Advanced Antenna Engineering

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I, the undersigned Tong Lin
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By submitting this course assignment material,

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

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2. TL The submitted material is my original work and no part of it has been copied from any other source except where due acknowledgement is made (see item 4 below on how to acknowledge use of allowed sources);
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;
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5. TL I understand that my submitted material will be compared and archived for plagiarism detection and benchmarking;
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7. TL I have discussed this assignment with the persons listed below[4],[5]; this item cannot be left blank: enter "none" if appropriate:

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[3] If in doubt about any material that could be used please ask the Instructor by email
[4] Instructors are excluded from this list
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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

Problem 1, Assignment 3

1. Array factor with no-uniform excitation coefficient.

① Excitation coefficient $[I]=[I_1, \dots, I_N]$

$$I_n = A_n \cdot \exp[j(n-1)\Phi].$$

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

As
$$t=\frac{\text{Amplitude at edge}}{\text{Amplitude at center}}=\frac{f(0)}{f(\frac{1}{2}L)}=\frac{f(L)}{f(\frac{1}{2}L)}=\cos k.$$

so, $k = \arccos t$.

Therefore, $A_n = \cos\left\{\arccos t\cdot\left[\frac{2(n-1)}{N-1}-1\right]\right\}$

Plot the figure of $n - A_n$, as figure 1.2.

② Array factor

$$AF=\sum_{n=1}^{N} I_n \exp[j(n-1)\varphi]$$
$$=\sum_{n=1}^{N} A_n\cdot\exp[j(n-1)\Phi]\cdot\exp[j(n-1)\varphi]$$
$$=\sum_{n=1}^{N}\cos\left\{\arccos t\cdot\left[\frac{2(n-1)}{N-1}-1\right]\right\}\cdot\exp[j(n-1)(\Phi+\varphi)]$$

$$F_N(\varphi)=\frac{|AF(\varphi,N)|}{\max|AF|} \Rightarrow F_N[dB]=10\cdot\log_{10}F_N.$$

In ~~our~~ this case,
$N=9$
$t=0.5, 0.7, 0.9$
$\varphi = kd\cos\alpha + \Phi$
where, $d=10$, $\alpha=[-\pi,\pi]$. $\Phi=0$.

Using Matlab to plot the relationship between $\frac{\varphi}{\pi}$ and $F_N[dB]$, as figure 1.1.

2. Uniform array factor $N = 2:10$

$$F_N(\varphi) = \frac{|AF(\varphi, N)|}{\max |AF|}$$

$$= \frac{1}{N} \left| \frac{\sin(N \cdot \frac{\varphi}{2})}{\sin \frac{\varphi}{2}} \right|$$

where $N = [2, 3, 4, \dots, 10]$

$\varphi = [0, \pi]$.

Using Matlab to plot the relationship $\frac{\varphi}{\pi} - F_N$, as figure 2.

3. & 4. Uniform array factor as a function of α.

$$F_N = \frac{1}{N} \left| \frac{\sin(N \cdot \frac{\varphi}{2})}{\sin(\frac{\varphi}{2})} \right|$$

where $\varphi = 2\pi \cdot \frac{d}{\lambda} \cdot \cos\alpha + \Phi$.

$\alpha = [-\pi, \pi]$.

Using Matlab to plot figures:

In figure 3, $\frac{d}{\lambda} = 1 - \frac{1}{N}$, $N = 8$, $\Phi = 0$.

In figure 4, $\frac{d}{\lambda} = 0.4375$, $N = 8$, $\Phi = -2\pi \frac{d}{\lambda}$.

Problem 2. Assignment 3

Array factor (uniform amplitude), $F_N = \frac{1}{N} \left| \frac{\sin(N \cdot \frac{\varphi}{2})}{\sin(\frac{\varphi}{2})} \right|$

where, $\varphi = 2\pi \cdot \frac{d}{\lambda} \cdot \cos\alpha + \Phi$.

$\alpha \in [-\pi, \pi]$

$N = 7$, which related with min complexity.

$\frac{d}{\lambda} = f_{GL}(N) = q(1 - \frac{1}{N})$, where $q = q_{BS} = 1$

$\Phi = 0$, which related with Broad-Side uniform.

($\alpha_{max} = \frac{\pi}{2}$, $\cos\alpha_{max} = \frac{-\Phi}{kd}$, so. $\Phi = 0$).

