القسم: الاتصالات — أسئلة الامتحان النهائي — المادة: هوائيات
لطلبة الفصل: السابع — رمز المادة: CM423 — التاريخ: 2022/11/09
للفصل الدراسي : ربيع2022 — اسم الأستاذ: أ. مبروكة العاقل — الزمن: ساعتان
اسم الطالب:.. — رقم القيد .... — المجموعة : ....

The total mark of this exam is:40

This exam paper consists of 3 pages

Question 1: [12 M]

i. An antenna has a uniform field E=2V/m (rms) at a distance of 100 m where: $\frac{\pi}{6} \le \boldsymbol{\theta} \le \frac{\pi}{3}, \mathbf{0} \le \boldsymbol{\varphi} \le \frac{\pi}{2}$ with E=0 elsewhere, the antenna terminal current is 3 A (rms), suppose antenna operates at 1 GHz. Find: **(Use: $\boldsymbol{U_n} = \mathrm{E}_{\boldsymbol{n}} = \mathbf{1}$)**
   a) the directivity of the antenna,
   b) effective aperture and
   c) radiation resistance.

ii. Show that the directivity for a source with a unidirectional power pattern given by: $\boldsymbol{U} = \boldsymbol{U_m cos^n\ \theta}$ can be expressed as D = 2(n+1). U has a value only for $\mathbf{0} \le \boldsymbol{\theta} \le \frac{\pi}{2}$. The patterns are independent of the azimuth angle φ.

iii. An 875 MHz signal is to be transmitted over a 1 Km distance using antenna with the gain of 5dBi (the transmitting and the receiving antennas are identical) the transmitter has 1 Watt of power available at the input terminals of the transmitter antenna which is perfectly matched. Find the signal strength (Power) at the terminal of the received antenna.

Question 2: [10 M]

For the following data: $N = 3, d = \frac{\lambda}{3}, \delta = \frac{\pi}{2}$ **,find the:**

a) Angles (in degrees) where the nulls of the array factor occur.
b) Angles (in degrees) where the maximum of the array factor occur.
c) Angles (in degrees) where the power is half of its maximum.
d) Angles (in degrees) where the side lobes maxima occur.
e) Draw the radiation pattern for the array factor.

Question 3: [10 M]

Estimate the relative field pattern (equation) of an array of two identical isotropic point sources along the z axis. where $d = \lambda, \delta = \pi$

Question 4: [8 M]

Design a *rectangular* microstrip antenna so that it will resonate at *2 GHz*. The idealistic lossless substrate (RT/Duroid 6010.2) has a dielectric constant of *10.2* and a height of *0.127 cm*. Determine:

a) The practical width that leads to good radiation efficiency.
b) The effective dielectric constant of the patch.
c) The effective length of the patch.
d) The actual length of the patch.

