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What is the best distance, and phase difference between the elements of Linear Antenna Array?

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Abstract

The aim of this paper is to make real observation by MATLAB codes, the first thing to do is find radiation pattern with different excitation current way, and different technique to choice the phase; for linear array.

Index Terms —Antenna, Radiation pattern, Linear array.

I. INTRODUCTION

Antenna array is a configuration of multiple antennas (elements) arranged to achieve a given radiation pattern. Antenna arrays are important components of present day wireless communication systems. The current wireless standards include advanced antenna array concepts such as adaptive antenna arrays and MIMO (Multiple- Input and Multiple-Output) systems to improve the performance of the communication system, as in wireless communication systems that having antenna arrays at both the base station and the wireless terminal, which will improve the spectral efficiency and quality of, service (QoS). In an array of identical elements, there are at least five controls that can be used to shape the overall pattern of the antenna. These are:

1. The geometrical configuration of the overall array (linear, rectangular, etc.)
2. The relative displacement between the elements
3. The excitation amplitude of the individual elements
4. The excitation phase of the individual elements
5. The relative pattern of the individual elements.

In a linear array, the elements are arranged along a straight line. The antenna array design process is fundamentally similar to the filter synthesis problem. This enables the use of the signal processing functions in antenna array analysis. In all simulation, we assume that the element of the array are uniformly-spaced with a separation distance *d* in the same line.

A simulation using *MATLAB*™ / signal processing toolbox is carried out to identify the radiation pattern in different cases.

II. OVERVIEW OF CHANGING OF INTER-ELEMENT SPACING FOR ANTENNA ARRAY

We will examine the pattern variation as a function of the element spacing, with wavelength 1 for 4 element, by using the following code to generate the radiation pattern as in Figure.1:

Code #1:

```
N=4;%number of element
k=2*pi;% wave number
d=0.5;% the inter-element spacing
phi=0 : 0.01 : 2*pi;   %  0 < phi < 2*pi
shi = k*d*cos(phi);% complex currents of the elements
Currents = [1,1.2,1.2,1];% current excitations
E = freqz(Currents, 1, shi);% E for different shi values
En=E/max(E);% normalized E
Polar2(phi, E);% Generating the radiation pattern
```

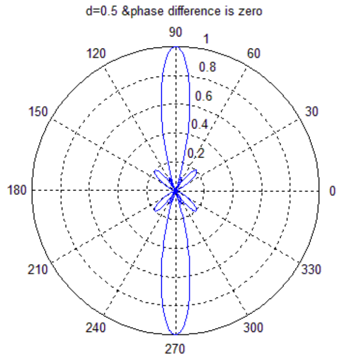

Fig.1. the radiation pattern of a four-element linear array with inter element spacing=0.5 & phase difference is zero

Now we will test the inter-element spacing *d=0.25* (we decrease *d*) and we will get the radiation pattern that shown in Figure.2:

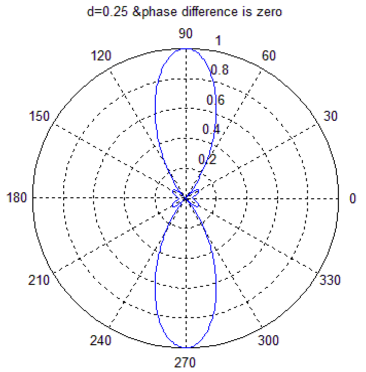

Fig.2. The pattern of four-element with inter element spacing=0.25 & phase difference is zero

As inter element spacing is increase the number of side lobes will increase and the peak of side lobes increase. However, when inter, element spacing is increased the main lobe become narrow (higher directivity) but there is grating lobe.In general, as the element spacing is increased, the main lobe beamwidth is decreased. However, *grating lobes* (maxima in directions other than the main lobe direction) are introduced when the element spacing is greater than or equal to one wavelength. If the array pattern design requires that no grating lobes be present, then the array element spacing should be chosen to be less than one wavelength. So as observed the radiation pattern in Figure.1 is the best, and the inter element spacing as in Figure.1 will be used in the following cases.

