ECE 5130/6130 Final Exam

May 2, 2001

Name ___Key___________________________

You may use your portfolio, lab notebook and calculator. No textbooks.

PLEASE TURN YOUR PORTFOLIO AND LAB BOOK INTO THE ECE OFFICE (BOX NEXT TO AMBER).

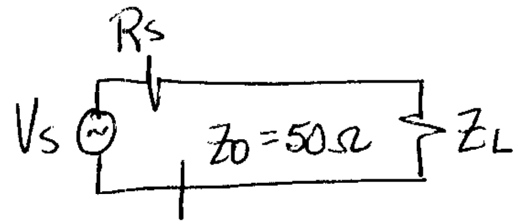
Time: 1 hour and 50 minutes

Part I (can be used to replace Midterm I)	=	Problems 1 and 2
Part II (can be used to replace Midterm II)	=	Problems 3 and 4
Part III (all students must complete)	=	Problems 5 and 6

Good Luck! Do well.

1. **Steady-state transmission lines:** (30 points)
A 50 ohm transmission line 5.2 meters long is connected to a 25 ohm generator. The voltage loss term, α, is 0.1 nepers / meter. The wavelength is 1 meter. The input impedance is measured to be 35 ohms. What is the load impedance?

Z_L = 85 − j67.5 ohms



$Z_{in} = 35 + j0\,\Omega$

Normalize & Plot:

$Z_{in(n)} = \frac{Z_{in}}{Z_0} = 0.7 + j0$

Compute loss

$e^{-2\alpha z} = e^{-2(0.1\,Np/m)(5.2m)} = 0.35$ } Not accounting for loss −10

Rotate Z_{in} 5.2λ TWL (= 0.2λ TWL) to $Z_L(a)$

Read $|\Gamma_a| = 0.18$ −5

Find $|\Gamma_{Load}|$, considering loss:

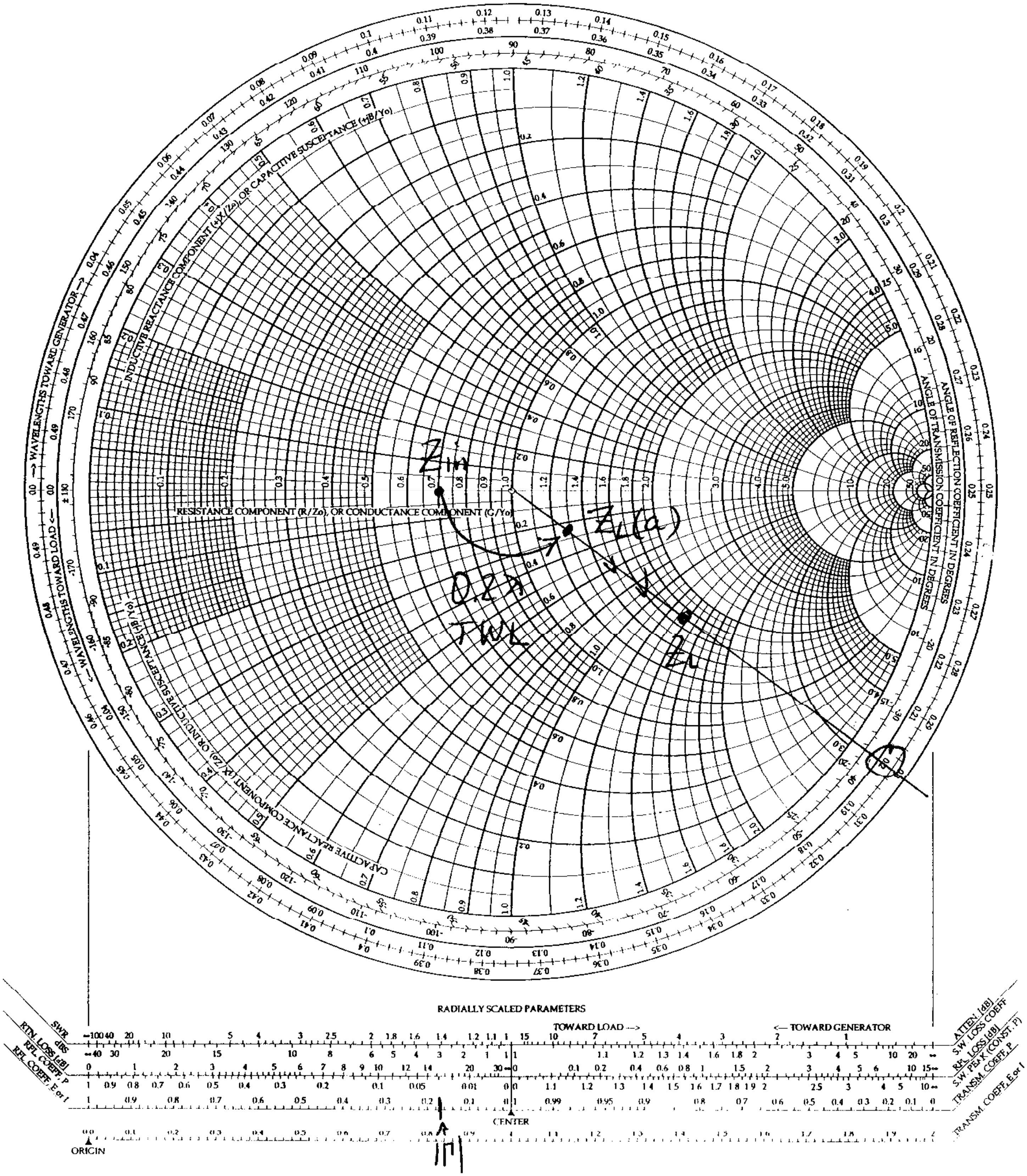
$|\Gamma_{Load}| = \frac{|\Gamma_a|}{e^{-2\alpha z}} = \frac{0.18}{0.35} = 0.51$ Plot Z_L

