Name: ______________________

GTID: ______________________

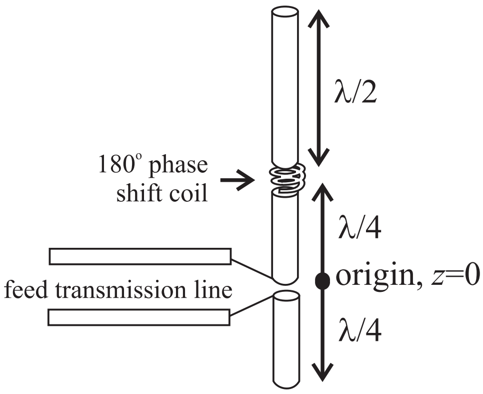
ECE 4370: Antenna Engineering
TEST 1 (Fall 2011)

- 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. **No internet-enabled devices.**
- Show all work. (It helps me to 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 page of this test.
- You have 80 minutes to complete this examination. When the proctor announces a "last call" for examination papers, he will leave the room in 5 minutes. The fact that the proctor does not have your examination in hand will not stop him.
- 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. **Wire Antenna:** Answer the following questions based on this offset-fed, full-wavelength wire dipole antenna. (**25 points**)



(a) Given an input current I_0, estimate and express mathematically the spatial current distribution of $I(z)$ that you would use to solve for radiation from this antenna. (**15 points**)

(b) Would you expect this antenna's θ_{HPBW} to be smaller or larger than a half-wave dipole? Why? (**5 points**)

(c) Why is this type of antenna superior to a center-fed full-wave dipole? (**5 points**)

2. **Antenna Pattern:** The directivity of an antenna pattern is given by the following equation:

$$D(\phi, \theta) = D_o \sin^3 \theta$$

Answer the following questions based on this scenario. (**30 points**)

(a) In what elevation direction(s) does this antenna experience peak gain? (**5 points**)

(b) In what elevation direction(s) does this antenna experience nulls? (**5 points**)

(c) What should the value of the constant D_o be in order to be a valid directivity? (**10 points**)

(d) What is the half-power beamwidth of this antenna? (**10 points**)

3. **Small Scale Fading:** A receiver antenna operating in a high-multipath environment must maintain a received signal strength of -90 dBm in order to conduct reliable communications. How much *average* local area power must be received in order to experience link reliability of at least 95% (less than 5% outage probability)? (**15 points**)

4. **Voltages on Antennas:** An RFID integrated manufacturer reports that their chip has a sensitivity of -20 dBm (i.e. their chip will power up if it receives at least -20 dBm of power from an antenna). This specification assumes an ideal conjugate-matched antenna impedance connected to the RFIC's $100 - j300\Omega$ input impedance. What is the magnitude of the voltage across the terminals of the RFIC/antenna junction under this minimal excitation condition? (**15 points**)

5. **Link Budget:** A Bluetooth earpiece operating at 2.4 GHz transmits line-of-sight to a smart phone in the shirt pocket of a user. If the transmit power is 5 mW, the transmit and receive antennas are essentially isotropic, and the separation distance is at most 50cm, how much power is received by the smart phone from the earpiece? Assume free space and report your answer in dBm. (**15 points**)

Cheat Sheet

$\lambda f = c \qquad c = 3 \times 10^8 \text{ m/s} \qquad \mu_o = 4\pi \times 10^{-7} \text{ H/m} \qquad \epsilon_o = 8.85 \times 10^{-12} \text{ F/m}$

$$P_R = P_T + G_T + G_R - 20\log_{10}\left(\frac{4\pi}{\lambda}\right) - 20\log_{10}(r) \qquad \text{Logarithmic Form}$$

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi r)^2} \qquad \text{Linear Form}$$

$$G = \eta_A \frac{4\pi}{\lambda^2} A_e \qquad G \approx \frac{30,000}{\theta_{\text{HPBW}}\phi_{\text{HPBW}}} \text{ (angles in degrees)}$$

Half-wave dipole current: $\tilde{I}_z(z) = I\cos(kz') \qquad \text{for } -\frac{\lambda}{4} \leq z \leq \frac{\lambda}{4}$

$$\lambda f = v_p \qquad \omega = 2\pi f \qquad k = \frac{2\pi}{\lambda}$$

Exponential Power PDF (Rayleigh envelope fading): $f_P(p) = \frac{1}{P_{av}} \exp(-p/P_{av})\, \mathrm{u}(p)$

$$\text{Directivity} = \frac{\text{Radiated Power Density in } (\phi, \theta)}{\text{Average Isotropically Radiated Power Density}}$$

$$D(\phi,\theta) = \eta\, G(\phi,\theta) \qquad \int_0^{\pi} d\theta \int_0^{2\pi} d\phi\, \sin\theta\, D(\phi,\theta) = 4\pi \,\text{steradians}$$

$$\int \sin^4(ax)\, dx = \frac{3x}{8} + \frac{\sin(2ax)}{4a} + \frac{\sin(4ax)}{32a} + C$$

load voltage: $V_L = \frac{2|\tilde{Z}_L|}{|\tilde{Z}_L + \tilde{Z}_A|}\sqrt{2P_R R_A}$

$$\tilde{A}_z(r,\phi,\theta) \quad = \quad \frac{\mu}{4\pi r}\exp(-jkr)\int_{-\infty}^{+\infty} \tilde{I}_z(z')\exp(+jkz'\cos\theta)\; dz'$$

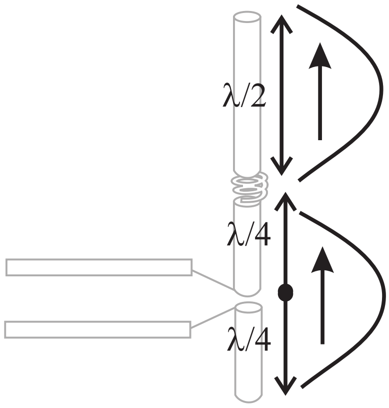
Radiated Power Density (W/m^2): $\quad = \quad \frac{k^2\eta\sin^2\theta}{2\mu^2}|\tilde{A}_z|^2$

ECE 4370: Antenna Engineering
Solutions to TEST 1 (Fall 2011)

1. **Wire Antenna:**

   (a) The current follows this distribution:

   $$I(z) = I_0 |\cos(kz)| \text{ for } -\frac{\lambda}{4} \leq z \leq \frac{3\lambda}{4}$$

   (b) Smaller, since HPBW decreases as the size of an antenna increases.

   (c) When fed from the center, the full-wave dipole has infinite input impedance; impossible to couple power into the device.

2. **Antenna Pattern:**

   (a) $\theta = 90°$

   (b) $\theta = 0°, 180°$

   (c) Condition must hold:

   $$\int_0^\pi d\theta \int_0^{2\pi} d\phi \, \sin\theta \, D(\phi, \theta) = 4\pi \,\text{steradians}$$

   $$\int_0^\pi d\theta \int_0^{2\pi} d\phi \, D_0 \, \sin^4\theta = \frac{3\pi^2 D_0}{4} = 4\pi \,\text{steradians}$$

   This implies $D_0 = \frac{16}{3\pi}$.

   (d) $\theta_{hp} = 52.5°$, $127.5°$, $\theta_{hpbw} = 74.9°$

3. **Small Scale Fading:** -77.1 dBm

4. **Voltages on Antennas:** 141 mV

5. **Link Budget:** -27.0 dBm