Advanced Antenna Engineering

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I, the undersigned Tong Lin
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upon my honor, and aware of the consequences of a false declaration under the Italian law[2], as well as those deriving from unfair conduct at Politecnico,

By submitting this course assignment material,

I declare (*dichiarazione sostitutiva di atto notorio*) that:

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3. TL With reference to the above, in particular: I have neither used, nor taken inspiration from codes (like Matlab scripts) written by others (e.g. Classmates), or written by me in collaboration with others;
4. TL In carrying out the tasks of this submitted material I have used only: a) the material(s) provided by the official course instructor(s) via the official course webpage, that does not need referencing; b) materials publicly available[3] (published books, journal papers, etc.) as duly acknowledged below. Any material in b) above MUST be clearly listed and precisely referenced in a separate sheet, signed at bottom, to be attached to the submitted paper as an Appendix. Absence of such an Appendix is a declaration that only materials in a) have been used;
5. TL I understand that my submitted material will be compared and archived for plagiarism detection and benchmarking;
6. TL I have not communicated anything with and will not communicate with anyone concerning this assignment for any reason; exceptions: course Instructor(s) and registered course classmates;
7. TL I have discussed this assignment with the persons listed below[4],[5]; this item cannot be left blank: enter "none" if appropriate:

[1] i.e. write your initials in the blank space (_____) at the beginning of each item
[2] chiunque rilascia dichiarazioni mendaci è punito ai sensi del codice penale e delle leggi speciali in materia, ai sensi e per gli effetti dell'art. 46 D.P.R. n. 445/2000
[3] If in doubt about any material that could be used please ask the Instructor by email
[4] Instructors are excluded from this list
[5] Peer-to-peer discussion with classmates is allowed as long as all other declaration items are not affected. Discussion with anyone else is not allowed (Instructors excluded)

TONG LIN

(Complete name, please print)

仝霖. Tong Lin signature[6]

Torino, 01/12/2021 (date)

[6] If your National language is not written in Latin characters (e.g. Chinese, Arabic), you must sign both with your name in Latin characters and as you sign official documents in your National language

**Questions:**

a) Why do we consider that min complexity corresponds to min number of radiating elements? (1 line max)

Due to BFN, larger N means more a complex BFN, which will cause higher losses, etc.

b) Explain why the presence of grating lobes makes the (max) directivity of the AF decrease (2 lines max)

The presence of the grating lobes when d is large enough that the side lobes become larger than the main lobe, thus decrease the main lobes' directivity.

c) What is the main limitation of uniform arrays? (1 line max)

Uniform amplitude has no control over Side-Lobe Level.

d) How can we overcome the main limitation of uniform arrays? (2 lines max)

By using non-uniform amplitudes or non-uniform spacing to improve the SLL.

e) By using examples, explain the trade-off between (max) directivity and SLL of the AF. (2 lines max)

By setting a proper N, to guarantee a higher value above beam-width condition and a lower value below grating lobes condition, for which the value N shall larger than 7.

f) In a tapered array, for a given N and SLL we choose the min value of tapering t (i.e. closest to 1): why?

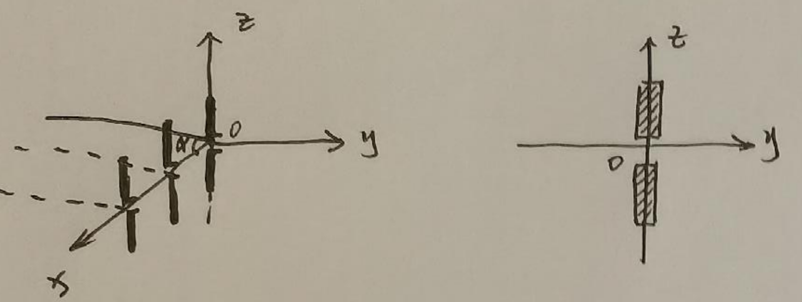
When t<1 reduces SLL, but also reduces directivity. Therefore, to have a trade-off, we set t closer to 1. Also, normally the amplitude is maximum at center, so t cannot be larger than 1.

g) For a given spec on beamwidth (e.g. HPBW) and min n. of elements, a uniform array (with no option of SLL) will require less elements than a tapered array with SLL requirement better than 13dB; why? Hint: look at the SLL of a uniform amplitude array (in φ) for N=4-10 on the slides, or beyond 10 using your scripts (see below)

As in the case of uniform array, the increasing element number will increase the SLL level, but with a tapered array, the increasing of n will increasing the main lobe's directivity due to the mathematical explanation, thus a tapered array need more elements numbers to improve performance.

Assignment 3 Problem 3

1. Envision antenna and choosen coordinate system.




2. Radiation Pattern.

For a single dipole, the radiation pattern is described as,

$$e_\theta = j \cdot 2 I_0 Z_0 \frac{\cos(\frac{\pi}{2}\cos\theta)}{\sin\theta}$$

$$e_\varphi = 0$$

For a array design,

$$e_{array.\theta} = e_\theta \cdot AF$$

$$= j 2 I_0 Z_0 \frac{\cos(\frac{\pi}{2}\cos\theta)}{\sin\theta} \cdot \sum_{n=1}^{N} A_n \exp[j(n-1)\frac{2\pi d}{\lambda}\cos\alpha].$$

where $A_n = \cos\left\{[\frac{2(n-1)}{N-1} - 1] \cdot k\right\}$.

