Optics and Radar based Observations

Assignment 3

Optimization of phased array antenna radiation pattern and array configuration

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23rd-May-2011

1. Introduction to the problem

In radar system, a phased array is defined as a group of individual antennas or radiating elements which made up of a directive antenna. The relative phases of the respective signals feeding the antennas are varied such that the radiation pattern of the array is reinforced either in a desired direction or undesired directions. Usually, the amplitude and phase of each element are composed to determine the radiation pattern. One of the advantage applied in the antenna is by changing the phase of the current at each element, we can steer the angle of the beam. [2]

As shown in the assignment instruction sheet, the diagram which was provided can be determined as a linear array. It consists of a number of antenna elements placed in a straight line and the distance between each of the element is usually keeping in constant. Consider the receiving linear array made up 64 lined up individual isotropic antennas so that the response signals are from all the directions and uniform. [4]

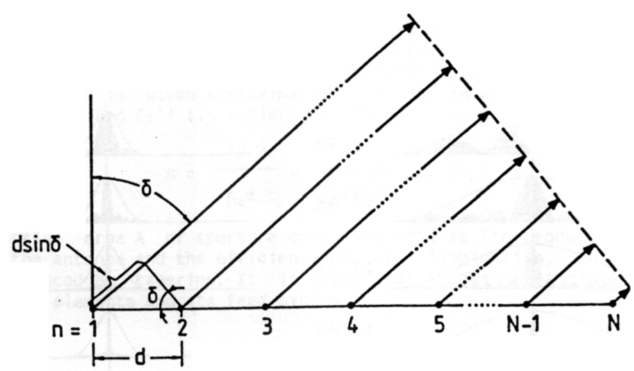

Figure 1 – Schematic of the antenna parameters on a phased array.

As shown in the figure, the difference between each path length with respect to angle θ is $d\sin\theta$, which also lead to a phase difference between the adjacent elements. That can be calculated as $\phi = 2\pi(d/\lambda)\sin\theta$ .For λ is the wavelength of the received signal. As described above, the sum of all the voltages from the individual elements, which is the field intensity function Ea, can be written as following:

$$E(\delta)=\sum_{n=1}^{N} En(\delta)\exp(i(\frac{2\pi(n-1)d}{n_0}\sin\delta+\phi_n)) \qquad (1)$$

There are two assumptions used to simplify the formula.

If we assume it is an isotropic antenna, the energy pattern (δ) of each individual element would be the same for all of them and also the phase angle between them is zero, φn = 0.

Since all the elements in the linear array are similar and ϕ are the same, the equation reduces to

$$\left|E_\phi(\theta)\right| = \left|\frac{\sin[N\pi(d/\lambda)\sin\theta]}{\sin[\pi(d/\lambda)\sin\theta]}\right| \qquad (2)$$

Where N is the number of the antenna elements.

θ is the angle between the antenna and the target with respect to horizon.

d is the constant distance between each antenna.

λ is the received wavelength of the signal

The above equation is the one used to demonstrate how the radiation pattern changes according to each parameter. [3]

2. Data Analysis and Discussion

It has been described how the radiation pattern of a phased array depends on several parameters and how these parameters relate between them to describe the radiation pattern of the antenna. It is intended to show now how the radiation pattern of the array changes when each one of the parameters varies.

