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Design and Analysis of Phased Array System by MATLAB Toolbox

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ABSTRACT

An array of antennas mounted on vehicles, ships, aircraft, satellites, and base stations is expected to play an important role in fulfilling the increased demand of channel requirement for these services.

In this paper toolboxes of MATLAB will use for the phased array system for different purposes of extraction of information about a validate results for antenna array and a comparison is made between different antenna array geometries, also this paper provides the background of the newly developed MATLAB Phased Array Toolbox. So, some effective parameters like the changing element spacing and the number of elements and the geometrical shape of the array on the antenna array radiation pattern along with the gain have been studied. The Phased Array Toolbox of MATLAB has also been used to validate the results.

Keywords: antenna array, phased array system toolbox, wireless mobile communication.

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تطبيق خوارزميات مختلفة في تشكيل الحزمة التكيفية في نظام اللاسلكي

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الملخص

من المتوقع أن تلعب مجموعة الهوائيات المركبة على المركبات والسفن والطائرات والأقمار الصناعية والمحطات القاعدية دورًا مهمًا في تلبية الطلب المتزايد لهذه الخدمات.

في هذا البحث، ستستخدم MATLAB Toolbox لنظام الصفيف الهوائي لأغراض مختلفة لاستخراج المعلومات حول التحقق من صحة نتائج مصفوفة الهوائي ويتم إجراء مقارنة بين الأشكال الهندسية المختلفة لمصفوفة الهوائي ، كما يوفر هذا البحث خلفية MATLAB Phased Array المطورة حديثًا لمجموعة أدوات المصفوفة. لذلك ، تمت دراسة بعض الخصائص المهمه مثل تباعد العناصر المتغير وعدد العناصر والشكل الهندسي للصفيف على مخطط إشعاع صفيف الهوائي إلى جانب ال (gain). كما تم استخدام مجموعة أدوات المصفوفة الهوائيه من MATLAB Toolbox للتحقق من صحة النتائج.

الكلمات الدالة: الصفيف الهوائبي، صندوق أدوات الصفيف الهوائي, الاتصالات المتنقلة اللاسلكيه.

1. Introduction

The smart antenna works on the concept of spatial processing which is the central idea of adaptive antennas systems [1]. The use of an antenna array adds an extra dimension and makes the utilization of spatial diversity possible. This is since the interferences rarely have the same geographical location as the user and therefore they are spatially separated.

Using antennas with very directive characteristics to meet the demands of high capacity can be achieved by forming an assembly of two or more radiating elements in electrical and geometrical configuration, which is referred to as an array. In a linear antenna array, antenna elements are placed along one axis. The antenna array produces a beam that is affected by changing the array geometry and by some other parameters such as inter-element

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spacing, and excitation of the individual element [2]. The non-uniform linear array was also investigated by considering the average element spacing such that a relationship between the array length, side lobe, and directivity was established [3].

Arrays may produce the desired radiation characteristics by properly exciting each element with certain amplitudes and phases to maximize the signal from the desired users [4]. This paper analyzed various array geometries such as uniform and non-uniform linear, uniform planner arrays, and three-dimensional arrays with the help of MATLAB program. The linear array has excellent directivity and narrowest main lobe in a given direction, but in all azimuthal directions it does not work equally well, a major drawback of the planner array is the question of presence on the opposite side of an additional large lobe of the same strength [5] an obvious advantage comes from the symmetry of the circular array structure since, it has no edge components, directional patterns synthesized with a circular array can be rotated electronically in the array plane without a significant change in the beamform [6].

In this paper, the phase array toolbox manages to create a beam pattern with the main lobe pointing in a specific direction, to produce development for an efficient array with enhanced direction of arrival (DOA) estimation and other array requirements like the lower sidelobe level and high directivity, narrower beamwidth …etc.

2. Phased Array Toolbox

MATLAB comes with an additional tool specially built for phased arrays, i.e. the Phased Array Toolbox, this tool would be discussed in this thesis.