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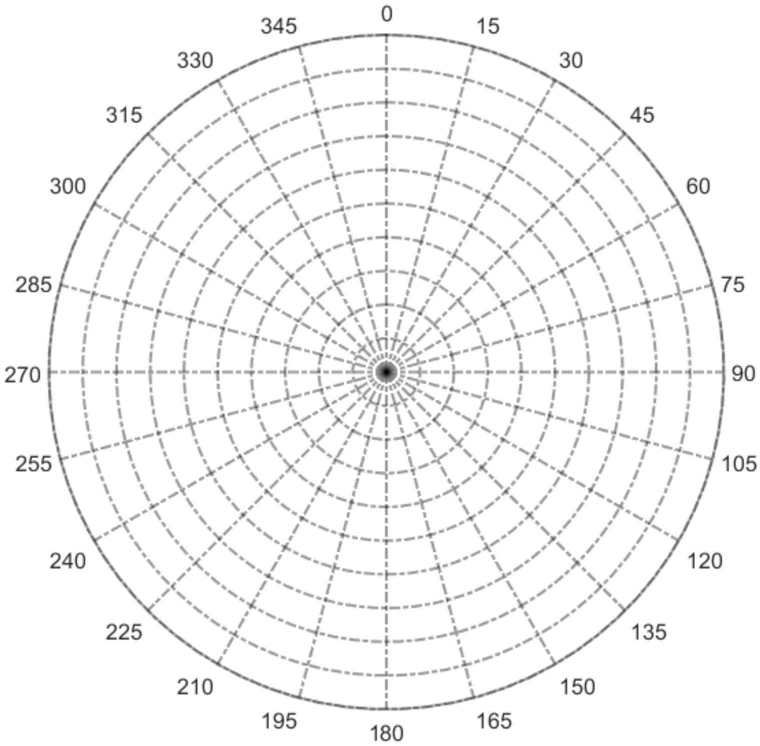
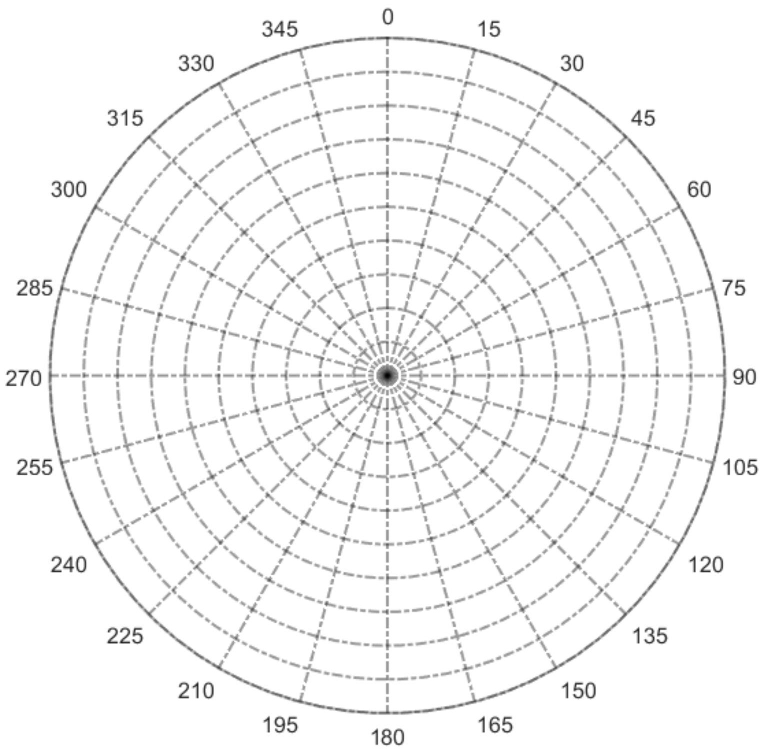
Radiation pattern for Question 2:



Radiation pattern for Question 3:



مع تمنياتي للجميع بالتوفيق والنجاح

Parameter	Formula	Parameter	Formula
Infinitesimal area of sphere	$dA = r^2 \sin\theta \, d\theta \, d\phi$	Elemental solid angle of sphere	$d\Omega = \sin\theta \, d\theta \, d\phi$
Average power density	$\mathbf{W}_{av} = \frac{1}{2}\mathrm{Re}[\mathbf{E} \times \mathbf{H}^*]$	Radiated power/average radiated power	$P_{rad} = \oiint_S \mathbf{W}_{av} \cdot d\mathbf{s} = \frac{1}{2}\oiint_S \mathrm{Re}[\mathbf{E} \times \mathbf{H}^*] \cdot d\mathbf{s}$
Radiation density	$W_{av} = \frac{P_{rad}}{4\pi r^2}$	Radiation intensity (far field)	$U = r^2 W_{av}$
Directivity $D(\theta,\phi)$	$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} = \frac{4\pi}{\Omega_A}$	Beam solid angle Ω_A	$\Omega_A = \int_0^{2\pi}\int_0^{\pi} U_n(\theta,\phi) \sin\theta \, d\theta \, d\phi$ $U_n(\theta,\phi) = \frac{U(\theta,\phi)}{U(\theta,\phi)_{\max}}$
Gain $G(\theta,\phi)$	$G = \frac{4\pi U(\theta,\phi)}{P_{in}} = e_{cd}\left[\frac{4\pi U(\theta,\phi)}{P_{rad}}\right] = e_{cd} D(\theta,\phi)$	Antenna radiation efficiency e_{cd}	$P_{rad} = e_{cd} P_{in}$ $\quad e_{cd} = \frac{R_r}{R_r + R_L}$
Maximum effective area A_{em}	$A_{em} = e_{cd}\left(\frac{\lambda^2}{4\pi}\right) D = \left(\frac{\lambda^2}{4\pi}\right) G$	Friis transmission equation	$\frac{P_r}{P} = \left(\frac{\lambda}{4\pi R}\right)^2 G_t G_r$
Aperture efficiency ε_{ap}	$\varepsilon_{ap} = \frac{A_{em}}{A_p} = \frac{\text{maximum effective area}}{\text{physical area}}$	Wave impedance Z_w	$Z_w = \frac{E_\theta}{H_\phi} \simeq \eta = 377 \text{ ohms}$

