Name: ______________________

GTID: ______________________

ECE 3065: Electromagnetics
TEST 2 (Spring 2004)

- Please read all instructions before continuing with the test.
- This is a **closed** notes, **closed** book, **closed** friend, **open** mind test. On your desk you should only have writing instruments, a calculator, and a compass+ruler for working Smith chart problems.
- Show all work. (It helps me give partial credit.) Work all problems in the spaces below the problem statement. If you need more room, use the back of the page. DO NOT use or attach extra sheets of paper for work.
- Work intelligently – read through the exam and do the easiest problems first. Save the hard ones for last.
- All necessary mathematical formulas are included either in the problem statements or the last few pages of this test.
- You have 75 minutes to complete this examination. When I announce a "last call" for examination papers, I will leave the room in 5 minutes. The fact that I do not have your examination in my possession will not stop me.
- I will not grade your examination if you fail to 1) put your name and GTID number in the upper left-hand blanks on this page or 2) sign the blank below acknowledging the terms of this test and the honor code policy.
- Have a nice day!

Pledge Signature: ______________________________________

I acknowledge the above terms for taking this examination. I have neither given nor received unauthorized help on this test. I have followed the Georgia Tech honor code in preparing and submitting the test.

1. **Short Answer Section (25 points)**

(a) ________________

True or False: The Helmholtz wave equation that we used to describe free-space propagation is valid for fields *inside* a waveguide.

(b) ________________

True or False: The group velocity of a wave can exceed the speed of light in a vacuum.

(c) ________________

You load a resonator and find that its Q-factor has dropped by $\frac{1}{2}$ from its unloaded value. This resonator has been [*Answer*] coupled.

(d) ________________

In a circular waveguide, the modal field solutions may be written in terms of sinusoids and [*Answer*] functions.

(e) ________________ (1) ________________ (2)

Name two detrimental effects of a multimode waveguide that are not as severe for a single-mode waveguide.

(f) ________________ (1) ________________ (2)

The [*Answer 1*] mode of the [*Answer 2*] waveguide is the only waveguide mode that can truly propagate at the speed of light.

(g) ________________

In a metallic waveguide, the normal electric fields on the surface of the conductor is proportional to the surface [*Answer*].

(h) ________________ (1) ________________ (2) ________________ (3)

List the first 3 resonance frequencies of a 10-cm transmission line with velocity of propagation 2×10^8 m/s, terminated with a short circuit on one end and an open circuit on the other.

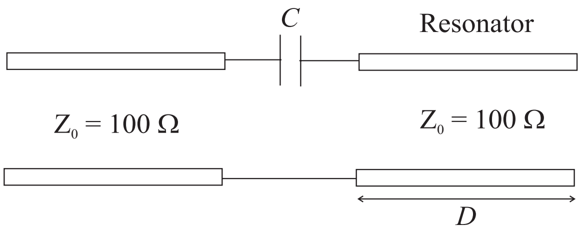
2. **Descriptive Answer Section (20 points)**
Write a **concise** answer to each question in the spaces provided beneath each problem statement. **Note:** Correct answers that are extremely verbose will be penalized.

(a) **Microwave Oven:** You are an engineer for a toy company that decides to make an "Easy-Bake Microwave Oven" – a miniature working microwave that will allow small children to reheat small amounts of leftover food. The kids will surely learn their home-economics skills with this fun new contraption! The tiny microwave chamber will be a cubic region that must support at least one resonant mode at 2.4 GHz. What is the smallest possible chamber size for this toy microwave? (**10 points**)

(b) **Waveguide Loss:** List 5 ways that you can change the construction or excitation of a rectangular, single-mode waveguide that would result in higher loss (dB/m). (**10 points**)

3. **Transmission Line Resonator:**

Your must design a critically-coupled stripline resonator at 5 GHz coupled to a 100Ω line. The velocity of propagation on the stripline is 1.8×10^8 m/s. (**30 points**)



(a) The ohmic loss of the transmission line results in an attenuation of 0.3 dB/m. What is the value of α in Np/m for this line? (**5 points**)

(b) What assumption about the source of loss in the transmission line are you making in your calculation of (a)? (**5 points**)

