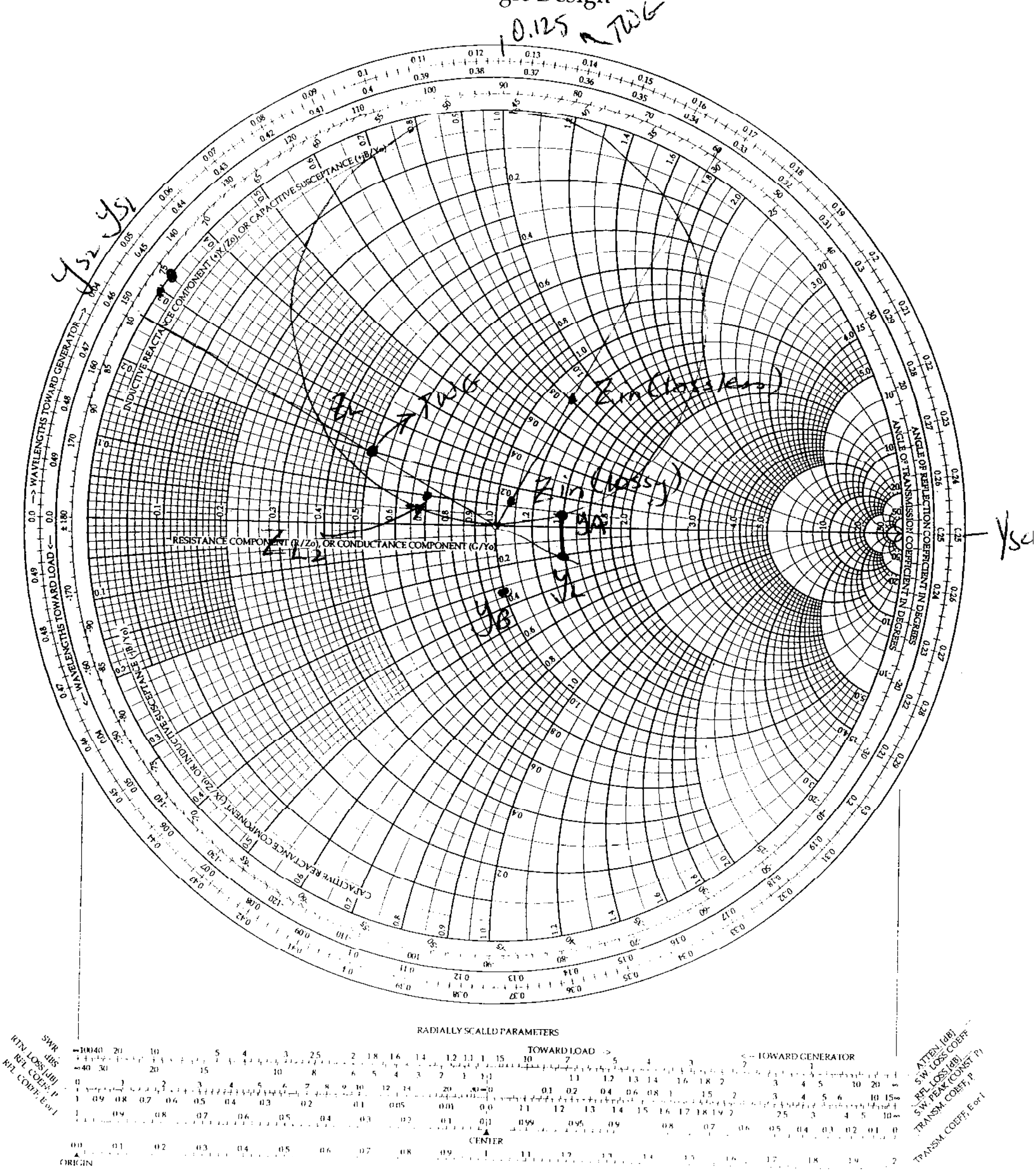
$L_1 = 0.25 - 0.05 = 0.2\lambda$

$L_2 = 0.25 - 0.048 = 0.22\lambda$

The Complete Smith Chart

Black Magic Design

Problem 1



Problem 2 (50 points) Steady State Transmission Lines

A 50 Ω transmission line is fed by a 1 V sinusoidal generator that has an impedance of 25 Ω. The line is 0.3 λ long. The load is 200 – j 10 Ω.