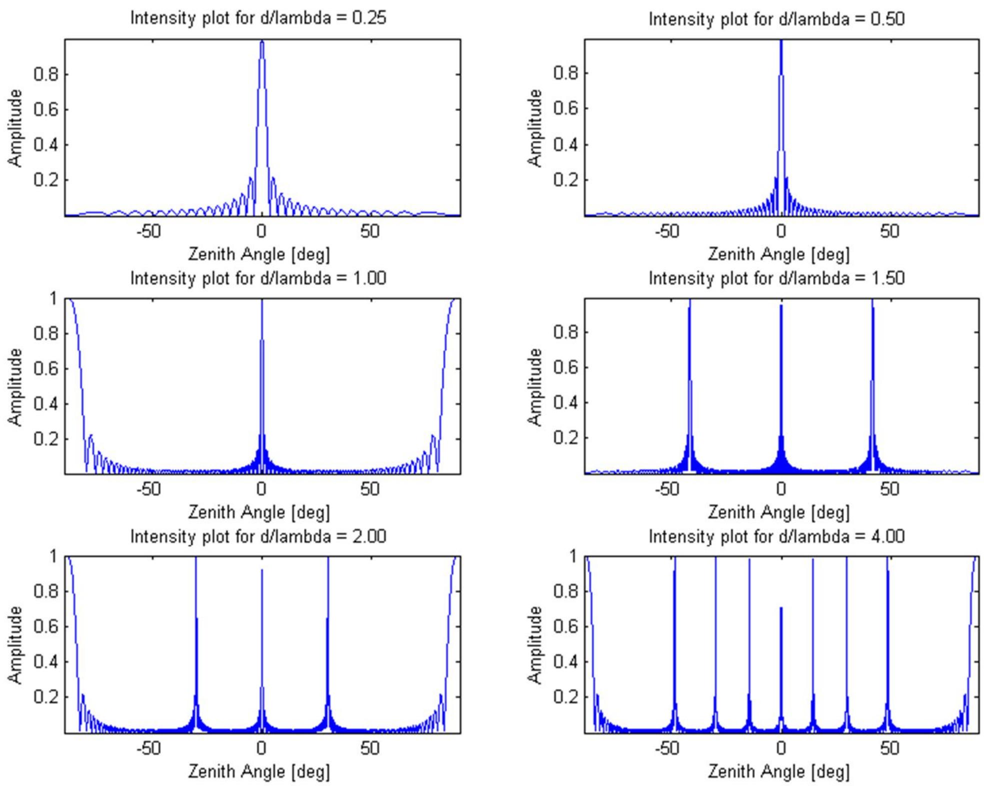

Figure 2 – Variation of the radiation pattern of a phased array when the ratio between the wavelength and distance between individual elements varies.

The ratio between the signal wavelength and the distance between the individual elements of the array is one of the parameters that affect the radiation pattern of antenna. Figure 2 shows the radiation pattern of a phased array of 64 elements with ratios equal to 0.25, 0.5, 1.0, 1.5, 2.0 and 4.0. When the ratio is equal to 1 it means that the distance between the individual elements is the same than the wavelength and we can see that the array will provide the largest amount of energy when the array is completely perpendicular (0 degrees) or parallel (+90 or -90 degrees) to the ground plane. In this case the ideal position would it be when the antenna is perpendicular to the ground because a parallel position of the antenna will find interference caused by the irregularities of the geography and these interferences might produce noise. In addition, it can be seen that the amount of sidelobes around zero degrees is smaller than the around +/- 90 degrees.

Having described the situation with a ratio equal to 1, we found two different situations when the ratio is smaller than one which means that the wavelength is larger than the distance between the individual elements and when the ratio is larger than 1 which means that the distance between the individual elements is larger than the wavelength.

A wavelength larger than the distance between the individual elements will cause the antenna to provide the largest amount of energy around zero degrees only without this occurring at any other angle. Also, it is seen that a large wavelength value (smaller ratio value) will produce larger sidelobes, and as the wavelength value is increased the amplitude of the sidelobes decreases.

The other observed situation is when the distance between the individual elements of the array is larger than the wavelength (ratio bigger than zero). This situation will produce more spikes with a large amplitude value at different angles different than zero, the bigger the ratio is the larger the amount of spikes that is produced. Also, it can be seen that as the ratio becomes larger and larger the energy value at zero degrees start to decrease and greater amount of energy will occur at angles different that zero.