Read $Z_L = 1.7 - j1.35$

Denormalize $Z_{L(n)} = (1.7 - j1.35)\,50\Omega = 85 - j67.5\Omega$

The Complete Smith Chart

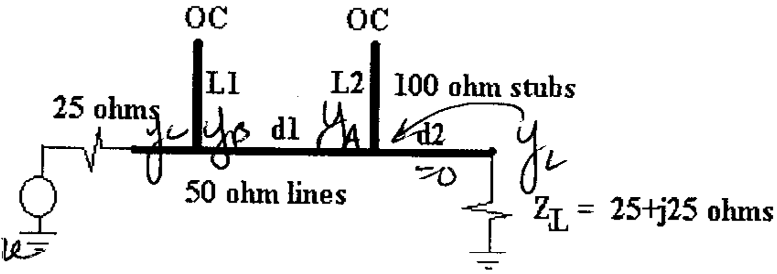
Black Magic Design



2. Impedance Matching

Design a double stub matching network. The load impedance is 25 + j 25 ohms. The generator impedance is 25 ohms. The characteristic impedance of all of the lines is 50 ohms. The characteristic impedance of the stubs is 100 ohms, and they are terminated by open circuits.

d2 ~~d1~~ =	0 wavelengths	L1 = 0 | 0.24	wavelengths
d1 ~~d2~~ =	0.125 wavelengths	L2 = 0.176 | 0.224	wavelengths



Normalize

$Z_L = \dfrac{25+j25\,\Omega}{50} = \frac{1}{2}+j\frac{1}{2}$. Plot, Reflect thru origin to $y_L = 1-j1$

Draw matching circle rotated .125λ TWL

Move y_L along constant real circle to rotated matching circle to y_{A1} or $y_{A2} = y_{stub\,2} + y_L$

Read $y_{A1} = 1+j0$ $\qquad$ $y_{A2} = 1+j2.0$

Calc. $y_{s2_1} = y_{A1} - y_L = (1+j0)-(1-j1) = j1$ $\qquad$ $y_{s2_2} = (1+j2)-(1-j1) = j3$

Denormalize to 50Ω & Renormalize to 100Ω. Plot. Rotate TWL to y_{oc}

$y_{s2_1} = (j1)\left(\frac{1}{50}\Omega\right)/\left(\frac{1}{100}\Omega\right) = j2$ $\qquad$ $y_{s2_2} = \dfrac{(j3)\left(\frac{1}{50}\Omega\right)}{\frac{1}{100}\Omega} = j6$