Antenna array performance is discussed by which phased array toolbox of MATLAB or also can be called it the basic array factor method. Insight into MATLAB has been given to better explain the entire design process, so, the effect of element spacing on the performance of an antenna array has been widely studied with the help of MATLAB. Programs and tools for designing phased array signal processing systems are provided by the phased array system toolbox. It also provides simulation and analysis capabilities which can be accomplished by MATLAB functions and MATLAB objects. This toolbox includes many algorithms that are mainly used for beamforming, target detection, space-time adaptive processing, and waveform generation. Also, array visualization applications assist in evaluating spatial or temporal performance. This toolbox can be a great help in modeling an end-to-end phased array system or using simple/complex algorithms to process gathered data [7].

3. Phased Array Design and Analysis

This toolbox contains examples that give a starting point for designing user-defined phased array systems. It helps to model, simulate, and analyze the common array geometries and user-defined array geometries. To define the desired array geometry, the following parameters are required: the number of elements, the element spacing, and the position of each element and its 3D space orientation. Each element can have a cosine shaped, isotropic, or user-defined 3D pattern as the response and radiation pattern. There is also an option of shading (tapering) over the entire array. Inhomogeneous arrays can also be designed by deploying multiple-element patterns.

Analysis of the toolbox provides ways to visualize and analyze the radiation pattern of the array as well as individual elements. Visualization may be rectangular, spherical, or u/v format. There are several helpful tools available where the following parameters can be visualized/analyzed: array geometry, array gain, array response, delay between elements, steering vector, element response,

4. Different Array Factor for Different Array Geometry

4.1 Linear Array

The array factor for the linear array with simply an equally spaced elements and equal amplitudes, and can easily implement by shifting the phase of the antennas current for each element axis and the phase shift δ is equal to zero. The AF for N elements can be considered as[8]

$$\mathrm{AF} = [1 + \mathrm{e}^{\mathrm{j(kd\sin\theta+\delta)}} + \mathrm{e}^{\mathrm{j2(kd\sin\theta+\delta)}} \dots . \mathrm{e}^{\mathrm{j(N-1)(kd\sin\theta+\delta)}}]^{\mathrm{T}} \quad (1)$$

And,$k = 2 * \frac{pi}{\lambda}$ is the phase constant, d is element spacing, θ is arrival angle. Equation (1) can be expressed by:

$$\mathrm{AF} = \sum_{n=1}^{N} W_n \, e^{j(n-1)\psi} \quad (2)$$

Where, $\psi = kd\ sin\theta + \ \delta$ and $\delta = -(kd + sin\theta)$ which is the progressive phase, k is the wavenumber and, $Wn = a_n * e^{jb}$

4.2 Non-Uniform Linear Array

The symmetrical radiation pattern can be generated by the unsymmetrical placement of the antenna array. The array factor is specified by [9]

$$\mathrm{AF} = \sum_{n=1}^{N} e^{j(n-1)(kd_n \sin\theta+\delta)} \tag{3}$$

From the schematic diagram, it is clear that the AF's amplitude and phase can be controlled in uniform arrays by carefully choosing the relative phase between the elements; in non-uniform arrays, the distance, amplitude, and phase could be utilized to monitor the composition and distribution of the total array element.

4.3 Circular Array

The array factor or circular array in the x-y plane, with uniform angular distribution between elements of value $\emptyset_n = \frac{2\pi(n-1)}{N}$. The nth array element is located at the radius (a) with the phase angleφ_n. The AF can be found in a similar procedure as was calculated with the LA as [10]

$$AF = \sum_{n=1}^{N} w_n e^{-j(ka\hat{\rho}.\hat{r}+\delta_n)} = \sum_{n=1}^{N} w_n e^{-j(ka sin\theta \cos(\varphi-\varphi_n)+\delta_n)} \tag{4}$$

4.4 Planar Array

This type is used to perform 2D beamforming (in both azimuth and elevation angles) with horizontal element spacing of ΔX and vertical element spacing of ΔY is shown in Fig.1. The AF for PA can be expressed as combining the AF of two LAs [11]. Pattern multiplication can be used to find the pattern of the entire M×N element array. Using pattern multiplication would have

$$AF = AF_x . AF_y = \sum_{m=1}^{M} a_m e^{j(m-1)(kd_x sin\theta \cos\varphi+\beta_x)} \sum_{n=1}^{N} b_n e^{j(n-1)(kd_y sin\theta \sin\varphi+\beta_y)}$$