Figure 2 provides the opportunity to see the impact of changing the distance between the individual elements only. As seen on the phased array energy equation the distance between the individual elements is proportional to the energy therefore it we assume that the wavelength is the same for all the plots on figure 2 then we can see that the changes in the plots will depend entirely on the distance between the individual elements. Besides the changes already described, we can see that increasing the distance between the elements will decrease the amplitude of the sidelobes around the amplitude spikes however it is also seen that the width of the spikes is decreasing as the distance increases. Therefore, it can be concluded that the distance between the elements causes a reduction on the sidelobes value and at the same time reduces the width of the spikes.

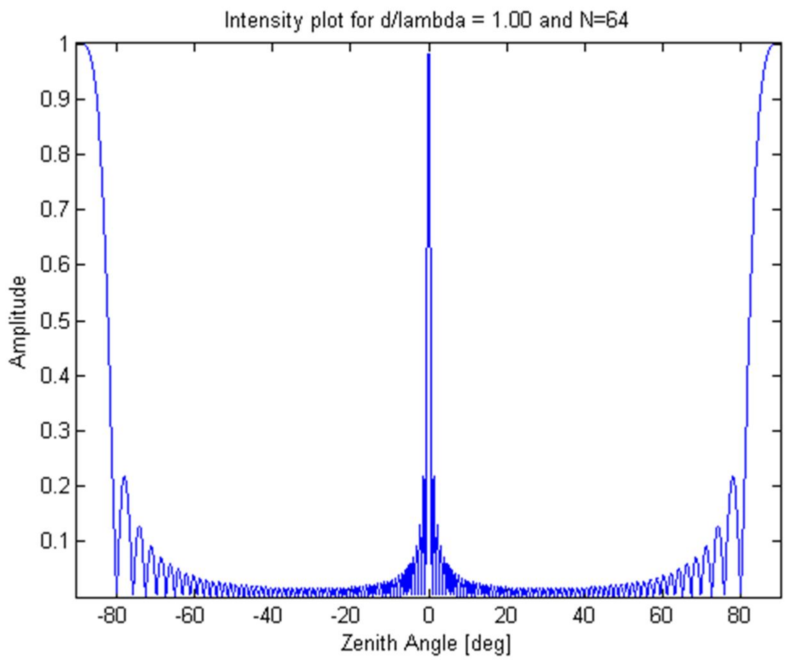

Figure 3 – Variation of the radiation pattern of a phased array according to the zenith angle (aspect sensitivity).

The above figure shows the energy pattern of a phased array with 64 elements and a ratio between the distance of the individual elements and wavelength equal to one. The purpose of the figure is to show how the energy pattern varies according to the zenith angle of the phased array. It can be seen that the largest amount of energy is found at 0, +90 and -90 degrees. The amplitude of the sidelobes around zero degrees is smaller than the spikes at +/- 90 degrees. Also, it is seen that the behaviour is symmetrical around zero degrees but asymmetrical between zero and +/- 90 degrees. Therefore if a large amount of energy is desired at an angle different than these other parameters must be change in order to obtain the desired energy.