$\cos\alpha = \sin\theta \sin\varphi$

$$e_{array.\varphi} = e_\varphi \cdot AF = 0.$$

Also, with the approximation $e_\theta(\theta.\varphi) \approx \tilde{e}_\theta(\theta,\varphi) = C(\sin\theta)^{\frac{3}{2}}$

$$C = e_{array.\theta}(\theta = \frac{\pi}{2})$$

$$= j 2 I_0 Z_0 \sum_{n=1}^{N} A_n \exp[j(n-1)\frac{2\pi d}{\lambda}\sin\varphi].$$

so, $e_{array.\theta} = \left\{ j 2 I_0 Z_0 \sum_{n=1}^{N} A_n \exp[j(n-1)\frac{2\pi d}{\lambda}\sin\varphi] \right\} \cdot (\sin\theta)^{\frac{3}{2}}$

Therefore, the radiation pattern can be described as,

$$\underline{E}(r.\theta.\varphi) = \frac{e^{-jk_0 r}}{4\pi r} \left\{ j 2 I_0 Z_0 \sum_{n=1}^{N} A_n \exp[j(n-1)\frac{2\pi d}{\lambda}\sin\varphi] \right\} (\sin\theta)^{\frac{3}{2}} \cdot \hat{\theta}$$

For the maximum radiation, where $\alpha_{max} = \frac{\pi}{2}$,

$$\underline{E}(r,\theta,\varphi) = \frac{e^{-jk_0 r}}{4\pi r}\left\{ j2I_0 Z_0 \sum_{n=1}^{N} A_n \right\} \cdot (\sin\theta)^{\frac{3}{2}}\,\hat{\theta}$$

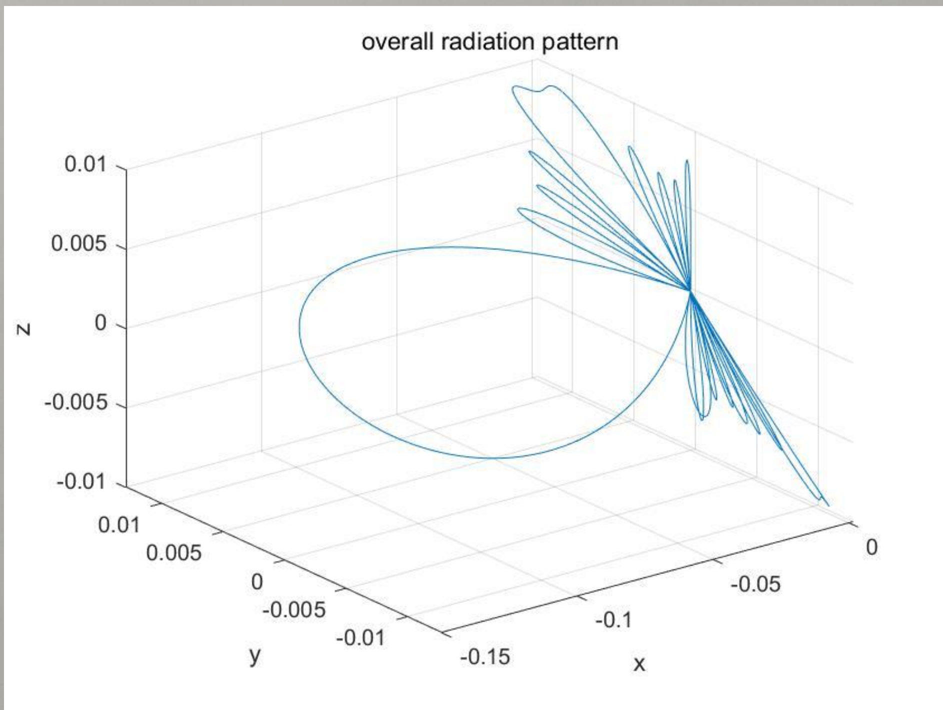
In the vertical plane: $\theta = 0$, $\varphi \in [0, 2\pi]$,