(5)

$$AF_{xy} = \sum_{m=1}^{M} \sum_{n=1}^{N} \ w_{mn} e^{j[(m-1)(kd_x sin\theta \cos\varphi+\beta_x)+(n-1)(kd_y sin\theta \sin\varphi+\beta_y)]} \tag{6}$$

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The AF for cube array can be expressed as combining the AF of three LAs, Pattern multiplication can be used to find the pattern of the entire M×N×Z elements array as follow

$$AF_{xyz} = \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{o=1}^{O} w_{mno}e^{j[(m-1)(kd_x sin\theta cos\varphi+\beta_x)+(n-1)(kd_y sin\theta \sin\varphi+\beta_y)+(o-1)(kd_z sin\theta+\beta_z)]}$$

Using pattern multiplication would have a few array geometries are shown in Fig.1 [7]. A sample 3D pattern plot for a rectangular array is shown in Fig.2 [7].

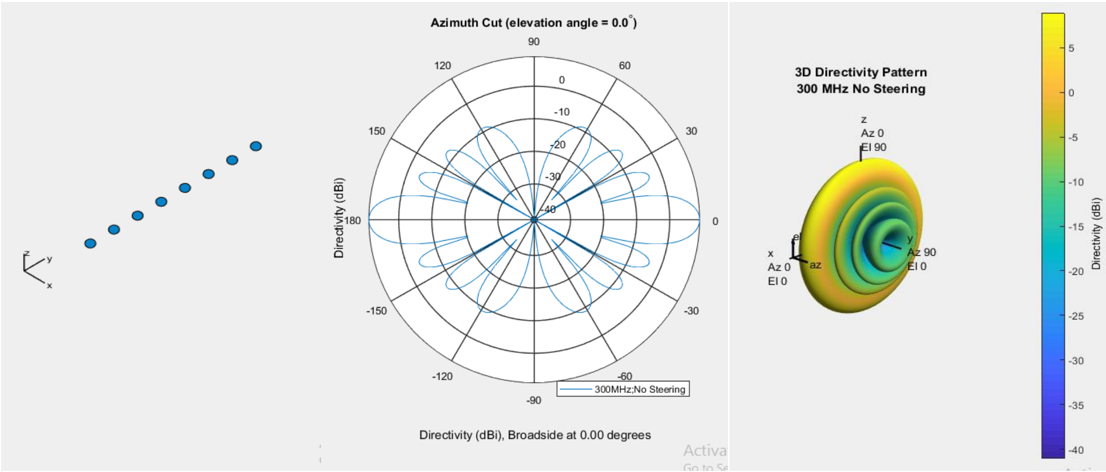

Fig.1 Linear array with 8 elements and DOA at 0°.

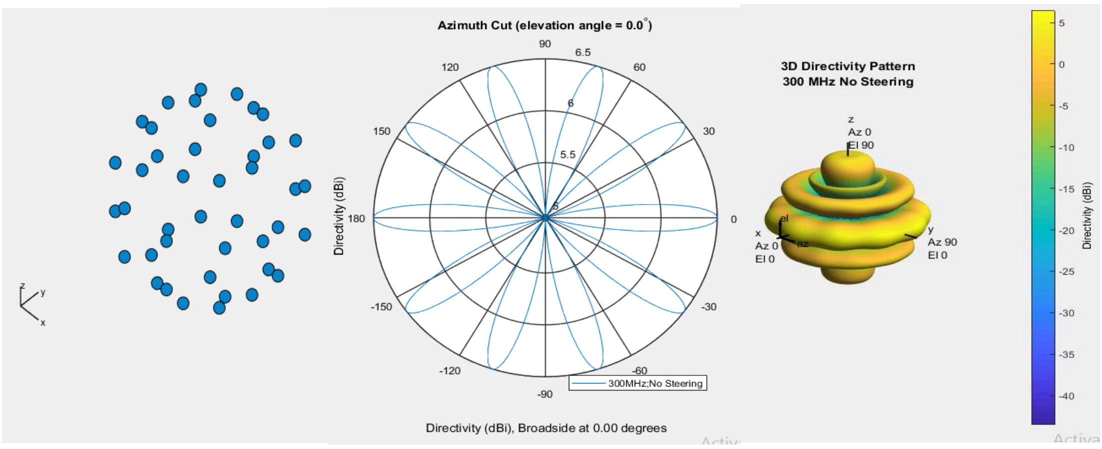

Fig.2 Spherical array with 10 elements at the center and DOA at 0°.