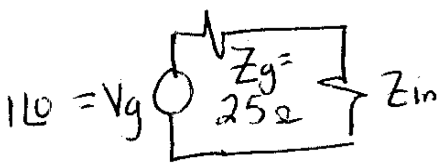
(a) Find the voltage standing wave ratio on the line.
(b) Write an expression for the positive traveling CURRENT on the line.
(c) Write a TIME DOMAIN expression for the TOTAL VOLTAGE on the line.

Note: If you do not have time to compute the complex values involved in this problem, write expressions for the items that you would use, including the values of all variables.

(a) $z_L = \frac{200 - j10}{50} = 4 - j0.2$

$$\boxed{VSWR = 4.0}$$

(b) $Z_{in} = (0.26 + j0.3)\, 50\,\Omega =$



$V_{in} = \frac{Z_{in}}{Z_{in} + Z_c} V_g =$

$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} =$

$V_{in} = V_0^+ e^{-j\beta L} + \Gamma_L V_0^+ e^{+j\beta L}$

$V_0^+ = \frac{V_{in}}{e^{-j\frac{2\pi}{\lambda}0.3\lambda} + \Gamma_L e^{+j2\pi(0.3)}}$

$$\boxed{I_0^+ = \frac{V_0^+}{Z_0} =}$$

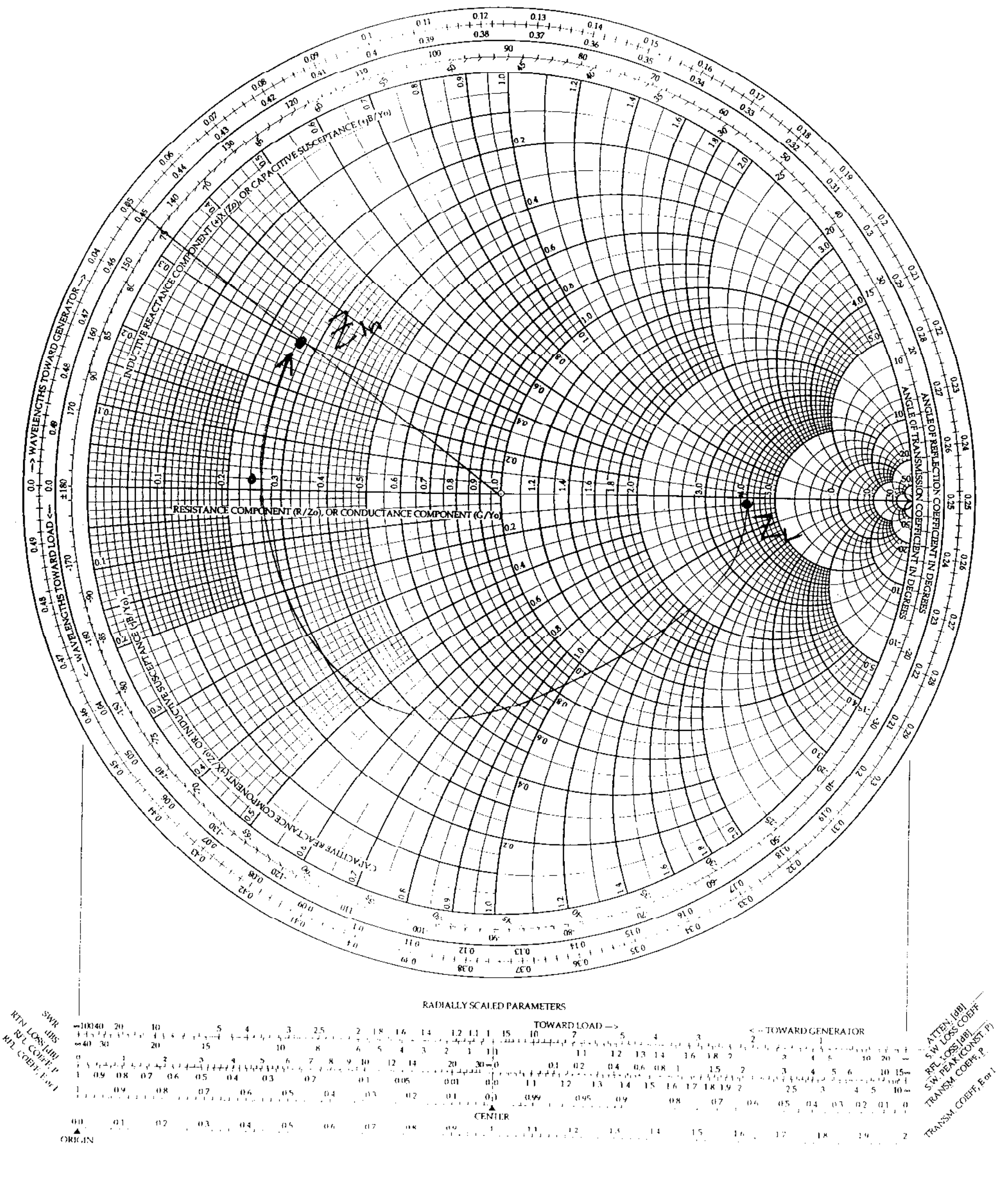
$\tilde{V}(z) = V_0^+ e^{-j\beta z} + \Gamma_L V_0^+ e^{+j\beta z}$