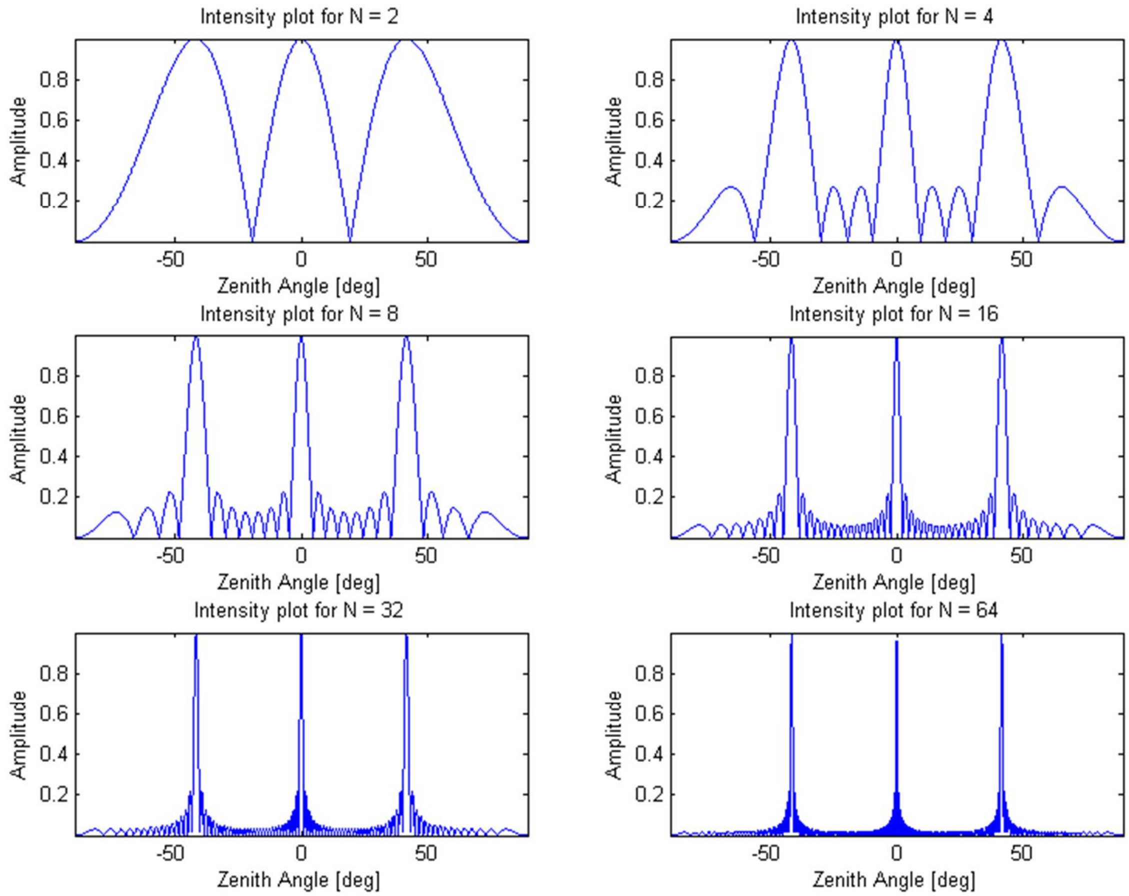

Figure 4 – Variation of the radiation pattern of a phased array when the number of antenna elements varies.

Figure 4 shows the variation of the radiation pattern of a phased array when the number of antenna elements changes. In all the plots the ratio between distance between individual elements and wavelength is equal to 1.5. It can be seen that the number of amplitude spikes and the zenith angle of these spikes are not affected by the number of antenna elements. The number of antenna elements affects the amplitude of the sidelobes around the spikes and the width of the sidelobes, also it is seen the reduction of the width is greater for the spike around zero degrees than for the spikes around other angles.

In order to find the optimal design for an antenna array it is necessary to consider which parameters can be modified constantly and which parameters must be fixed and cannot be changed continuously. Because of the required effort it can be concluded that the number of antenna elements and the distance between them must be a fixed number and the energy pattern should depend entirely on the signal wavelength and the zenith angle. Therefore, to get an optimal design a large number of antenna elements is recommended in order to obtain signals with small widths and small amplitude on the sidelobes, also the ideal distance between these elements should be value near the typical wavelength therefor on this way it will be able to provide ratios bigger than or smaller than a unit. The parameters that can be modified continuously are the wavelength and the zenith angle. A variation on the wavelength with a fixed distance between antenna elements will cause the variation on the ratio. This variation on the angle will help to produce large amplitude energy spikes at different zenith angles in accordance to the desired requirements for the signal.

