Advanced Antenna Engineering

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I, the undersigned Tong Lin

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TONG LIN
(Complete name, please print)

全霖. Tong Lin

signature[6]

Torino, _____________ _______ (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

Assignment 5 TONG LIN S287649

1. Design a BS AF of Dolph-Chebyshev.

To achieve min complexity and an optimum solution, the system should satisfy this conditions,

$$f_{BW}(N') \le \frac{d}{\lambda} \le f_{GL}(N')$$

where $N' = N - 1$.

To be specified,

① $f_{GL}(N') = \dfrac{\frac{1}{\pi}\cos^{-1}\left[\frac{-1}{x_0(N')}\right]}{1 + |\cos\alpha_{max}|}$

where,

- $x_0(N') = \cosh\left(\frac{\cosh^{-1} R_0}{N'}\right)$, $R_0 = \frac{1}{SLL}$
- $\cos\alpha_{max} = -\frac{\Phi}{kd} = 0$, according to the Broadside design, $\Phi = 0$.

② $f_{BW}(N') = \dfrac{\phi_{BW}^{(N)}/2}{\sin\Delta\beta}$

$$= \frac{1}{\pi \sin\Delta\beta} \cos^{-1}\left[\frac{x_{BW}(N')}{x_0(N', R_0)}\right].$$

where,

- $x_{BW}(N') = x_{HP}(N', R_0)$
  $= \cosh\left[\frac{1}{N'}\cosh^{-1}\left(\frac{R_0}{\sqrt{2}}\right)\right]$, $R_0 = \frac{1}{SLL}$
- $x_0(N', R_0) = \cosh\left(\frac{1}{N'}\cosh^{-1} R_0\right)$.
- $\Delta\beta = \frac{1}{2}BW = \frac{1}{2}HPBW \le 5°$

Applying the conditions from the question, that $SLL \le -20dB$ and $HPBW \le 10°$, the result can be compulated ~~by~~ using Matlab.

$$N = 10, \quad \frac{d}{\lambda} = 0.9430$$

To verify this results, SLL and HPBW have be calculated again using Matlab, where $SLL = -20dB$, $HPBW = 7.69°$.

Here also, 'x to ψ mapping' and 'Chebyshev Polynomials' have been plotted using Matlab, to verify the design, as shown in figure 1.1 and figure 1.2.

The normalized amplitude (excitation coefficients) $a_n = \frac{I_n}{I_{max}}$, has been ~~pole~~ plotted in figure 1.3.

The plot of AF vs. observable angle α comparing with the uniform array is as shown in figure 2.1.