The isotropic antenna has quite a gain of 0 dB in the sphere around it and a 100 % efficiency. Which is used as a guideline for presenting the actual antennas' directive properties [12], but for more guideline, the MATLAB phase array toolbox could exam with different antenna types like cosine antenna, omnidirectional microphone, and cardioid microphone,

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because the definition of an isotropic is ideal and yet physically realizable. Fig.3 presents the linear array pattern for different antenna types with 12 elements and 45°. The directivity found equal to 16.78 dBi, 10.79 dBi and 13.69 dBi for cosine, omnidirectional and cardioid, respectively.

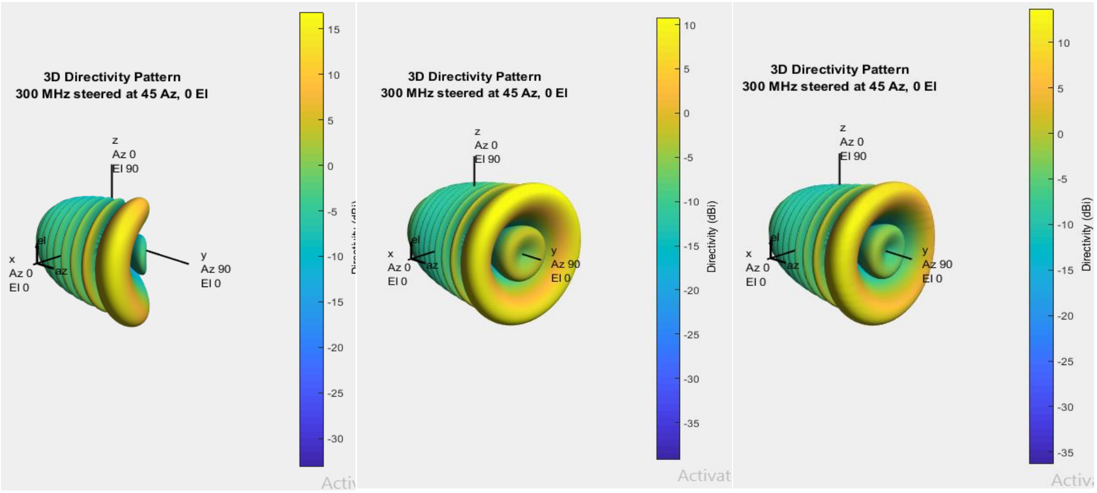


Fig.3 3D array pattern for cosine antenna, omnidirectional microphone, and cardioid microphone.

5. Simulation and Analysis

The phased array toolbox in MATLAB is used here to get results of different arrays that have been considered in the different algorithms of the smart antenna system. Phased array analysis in MATLAB only computes array factors of various built-in sources and does not include any mutual interactions. It is useful to visualize the effects of different element spacing on the array pattern for the side lobes level, grating lobes, and the directivity, however, it is not an exhaustive analysis, such as that from an analysis algorithm. It has limited usefulness if it is the only tool available.

In this paper the simulation will be done by comparison between designs from the toolbox and other how will built-in with toolbox by the author, the comparison will be in different array dimension as follow.

i. one dimension array

Fig.5 represents 4 elements of linear array results for uniform linear array and non-uniform linear array and linear array with 45° angle, Table.1 shows the numerical comparison result with respect to the uniform liner array.