Using Matlab to plot the relationship between α [°] and F_N [dB]. Adjusting the ~~x~~, y label range, $x \in [50, 130]$, $y \in [-50, 0]$, we can figure out FNBW ≤ 20°, and HPBW ≤ 9.69°, as figure P2.1 and figure P2.2 (in polar coordinate).

1. N=9, amplitude: cosine over pedestal expression[6] on slide 56, t=1 and t=0.7; reference fig: in slide 59 (59), dB format (as a function of ψ)

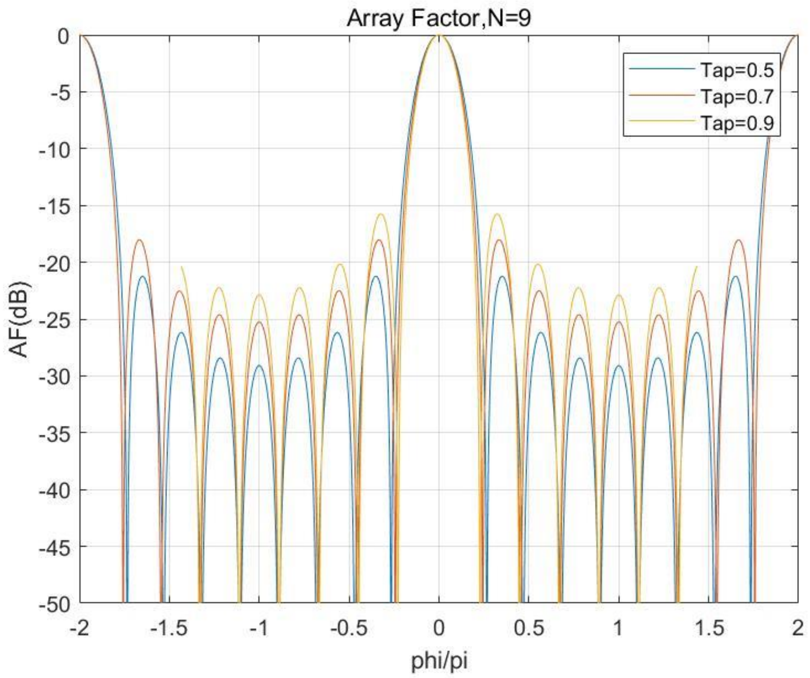

Figure 1.1: Non-Uniform Array Factor[dB]