Parameter	Formula	Parameter	Formula
	Infinitesimal Dipole $(l \le \lambda/50)$		***Small Dipole*** $(\lambda/50 < \ell \le \lambda/10)$
Radiation resistance R_r	$R_r = \eta\left(\frac{2\pi}{3}\right)\left(\frac{l}{\lambda}\right)^2 = 80\pi^2\left(\frac{l}{\lambda}\right)^2$	Radiation resistance R_r	$R_r = 20\pi^2\left(\frac{l}{\lambda}\right)^2$
Half-power beamwidth	$\text{HPBW} = 90^\circ$	Half-power beamwidth	$\text{HPBW} = 90^\circ$
	Half Wavelength Dipole $(l = \lambda/2)$		***Finite length Dipole*** $(l > \lambda/10)$
Radiation resistance R_r	$R_r = \frac{\eta}{4\pi} C_{in}(2\pi) \simeq 73 \text{ ohms}$	Electric field intensity E_θ	$E_\theta \simeq j\eta \frac{I_0 e^{j\beta r}}{2\pi r}\left[\frac{\cos\left(\frac{\beta l}{2}\cos\theta\right) - \cos\left(\frac{\beta l}{2}\right)}{\sin\theta}\right]$
Half-power beamwidth	$\text{HPBW} = 78^\circ$		

	2 Isotropic Sources with Same amplitude with any phase difference
ARRAY FACTOR	$(E)_n = \cos[\frac{1}{2}(\beta d \cos\theta + \delta)]$

Patch Microstrip Antanna

$$\boldsymbol{W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}}$$

$$\boldsymbol{\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12h}{W}\right]^{-\frac{1}{2}}}$$

$$\boldsymbol{\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}}$$

$$\boldsymbol{L_{eff} = \frac{c}{2f_r}\sqrt{\frac{1}{\varepsilon_{reff}}}}$$

$$\boldsymbol{L = L_{eff} - 2\Delta L}$$

N-ELEMENT LINEAR ARRAY: UNIFORM AMPLITUDE AND SPACING

ARRAY FACTOR

where $\psi = \beta d \cos\theta + \delta$

$$(E)_n \simeq \left[\frac{\sin\left(\frac{N}{2}\psi\right)}{\frac{N}{2}\psi}\right]$$

Nulls

$$\sin\left(\frac{N}{2}\psi\right) = 0 \Rightarrow \frac{N}{2}\psi\big|_{\theta=\theta_n} = \pm n\pi$$

$n = 1, 2, 3, \ldots$

$n \neq N, 2N, 3N, \ldots$

Maximum

$\psi = 0$

3 - dB point

$$\frac{N}{2}\psi = \frac{N}{2}(\beta d \cos\theta + \delta)|_{\theta=\theta_h} = \pm 1.391$$

Side lobes Maxima

$$\frac{N}{2}\psi = \pm\frac{(2s+1)}{2}\pi$$

$s = 1, 2, 3, \ldots$

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Q1 i $E = 2V/m$, $\frac{\pi}{6} \leq \theta \leq \frac{\pi}{3}$, $0 \leq \phi \leq \frac{\pi}{2}$

$r = 100\,m$, $I_{rms} = 3A$, $f = 1\,GHz$

a) $$D = \frac{4\pi}{\Omega_A} = \frac{4\pi}{\int_{\pi/6}^{\pi/3} \sin(\theta)\,d\theta \int_0^{\pi/2} d\phi} = \frac{4\pi}{\left[-\cos(\theta)\right]_{\pi/6}^{\pi/3} \left[\phi\right]_0^{\pi/2}}$$ 2

$$= \frac{4\pi}{\frac{\pi}{2}\left[\cos(\frac{\pi}{6}) - \cos(\frac{\pi}{3})\right]} = \frac{8}{\frac{\sqrt{3}}{2} - \frac{1}{2}} = \frac{16}{\sqrt{3}-1} = 21.856$$