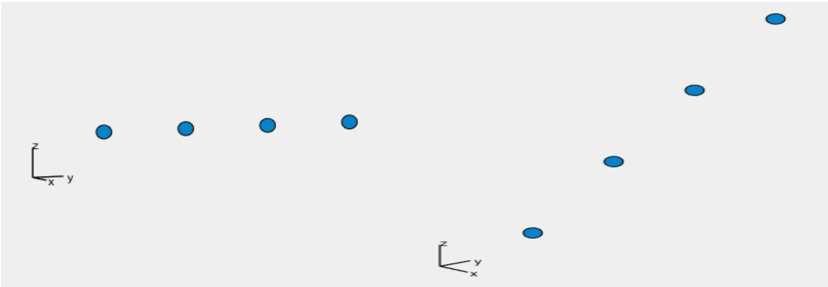
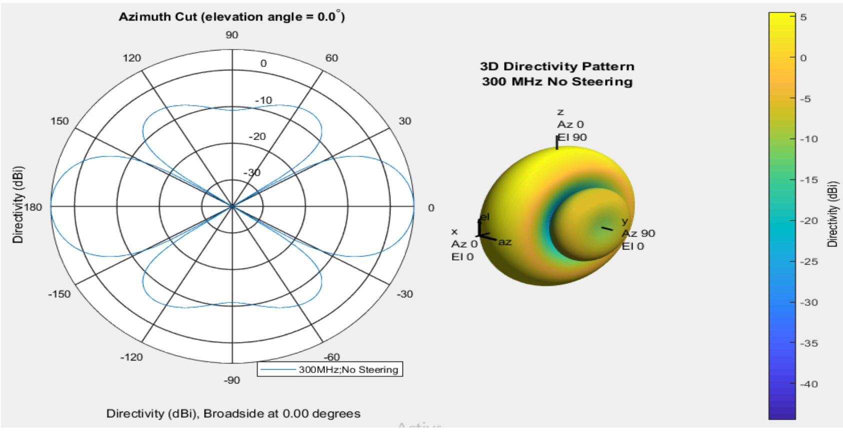
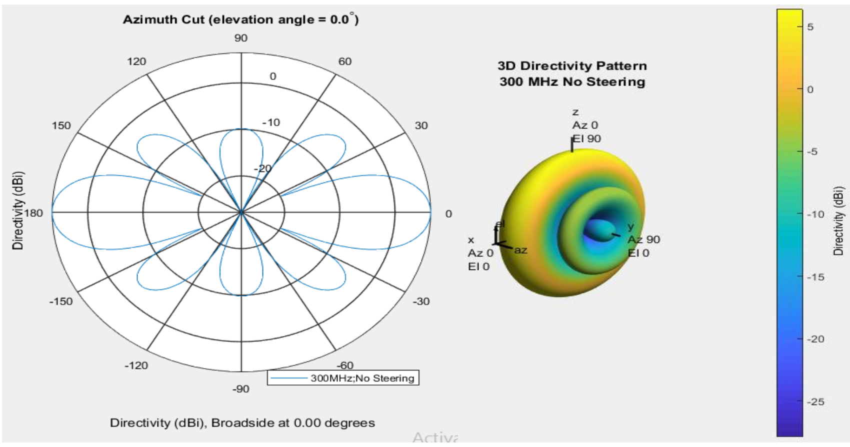


Fig.4 non-uniform linear and 45° angle array



(a)



(b)

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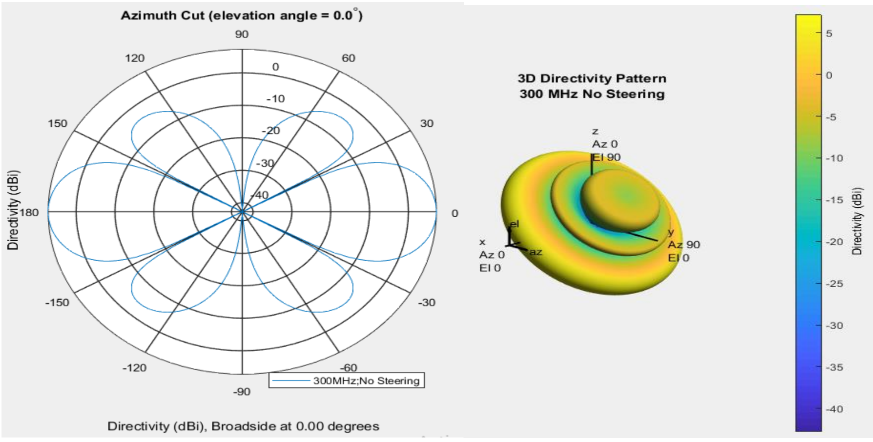

(c)

Figure.5 2D&3D antenna array pattern for (a) linear (b) non-uniform linear (c) linear with 45° angle

Table.1 numerical result

Array type	Uniform	Non-uniform	With 45° angle
Directivity(**dBi**)	5.58	6.45	7.22
BW	42.3	35.8	43.6
Spacing distance	[0.45 0.45 0.45 0.45;0 0 0 0;0 0 0 0]	[0.3 0.8 1.4 2;0 0 0 0;0 0 0 0]	[0 0.5 1 1.5;0 0.5 1 1.5;0 0 0 0]