III. OVERVIEW THE EFFECT OF PHASE DIFFERENCE FOR ANTENNA ARRAY

In this section we will test the effect of changing the phase difference, by using the following code to generate the radiation pattern as shown in Figure.3:

Code #2:

```
alpha=90; N=4;%number of element
```

```
d=0.5;% the inter-element spacing
phi=0 : 0.01 : 2*pi;      %  0 < phi < 2*pi
shi = alpha+k*d*cos(phi);% complex currents of the elements
Currents = [1,1.2,1.2,1];% current excitations
E = freqz(Currents, 1, shi);% E for different shi values
En=E/max(E);
Polar2 (phi, En);% radiation pattern
```

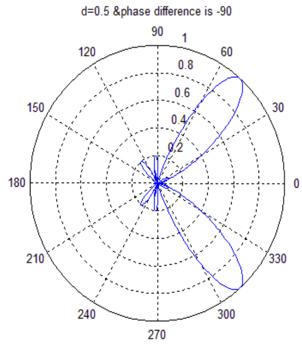

Fig.3. Inter element spacing=0.5 & phase difference is - 90°

We will test the phase difference 90° and we will get the radiation pattern which shown in Figure.4.

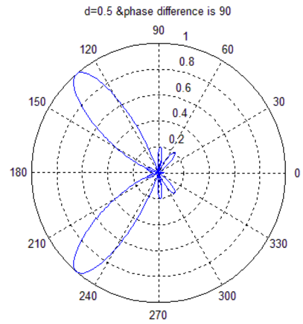

Fig.4. Inter element spacing=0.5 & phase difference is 90°

Now we will test the phase difference =-45° and 45° also -35°; we will get the radiation patterns as in Figures 5, 6 &7.

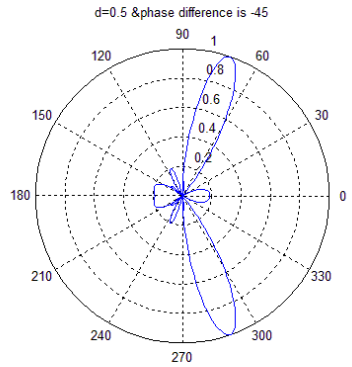

Fig.5. Inter element spacing=0.5 & phase difference is- 45°

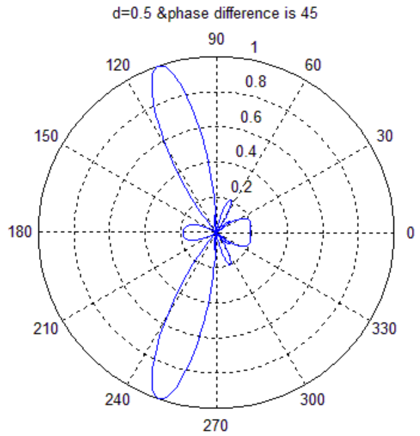

Fig.6. Inter element spacing=0.5 & phase difference is 45°

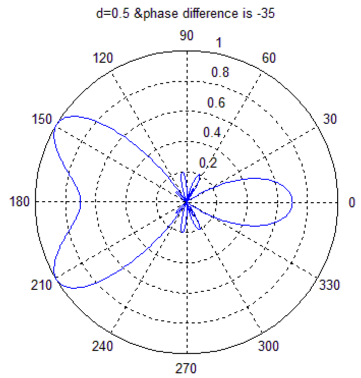

Fig.7. Inter element spacing=0.5 & phase difference is -35°

We observe from figures, which presented in this section that the direction of the radiation pattern is change as the phase difference change; also, as we see that the shape of the radiation pattern is changing. About the effect of the phase, difference on the directivity of the main lobe is small but when the phase difference is small angle as -35° the main lobes is overlaps.

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IV. LINEAR ARRAY

This section will be discuses the radiation pattern of the linear array of uniform excitation current, Binomial array and different amplitude of excitation current and also chebyshev array; in each case the different technique to choice the phase had been discussed.

The different technique to choice the phase that will be discussed in this section are end-fire array, Hansen woodyard end fire array and broadside array. The code#1 will be used in this section with simple modification as will be seen.

For **equal excitation current** [1,1,1,1] the code #2 will be used, but replace line 5 with the following line:

Currents = [1,1,1,1];% current excitations

The radiation patterns of equal excitation current with **phase difference 60°** shown in Figure 8.