Plot & Rotate .125λ TWG Back to regular matching circle. Read

$y_{B1} = 1+j0$ $\qquad$ $y_{B2} = 1-j2$

Want $y_c = 1+j0 = y_{stub1} + y_B$

$y_{stub1_1} = 0j$ $\qquad$ $y_{stub1_2} = +j2$

Denormalize (50Ω); Renormalize (100Ω); Plot

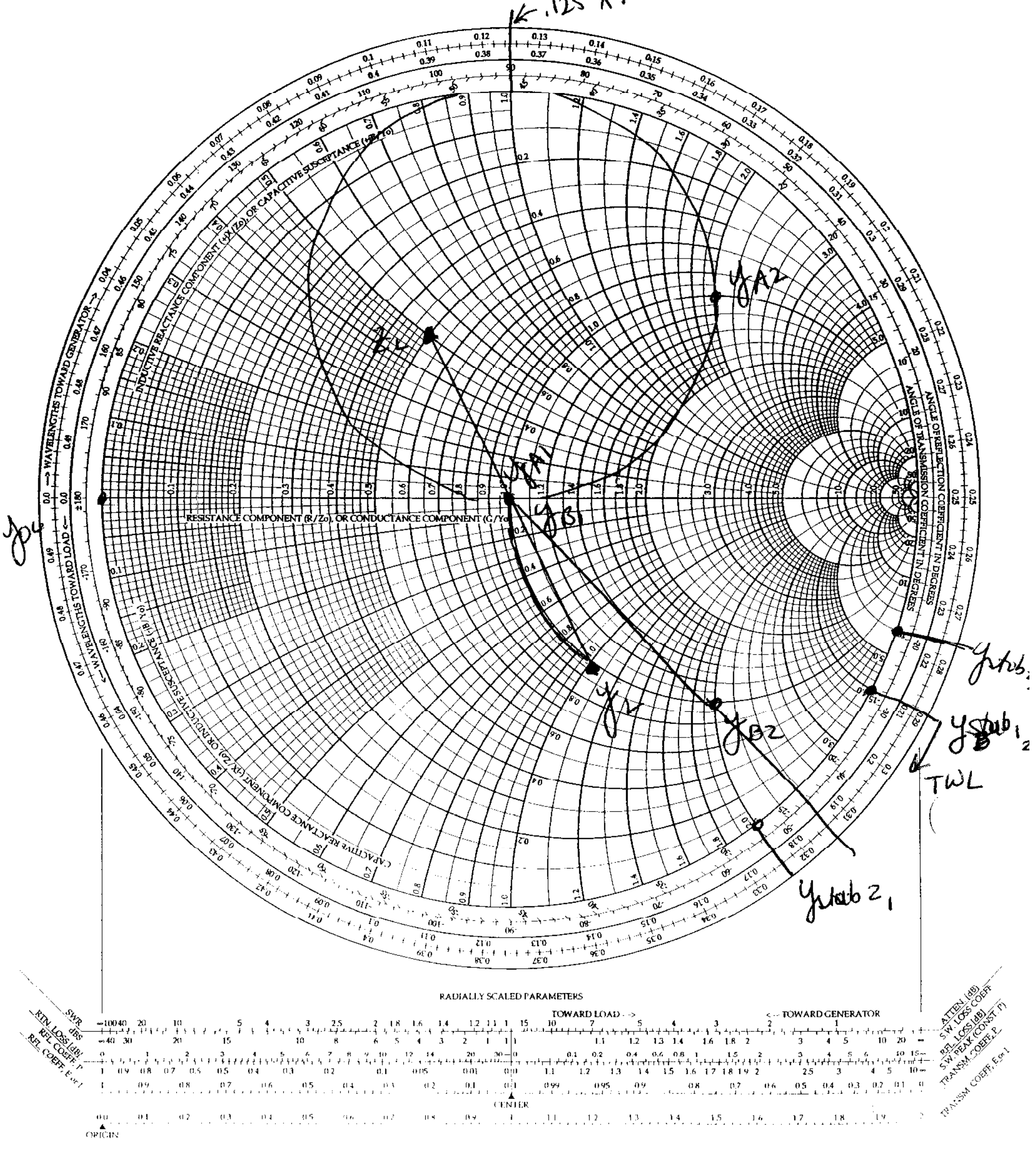
$y_{stub\,1_1} = 0\,\dfrac{1/50}{1/100} = j0$ $\qquad$ $y_{stub\,2} = (j2)\dfrac{1/50}{1/100} = j4$