b) $$A_e = \frac{\lambda^2}{4\pi}(D) = \frac{\lambda^2}{4\pi}(21.856) = 1.739\lambda^2 = 1.739\left(\frac{3\times10^8}{1\times10^9}\right)^2$$

$$= 0.1565\ m^2$$ 2

c) $R_r \Rightarrow \frac{1}{2} I_0^2 R_r = P_r = 9R_r$

$$P_r = \oiint_s W_{av} \cdot r^2 \sin(\theta)\,d\theta\,d\phi$$

$$\Rightarrow W_{av} = \frac{1}{2} R_e\left[E \times H^*\right] = \frac{1}{2}\frac{E^2}{\eta} = \frac{1}{2}\frac{(2)^2}{120\pi} = \frac{1}{60\pi}$$

$$P_r = \iint_s \frac{1}{60\pi}(100)^2 \sin(\theta)\,d\theta\,d\phi$$

$$= 53.05 \int_0^{\pi/2}\int_{\pi/6}^{\pi/3} \sin(\theta)\,d\theta\,d\phi = 53.05(0.575)$$

$$= 30.5\,W$$

$P_r = 30.5W = 9R_r \Rightarrow R_r = 3.389\,\Omega$ 2

(2)

(ii) $U = U_m \cos^n(\theta)$

$$D = \frac{4\pi}{\iint_S U_n \sin(\theta)\, d\theta\, d\phi}$$

$$U_n = \cos^n(\theta)$$

$$D = \frac{4\pi}{\int_0^{\frac{\pi}{2}} \cos^n(\theta)\sin(\theta)\, d\theta \int_0^{2\pi} d\phi} = \frac{4\pi}{2\pi\left[-\frac{\cos^{(n+1)}(\theta)}{n+1}\right]_0^{\frac{\pi}{2}}}$$

(4)

$$= \frac{2}{-\left[0 - \frac{1}{n+1}\right]} = \frac{2}{\left[\frac{1}{n+1}\right]} = 2(n+1)$$

(iii) $f = 875\,\text{MHz}$, $R = 1\times10^3\,\text{m}$, $G_t = G_r = 5\,\text{dB}_i = 3.162$

$P_t = 1\,\text{W}$ $\quad P_r = ?$

$$\lambda = \frac{3\times10^8}{875\times10^6} = 0.343\,\text{m}$$

$$P_r = \left(\frac{\lambda}{4\pi R}\right)^2 G_t\, G_r$$

(3)

$$P_r = (0.0000273)^2\,(3.162) = 7.74.89\times10^{-9}\,\text{W} = 7.7489\,\text{nW}$$

$$= -81.106\,\text{dBW}$$

3

Q2 :- $N = 3$, $d = \frac{\lambda}{3}$, $\delta = \frac{\pi}{2}$

$\beta d = \frac{2\pi}{\lambda}\left(\frac{\lambda}{3}\right) = \frac{2\pi}{3}$

For max $\psi = 0 \Rightarrow \beta d \cos(\theta_m) + \delta = 0$

$$\frac{2\pi}{3}\cos(\theta_m) + \frac{\pi}{2} = 0 \Rightarrow \cos(\theta_m) = -\frac{3}{4}$$

$$\theta_m = \pm 138.59^\circ \Rightarrow 138.59^\circ , 221.41^\circ$$

2

For Nulls :- $\frac{N}{2}\psi = \pm n\pi$

$$\frac{3}{2}\psi = \pm n\pi \Rightarrow \psi = \pm \frac{2}{3} n\pi$$

$$\frac{3}{2}\left(\frac{2\pi}{3}\cos(\theta_n) + \frac{\pi}{2}\right) = \pm n\pi$$

$$\frac{2}{3}\cos(\theta_n) + \frac{1}{2} = \pm \frac{2}{3} n$$

$$\cos(\theta_n) = \frac{3}{2}\left(-\frac{1}{2} \pm \frac{2}{3} n\right)$$

for $n = 1 \Rightarrow \cos(\theta_n) = \frac{3}{2}\left(-\frac{1}{2} \pm \frac{2}{3}\right)$ $\nearrow \frac{1}{4} \Rightarrow \pm 75.5^\circ$ $\searrow -1.755$ rejected.