$V(z,t) = |V_0^+| \cos(\omega t - \beta z + \phi_{V_0^+})$

$+ |\Gamma_L| |V_0^+| \cos(\omega t + \beta z + \phi_{V_0^+} + \phi_{\Gamma_L})$

The Complete Smith Chart

Black Magic Design



Problem 3 (50 points) Couplers and Power Dividers

(a) Design a Wilkinson power divider for equal power combining. All input and output lines are 50 Ω. Specify R and Z below.

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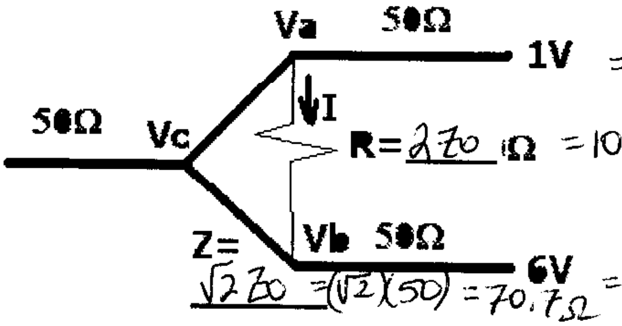


1V − 6V = 2Vo

Vo = −2.5 V

Ve = 3.5 V

(b) If the input voltages are 1 V and 6 V, find:

10 Va = ________ V = 1.75 + −1.25 = 0.5

10 Vb = ________ V = 1.75 + 1.25 = 3

10 Vc = ________ V = $-j\frac{3.5}{\sqrt{2}} + 0$ =

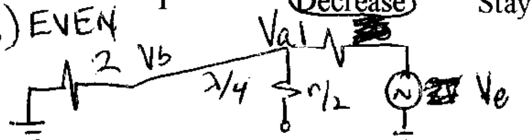
10 I = −25 mAmps = 0 − .025 A

(c) If a mistake is made in manufacturing, and a resistor that is twice as large as it should be (=2R) is installed, what will happen to each value:

10

Va	Decrease	Stay the same	(Increase)	Va even stays same, Va odd ↑
Vb	(Decrease)	Stay the same	~~Increase~~	Vb odd ↓
Vc	Decrease	(Stay the same)	Increase	(Approx)
I	(Decrease)	Stay the same	Increase	

(b) EVEN



even

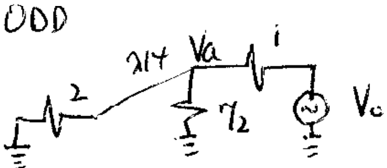
$Va = \frac{Ve}{2}$ (matched by λ/4 transformer) $= Vb$

