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UNIVERSITY OF UTAH
ELECTRICAL & COMPUTER ENGINEERING DEPARTMENT

ANTENNA THEORY AND DESIGN

ECE 5324/6324

MIDTERM I

February 13, 2009

1. (25 points)

pts

0.375

7 a. Calculate the directivity D of a $3\lambda/8$ **monopole** antenna ($L/2 = \cancel{0.625}\lambda$) that is mounted vertically above a horizontal perfectly conducting ground plane. For this antenna used at a frequency of 1635 MHz, calculate the following

4 b. The antenna resistance R_a.

7 c. The maximum effective aperture A_{em} that can be derived from the directivity.

7 d. The open-circuit voltage developed across the antenna terminals for an incoming signal of power density $S_{inc} = 1\ \mu W/m^2$

Midterm I – Solutions

Feb. 13, 2009

1\. b. From p.7 of Class Notes

$$R_a\Big|_{L/2=0.37\lambda} = 171.48\,\Omega \; ; \; R_a\Big|_{L/2=0.38\lambda} = 201.86\,\Omega$$

$$R_a\Big|_{L/2=0.375\lambda} = \frac{171.48+201.86}{2} = 186.67\,\Omega$$

a. From Eq. (4) on p. 6 of Class Notes

$$D = \frac{120}{R_a}\,\frac{\overbrace{F^2(\theta)}^{2.9142}}{\underbrace{\sin^2(\pi L/\lambda)}_{0.5}}\Bigg|_{\theta=90^\circ} = \boxed{3.747}$$

$L/\lambda = \frac{3}{8}\times 2 = 0.75$

From Eq. (1) on p. 6 of Class Notes

$$F(\theta) = \frac{\cos(\pi L/\lambda\,\cos\theta) - \cos(\pi L/\lambda)}{\sin\theta}\Bigg|_{\theta=90^\circ} = \frac{1-\cos(0.75\pi)}{1} = 1.7071$$

c. $D = \dfrac{4\pi A_{em}}{\lambda^2} \Rightarrow A_{em} = \dfrac{\lambda^2}{4\pi} D$

$\lambda = \dfrac{30}{1.635} = 18.348$ cm

$\boxed{A_{em} = 100\ \text{cm}^2} \Rightarrow 0.01\ \text{m}^2$

d. Following a procedure similar to Example 6 on p.22 of Class Notes

$$V_{oc} = \sqrt{8 R_a S_{inc} A_{em}} = \sqrt{8\times 186.67\times 10^{-6}\times 10^{-2}} = \boxed{3.86\,\text{mV}}$$

$S_{inc} = 1\ \dfrac{\mu W}{m^2}$

2. (25 points)

A 100-turn air-core circular loop of diameter 0.3 m is to be used as an antenna at 5 MHz. For this antenna, calculate:

pts

5 a. The radiation resistance.

5 b. The directivity.

5 c. The ohmic resistance if it is wound with an AWG12 copper wire (from Appendix B, p. 623, of the Text, diameter of AWG12 wire = 2.053 mm).

5 d. The radiation efficiency $e_r = \frac{R_r}{R_r + R_{ohmic}}$.

5 e. The inductance of the loop antenna. Note that $\mu_{eff} = 1.0$ for an air-core antenna.

2. From Table 2 on p. 18 of Class Notes (also Eq. 2-58 of Text 2)

a. $R_r = 31{,}200 \left(\frac{\cancel{100}\,\pi b^2}{\lambda^2}\right)^2 = 31{,}200 \left(\frac{\cancel{100} \times \pi \times 0.15^2}{\cancel{4}\; 36\cancel{00}}\right)$

$\lambda = 60$ m $\qquad = 0.12\ \Omega$

$\lambda^2 = 3600$

radius $b = 0.3/2 = 0.15$ m

From Eq. 10 on p. 17 of Class Notes (also Eq. 2-63 of the Text 4)

c. $R_{ohmic} = \frac{N b R_s}{a} = 100 \times (0.3/2) \times \frac{0.589 \times \cancel{10^{-3}}}{1.0265 \times \cancel{10^{-3}}}$