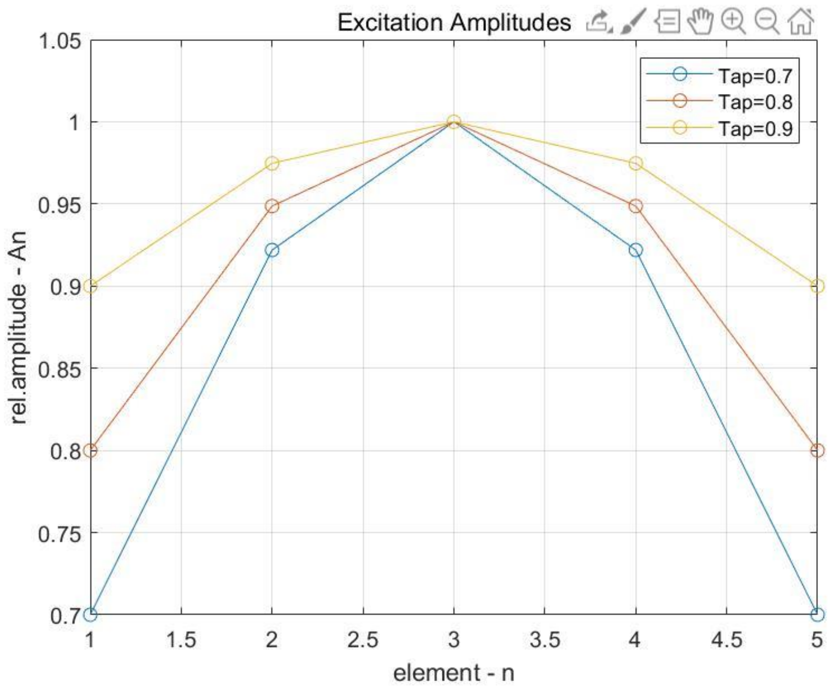

Figure 1.2: Excitation Amplitudes

2. N=2,…10, uniform amplitude; reference fig: in slide 9 (9) (as a function of ψ)

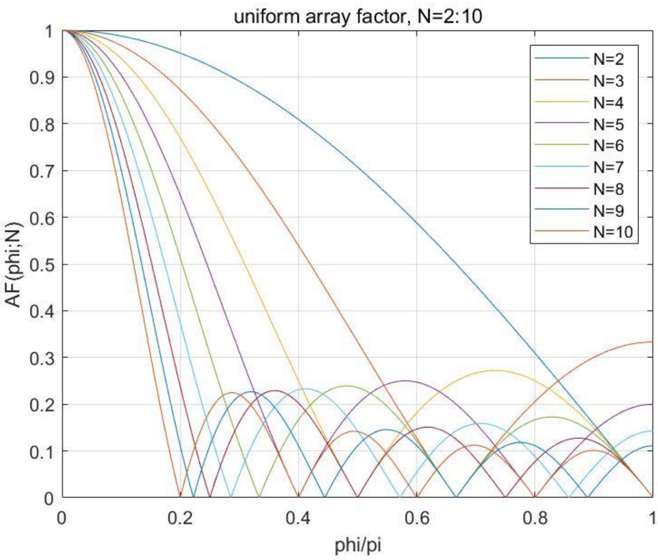

Figure 2: Uniform Array Factor (N=2,3,⋯,10)

3. N=8, uniform amplitude; $\Phi = 0$, $d / \lambda = 1 - 1 / N$; reference: figure below (as a function of α)

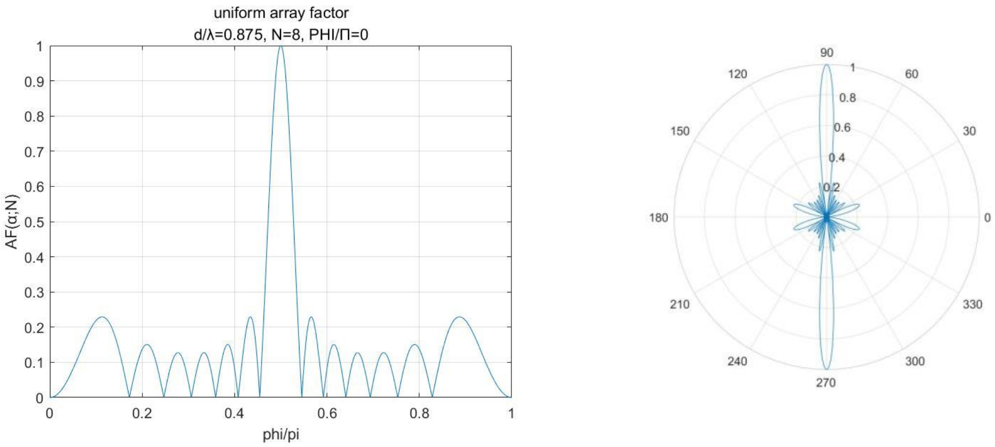

Figure 3: Uniform Array Factor with α

4. N=8, uniform amplitude; $\Phi = -kd$, $d / \lambda = 0.5(1 - 1 / N)$; reference: figure below (as a function of α)

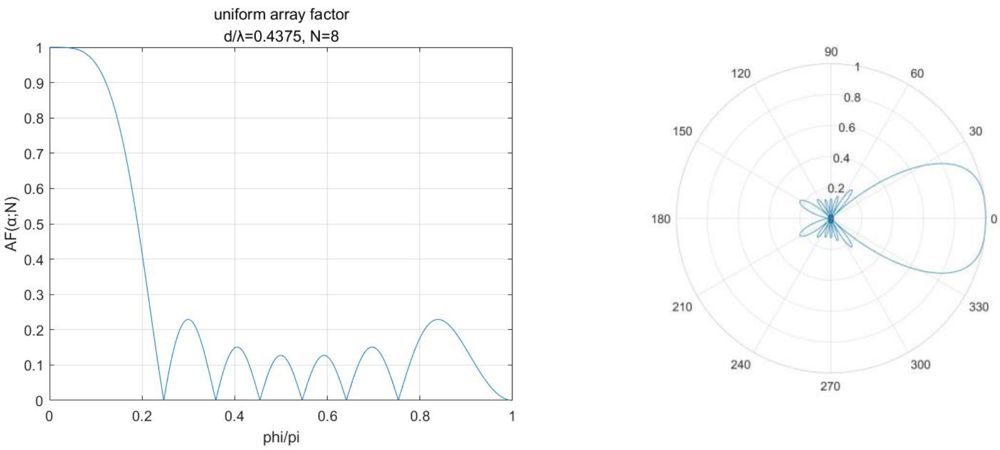

Figure 4: Uniform Array Factor with α

Problem no. 2- Array Factor Design

Design the array with AF pattern with omni-directional coverage in the horizontal plane, and directive pattern in the vertical plane with max radiation in the horizontal plane. The design should yield: N, d/lambda, Phi.