$n = 2, 3, 4,$ rejected

$$\theta_n = 75.5^\circ , 284.5^\circ$$

2

For Sidelobes :- $\frac{N\psi}{2} = 1 \Rightarrow \frac{3\psi}{2} = \pm \frac{(2s+1)}{2}\pi$

$$\psi = \frac{(2s+1)}{3}\pi \Rightarrow \frac{2\pi}{3}\cos(\theta_s) + \frac{\pi}{2} = \pm \frac{(2s+1)\pi}{3}$$

$$\cos(\theta_s) = \frac{3}{2}\left(-\frac{1}{2} \pm \frac{(2s+1)}{\pi}\right)$$

for $s = 0 \Rightarrow \theta_s = \pm 104.47 \Rightarrow$ rejected within the main lobe

for $s = 1 \Rightarrow \cos(\theta_s) = \frac{3}{2}\left(-\frac{1}{2} \pm 1\right) \Rightarrow \cos(\theta_s) = \pm 41.409^\circ$

$$\theta_s = 41.409^\circ , 318.6^\circ$$

2

4

Half power: $\frac{N\psi}{2} = \pm 1.391$

$$\frac{3}{2}\psi = \pm 1.391$$

$$\psi = \pm \frac{2}{3}(1.391) = \pm 0.9273$$

$$\frac{2\pi}{3}\cos(\theta_h) + \frac{\pi}{2} = \pm 0.9273$$

$$\frac{2}{3}\cos(\theta_h) + \frac{1}{2} = \pm 0.2952$$

$$\cos(\theta_h) = \frac{3}{2}\left(-\frac{1}{2} \pm 0.2952\right)$$

$$\cos(\theta_h) = -0.3072 \Rightarrow \theta_h = \pm 107.89^\circ$$

$$\theta_h = 107.89^\circ, \; 252.14^\circ$$

2

2 marks for radiation pattern.

Q3:-

(5)

$d=\lambda$, $\delta=\pi$

$$E_n = \cos\left(\frac{\beta d \cos\theta + \delta}{2}\right) = \cos\left(\frac{\frac{2\pi}{\cancel{\lambda}}\cancel{\lambda}\cos\theta + \pi}{2}\right)$$

$$E_n = \cos\left(\pi\cos(\theta) + \frac{\pi}{2}\right)$$

For max $\quad E_n = \pm 1$

$$\pi\cos(\theta_m) + \frac{\pi}{2} = \pm n\pi$$

$$\cos(\theta_m) = -\frac{1}{2} \pm n$$

for $n=0 \Rightarrow \cos(\theta_m) = -\frac{1}{2} \Rightarrow \theta_m = \pm 120^\circ \Rightarrow 120^\circ, 240^\circ$ (2)

for $n=1 \Rightarrow \cos(\theta_m) = -\frac{1}{2} \pm 1$ $\nearrow -\frac{3}{2} \Rightarrow$ rejected

$\searrow \frac{1}{2} \Rightarrow \theta_m = 60^\circ, 300^\circ$

For nulls:- $\quad E_n = 0$

$$\pi\cos(\theta_n) + \frac{\pi}{2} = \pm(2n+1)\frac{\pi}{2}$$

$$\cos(\theta_n) = -\frac{1}{2} \pm \frac{(2n+1)}{2}$$

for $n=0$:- $\cos(\theta_m) = -\frac{1}{2} \pm \frac{1}{2}$ $\nearrow -1 \Rightarrow \theta_n = 180^\circ$

$\searrow 0 \Rightarrow \theta_n = 90^\circ, 270^\circ$ (2)

For $n=1$:- $\cos(\theta_n) = -\frac{1}{2} \pm \frac{3}{2}$ $\nearrow -2 \Rightarrow$ rejected

$\searrow 1 \Rightarrow \theta_n = 0^\circ$

For half points $\Rightarrow E_n = \pm\frac{1}{\sqrt{2}}$

$$\pi\cos(\theta_h) + \frac{\pi}{2} = \pm(2n+1)\frac{\pi}{4}$$

$$\cos(\theta_h) = -\frac{1}{2} \pm \frac{(2n+1)}{4}$$

for $n=0 \Rightarrow \cos(\theta_h) = -\frac{1}{2} \pm \frac{1}{4}$ $\nearrow -\frac{3}{4} \Rightarrow \theta_h = 138.6^\circ, 221.41^\circ$ (2)