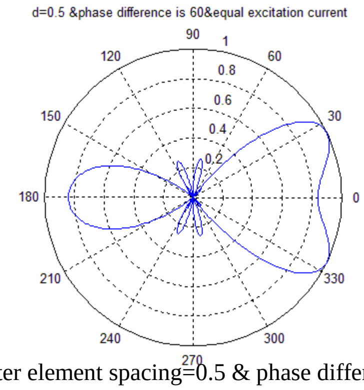

Fig.8. Inter element spacing=0.5 & phase difference is 45°

The phasing of the uniform linear array elements may be chosen such that the main lobe of the array pattern lies along the array axis (*end-fire array*) or normal to the array axis (*broadside array*) or (*Hansen woodyard end-fire array*). Now we test **broadside array** with using code#1 with excitation currents [1,1,1,1] and the resulting radiation pattern as Figure.9:

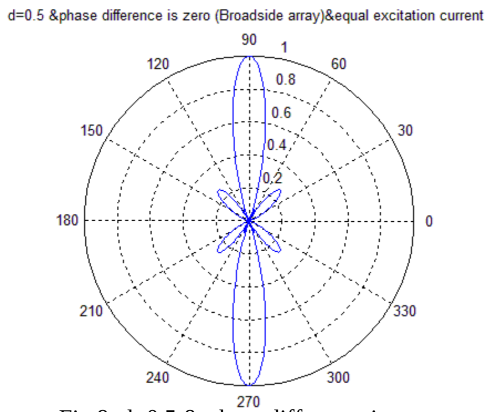

Fig.9. d=0.5 & phase difference is zero (Broadside array) & equal excitation current

For **End-fire array** the phase difference (alpha=-k*d the main lobe at $\theta = 0$ and alpha=k*d the main lobe at $\theta = 180$) use code#1 with excitation current [1,1,1,1], and the resulting radiation pattern as Figure.10.

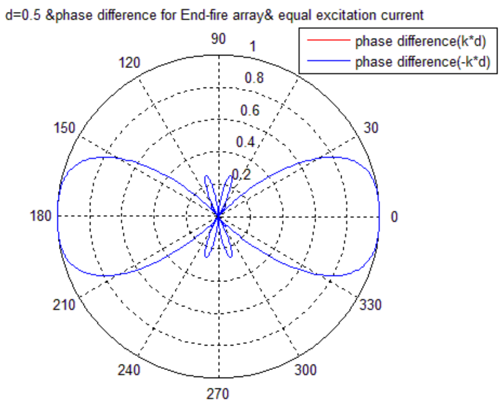

Fig.10. d=0.5 & phase difference is (kd) &(-kd), equal excitation current

The **Hansen-Woodyard end-fire array** is a special array designed for maximum directivity. The phase difference $\pm(kd + \delta)$, the design shown here does not necessarily produce the maximum directivity for a given linear array but does produce a directivity larger than that of the ordinary end-fire array; $\delta = \frac{\pi}{N}$ the inter element spacing $d = \frac{\lambda}{4}(1 - \frac{1}{N})$, but if number of element is large then d=λ/4, we will use the following code:

Code#3

```
 d=0.25*(1-(1/N)); %d=(landa/4)*(1-(1/N))
alpha=(k*d)+(pi/N);%alpha =-((k*d)+(pi/N));
shi = alpha+k*d*cos(phi);% complex currents of the elements
Currents = [1,1,1,1];% current excitations
E = freqz(Currents, 1, shi);% E for different shi values
En=E/max(E);
Polar2(phi, En);% radiation pattern
```

and the resulting radiation pattern as Figure.11:

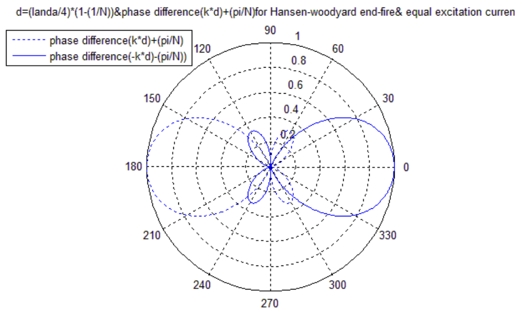

Fig.11. d=0.5 &Hansen woodyard end fire array& equal excitation current

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The same steps that discussed in this section will be applied for excitation current [1.2,1,1,1.2] & binomial array and chebyshev array.