(c) What length D (in meters) should the stripline resonator be? (**5 points**)

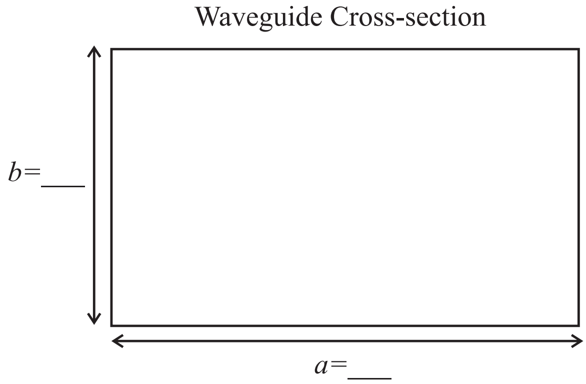
(d) What should the value of the coupling capacitor C be? (**5 points**)

(e) If this whole circuit is used as a filter, what will be its bandwidth in MHz? (**5 points**)

(f) Would the bandwidth of the filter increase or decrease if the resonator were terminated on the right side with a 10kΩ resistor instead of an open circuit? Why? (**5 points**)

4. **Mystery Waveguide:** You are told that a rectangular, metallic, air-filled waveguide has cut-off frequencies of 3 GHz, 6 GHz, and 7.5 GHz for its first three modes. Answer the following questions based on this scenario. (**25 points**)

(a) Calculate the dimensions of this waveguide. Label the dimensions in meters below. (**15 points**)



(b) What is the dominant mode for this waveguide? (**5 points**)

(c) In your diagram for part (a), sketch the E-field distribution for this dominant mode? (**5 points**)

Cheat Sheet

$$\epsilon_0 = 8.85 \times 10^{-12}\ \text{F/m} \qquad \mu_0 = 4\pi \times 10^{-7}\text{H/m}$$

$$\lambda f = v_p \qquad \omega = 2\pi f \qquad \beta = \frac{2\pi}{\lambda} \qquad D = T v_p$$

$$Q = \frac{\text{Total Energy Stored}}{\text{Power Lost}} = \frac{\text{Resonant/Center Frequency}}{\text{Bandwidth}} \qquad \frac{1}{Q_L} = \frac{1}{Q_U} + \frac{1}{Q_{ext}}$$

$$\text{Loss (dB/m)} = 8.7\alpha \qquad \alpha = \alpha_c + \alpha_d$$

Loss in a Rectangular Waveguide

$$(\alpha_c)_{\text{TE}_{10}} = \frac{1}{\eta b}\sqrt{\frac{\pi f \mu_c}{\sigma_c[1-(f_c/f)^2]}}\left[1 + \frac{2b}{a}\left(\frac{f_c}{f}\right)^2\right] \qquad \alpha_d = \frac{\sigma\eta}{2\sqrt{1-(f_c/f)^2}}$$

Unloaded Resonance of a Transmission Line

Open-Open or **Short-Short**: $f_0 = n\frac{\lambda}{2}$ **Open-Short**: $f_0 = \left(n + \frac{1}{2}\right)\frac{\lambda}{2}$

Ring: $f_0 = n\lambda$

Design of a Transmission Line Resonator

$$D = \frac{1}{\beta}[\pi - \tan^{-1}(\sqrt{\alpha D})] \qquad \omega_0 C Z_0 = -\tan(\beta D) \qquad Q_U = \frac{\beta}{2\alpha}$$

$$v_g = \frac{1}{\sqrt{\epsilon\mu}}\sqrt{1-\left(\frac{f_c}{f}\right)^2} \qquad \lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

Circular Waveguide: $(f_c)_{\text{TM}_{01}} = \frac{0.383}{a\sqrt{\epsilon\mu}}$ $\quad (f_c)_{\text{TE}_{11}} = \frac{0.293}{a\sqrt{\epsilon\mu}}$

Planar Waveguide: $(f_c)_m = \frac{m}{2a\sqrt{\mu\epsilon}}$

Rectangular Waveguide: $(f_c)_{mn} = \frac{1}{2\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$

Rectangular Cavity Resonator: $(f_c)_{mnp} = \frac{1}{2\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2}$