Rotate TWL to y_{oc}

$L_{1_1} = 0$ $\qquad$ $L_{1_2} = 0.24λ$

The Complete Smith Chart

Black Magic Design



3. Filters

(a) Design a maximally flat high pass filter with a cutoff frequency of 3 GHz, impedance of 50 ohms, and at least 15 dB of insertion loss at 2 GHz. Sketch the filter and specify the L,C components that will be used for a lumped element filter.

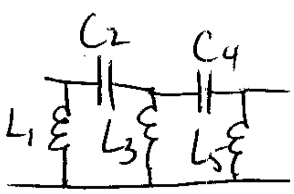
(b) Design a stepped impedance filter for a low pass design with cutoff at 2 GHz and at least 15 dB of insertion loss at 3 GHz. (Note that this can be done by converting the values you obtained in part a above.) Match your filter to a 50 ohm line. The minimum impedance that can be used is 10 ohms, and the maximum is 100 ohms.

(c) Sketch your design, and clearly specify the lengths and impedances of all lines.

(a) $\left|\frac{\omega_c}{\omega}\right| - 1 = \left|\frac{3}{2}\right| - 1 = 0.5 \Rightarrow$ Fig 8.26 p450 $\boxed{N=5}$

Table 8.3 : $g_1 = 0.6180$ $g_2 = 1.6180$ $g_3 = 2.0$

$g_4 = 1.6180$ $g_5 = 0.6180$ $g_6 = 1.0$



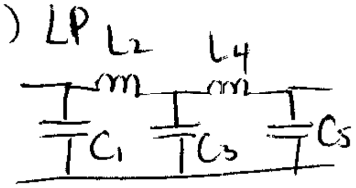
$L_1 = \frac{R_0}{\omega_c g_1} = \frac{50}{(2\pi\, 3e9)(0.6180)} = 4.29\,nH$

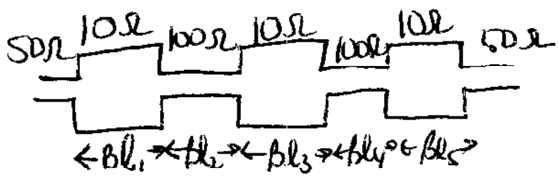
$C_2 = \frac{1}{R_0 \omega_c g_2} = \frac{1}{(50)(2\pi\, 3e9)(1.6180)} = .656\,pF$