Now we want to test the excitation current that the maximam value at the ends and the value reduce as go to center, the current assumed to be [1.2,1,1,1.2], To plot radiation patterns of excitation current [1.2,1,1,1.2], with **phase difference -60° and 60°** code#2 will be used and the resulting polar plot is Figure12:

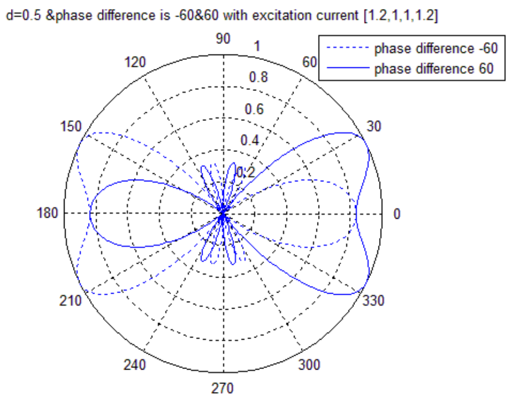

Fig.12. d=0.5 & phase difference is -60°&60° & excitation current [1.2,1,1,1.2]

Now we test **broadside array** with using code#1 with excitation currents [1.2,1,1,1.2] and the resulting radiation pattern as Figure 13:

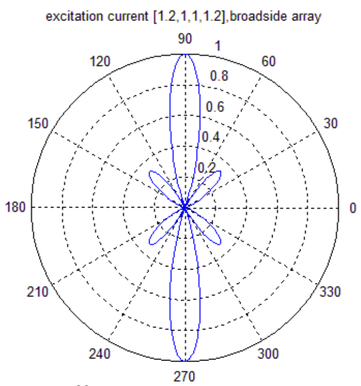

Fig.13. phase difference is zero& excitation current [1.2,1,1,1.2]

For **End-fire array** the phase difference (alpha=-k*d the main lobe at $\theta = 0$ and alpha=k*d the main lobe at $\theta = 180$) use code#1 with excitation current [1.2,1,1,1.2], and the resulting radiation pattern as Figure.14.

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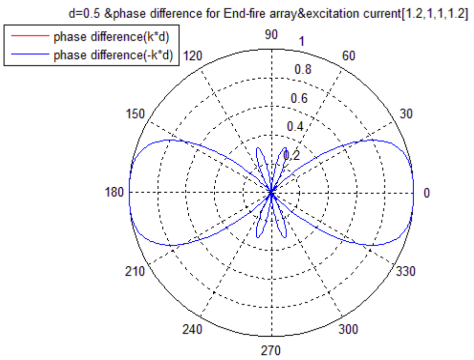

Fig.14. d=0.5 & phase difference for End-fire array& excitation current [1.2,1,1,1.2]

For **Hansen-Woodyard end-fire array** the code#3 will be used and the excitation current [1.2,1,1,1.2], and the resulting radiation pattern as Figure.15.

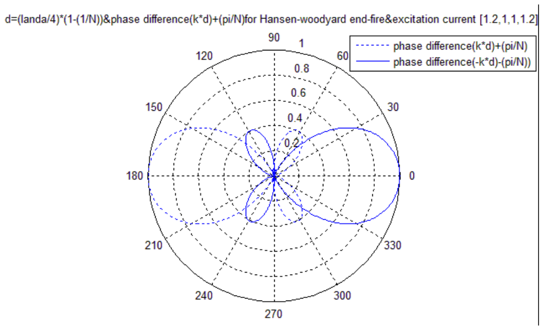

Fig.15. d=0.5 &Hansen woodyard end fire array& excitation current [1.2,1,1,1.2]

Now we want to test the excitation current for **binomial array**, From Pascal's triangle for number of element N=4 the excitation coefficient for the binomial array is [1,3,3,1] To plot radiation patterns of excitation current [1,3,3,1], with **phase difference -60° and 60°** code#2 will be used and the resulting polar plot is Figure16

.

