Name: ______________________________

GTID: ______________________________

ECE 3065: Electromagnetics

TEST 2 (Spring 2006)

- 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 and a calculator.

- 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.

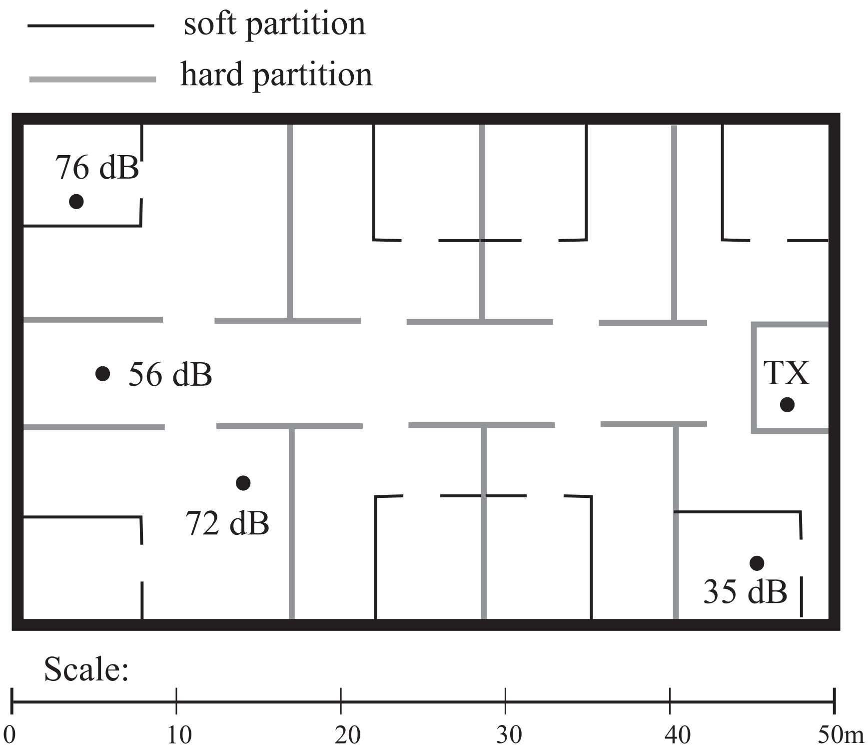
- I will not grade your examination if you fail to 1) put your name and GTID number in the upper left-hand blanks on this page or 2) sign the blank below acknowledging the terms of this test and the honor code policy.

- Have a nice day!

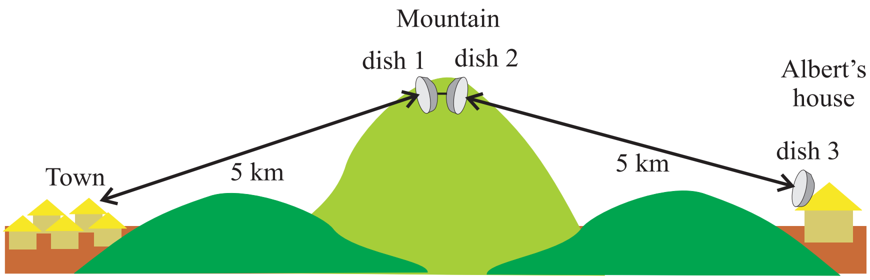
Pledge Signature: ____

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. **Path Loss Modeling:** (**15 points**) Below are 4 path loss measurements (w.r.t. 1m free space) made in a small office building. You are going to use these spot measurements to construct a partition-based model for planning a wireless LAN. Construct a system of equations in matrix form that allow you to calculate partition values for hard (cinderblock walls) partitions and soft (drywall) partitions. You may make rough estimates of distances. Do **not** solve for the optimum parameters – just set the problem up in the form $A\vec{x} = \vec{b}$.



2. **Stealing WiFi:** (**20 points**) Albert lives in a quiet valley in North Georgia where he operates a winery and vineyard. Set apart from civilization, he has no access to cable, DSL, phone lines, or any other wired conduit of internet access. But Albert is a crafty graduate of the Georgia Institute of Technology and devises a clever way to steal WiFi service from the nearby town of Unprotectedlinksville, population 53. This town is 10 kilometers away from Albert, on the other side of a large mountain, and has several unprotected home WiFi servers broadcasting local internet service. His plan is to purchase 3 **identical** dish antennas that operate at 2.45 GHz and arrange them in the following configuration:



With this set-up, a signal will propagate from the town to the first dish in the link, which is pointed toward the town. The received power of this dish is piped directly to another dish which is pointed towards Albert's vineyard. Thus, this pair of dish antennas acts like a passive repeater that does not require any power or maintenance. A third dish is mounted on top of Albert's home, where a minimum value of -95 dBm must be received in order to maintain a wireless internet link on his home computer. Answer the following questions assuming matched and lossless cables. Assume that the antenna gain of the WiFi access point in town is 5 dBi, that the transmit power of this link is 30 dBm, and that both links are essentially free space (no excess loss).