$L_3 = \frac{50}{(2\pi 3e9)(2.0)} = 1.33\,nH$

$C_4 = C_2$ $\quad L_5 = L_1$

(b) LP





$Z_\ell = 10\Omega$ $\quad Z_h = 100\Omega$

$\beta\ell_1 = \frac{g_1 Z_\ell}{R_0} = \frac{(.6180)(10)}{50} = .1236$

$\beta\ell_2 = \frac{g_2 Z_0}{Z_h} = (1.6180)\frac{50}{100} = .809$

$\beta\ell_3 = \frac{g_3 Z_\ell}{R_0} = (2.0)\frac{(10)}{50} = 0.4$

$\beta\ell_4 = \beta\ell_2$

$\beta\ell_5 = \beta\ell_1$

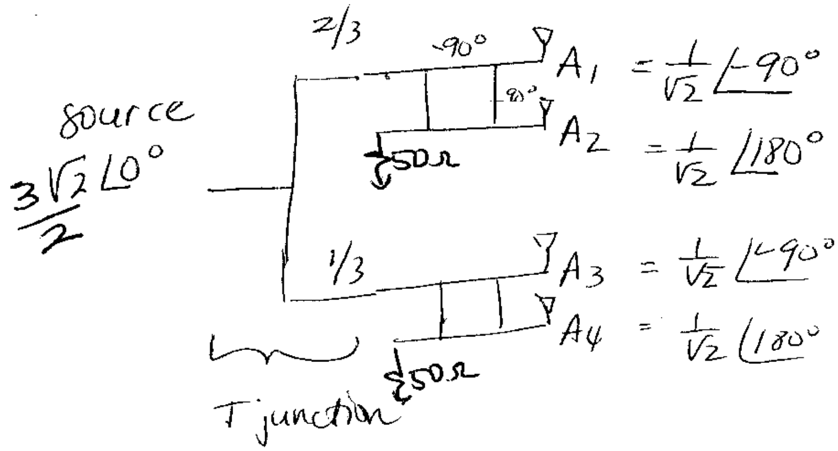
4. Power Dividers

Design a power divider to feed four antennas with the following magnitudes, phases, and characteristic impedances:

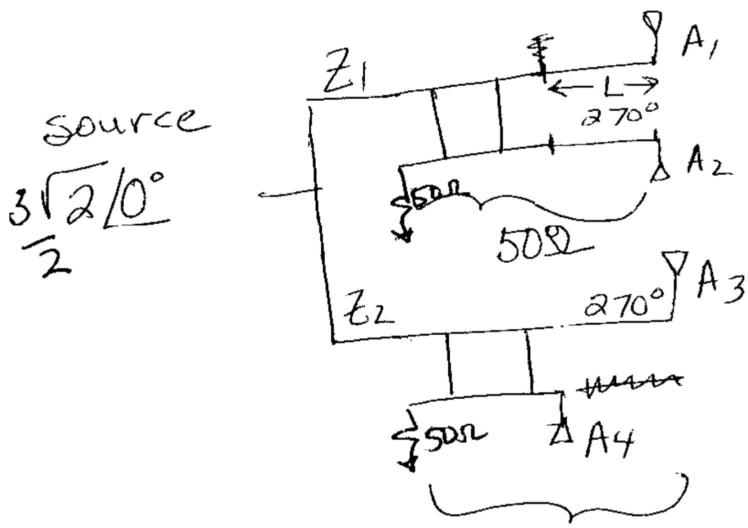
Antenna 1:	1.0 ∠0° volts	50 ohms
Antenna 2:	1.0 ∠-90° volts	50 ohms
Antenna 3:	0.5 ∠0° volts	100 ohms
Antenna 4:	0.5 ∠180° volts	100 ohms

There are many ways to solve this problem...

You may use any combination of the power dividers we have studied, lossless transmission lines, matching networks, etc. Sketch your system and clearly label all parts of the network, the location where each antenna is connected, and what the input voltage should be.



Add length of line 270° to get ∠0° & ∠-90°



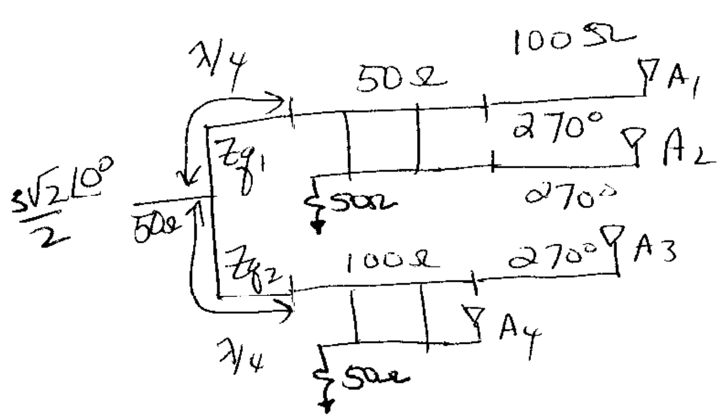
$Z_1 = \frac{3}{2} Z_0 = 75\Omega$

$Z_2 = 3Z_0 = 150\Omega$

Design Qwave TX between Z_1, Z_2 & Qcouplers

$Z_{q1} = \sqrt{Z_1 \, 50\Omega} =$

$Z_{q2} = \sqrt{Z_2 \, 100\Omega} =$



5. **Rectangular Waveguides**
An X-band waveguide has a recommended frequency range of 8.20-12.4 GHz. This WR-90 waveguide has inside dimensions of 2.286x1.016 cm .