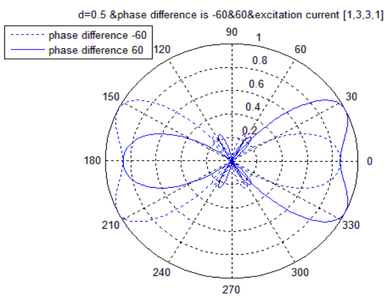

Fig.16. phase difference is -60°&60° & Binomial array

Now we test **broadside array** with using code#1 with excitation currents [1,3,3,1] and the resulting radiation pattern as Figure.17:

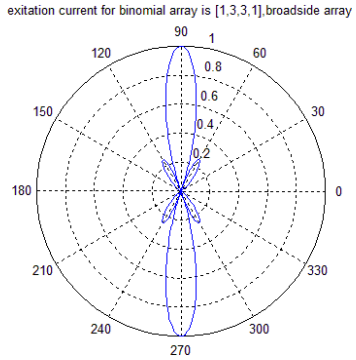

Fig.17. excitation current Binomial array& broadside array phase difference

For **End-fire array** the phase difference (alpha=-k*d the main lobe at $\theta = 0$ and alpha=k*d the main lobe at $\theta = 180$) use code#1 with excitation current [1,3,3,1], and the resulting radiation pattern as Figure.18.

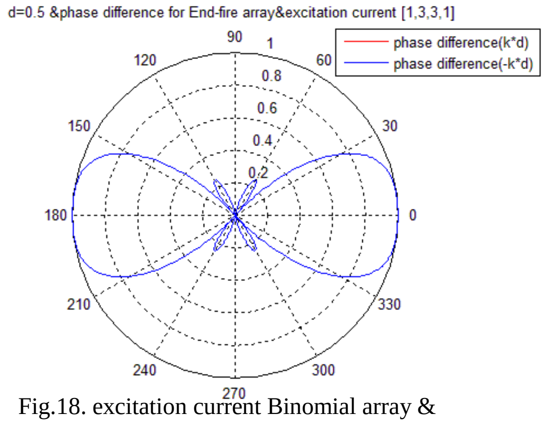

Fig.18. excitation current Binomial array & End-fire array phase difference

For **Hansen-Woodyard end-fire array** the code#3 will be used and the excitation current [1,3,3,1], and the resulting radiation pattern as Figure.19:

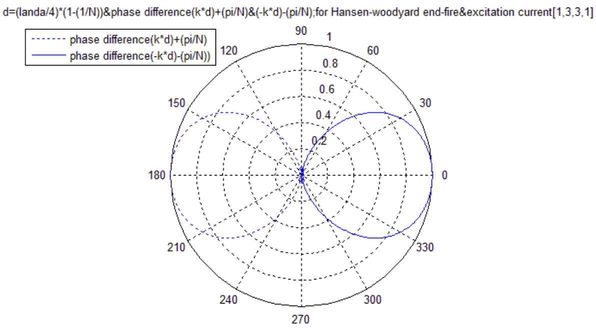

Fig.19. Hansen woodyard end fire array& excitation current Binomial array

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Now we want to test the excitation current for **chebyshev array**, the chebwiri function, available in the signal-processing toolbox**.** The fuanction *chebwin (N, Ro)* returns the n-point Chebychev window with a sidelobe level of r dB. The window values are the current excitations of the array elements. the required main lobe to side lobe ratio (*Ro*) that used in this paper is -26dB. For chebyshev array analysis we use the following code:

Code#4:

```
R=26;%dB
k=2*pi;% wave number
d=0.5;% the inter-element spacing
phi=0 : 0.01 : 2*pi;      %  0 < phi < 2*pi
shi = k*d*cos(phi);% complex currents of the elements
Currents = chebwin(N,R);% current excitations
E = freqz(Currents, 1, shi);% E for different shi values
En=E/max(E);
Polar2(phi, En);% Generating the radiation pattern
```

However, with **phase difference -60° and 60°** code#4will be used and the resulting polar plot is Figure 20.