$= 1.75V$

$V_c = -j\frac{Ve\sqrt{2}}{2} = -j\frac{3.5}{\sqrt{2}} =$

$I = 0$

ODD



$Va = \frac{Vo}{2} = -Vb$ = −1.25 = Va

1.25 = Vb

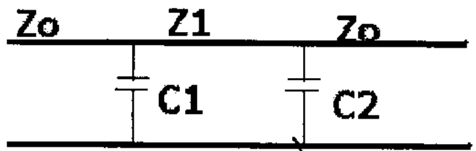
$V_c = 0$

$I = \frac{2Va}{100\,\Omega} = \frac{-2.5}{100}$ A = −.025A

V

Problem 4 (50 points) Filters

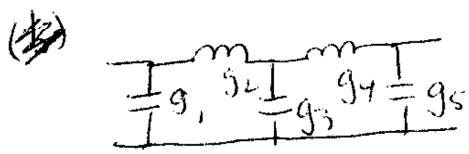
(a) Find the normalized coefficients ("g" values) for a maximally flat low pass filter that has a cutoff frequency of 1 GHz and passes less than –40 dB at 3 GHz.
(b) Demonstrate how to apply the Kuroda identities to this filter design. Numerically compute the values of one of the identities, and demonstrate the rest simply by drawing them.
(c) Show how to implement the system below using open circuited stubs.

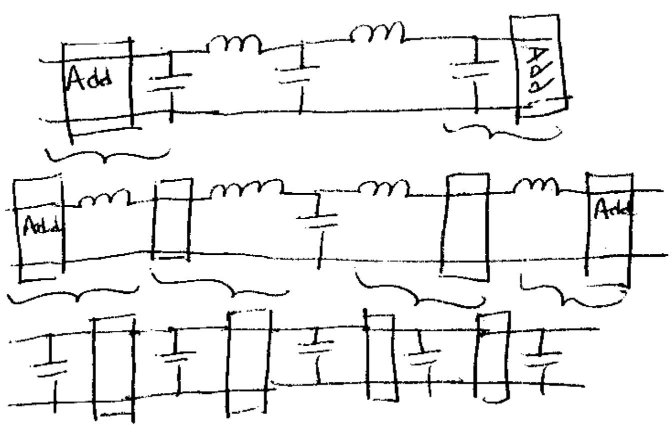


(a) From Fig 8.26 p 450 $\left|\frac{\omega}{\omega_c}\right| - 1 = \left|\frac{3}{1}\right| - 1 = 2.0$

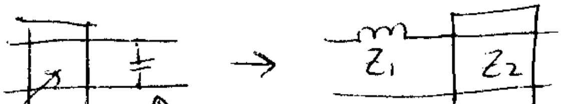
For 40dB, you need a 5th order filter From Table 8.3 p 449

$g_1 = 0.6180$, $g_2 = 1.6180$, $g_3 = 2$, $g_4 = 1.6180$, $g_5 = 0.6180$, $g_6 = 1.0$





(b)



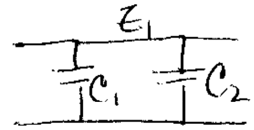
$n^2 Z_1 = 1$ $\quad \frac{1}{n^2 Z_2} = g_1$

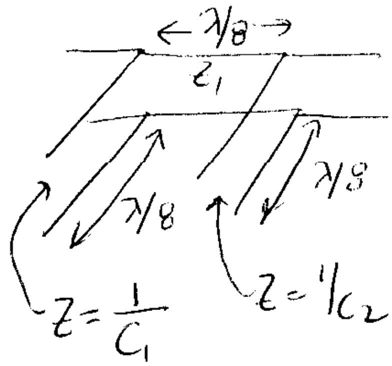
$n^2 = 1 + Z_2/Z_1 = 1 + \frac{\frac{1}{n^2 g_1}}{\frac{1}{n^2}} = 1 + \frac{1}{g_1} = 2.6$

$Z_1 = \frac{1}{n^2} = .382$

$Z_2 = \frac{1}{g_1 n^2} = .618$

(c)