(a) What is the minimum gain in dBi of these antennas to make this system work? (Ignore the effects of small-scale fading.) (**15 points**)

(b) If these are ideal circular dishes with 100% efficiency, what is the minimum radius based on your answer in part (a)? (Hint: Peak dish linear gain is $G = \frac{4\pi A}{\lambda^2}$ where A is the dish area) (**5 points**)

3. **Small-Scale Fading (40 points):** Sugimoto-san is calling his wife on his *keitai denwa* (mobile phone) while riding at 200 km/hr (55.6 m/s) on the *Shinkansen* (Japanese bullet train) through Tokyo. His NTT DoCoMo phone is communicating with an 1800 MHz base station. You may approximate the angular distribution of plane waves arriving at his handset with the uniform azimuth spectrum ($p(\phi) = \frac{P_R}{2\pi}$). Answer the following questions based on this scenario. (Hint: you should not have to do any math to compute shape factors.)

   (a) If the average received power is -90 dBm and the phone requires at least -100 dBm of received power to communicate, what percentage of the time will this radio link be unusable? (**10 points**)

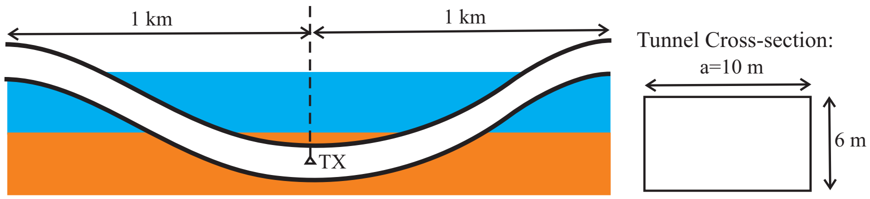
   (b) How many times per second will the instantaneous received power fall below the critical level? (**10 points**)

   (c) If the instantaneous power drops below the critical level, how long will the average fade last? (**10 points**)

   (d) If an engineer wanted to place a second co-polar monopole antenna on the handset to boost link performance, how far should the two antennas be separated in space? (**10 points**)

   (e) Assuming that the mobile handset's radio can select between the two-element diversity antennas of part (d) and can choose the element with the strongest received signal, what percentage of the time will the modified handset experience an unusable radio link? (**Bonus: +5 points**)

4. **Waveguide Propagation (25 points):** A section of the Chesapeake bay-bridge tunnel is 2 kilometers long with a width of 10 meters and a height of 6 meters. In the middle of this tunnel is a small 850 MHz cellular base station that provides coverage for mobile users in the tunnel. This station is low-powered and uses the tunnel like a rectangular waveguide to communicate with motorists. Answer the following questions based on this scenario, which is illustrated below:



(a) Find the highest value for x such that the TE_{x0} mode still propagates through this tunnel. (**10 points**)

(b) For a cell phone user operating at the end the tunnel, what is the dispersion (in nanoseconds) between the power carried by the dominant TE_{10} mode and the TM_{77} mode. You may approximate the tunnel to be a straight (horizontal) two kilometers. (**10 points**)

(c) What assumption are you making about the material properties of the tunnel in this problem? (**5 points**)

Cheat Sheet

$$\epsilon_0 = 8.85 \times 10^{-12}\ \text{F/m} \qquad \mu_0 = 4\pi \times 10^{-7}\text{H/m} \qquad c = 3.0 \times 10^{8}\text{m/s}$$

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

Link Budget Formulas

$$\mathrm{P}_R = \mathrm{P}_T + G_T + G_R \quad \underbrace{-20\log_{10}(4\pi/\lambda)}_{-\text{Reference Path Loss}} \quad \overbrace{-20\log_{10}(r) - \text{Extra Loss}}^{-\text{Path Loss wrt 1m FS}}$$

Partition Loss Model

$$\text{Path Loss w.r.t. 1m FS} = 20\log_{10} r + aX_a + bX_b + \cdots$$

Waveguide Formulas

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

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

Small-Scale Fading Formulas

$$\text{Envelope: } f_r(r) = \frac{2r}{P_T}\exp\left(-\frac{r^2}{P_T}\right)\mathrm{u}(r) \qquad \text{Power: } f_P(p) = \frac{1}{P_T}\exp\left(-\frac{p}{P_T}\right)\mathrm{u}(p)$$

$$AFD = \frac{\lambda\left[\exp(\rho) - 1\right]}{\sqrt{2\pi}v\rho\Lambda\sqrt{1 + \gamma\cos\left[2(\phi - \phi_{\text{max}})\right]}}\ \text{seconds} \qquad \rho = \frac{P_{\text{thresh}}}{P_R} = \frac{R^2_{\text{thresh}}}{R^2_{\text{RMS}}}$$

$$LCR = \frac{\sqrt{2\pi}\Lambda\rho v}{\lambda}\sqrt{1 + \gamma\cos\left[2(\phi - \phi_{\text{max}})\right]}\exp\left(-\rho^2\right)\ \text{crossings/seconds}$$

$$\text{De-correlation Length} = \frac{\lambda}{\Lambda\sqrt{23(1 + \gamma\cos[2(\phi - \phi_{\text{max}})])}}$$

$$F_n = \int_0^{2\pi} P(\phi) exp(jn\phi)\, d\phi$$

$$\text{Angular Spread: } \Lambda = \sqrt{1 - \frac{|F_1|^2}{|F_0|^2}} \qquad 0 \le \Lambda \le 1$$

$$\text{Angular Constriction: } \gamma = \frac{|F_2F_0 - F_1^2|}{|F_0|^2 - |F_1|^2} \qquad 0 \le \gamma \le 1$$

$$\text{Direction of Max. Fading: } \phi_{\text{max}} = \frac{1}{2}\arg\{F_2F_0 - F_1^2\}$$