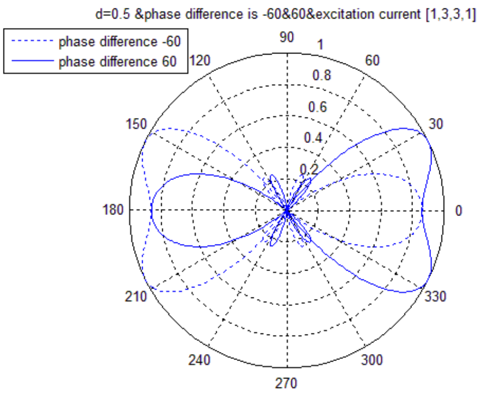

Fig.20. phase difference -60°&60°& excitation current Chebyshev array

Now we test **broadside array** with using code#4 with excitation currents **chebyshev array** and the resulting radiation pattern as Figure.21:

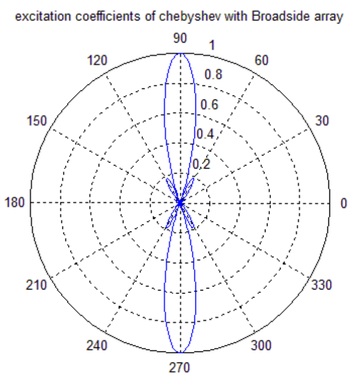

Fig.21. Broadside array phase difference & excitation coefficients of chebyshev

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For **End-fire array** the phase difference (alpha=-k*d the main lobe at $\theta = 0$ and alpha=k*d the main lobe at $\theta = 180$) use code#4, and the resulting radiation pattern as Figure.22:

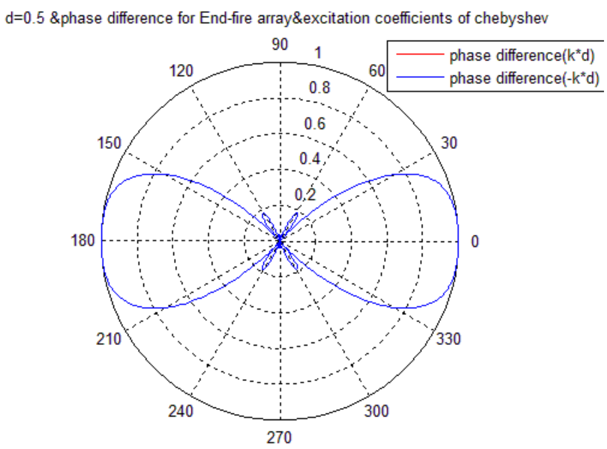

Fig.22. phase difference for End-fire array & excitation coefficients of chebyshev

For **Hansen-Woodyard end-fire array** the code#3 will be use and replace of line#4 with line#6 of codes#4 with excitation current chebyshev array, and the resulting radiation pattern as Figure.23.

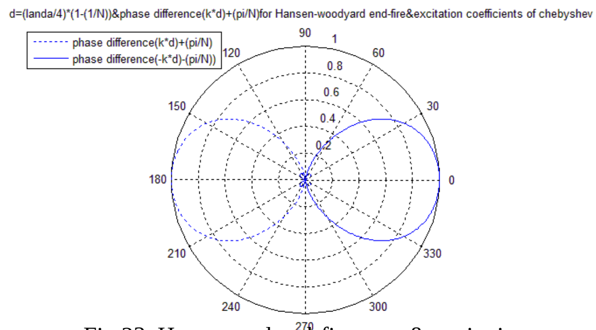

Fig.23. Hansenyard end-fire array& excitation coefficients of chebyshev

For *Hansen-Woodyard end-fire array* instead of $\delta = \frac{\pi}{N}$ practically $\delta = \frac{2.92}{N}$ is used, we will take case Hansen woodyard end-fire array& excitation coefficients of chebyshev and use $\delta = \frac{2.92}{N}$, Figure.26 will be appear:

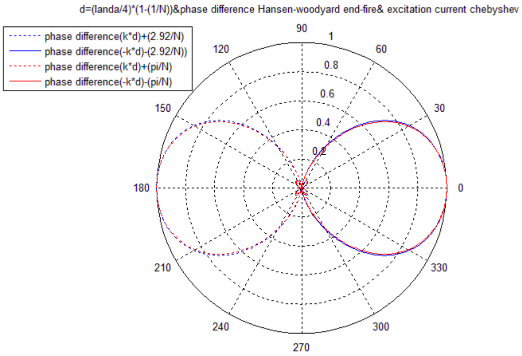

Fig.24. Hansen woodyard end-fire array& excitation coefficients of Chebyshev

As we see in Figure.26 there is no change if we put $\delta = \frac{\pi}{N}$ or $\delta = \frac{2.92}{N}$, the radiation pattern for two cases are identical for all conditions of excitation current with different phase difference.