It can show that by changing the distance between each element the directivity would be increased by about 1 dBi also it can conclude that the length of array decreases from 1.8 λ to 1.5 λ, and by elevating the element with 45° angle the directivity increase about 1.6 dBi with reducing in the number and the level of the side lobe.

i. two-dimension array

In this section two geometry will be discussed, the circular and hexagonal array as illustrated in Fig.6 Each array consist of 6 elements, and the comparison would done with respect to the circular array which exist by the MATLAB toolbox.

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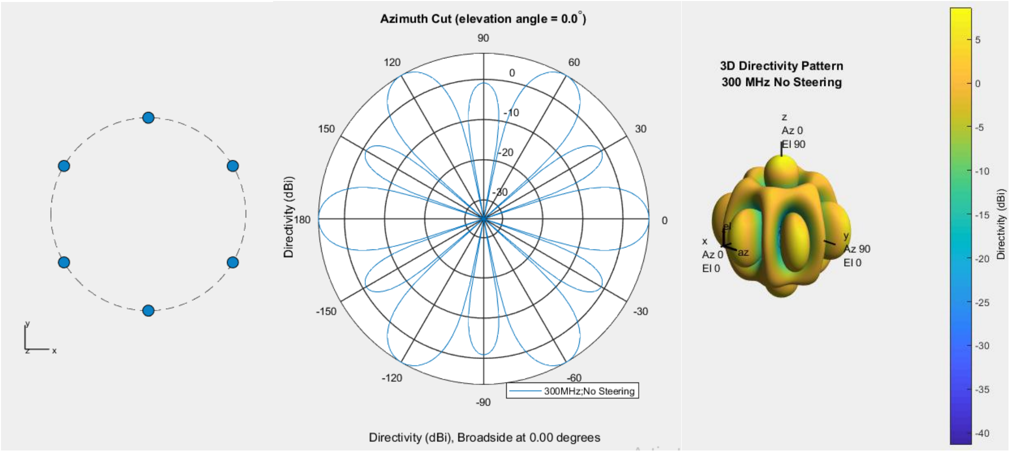
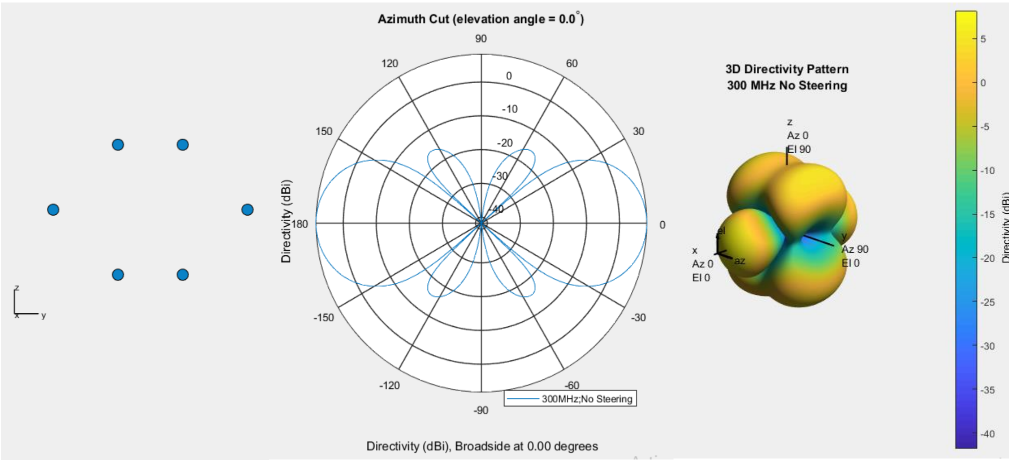


(a)



(b)

Figure.6 2D&3D antenna array pattern for (a) circular (b) hexagonal

Table.2 numerical result

Type of array	Circular	Hexagonal
Directivity($\boldsymbol{dBi}$)	6.47	8.22
SLL	-7	-24
Spacing distance	1λ radius	[0.5 1 0 1.5 0.5 1;0 0 0.5 0.5 1 1;0 0 0 0 0 0]

The result shows that with designed shape (hexagonal array) the directivity increase 1.75 dBi, besides the clear reducing in the number and the level of the side lobe.