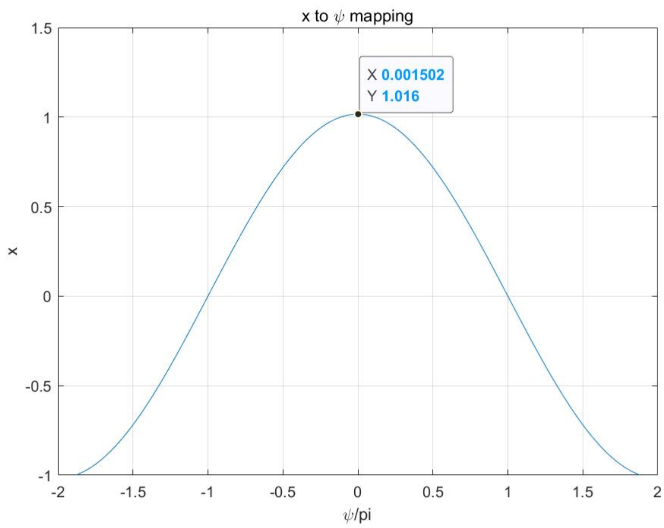

Figure 1.1: x to ψ Mapping

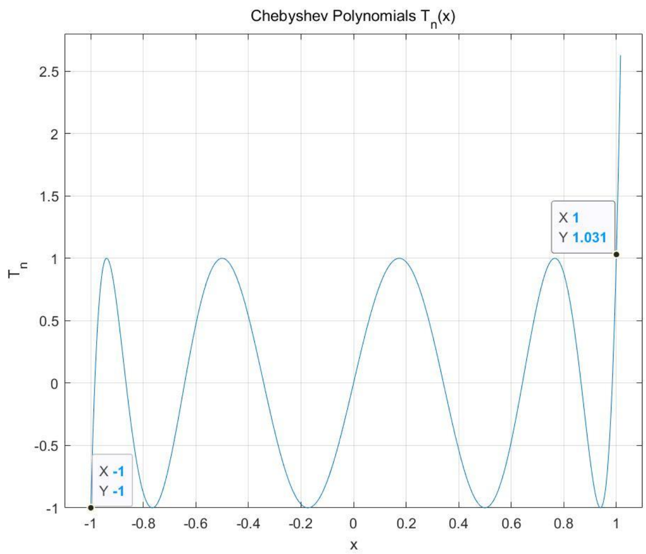

Figure 1.2: Chebyshev Polynomials $T_n(x)$

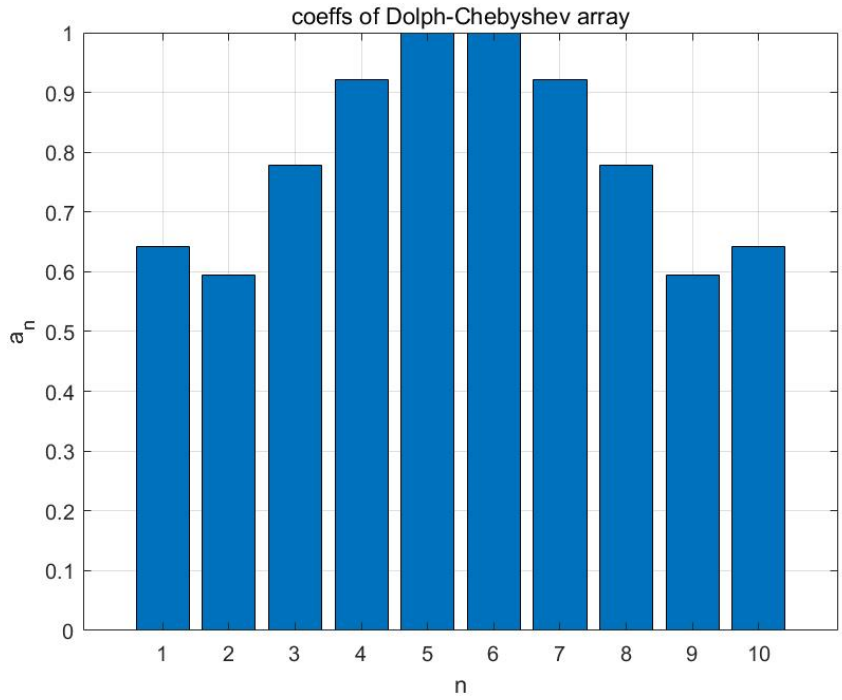

Figure 1.3: Excitation Coefficients

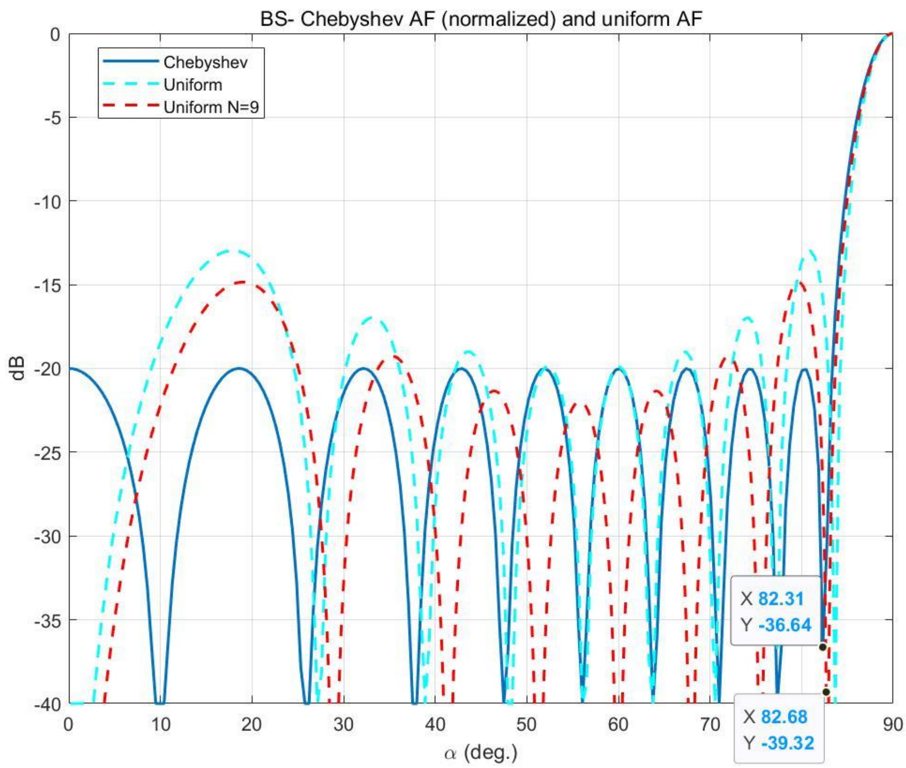

Figure 2.1: Chebyshev vs. Uniform AFs

2. Uniform Array

Applying the same specifications, that SLL ≤ -20 dB, and HPBW $\le 10°$, and using the conditions,

$$f_{BW}(N_x) \le \frac{d}{\lambda} \le f_{GL}(N_x).$$

where, $f_{BW}(N_x) = \frac{\gamma_{BW}}{\sin\frac{1}{2}BW} \cdot \frac{1}{N_x}$

- $\gamma_{BW} = 0.45$
- $BW = HPBW \le 10°$

$$f_{GL}(N_x) = 1 - \frac{1}{N_x}$$

$$N = N_x + 1.$$

The resulots can be cauculated using Matlab.

$$\begin{cases} N = 9 \\ \frac{d}{\lambda} = 0.8889. \end{cases}$$

Plot the both AF f satisticis in the same figure as shown in figure 2.1.

The line of 'Chebyshev' and 'Uniform' are plotted with the same ~~con~~ design, with $N = 10$, $\frac{d}{\lambda} = 0.9430$.

The line of 'Uniform $N=9$' is plotted with $N=9$, $\frac{d}{\lambda} = 0.8889$ accroding to the same specifications as Chebyshev array.