To compare the directivity of the three technique of phase difference Broadside array, End-fire array and Hansen Woodyard end fire array, all radiation pattern must be plotted under same condition through the inter element spacing and number of element also same excitation current. *Thus for a large uniform array, the Hansen-Woodyard condition can only yield an improved directivity provided the spacing between the elements is approximately λ/4*, so we will test for *d=λ/4 and N=4* and the Chebyshev array of current excitation and code#4 will be used, the resulting radiation patterns are shown in Figures.25&26&27

:

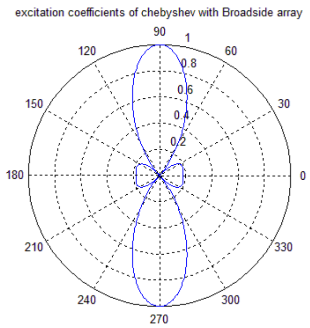

Fig.25. d=0.25&N=4, Broadside array& excitation coefficients of Chebyshev

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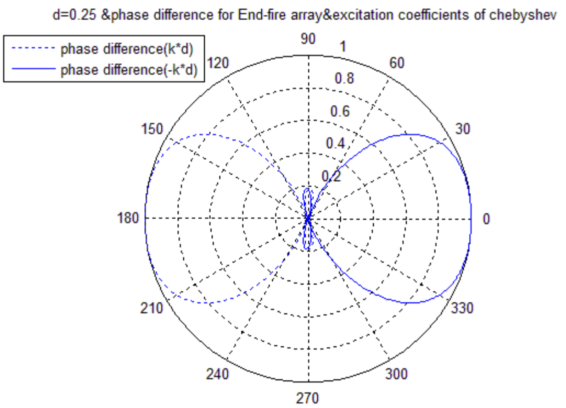

Fig.26. d=0.25&N=4, End-fire array & excitation coefficients of Chebyshev

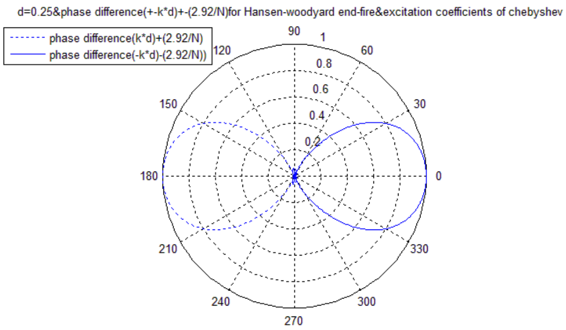

Fig.27. d=0.25&N=4, Hansen Woodyard end-fire array & excitation coefficients of Chebyshev

From Figures.26 &27 It is apparent that the major lobe of the ordinary end-fire is wider than that of the Hansen-Woodyard; thus, higher directivity for the Hansen-Woodyard.

We observed from all cases of phase difference for different excitation current the amplitude of side lobes is changed as we saw from normalized radiation patterns in this section, for [1.2,1,1,1.2] the amplitude of side lobes is larger than other excitation currents, **Chebyshev array** is best way to control the level of side lobes.

Other observed point from all cases of current excitation as the phase difference changes from -60° to 60° the direction of the radiation pattern changed. Also for **Broadside array** as we see the mainlobe at $\theta = 90°$, in other words, all elements of the array must be driven with the same phase. For **End-fire array** the main beam of the array is along the array axis in $\theta = 0°$ & $\theta = 180°$ because *d=λ/2* as Figures.10,14,18 & 22, direction for phase difference $-kd$ the maximum mainlobe at $\theta = 0°$ and the phase difference kd the mainlobe at $\theta = 180°$ if *d < λ/2 or λ/2<d< λ*. Finally as we saw the **Hansen-Woodyard end-fire array** produce a directivity larger than the directivity for end-fire array but not produce the maximum directivity, the Hansen-Woodyard end-fire array design increases the directivity of the array at the expense of higher side lobe levels and *maximum along* $\theta = 0^{o}$ *or* 180^{o}.

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V. REFERENCES

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