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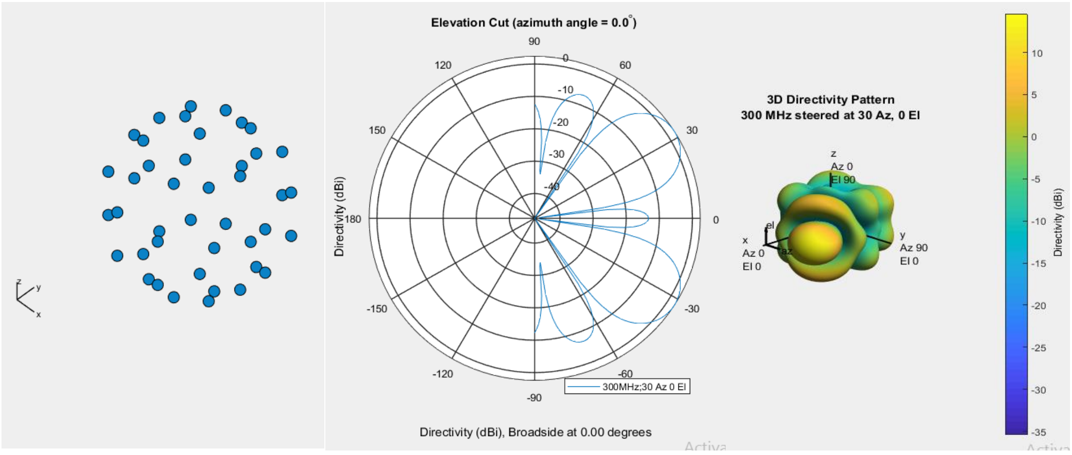
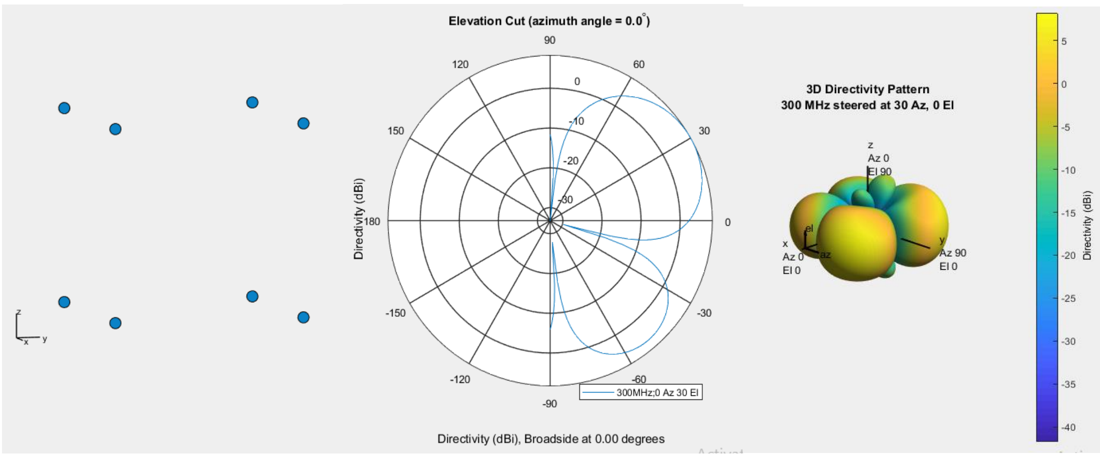
ii. three direction array