1. Design a Broad-Side uniform linearly-phased array with <u>min complexity</u>, with first-null beam width $FNBW \leq 20^{\circ}$; to verify your design, draw the array factor pattern in the horizontal and vertical planes and check specs are complied width.
2. Repeat the design considering the HP beamwidth as $HPBW \leq 16^{\circ}$, and verify your design against the specs as above.

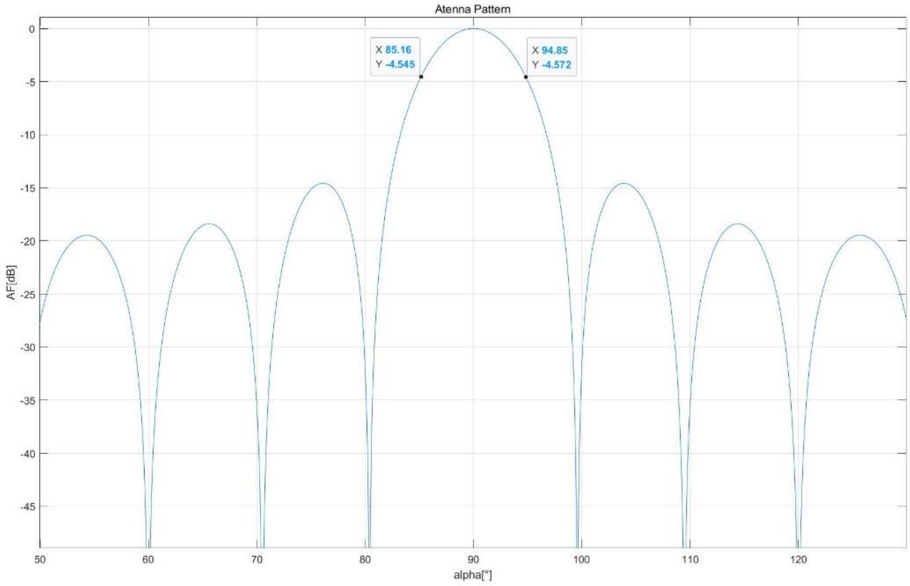

Figure P2.1: Antenna Pattern

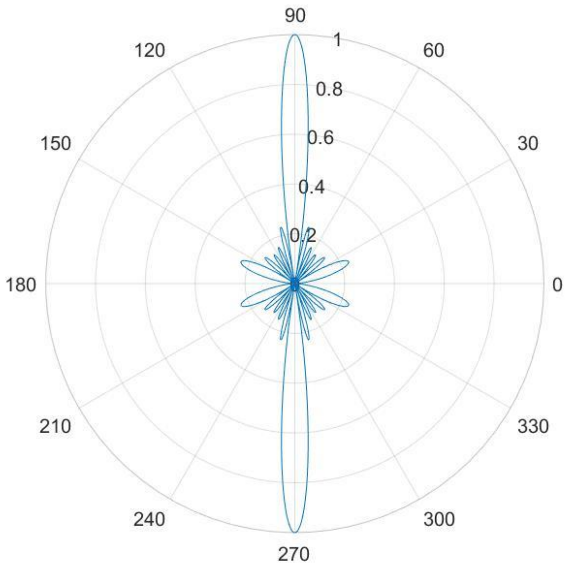

Figure P2.2: Antenna Pattern in Polar Coordinates

Appendix: Matlab codes

Problem 1

```
clear all;
close all;
clc
%1.3 uniform:I=1
j = sqrt(-1);
phi1 = 0:0.001:pi;      %phi = k*d*cos(alp)+PHI;
figure
for N=2:10
    AF = 0;
    F_N = (1/N)*abs(sin(N*phi1/2)./sin(phi1/2));
    for n=1:N
        AF = AF+exp(j*(n-1)*phi1);    %uniform phased
    end
    %plot(t,abs(real(AF/N)));
    plot(phi1/pi,F_N);
    hold on
end
xlabel('phi/pi');
ylabel('AF(phi;N)');
title('uniform array factor, N=2:10');
legend('N=2','N=3','N=4','N=5','N=6','N=7','N=8','N=9','N=10');
grid on

%1.4 uniform:I=1 with alpha
alp = -pi:0.001:pi;
d_lamuda = 0.4375;
PHI = -2*pi*d_lamuda;
phi2 = 2*pi*d_lamuda*cos(alp)+PHI;
N = 8;
F_N = (1/N)*abs(sin(N*phi2/2)./sin(phi2/2));
figure
plot(alp/pi,F_N);
xlabel('phi/pi');
ylabel('AF(¦Á;N)');
title({'uniform array factor';'d/¦Ë=0.4375, N=8'});
axis([0 1 0 1]);
grid on

figure
polarplot(alp,F_N);
```

```
%1.4 uniform:I=1 with alpha, other parameters
alp = -pi:0.001:pi;
PHI = 0;
N = 8;
d_lamuda = 1-1/N;
phi2 = 2*pi*d_lamuda*cos(alp)+PHI;
F_N = (1/N)*abs(sin(N*phi2/2)./sin(phi2/2));
figure
plot(alp/pi,F_N);
xlabel('phi/pi');
ylabel('AF(¦Á;N)');
title({'uniform array factor';'d/¦Ë=0.875, N=8, PHI/¦°=0'});
axis([0 1 0 1]);
grid on

figure
polarplot(alp,F_N);

%test An
N = 5;
t = [0.7 0.8 0.9];
k = acos(t);
d = 1;
a = [];
for n = 1:1:N
    An = cos(k*(((n-1)*d*2)/((N-1)*d)-1));
    a = [a;An];
end
