Name: ______________________________

GTID: ______________________________

ECE 6390: Satellite Communications and Navigation Systems
TEST 1 (Fall 2009)

- 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 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. **Short Answer Section** (**10 points**)

   (a) ________________
   A *Answer* is the only feasible power source for long-lasting, deep space missions.

   (b) ________________
   True or False: an antenna's gain pattern is always less than its directivity.

   (c) ________________
   Which of the 4 medium conditions used to derive the Helmholtz wave equation is most clearly violated when we introduce a radiating source?

   (d) ________________
   A *Answer* is an RF device that relays a radio signal without any regenerative repeating.

   (e) ________________
   A common noble-gas propellant for ion drives is *Answer*.

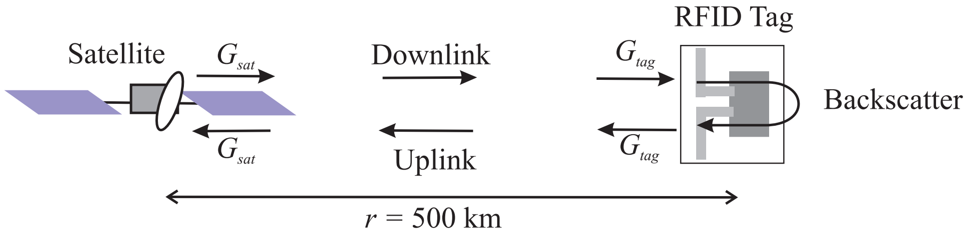
2. **Polar Orbit:** You are to design a polar orbit (90-degree inclination) for a satellite with apogee radius of 30,000 km occurring directly above the North pole. Answer the following questions based on this scenario. (**30 points**)

   (a) Given that the orbit must clear the earth's radius + 500 km at perigee, what is the shortest possible period for this orbit? (**10 points**)

   (b) Given the conditions in part (a), what is the maximum eccentricity for this orbit? (**10 points**)

   (c) When the satellite is at apogee, what is the lowest possible latitude an earth station could have and still theoretically receive a radio transmission? (**10 points**)

3. **Satellite Conspiracy Theory:** An engineer files a complaint with the FCC claiming that it may be possible to interrogate RFID tags from an LEO satellite (500 km overhead), violating the privacy of anyone who happens to be wearing a Wal-Mart shirt with an inventory tag still attached or driving their car with an automatic toll-paying tag on the windshield. There are two types of proposed RFID tags for inventory control, tollway payments, and other identification purposes. The first type is a *battery-assisted* tag that uses a small, internal battery to drive its modulating circuitry; all power backscattered by this type of tag is due to the partial reflection of an incident wave. Highway toll tags are a common example of this type of tag. The second type is a *purely passive* tag that actually powers its modulating circuitry from the incident radio wave. Inventory tags are a common example of purely passive RFID tags. Both types of RFID tags operate in the 915 MHz ISM band and have antenna gains of approximately 0 dBi. Assume that a 915 MHz satellite interrogator can transmit and receive with 10 dBi of antenna gain. Based on this scenario, answer the following questions. (**30 points**)



(a) For a passive tag, at least 20μW must be received by the tag from the satellite interrogator in order for the tag to power-up. How much transmit power must be sent by the interrogating satellite to make this happen? Based on your knowledge of spacecraft power systems, does this seem reasonable? (**15 points**)

(b) At least -100 dBm of back-scattered power must be received by the satellite in order to read *any* RFID tag's data. How much transmit power must be sent by the interrogating satellite to make this happen? Does this seem reasonable? Hint: In a backscatter radio link, power is transferred from satellite to RFID tag for the first leg of the link; the received power then becomes the transmit power for the tag (assuming no internal losses) and is send back to the satellite on a second link. (**15 points**)