Another option that could be implemented on the phased array is the electrical weighting which will consist on applying a different amount of energy to antenna element therefore focusing the energy beam around one point at the array and reducing energy around this point to the outer antenna element. This action would be useful to increase width of the central point since more power will flow to this point and surrounding points in the array will have smaller widths because of the reduction on power that is given to this central point. [4]

3. References

[1] Antenna Arrays URL http://www.antenna-theory.com/arrays/main.php

[2] Phased Array, Wikipedia URL http://en.wikipedia.org/wiki/Phased_array
Last updated: 9th-May-2011

[3] Rottger, Juregn, The Instrumental Principles of MST Radar And Incoherent Scatter Radars and The Configuration of Radar System Hardware, 1989

[4] Skolnik, Merrill, Introduction to Radar Systems, 3rded. McGraw-Hill Education, 2001

Implemented MatLab Codes

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% Radar Assignment3

%Sergio Martin del Campo Barraza
%Diwei Zhang
%
%Code to process variations of the antenna radiation pattern by modyfing
%the ratio between the distance elements and the wavelength

N = 64;
tetha=-90:0.1:90;
ratio=[.25,.5,1,1.5,2,4];
for i=1:length(tetha)
    for j=1:length(ratio)

Ea(j,i)=(sin(N*pi*(ratio(j))*sin(tetha(i)*pi/180)))/(sin(pi*(ratio(j))*si
n(tetha(i)*pi/180)));
    end
end

%Plotting of the graphs at different ratios
figure
subplot(3,2,1);
plot(tetha,abs(Ea(1,:))/N)
axis tight
title('Intensity plot for d/lambda = 0.25 ')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
subplot(3,2,2)
plot(tetha,abs(Ea(2,:))/N)
axis tight
title('Intensity plot for d/lambda = 0.50 ')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
subplot(3,2,3)
plot(tetha,abs(Ea(3,:))/N)
axis tight
title('Intensity plot for d/lambda = 1.00 ')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
subplot(3,2,4)
plot(tetha,abs(Ea(4,:))/N)
axis tight
title('Intensity plot for d/lambda = 1.50 ')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
subplot(3,2,5)
plot(tetha,abs(Ea(5,:))/N)
axis tight
title('Intensity plot for d/lambda = 2.00 ')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
subplot(3,2,6)
plot(tetha,abs(Ea(6,:))/N)
```

```
axis tight
title('Intensity plot for d/lambda = 4.00 ')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')

%Plotting of the graph at ratio equal one
figure
plot(tetha,abs(Ea(3,:))/N)
axis tight
title('Intensity plot for d/lambda = 1.00 and N=64')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
```

```
%Assigmnent3 radar part2

%Code to process variations of the antenna radiation pattern by modyfing
%the number of elements on the array

ratio=1.5;
tetha=-90:0.1:90;
N=[2,4,8,16,32,64];
for i=1:1:length(tetha);
    for j=1:length(N);

Ea(j,i)=(sin(N(j)*pi*(ratio)*sin(tetha(i)*pi/180)))/(sin(pi*(ratio)*sin(t
etha(i)*pi/180)));
    end
end

%Plotting of the graphs at different element numbers
figure
subplot(3,2,1);
plot(tetha,abs(Ea(1,:))/N(1))
axis tight
title('Intensity plot for N = 2')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
subplot(3,2,2)
plot(tetha,abs(Ea(2,:))/N(2))
axis tight
title('Intensity plot for N = 4')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
subplot(3,2,3)
plot(tetha,abs(Ea(3,:))/N(3))
axis tight
title('Intensity plot for N = 8')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
subplot(3,2,4)
plot(tetha,abs(Ea(4,:))/N(4))
axis tight
title('Intensity plot for N = 16')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
subplot(3,2,5)
plot(tetha,abs(Ea(5,:))/N(5))
axis tight
title('Intensity plot for N = 32')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
subplot(3,2,6)
plot(tetha,abs(Ea(6,:))/N(6))
axis tight
title('Intensity plot for N = 64')
ylabel('Amplitude')
xlabel('Zenith Angle [deg]')
```

Confirmation of Participation

The purpose of this document is to confirm our participation in the realization of this assignment. The members of this team participated on the investigation of the required information to solve the assignment, generated their code to perform the calculations and discussed the results.

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Diwei Zhang

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Sergio Martin del Campo Barraza