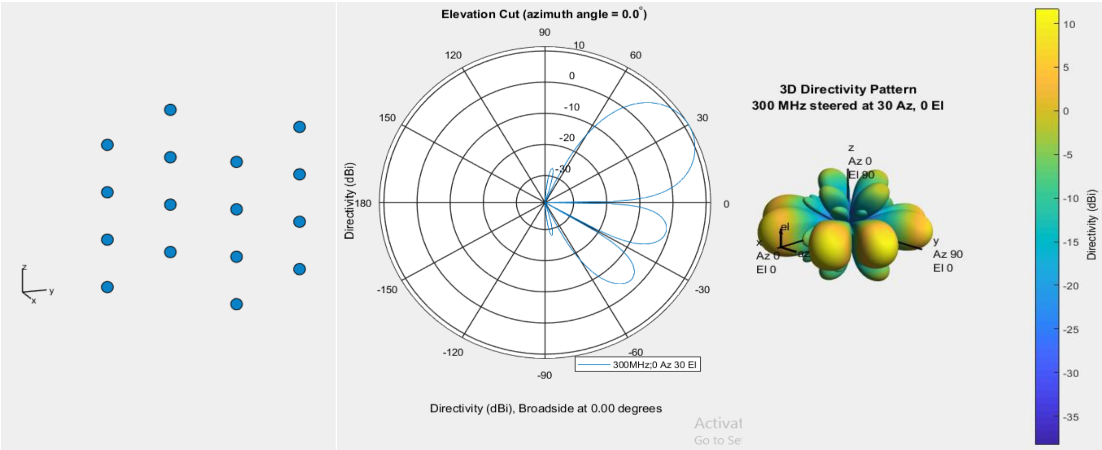
Three designs will be present in this part which can illustrate in Fig.7 with DOA equal to 30 for each; Table.3 gives the numerical result for comparison with respct to spherical geometry.



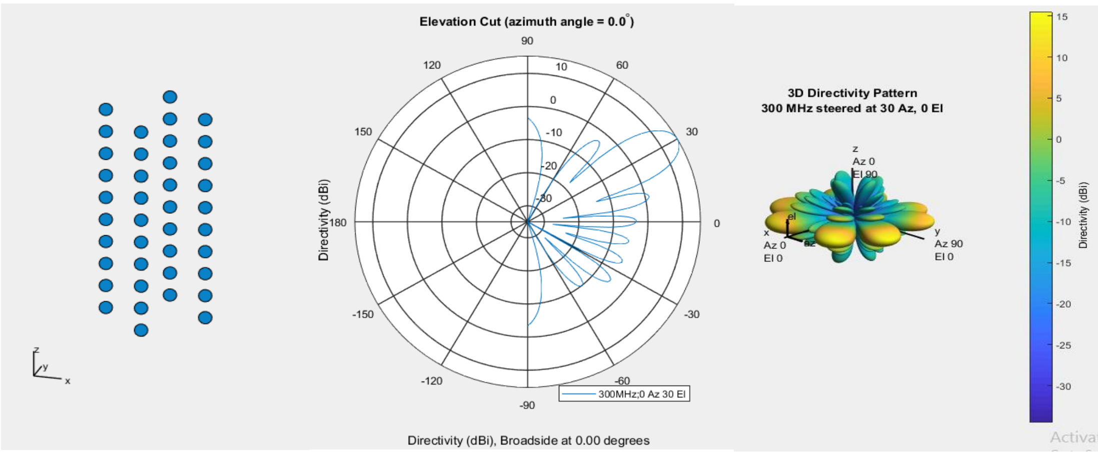
(a)



(b)



(c)



(d)

Figure.7 2D&3D antenna array pattern for (a) spherical (b) 2*2*2 cube (c) 2*4*2 cube (d) 2*10*2 cube.

Table.3 numerical result

Array type	Spherical	2*2*2 cube	2*4*2 cube	2*10*2 cube
Directivity(dBi)	14.1	8.25	11.72	15.82
No. elements	42	8	16	40
SLL	-8	-3	-11	-13.3
Spacing distance	1λ radius	[0 0.65 0 0.65 0 0 0.65 0.65;0 0 0.65 0.65 0 0.65 0 0.65;0 0 0 0.65 0.65 0.65 0.65]	0.5λ between each elements	0.5λ between each elements

As present in Table.3 above that the cube array most useful than the spherical array in the side of directivity with respect to the number of elements, and also from the side of SLL comparing with the number of antenna elements.

6. Conclusion

This thesis aimed to develop a novel design for a phased array antenna with different dimensions, varieties of antenna arrays is designed such as a non-uniform linear array, hexagonal planar array, and cubic arrays to meet the higher demands of present communication systems. Generally, this paper gives information about the MATLAB Phased Array Toolbox and presents array results generated by this toolbox.

It can conclude that the MATLAB toolbox would be the most effeteness tool to design and checking the suitable antenna geometry with good characteristics before applying to simulate with different sorts of an adaptive algorithm for smart antenna or adaptive system.

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