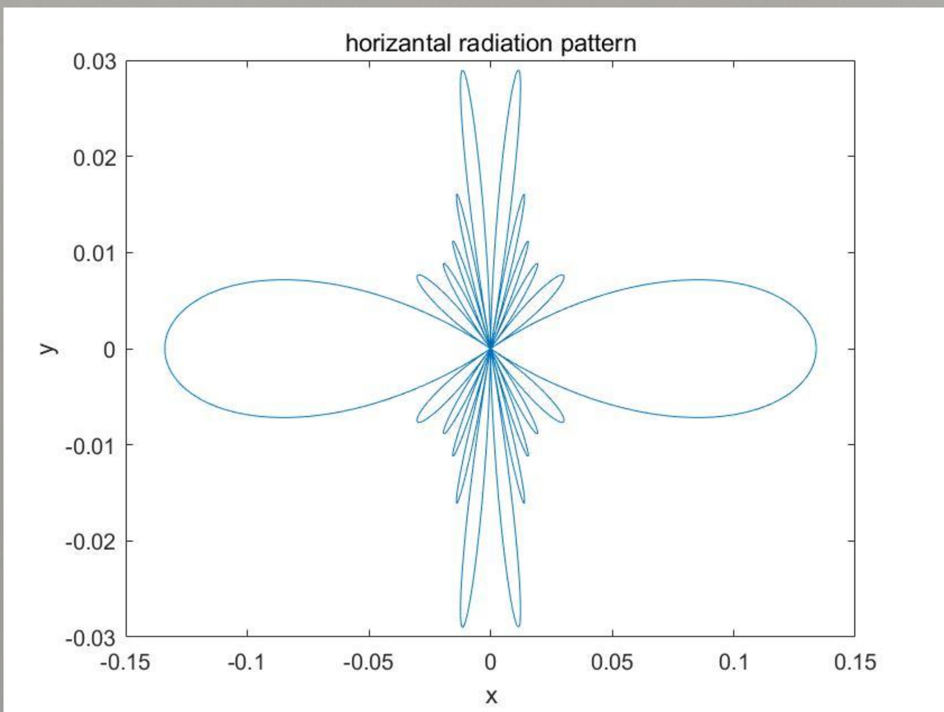
$$\underline{E}(r,\theta,\varphi) = \frac{e^{-jk_0 r}}{4\pi r}\left\{ j2I_0 Z_0 \sum_{n=1}^{N} A_n \cdot \exp\left[j(n-1)\frac{2\pi d}{\lambda}\sin\varphi\right]\right\} \cdot (\sin\theta)^{\frac{3}{2}}$$

$$= 0$$

In the horizantal plane: $\theta = \frac{\pi}{2}$, $\varphi \in [0, 2\pi]$,

$$\underline{E}(r,\theta,\varphi) = \frac{e^{-jk_0 r}}{4\pi r}\left\{ j2I_0 Z_0 \sum_{n=1}^{N} A_n \exp\left[j(n-1)\frac{2\pi d}{\lambda}\cdot\sin\varphi\right]\right\}$$



# Appendix: Matlab codes

```
clear all;
close all;
clc

j = sqrt(-1);
k0 = 1;   %normalized
r = 1;
I0 = 1;    %nromalized
Z0 = 1;   %nromalized
N = 7;
d_lamuda = 1-1/N;
lamuda0 = 3e8/850e6;
k = 2*pi/lamuda0;

theta0 = 0:0.0001:pi;
phi0 = 0:0.0002:2*pi;
PHI = 0;
cosalp = sin(theta0).*sin(phi0);
phi = 2*pi*d_lamuda*cosalp+PHI;
F_N = (1/N)*abs(sin(N*phi/2)./sin(phi/2));
E = exp(-j*k0*r)*j*2*I0*Z0*F_N.*sin(theta0).^1.5/(4*pi*r);
x = E.*sin(theta0).*cos(phi0);
y = E.*sin(theta0).*sin(phi0);
z = E.*cos(theta0);
figure
plot3(x,y,z);
title('overall radiation pattern');
xlabel('x');
ylabel('y');
zlabel('z');
grid on

%horizantal
theta0h = pi/2;
phi0 = 0:0.0002:2*pi;
PHI = 0;
cosalp = sin(theta0h).*sin(phi0);
phi = 2*pi*d_lamuda*cosalp+PHI;
F_N = (1/N)*abs(sin(N*phi/2)./sin(phi/2));
E = exp(-j*k0*r)*j*2*I0*Z0*F_N.*sin(theta0h).^1.5/(4*pi*r);
x = E.*sin(theta0h).*cos(phi0);
y = E.*sin(theta0h).*sin(phi0);
```

```
z = E.*cos(theta0h);
figure
plot(x,y);
title('horizantal radiation pattern');
xlabel('x');
ylabel('y');

%vertical
theta0v = 0;
phi0 = 0:0.0002:2*pi;
PHI = 0;
cosalp = sin(theta0v).*sin(phi0);
phi = 2*pi*d_lamuda*cosalp+PHI;
F_N = (1/N)*abs(sin(N*phi/2)./sin(phi/2));
E = exp(-j*k0*r)*j*2*I0*Z0*F_N.*sin(theta0v).^1.5/(4*pi*r);
x = E.*sin(theta0v).*cos(phi0);
y = E.*sin(theta0v).*sin(phi0);
z = E.*cos(theta0v);
figure
plot(y,z,'*');
```

## Reference:


1. linear_AF_7x3.pdf, in section ‘Handouts’
2. 《天线原理与设计》王建, *Antenna Theory and Design*, by Wang Jian


## Discussed with student Zhang Zhifan.