$= 8.61\ \Omega$

$a = \frac{2.053}{2} = 1.0265$ mm $\rightarrow 1.0265 \times 10^{-3}$ m

$R_s = 1.988 \times \sqrt{\frac{5}{\cancel{\sigma_{cu}}\ 5.7 \times 10^{7}}} = 0.589 \times 10^{-3}\ \Omega/\square$

d. $e_r = \frac{R_r}{R_r + R_{ohmic}} = \frac{0.12}{8.73} = \boxed{0.014}$ or 1.4%

b. from p. 18 of Class Notes

$D = 1.5$ for directivity of small diameter loop antennas

e. From Eq. (11) on p. 17 of Class Notes

$L = N^2 b \cancel{\mu_{eff}}^{\,1} \cancel{\mu_o}\, 4\pi \times 10^{-7} \left[\ln\left(\frac{8b}{a}\right) - 1.75\right]$

$= 10^4 \times 0.15 \times 4\pi \times 10^{-7} \left[\cancel{\ln\left(\frac{1.2}{1.0265 \times 10^{-3}}\right)}^{\,7.064} - 1.75\right]$

$= 1.0 \times 10^{-2}$ H $\rightarrow 0.01$ H

$\Rightarrow 10$ mH

3. (25 points)

pts

9 a. For a communication link using a satellite at 12 GHz, the gains of the transmitting and receiving antennas are 52 dBi and 8 dBi, respectively. For a transmitted power of 100W, calculate the maximum power that may be received by the receiving antenna at a distance of 40,000 km from the transmitting satellite.

6 b. Calculate the effective areas of both the receiving and transmitting antennas in the direction of the communication link in m^2.

10 c. Calculate the **rms** value of the open-circuit voltage developed across the terminals of the receiving antenna for which the antenna impedance is given to be $90 - j130\Omega$. Note that this would be the signal available for amplification by a "high" input impedance amplifier of the receiver.

3. a. This problem is similar to Example 5 on pp. 21/22 of Class Notes (also similar to Problem of the homework)

From Eq. 2-99 of the Text

$$P_r(\text{dBm}) = 56 + 52 + 8 - \overbrace{20\log(\cancel{40{,}000})}^{92.04}$$

$$- \underbrace{\boxed{20\log \cancel{f(\text{MHz})}\,(12000)}}_{81.58} - 32.44$$

$$= 110 - 92.04 - 81.58 - 32.44$$

$$= -96.06 \text{ dBm} \Rightarrow -100 + 3.94$$

$$P_r\Big|_{mW} = 2.477 \times 10^{-10} \Rightarrow 2.477 \times 10^{-13}\ W$$

b. $$A_{e,t} = \frac{\lambda^2}{4\pi} \times 10^{5.2} = 0.788 \times 10^{5}\ \text{cm}^2 = 7.88\ \text{m}^2$$

$$A_{e,r} = \frac{\lambda^2}{4\pi} \times 10^{0.8} = 3.138\ \text{cm}^2 \Rightarrow 3.138 \times 10^{-4}\ \text{m}^2$$

c. $$V_{oc}\Big|_{peak} = \sqrt{8 R_A S_{inc} A_{e,r}} = \sqrt{8 R_A P_r} = \sqrt{8 \times 90 \times 2.477 \times 10^{-13}}$$

$$= 13.35\ \mu V$$

From Eq. 2-88 of Text

$$P_r = S_{inc} A_{e,r} \Rightarrow S_{inc} = \frac{2.477 \times \cancel{10^{-13}}\,10^{-9}}{3.138 \times \cancel{10^{-4}}}$$

$$= 0.79 \times 10^{-9}\ W/m^2$$

$$V_{oc}\Big|_{rms} = \frac{13.35}{\sqrt{2}} = 13.35 \times 0.707 = 9.44\ \mu V$$

ECE 5324/6324

Name ____

Score:

Problem 1	_________	of a possible 25 points
Problem 2	_________	of a possible 25 points
Problem 3	_________	of a possible 25 points
Total	_________	of a possible 75 points