(a) What are the first three waveguide modes and their cutoff frequencies?

(b) Why is the recommended frequency range of this waveguide given as 8.20-12.4 GHz?

(c) Assume the wave is propagating in the z-direction. Write an equation for Ex if all of the first three modes are propagating.

(a) $f_c = \frac{c_0}{2\pi\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$

TE_{10} $f_c = \frac{c_0}{2\pi}\sqrt{\left(\frac{\pi}{2.286e\text{-}2}\right)^2} = 6.56\ GHz$

TE_{20} $f_c = \frac{c_0}{2\pi}\sqrt{\left(\frac{2\pi}{2.286e\text{-}2}\right)^2} = 13.12\ GHz$

TE_{01} $f_c = \frac{c_0}{2\pi}\sqrt{\left(\frac{\pi}{1.016e\text{-}2}\right)^2} = 14.76\ GHz$

} First 3 modes

TE/TM_{11} $f_c = \frac{c_0}{2\pi}\sqrt{\left(\frac{\pi}{2.286e\text{-}2}\right)^2 + \left(\frac{\pi}{1.016e\text{-}2}\right)^2} = 16.16\ GHz$

(b) This is slightly higher than the cutoff for first mode, which ensures it will propagate. ~~It is~~ slightly lower than the second mode, ensuring that it will not propagate.

(c) $E_x = \frac{j\omega\mu n\pi}{k_c^2 b} A_{mn} \cos\frac{m\pi x}{a} \sin\frac{n\pi y}{b} e^{-j\beta z}$

$A_{mn} = \frac{j\omega\mu A}{k_c^2}$ $\quad k_c = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$ $\quad \beta = \sqrt{k^2 - k_c^2}$

$k = \omega\sqrt{\mu\varepsilon}$

Sum 3 modes

$E_x = \underbrace{\frac{j\omega\mu(0)\pi}{k_{c_{10}}^2 b}}_{TE_{10}} \to 0 + \underbrace{\frac{j\omega\mu(0)\pi}{k_{c_{20}}^2 b}}_{TE_{20}} \to 0 + \frac{j\omega\mu(1)}{k_{c_{01}}^2 b} \cos 0 \sin\frac{\pi y}{b} e^{-j\beta z}$ ← air

$\uparrow = \pi/b$

6. Circular Waveguide

Acircular waveguide is filled with sea water $\varepsilon_r = 80.0$ and $\sigma = 0.1$ S/m (ignore changes in the electrical properties as a function of frequency). The radius of the waveguide is 3 cm.

(a) Write the equation you will use to find the cutoff frequency of the modes in the waveguide.
(b) What is the first mode of the waveguide and its cutoff frequency?
(c) In the derivation of the modes of a circular waveguide, we were able to eliminate the $Y_n(\,)$ term. Why?
(d) Describe what would happen to a pulse with an "infinite" bandwidth in this waveguide. Tell what will happen to ALL of the power in the pulse (for any power that is not transmitted, tell where it goes). Explain what causes any changes to the shape of the pulse as it transmits through the waveguide.

(a) $f_c = \dfrac{k_c v_p}{2\pi} = \dfrac{p_{nm}\, c_0}{2\pi\ a} =$

(b) TE_{11} (first mode)

$f_c = \dfrac{p'_{11}\, c_0}{2\pi a} = \dfrac{(1.8)\, 3e8\ m/s}{2\pi(.03)} =$

(c) $Y_n(x) = -\infty$ @ $x = 0$ (center of waveguide)

Nonphysical sol^n can be removed

(d) ① Freqs below cutoff will be made into evanescent waves & won't propagate

② Propagating modes each have different v_p, resulting in ~~attenuation~~ dispersion

③ All fields will attenuate, each mode/freq. @ a different rate

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Problem 1	________ / 30		
Problem 2	________ / 30	Total of 1&2	________ / 60
Problem 3	________ / 30		
Problem 4	________ / 30	Total of 3&4	________ / 60
Problem 5	________ / 30		
Problem 6	________ / 30	Total of 5&6	________ / 60
Total	________ / 180		