It can be easily telled by the figure, that the bandwidth of the uniform design is slightly smaller than the Chebyshev design, whereas the number of element with uniform design is smaller than the Chebyshev design when acheive the same specifications. However, accroding to the parameter of side lobe level, Chebyshev design shows much better behavior compares with the uniform design, and also better behavior accroding to the max directivity.

Appendix: Matlab codes

Problem 1: Design of question 1

```
close all;
clear all;
clc

SLL = -20;      % -20dB
HPBW = 10;      % [degree]
%R0 = real(10*log10(1./SLL));
R0 = 1/SLL;
delta_beta = HPBW*pi/360;   %[rad]
N1 = 1:1:100;

x0 = cosh(acos(R0)./N1);
xBW = cosh(acosh(R0/sqrt(2))./N1);
fGL = real(acos(-1./x0)/pi);
fBW = real(acos(xBW./x0)./(pi*sin(delta_beta)));

a = [fBW;fGL];      % ---N1=9; N=10

%verify
N1 = 9;
N = N1+1;
x0 = cosh(acos(R0)./N1);
xBW = cosh(acosh(R0/sqrt(2))./N1);
fGL = real(acos(-1./x0)/pi);
d_lamuda = fGL;
alp = 0:0.001:pi;
phi = 2*pi*d_lamuda*cos(alp);
T0 = cosh(N1*acos(x0));
R0 = T0;
SLL = 1/R0;
  %HPBW accroding to the figures

figure
x = x0*cos(phi/2);
plot(phi/pi,x);
xlabel('\psi/pi');
ylabel('x');
title('x to \psi mapping');
grid on
figure
TN1 = cos(N1*acos(x));
```

```
plot(x,TN1);
xlabel('x');
ylabel('T_n');
title('Chebyshev Polynomials T_n(x)');
axis([-1.1 1.1 -1 2.8]);
grid on
```