Problem 5 (50 points) Waveguides

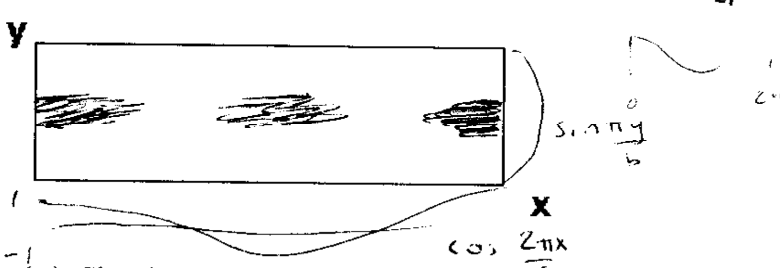
A rectangular waveguide has a cross section of 12 cm x 4 cm and is filled with ceramic that has $\varepsilon_r = 9.0$

10 (a) Calculate the cutoff frequencies for the first four modes.

Mode	Fc (Hz)
TE_{10}	0.41 G
TE_{20}	0.83G
TE_{01}, TE_{30}	1.24G
TE_{11}, TM_{11}	1.30G

20 (b) Sketch the |Ex| for the TM_{21} mode by shading the areas with high |Ex| dark and other areas light.

$$E_{x\,TM_{21}} = K \cos\frac{2\pi x}{a} \sin\frac{\pi y}{b} e^{-j\beta z}$$



20 (c) Sketch a method of feeding the TM_{21} mode using aperture coupling for the electric field that DOES NOT allow the TE_{21} mode to be excited.

(a) $$f_c = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} = .0158\times10^9\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$

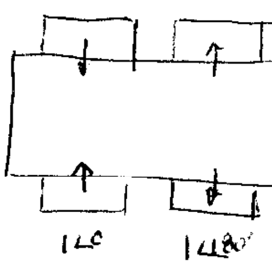
$\mu = 1.26\times10^{-6}$

$\varepsilon = \varepsilon_r\varepsilon_0 = (9)(8.854\times10^{-12})$

$a = 12\text{cm}$ $b = 4\text{cm}$

10	.41G
20	.83G
30	1.24G
40	1.65G
11	1.30G
01	1.24G

(b)



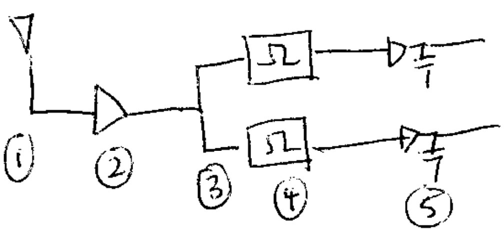
For example
(But it allows TE_{21} to propagate)

Problem 6 (50 points) Noise

Find the effective noise temperature of the WLAN receiver discussed in class. Consider one arm of the receiver containing an antenna, amplifier, splitter, filter, detector.

Given:
The ambient temperature is 290 K.
The antenna is a monopole with a gain of 3 (linear, not dB)
The amplifier is the only active device and has a noise temperature of 350 K. It has a gain of 15 dB.
The power divider is a 3dB splitter.
The filters are coupled line bandpass filters with a gain of –5 dB in the passband.
The diode detectors are perfectly matched (☺) and have a gain of 0 dB.

$$T_{cas} = T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \frac{T_{e4}}{G_1 G_2 G_3} + \frac{T_{e5}}{G_1 G_2 G_3 G_4}$$



$T_{e1} = 290°K$ $\quad G_1 = 3$

$T_{e2} = 350°K$ $\quad G_2 = 10^{15/10} = 31.6$

$T_{e3} = 290°K$ $\quad G_3 = 10^{-3/10} = 0.5$

$T_{e4} = 290°K$ $\quad G_4 = 10^{-5/10} = 0.316$

$T_{e5} = 290°K$ $\quad G_5 = 1.0$

$$T_{cas} = (290) + \frac{350}{3} + \frac{290}{(3)(31.6)} + \frac{290}{(3)(31.6)(0.5)}$$

$$+ \frac{290}{(3)(31.6)(0.5)(1.0)} = \boxed{421.96\ °K = T_{cas}}$$

Name ______________________________

Problem 1 _____ / 50 points

Problem 2 _____ / 50 points

Midterm I replacement total ________

Problem 3 _____ / 50 points

Problem 4 _____ / 50 points

Midterm II replacement total ________

Problem 5 _____ / 50 points

Problem 6 _____/ 50 points

Midterm III replacement total ________