n = 1:1:N;
figure
plot(n,a,'-o');
title('Excitation Amplitudes');
xlabel('element - n');
ylabel('rel.amplitude - An');
legend('Tap=0.7','Tap=0.8','Tap=0.9');
grid on

% with amp In, without alpha ---WRONG: not 1/N, but maxAF
phi3 = pi*(-2:0.001:2);
t = [0.7 0.8 0.9];
An = t/1;
d_lamuda = 0.875;
N = 9;
```

```
PHI = 0;
In = An*exp(j*(N-1)*PHI);
figure
for at = 1:1:3
    I = In(at);
    F_N = I*(1/N)*abs(sin(N*(phi3+PHI)/2)./sin((phi3+PHI)/2));
    F_Np = 10*log(real(F_N));
    plot(phi3/pi,F_Np);
    hold on
end
axis([-2 2.1 -40 0]);
xlabel('phi/pi');
ylabel('AF(dB)');
title({'Array Factor';'d/¦Ë=0.875, N=9'});
legend('Tap=0.7','Tap=0.8','Tap=0.9');
grid on
%-------WRONG------

% with amp In, with alpha
alpha = -pi:0.001:pi;
t = [0.5 0.7 0.9];
kn = acos(t);
d = 10;
N = 9;
PHI = 0;
figure
for at = 1:1:3
    k = kn(at);
    AFx = 0;
    FNx = [];
    A = [];
    for n = 1:1:N
        phi3 = k*d*cos(alpha)+PHI;
        An = cos(k*(2*(n-1)/(N-1)-1));
        A = [A,An];
        x = (n-1)*(phi3+PHI);
        AFx = AFx+An*exp(j*x);
    end
    FNx = [FNx,abs(AFx)/max(abs(AFx))];
    %F_N = (1/N)*abs(sin(N*(phi3+PHI)/2)./sin((phi3+PHI)/2));
    %F_Np = 10*log(real(F_N));
    FNx_db = 10*log(FNx);
    plot(phi3/pi,FNx_db);
    hold on
```

```
end
axis([-2 2 -50 0]);
xlabel('phi/pi');
ylabel('AF(dB)');
title('Array Factor,N=9');
legend('Tap=0.5','Tap=0.7','Tap=0.9');
grid on
```

Problem 2:

```
clear all;
close all;
clc

%yield N, d/lamuda, Phi
j = sqrt(-1);
N = 7;
alp = -pi:0.001:pi;
d_lamuda = 1-1/N;
PHI = 0;

%1. min complexity, FNBW<=20
%2. HPBW<=16
phi = 2*pi*d_lamuda*cos(alp)+PHI;
F_N = (1/N)*abs(sin(N*phi/2)./sin(phi/2));
F_Ndb = 10*log(F_N);
figure
plot(alp*180/pi,F_Ndb);
xlabel('alpha[¡ã]');
ylabel('AF[dB]');
title('Atenna Pattern');
axis([50 130 -50 0]);
grid on
figure
polarplot(alp,F_N);
```

Reference:

1. linear_AF_7x3.pdf, in section ‘Handouts’

Discussed with student Zhang Zhifan.