Problem 2: Design of question 2

```
clear all;
close all;
clc

N1 = 0:1:15;
xBW = 0.45;
BW = 10*pi/180;  %[rad]

fBW = (1./N1).*xBW./sin(0.5*BW);
fGL = (1-1./N1);

A = [fBW;fGL];

N = 9;
d_lamuda = 1-1/N;

%yield N, d/lamuda, Phi
j = sqrt(-1);
alp = -pi/2:0.001:0;
PHI = 0

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);
axis([-90 0 -40 0]);
grid on
```

Problem 1: Analyzations

```
% Dolph_Chebyshev array coefficients
clear all;
close all;
clc
% input pars
N=10; % number of elements
```

```
R0dB=-20; %SLL in dB
nsamp=200; %n. of samples for plot in psi
bottom=-40; %dB, bottom of scale        ?????????

%----------- start -------------
clear p
clear xz
clear psiz
clear psizu

P=N-1;
R0=10^(abs(R0dB)/20);
x0=0.5*( (R0+sqrt(R0^2-1))^(1/P)+(R0-sqrt(R0^2-1))^(1/P));

%zeros in x and zeros in psi
if parity(P)==0
  PP=P/2;
  p=(1:1:PP);
  xzp=cos(pi*(2*p-1)/(2*P));
  psizp=2*acos(xzp/x0);
  psiz(1:PP)=psizp;
  psiz(PP+1:P)=-fliplr(psizp);
  % zeri della schiera uniforme
  %psizup=p*(2*pi/P);
  psizup=p*(2*pi/N);
  psizu(1:PP)=psizup;
  psizu(PP+1:P)=-fliplr(psizup);
  % fine
else
  PP=fix(P/2);
  p=(1:1:PP);
  xzp=cos(pi*(2*p-1)/(2*P));
  psizp=2*acos(xzp/x0);
  psiz(1:PP)=psizp;
  psiz(PP+1)=pi;
  psiz(PP+2:P)=-fliplr(psizp);
  % zeri dell'uniforme
  %psizup=p*(2*pi/P);
  psizup=p*(2*pi/N);
  psizu(1:PP)=psizup;
  psizu(PP+1)=pi;
  psizu(PP+2:P)=-fliplr(psizup);
end
% zeros in w
```

```
clear wz
wz=exp(j*psiz);
clear a;
clear an
a(1)=-wz(1);
a(2)=1;
for k=2:P;
   wzk=wz(k);
   an(1)=-wzk*a(1);
   an(2:k)=a(1:(k-1))-wzk*a(2:k);
   an(k+1)=a(k);
   a=an;
end
a=real(a); %clean up num. noise
% schelkunoff's circle
figure(1);
polar(psiz,ones(size(psiz)),'bo');
hold on;
polar(psizu,ones(size(psiz)),'r+');
hold off;
title('zeros; o=Chebyshev, +=uniform');

aa=a/max(a);
%figure(2);bar(real(aa),0.1) % (a should be real except for num. roundoff)
figure(2);bar(real(aa)) % (a should be real except for num. roundoff)
title('coeffs of Dolph-Chebyshev array')
xlabel('n');
ylabel('a_n');
grid on
% AF in psi plane
psi=linspace(0,pi,nsamp);
% uniform array, normalized to 1
afu=af(psi,N);
% Cheb. array
afc=af_nu(psi,a);
aaa=max(abs(afc));
afc=afc/aaa;
figure(3);plot(psi/pi,abs(afc),psi/pi,abs(afu),'--');
title('Chebyshev AF (normalized) and uniform AF');
xlabel('\psi/\pi')
legend('Chebyshev','Uniform');
grid on
cdb=db(abs(afc).^2,bottom);
udb=db(abs(afu).^2,bottom);
```

```
figure(4);plot(psi/pi,cdb,psi/pi,udb,'--');
title('Chebyshev AF (normalized) and uniform AF');
xlabel('\psi/\pi')
ylabel('dB')
legend('Chebyshev','Uniform');
grid

% BS case, optimal d/lambda and plot in obs. angle
dlam_u=1-1/N;
dlam_c=(acos(-1 ./x0))/pi

%dlam_c=0.8

beta=linspace(0,pi/2,200);
psiu=2*pi*dlam_u*sin(beta);
psic=2*pi*dlam_c*sin(beta);
% uniform array, normalized to 1
afu=af(psiu,N);
% Cheb. array
afc=af_nu(psic,a);
aaa=max(abs(afc));
afc=afc/aaa;

bottom=-40; %dB, bottom of scale
cdb=db(abs(afc).^2,bottom);
udb=db(abs(afu).^2,bottom);
figure(5);plot((pi/2-beta)*180/pi,cdb,(pi/2-beta)*180/pi,udb,'c--
','LineWidth',1.5);
hold on
%uniform
N = 9;
d_lamuda = 1-1/N;
j = sqrt(-1);
alp = 0:0.001:pi/2;
PHI = 0
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);
plot(alp*180/pi,F_Ndb,'r--','LineWidth',1.5);
axis([0 90 -40 0]);
grid on
title('BS- Chebyshev AF (normalized) and uniform AF');
xlabel('\alpha (deg.)')
ylabel('dB')
```

```
legend('Chebyshev','Uniform','Uniform N=9');
grid on
```