$\searrow -\frac{1}{4} \Rightarrow \theta_h = 104.47^\circ, 255.52^\circ$

⑥

For $n=1 \Rightarrow \cos(\theta_n) = -\frac{1}{2} \pm \frac{3}{4}$ $\nearrow -\frac{5}{4} \Rightarrow$ rejected ; $\searrow \frac{1}{4} \Rightarrow 75.52^\circ, 284.47^\circ$

For $n=2 \Rightarrow \cos(\theta_n) = -\frac{1}{2} \pm \frac{5}{4}$ $\nearrow -\frac{7}{4} \Rightarrow$ rejected ; $\searrow \frac{3}{4} \Rightarrow 41.41^\circ, 318.6^\circ$

2

Q4:- $F = 2GHz$, $\varepsilon_r = 10.2$, $h = 0.127$ cm

+2 for radiation pattern

$$W = \frac{3\times10^8}{2\times2\times10^9}\sqrt{\frac{2}{10.2+1}} = \frac{0.3}{4}\sqrt{\frac{2}{11.2}} = 3.169\text{ cm}$$ 2

$$\varepsilon_{reff} = \frac{11.2}{2} + \frac{9.2}{2}\left(\sqrt{1+\frac{12(0.127)}{3.169}}\right) = 5.6 + \frac{4.6}{\sqrt{1.481}}$$

$$= 5.6 + \frac{4.6}{1.217} = 5.6 + 3.78 = 9.38$$ 2

$$\frac{\Delta L}{h} = 0.412\,\frac{(9.38+0.3)\left(\frac{3.169}{0.127}+0.264\right)}{(9.38-0.258)\left(\frac{3.169}{0.127}+0.8\right)}$$

$$\frac{\Delta l}{0.127} = 0.412\,\frac{(9.68)(24.953+0.264)}{(9.122)(24.953+0.8)}$$

$$\frac{\Delta l}{0.127} = 0.412\,\frac{(9.68)(25.217)}{(9.122)(25.753)}$$

$$\Delta L = (0.127)(0.412)\frac{244.1}{234.92}$$

$$\Delta L = (0.0523)(1.0391) = 0.0543\text{ cm}$$ 2

$$L_{eff} = \frac{3\times10^8}{2\times2\times10^9}\sqrt{\frac{1}{9.38}} = \frac{0.3}{4}(0.3265) = 2.448\text{ cm}$$ 1

$$L = L_{eff} - 2\Delta L = 2.448 - 2(0.0543) = 2.34\text{ cm}$$ 1

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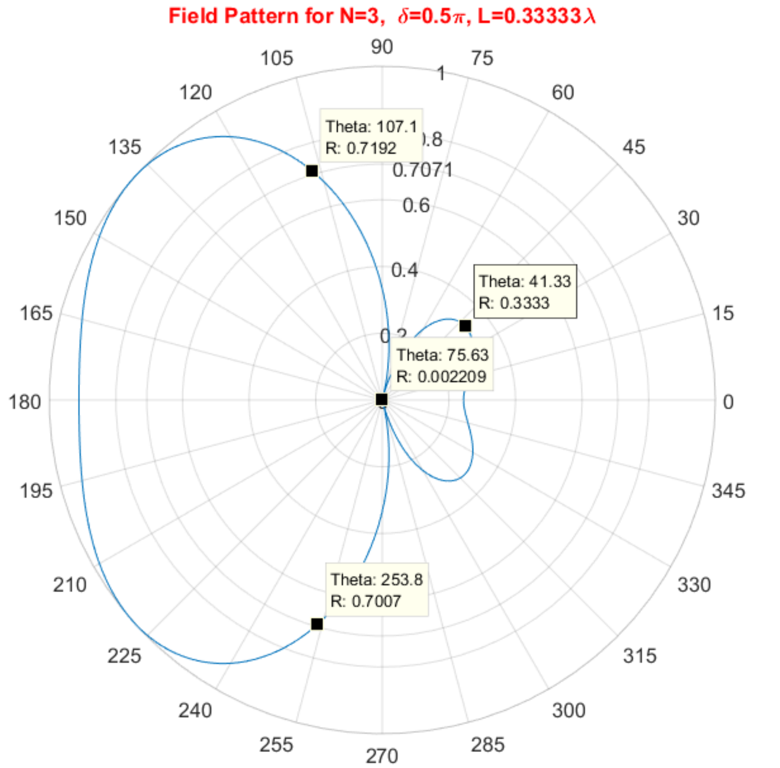
Radiation pattern for Question 2:



Radiation pattern for Question 3: