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EE162A Midterm

Spring 2018

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Problem #1 (34 points). A dipole antenna and a circular loop antenna are both designed to operate at 1MHz. Each antenna has a maximum dimension of 1 meter and is made of 4mm diameter copper wire.

(a) What are the directivities of both antennas? +6

(b) Compute the impedance of both antennas. +6

(c) Find the radiation efficiency of both antennas. +4

(d) If both antennas are radiating the same amount of power of 100Watt, find the strength of the maximum electric field at 10 meter away for both antennas and compare them. +6

(e) Redo the loop antenna case for (b)-(d) when the loop is now made of 10 turns. +6

1a) $D_{dipole} = 1.5 = 1.76\,dB$

$D_{loop} = 1.5 = 1.76\,dB$

↑ dual of dipole

b) $Z = R + jX$ $\sigma_{copper} = 5.8\times10^{7}$

Dipole: $R_s = \sqrt{\frac{\omega\mu}{2\sigma}}$ $a = 2mm$

$= \sqrt{\frac{2\pi(1MHz)(4\pi\times10^{-7})}{2(5.8\times10^{7})}}$

$= 2.61\times10^{-4}$

$R_{loss} = \frac{R_s}{2\pi a} l$

$= \frac{2.61\times10^{-4}}{2\pi(2\times10^{-3})}$

$= 0.021$

$R_r = 80\pi^2\left(\frac{l}{\lambda}\right)^2$ $\lambda = 300m$

$= 8.77\times10^{-3}$

$X = -\frac{120}{\pi l/\lambda}\left(\ln\frac{l}{2a} - 1\right)$

$= -51812$

$Z_{dipole} = 0.03 - j51812\ \Omega$

$Z = R + j\omega L$

Loop: $R_s = 2.61\times10^{-4}$

$2\pi b$ = circumference of loop

$R_{loss} = \frac{R_s}{2\pi a}(2\pi b)$

diameter = 1 m = 2b

$= \frac{2.61\times10^{-4}}{2\pi(2\times10^{-3})}(2\pi(0.5))$

$= 0.065$

$R_r = 31200\left(\frac{S}{\lambda^2}\right)^2$ $S = \pi b^2$

$= 31200\left(\frac{\pi(0.5)^2}{300^2}\right)^2$

$= 2.38\times10^{-6}$

$L = \mu b\left(\ln\frac{8b}{a} - 2\right)$

$= 4\pi\times10^{-7}(0.5)\left(\ln\frac{8(0.5)}{2\times10^{-3}} - 2\right)$

$= 3.52\times10^{-6}$

$Z_{loop} = 0.065 + j(2\pi(1\times10^{6}))(3.52\times10^{-6})$

$= 0.065 + j22.12\ \Omega$

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c) $e_r = \frac{R_r}{R_r + R_{loss}}$

Dipole : $e_r = \frac{8.77\times10^{-3}}{8.77\times10^{-3} + 0.021}$

$= \boxed{29.5\%}$ 24%

Loop: $e_r = \frac{2.35\times10^{-6}}{2.35\times10^{-6} + 0.065}$

$= \boxed{3.66\times10^{-5}}$

d) P=100W r=10m

$r_{ff} = \frac{2D^2}{\lambda}$

$= 0.015 \ll r$

$\Rightarrow$ far field (same |E| for dipole & loop)

$S = \frac{|E|^2}{2\eta_0}$ $\eta_0 = 120\pi$

$S = \frac{P}{4\pi r^2} D$

$= \frac{100}{4\pi(10)^2}(1.5)$

$= 0.12$

$\boxed{|E| = 9.49\ V/m}$ ← same for dipole & loop because far field

e) N=10

$R_{loss} = \frac{R_s}{2\pi a}(2\pi b) N^2$

$= 6.5$

$R_r = 31200\left(\frac{NS}{\lambda^2}\right)^2$

$= 2.38\times10^{-4}$

$L = \mu b\left(\ln\frac{8b}{a} - 2\right) N^2$

$= 7.52\times10^{-4}$

$\boxed{Z = 6.5 + j\,2212\ \Omega}$

$e_r = \frac{R_r}{R_r + R_{loss}}$

$= \frac{2.38\times10^{-4}}{2.38\times10^{-4} + 6.5}$

$= \boxed{3.66\times10^{-5}}$

$S = \frac{P}{4\pi r^2} D$

$= 0.12$

$\Rightarrow \boxed{|E| = 9.49\ V/m}$

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Problem #2 (33 points) A 20Km long communication link is setup with two aperture antennas with all components properly matched. If Pt=1W and f=4GHz and the transmitted antenna has a gain of 20dB. Determine

(a) What is the power density at the receiving antenna assuming proper alignment? +8

(b) If the noise temperature of the receiver is 500K and the receiver bandwidth is 20MHz, in order to achieve a signal to noise ratio of 30dB, how much gain is required for the receiving antenna? +8

(c) What is the minimum area required for the receiving antenna? +8

(d) If frequency is changed to 12GHz, with everything else staying the same including the area of the receiving antenna, how far can this communication link be constructed now? +6

a) $f = 4\,GHz \Rightarrow \lambda = 0.075\ m$

$S = \frac{P_t}{4\pi R^2} G_t \qquad G_t = 20\,dB \Rightarrow G_t = 100$

$= \frac{1}{4\pi (20k)^2} (100)$

$= 1.99 \times 10^{-8}$

$P_r = S A_{er}$

$\boxed{\frac{P_r}{A_{er}} = 1.99 \times 10^{-8}}$

b) $T = 500K \qquad B = 20\,MHz \qquad SNR = 30\,dB \Rightarrow SNR = 10^3$

$P_n = kTB$

$= 1.38 \times 10^{-23} (500)(20\ MHz)$

$= 1.38 \times 10^{-13}$

$SNR = \frac{P_r}{P_n}$

$10^3 = \frac{P_r}{1.38 \times 10^{-13}}$

$P_r = 1.38 \times 10^{-10}$

$P_r(dB_m) = P_t(dB_m) + G_t(dB) + G_r(dB) - 20\log R(km) - 20\log f(MHz) - 32.44$

$G_r(dB) = 10\log(1.38 \times 10^{-7}) - 10\log 1000 - 20 + 20\log 20 + 20\log 4000 + 32.44$

$= \boxed{11.9\ dB}$

$= 15.5$

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c) $A_{er} = \frac{\lambda^2}{4\pi} G_r$

$= \boxed{6.93 \times 10^{-3}\ m^2}$

d) $f = 12\,GHz \Rightarrow \lambda = 0.025\ m$

$P_r = P_t \frac{1}{(R\lambda)^2} A_{et} A_{er}$

P_r, P_t, A_{et}, A_{er} all stay the same

$\Rightarrow$ Take ratio of $\frac{P_{r,old}}{P_{r,new}}$

$1 = \frac{(R_{new}\lambda_{new})^2}{(R_{old}\lambda_{old})^2}$

$R_{new}^2 = \left(\frac{R_{old}\lambda_{old}}{\lambda_{new}}\right)^2$

$= \left(\frac{20km\,(0.075)}{0.025}\right)^2$

$\boxed{R_{new} = 60\ km}$

+33

Problem #3 (33 points). For a linear, uniform array of 8 elements.

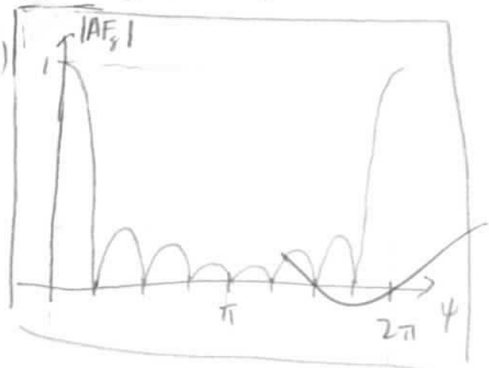
(a) Plot the universal array factor. +8

(b) Assume that the spacing between adjacent elements is half-wavelength spacing, plot the array factor of the radiation pattern in polar plot when the antenna beam is pointing to the broadside. +8

(c) What if the beam is pointing to +60 degree away from broadside? What is the progressive phase shift in this case? Show the radiation pattern in polar plot derived from universal factor. +8

(d) Design the array in the manner of an ordinary endfire array and a Hansen-Woodyard array. +9

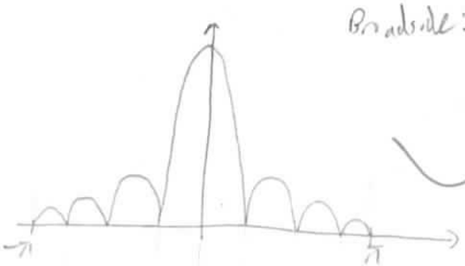
a)

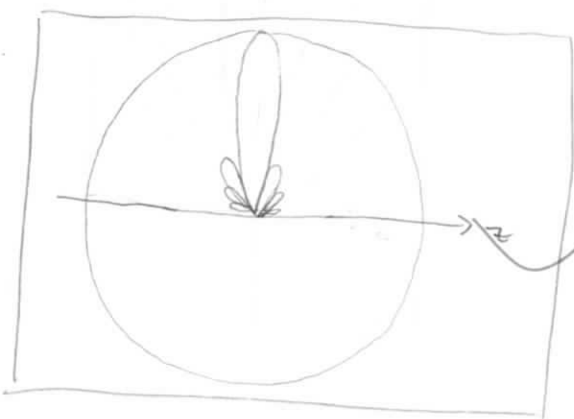


8 elements ⇒ 8 lobes

b) $d = \frac{\lambda}{2} \Rightarrow \beta d = \pi$

Broadside: $\theta = 90^\circ \Rightarrow \alpha = 0$





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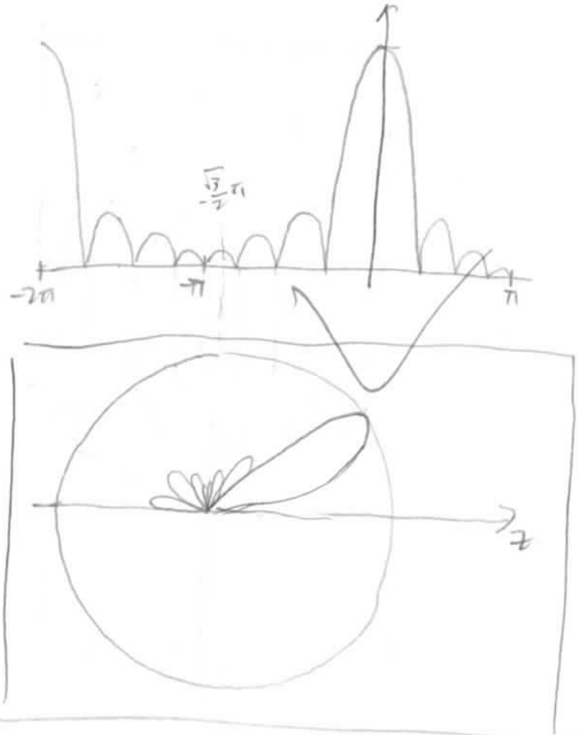
c) +60° away from broadside ⟹ $\theta_0 = 30^\circ$

$\alpha = -\beta d \cos\theta_0$

$= \boxed{-\frac{\sqrt{3}}{2}\pi}$



d) Ordinary Endfire: $\theta_0 = 0°, 180°$

$\alpha = \pm\beta d$

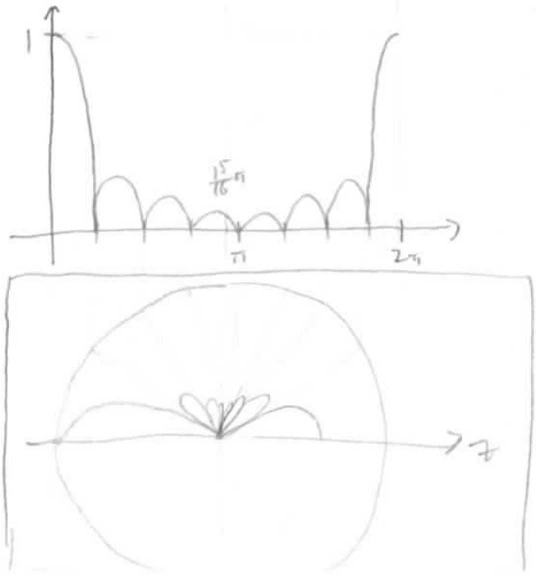
$= \pm\pi$ ⟹ grating lobes (decrease d)

$2\beta\lambda \le 2\pi - \frac{\pi}{N}$

$d \le \frac{\lambda}{2}\left(1 - \frac{1}{2N}\right)$ $N = 8$

$= \frac{15}{32}\lambda \Rightarrow \beta d = \frac{15}{16}\pi$

$\Rightarrow \alpha = \pm\frac{15}{16}\pi$



Hansen-Woodyard Endfire: $\alpha = \pm(\beta d + \delta)$

$\delta \approx \frac{\pi}{N}$ $= \pm\frac{9}{8}\pi$

$= \frac{\pi}{8}$