4. **Plane Waves:** A UHF satellite is transmitting a circularly polarized wave to a boat on the surface of a calm lake. In the immediate area around the boat, the radio wave behaves like a plane wave. The equation for its electric field is

$$\tilde{\vec{\mathrm{E}}}(\vec{\mathrm{r}}) = 100\,(\hat{\mathrm{x}} + \hat{\mathrm{z}})\exp(-j60[\hat{\mathrm{x}} - \hat{\mathrm{z}}] \cdot \vec{\mathrm{r}})\,\mu\mathrm{V/m}$$

where the direction $\hat{\mathrm{z}}$ is the zenith (directly overhead) and $\hat{\mathrm{y}}$ corresponds to $0°$ azimuth (due north). Answer the following questions accordingly. (**30 points**)

(a) The boat on the surface of the water is measuring the angles-of-arrival for this radio wave (and, hence, the position in the sky of the satellite). What is the azimuth and elevation angles-of-arrival for this radio wave? (**10 points**)

(b) What is the corresponding magnetic field for the incident plane wave? (**10 points**)

(c) What is the frequency for this radio wave? (**5 points**)

(d) Estimate the amount of power that a dish antenna with 2 square-meters of aperture could receive from this plane wave if pointed properly. (**5 points**)

Cheat Sheet

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

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

$$\ddot{r} = r\dot{\theta}^2 - \frac{GM_P}{r^2} \qquad \ddot{\theta} = -\frac{2\dot{r}\dot{\theta}}{r}$$

$$T^2 = \frac{4\pi^2 a^3}{\mu} \qquad \mu = GM_p \qquad G = 6.672 \times 10^{-11}\ \text{Nm}^2/\text{kg}^2 \qquad M_E = 5.974 \times 10^{24}\ \text{kg}$$

$$V = \sqrt{\frac{\mu}{R}} \qquad b = a\sqrt{1-e^2} \qquad \text{perigee} = (1-e)a \qquad \text{apogee} = (1+e)a$$

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

Earth radius: $R_E = 6380$ km

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

Phasor Transform: $A\cos(2\pi f t + \phi) \longrightarrow A\exp(j\phi)$

Reverse Transform: $x(t) = \longrightarrow \text{Real}\left\{\tilde{x}\exp(j2\pi f t)\right\}$

$$\begin{aligned} \tilde{\vec{\mathsf{E}}}(\vec{\mathrm{r}}) &= E_0 \hat{\mathrm{e}} \exp(j[\phi - k\hat{\mathrm{k}} \cdot \vec{\mathrm{r}}]) \\ \tilde{\vec{\mathsf{H}}}(\vec{\mathrm{r}}) &= H_0 \hat{\mathrm{h}} \exp(j[\phi - k\hat{\mathrm{k}} \cdot \vec{\mathrm{r}}]) \end{aligned}$$

$$H_0 = \frac{E_0}{\eta} \qquad \eta = \sqrt{\frac{\mu}{\epsilon}} \qquad v_p = \frac{1}{\sqrt{\mu\epsilon}} \qquad \hat{\mathrm{e}} \times \hat{\mathrm{h}}^* = \hat{\mathrm{k}} \qquad \hat{\mathrm{h}} = (\hat{\mathrm{k}} \times \hat{\mathrm{e}})^*$$

$$-\hat{\mathrm{k}} = \cos\varphi\cos\theta\,\hat{\mathrm{x}} + \sin\varphi\cos\theta\,\hat{\mathrm{y}} + \sin\theta\,\hat{\mathrm{z}}$$

$$\theta = \tan^{-1}\frac{-k_z}{\sqrt{k_x^2 + k_y^2}} \qquad \varphi = \tan^{-1}\frac{k_y}{k_x} \quad (\text{add } \pi \text{ if } k_x > 0)$$

$$\text{Cross Product: } \vec{\mathrm{a}} \times \vec{\mathrm{b}} = \det\begin{vmatrix} \hat{\mathrm{x}} & \hat{\mathrm{y}} & \hat{\mathrm{z}} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$