Appendix: Additional plotted figures of Problem 1

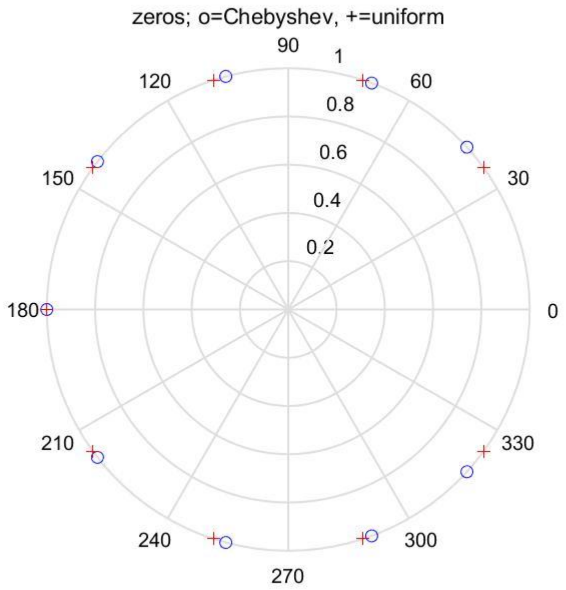

Figure 1.4: Zeros of Chebyshev and Uniform design with same N and d/λ plot in polar coordinates

