ECE 123 FINAL EXAMINATION Spring 2006

This examination is **closed book**. You may use a calculator but no reference materials.
Show your work clearly and carefully, **no credit** will be given for unsupported answers.

Given formulas and constants:
Boltzman's constant $k = 1.38 \times 10^{-23}$ w/K/Hz.
If φ is $N(0, \sigma^2)$ then $\langle\exp(j\varphi)\rangle = \exp(-\sigma^2/2)$.
The far field of an aperture distribution is $E(\sin\theta_X/\lambda, \sin\theta_Y/\lambda) = (\exp(-jkr)/\lambda r)\, FT\{E(x,y)\}$.
Effective Area = $G_{MAX} * \lambda^2/4\pi$.
$FT(\prod(x)) = \mathrm{sinc}(s) = \sin(\pi s)/\pi s$.
The magnetic field of a small electric dipole oriented in the z direction is $H_\varphi(r) = j\, k\, m \sin\theta \exp(-jkr)/4\pi r$.
The reciprocity theorem is:

$$\int_V [\vec{J}_A \cdot \vec{E}_B - \vec{J}_B \cdot \vec{E}_A] dV = \int_S [\vec{E}_A \times \vec{H}_B - \vec{E}_B \times \vec{H}_A] \cdot d\vec{S}$$

Stokes' theorem is:

$$\oint \vec{A} \cdot d\vec{l} = \iint \nabla \times \vec{A} \cdot d\vec{S}$$

Questions:

1 . Consider the design of a satellite radio system. You are preparing a bid on the power amplifier and the antenna, so you need a rough estimate of the total radiated power and the antenna size. The system constraints follow.

The satellite must be in a synchronous orbit (radius = 42000 km, the Earth's radius is 6400 km). The receivers are mobile and so the mobile antennas must have a broad beam and low gain because they cannot be pointed at the satellite. The satellite antenna must illuminate the whole continental USA, (about 8×10^6 km^2 at an average latitude of 45^0N). The mobile antenna gain will be 3.0 and the mobile noise temperature will be 500^0K. The frequency is 2.4 GHz. The channel bandwidth is 250 KHz, and the total bandwidth is 12.5 MHz. The user will tune only one channel at a time. A signal to noise ratio of 10 is required for adequate performance. The satellite will transmit on all 50 channels simultaneously.

(a) Find the total transmitted power needed.
(b) Find the beam solid angle of the transmitting antenna.
(c) Find the area of the transmitting antenna.
(d) What polarization will you need? Why?

2 . You are designing a 2.4 GHz cell-phone system to serve Catalina Island from Los Angeles. The island subtends 30^0 at the headland on the Palos Verde peninsula where you will locate the base-station. You need more gain than usual to compensate for the 50 km distance to the island, so you decide to multi-beam the base-station array. You wish to have 10 beams covering the island in azimuth. The beams will overlap at the –4 dB level. The maximum elevation of the island, as viewed from the base-station, is only 2^0 so you can use array elements which have only 2^0 beam-width in elevation. The phased array elements are slotted waveguide arrays but they are phased for a fixed broadside beams so their design is straightforward. The waveguide mode is a fast wave with phase velocity = 1.5 c. The electric field polarization must be vertical.

(a) Find the total height of each subarray (element) (m).
(b) Find the slot spacing (m) in the subarrays.
(c) Should the slots be vertical or horizontal?
(d) Find the total width of the phased array (m).
(e) Find the gain of the whole array for the broadside beam.
(f) Find the number of phased elements.

3 (a) Use the given formula for the far-field of a large aperture antenna to derive a formula for the aperture efficiency of the antenna when the electric field distribution over its aperture $E_{AP}(x,y)$, is known.

(b) Use your result to find the aperture efficiency of a lens-corrected horn excited with TE_{10} mode in rectangular waveguide. Here $E_{AP}(x,y) = \cos(\pi x/a)\prod(x/a)\prod(y/b)$, where $\prod(x)$ is the unit rectangle.

(c) Suppose you were to adjust the horn width-to-height ratio a/b until the width of the pattern was the same in both the x-plane and the y-plane. Which would be larger a or b? Why?

4. Use the reciprocity theorem and Stokes' theorem to find the far electric field of a small current loop. Explain your procedure carefully.

5. (a) Derive a formula for the power received by a radar scattered by a target with cross-sectional area σ which re-radiates isotropically. Write the expression in terms of the power transmitted P_T, the area of the radar antenna A_T, the distance and the wavelength.

(b) Suppose the target is a corner reflector of cross-sectional area σ. Revise the formula to calculate the received power.