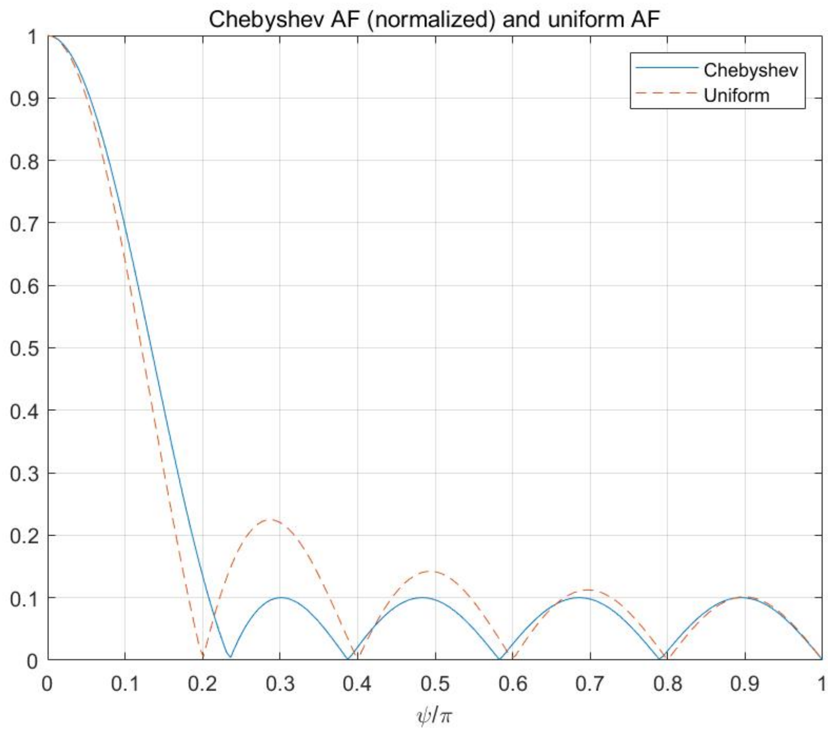

Figure 1.5: Array Factors of Chebyshev and Uniform design with same N and d/λ

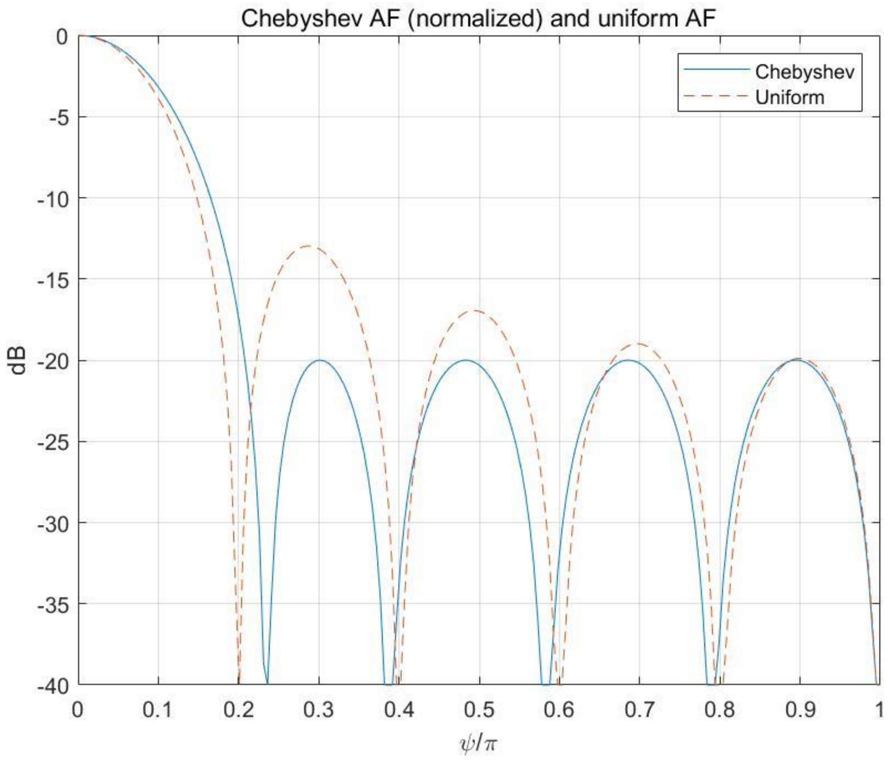

Figure 1.6: Array Factors [dB] of Chebyshev and Uniform design with same N and d/λ

Reference:

1. linear_AF_7x3.pdf, in section 'Handouts';
2. Cheb_design_v6x0.pdf, in section 'Handouts';
3. Matlab codes in 'chebyshev_matlab_v5x1'.