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Beam Steering Using the Active Element Pattern of Antenna Array

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Abstract

An antenna array is a set of a combination of two or more antennas in order to achieve improved performance over a single antenna. This paper investigates the beam steering technique using the active element pattern of dipole antenna array. The radiation pattern of the array can be obtain by using the active element pattern method multiplies with the array factor. The active element pattern is crucial as the mutual coupling effect is considered, and it will lead to an accurate radiation pattern, especially in determining direction of arrival (DoA) of a signal. A conventional method such as the pattern multiplication method ignores the coupling effect which is essential especially for closely spaced antenna arrays. The comparison between both techniques has been performed for better performance. It is observed that the active element pattern influenced the radiation pattern of antenna arrays, especially at the side lobe level. Then, the beam of the 3x3 dipole antenna array has been steered to an angle of 60° using three techniques; Uniform, Chebyshev and Binomial distribution. All of these are accomplished using CST and Matlab software

Keywords*: Active element pattern (AEP); Dipole antenna array; Beam steering; Pattern multiplication; Edge effect*

1. Introduction

Antenna is a metallic device which is used for radiating or receiving radio waves. It may be present in many types (wire, microstrip, array, and reflector) but with different advantages and abilities, depending to the designer's specification. A single antenna may has low performance as to compare with the combination of two or more of the individual antenna.

The combination of more than one element is called an array which may improve the directivity of the antenna and provide a narrower radiation pattern with high directivity. Directional means that the antenna is radiated or received greater power in specific directions resulting better performance while reducing interference from unwanted sources [1]. Antenna array may be formed to various configuration such as linear, circular, planar and more. Generally, the radiation pattern of an antenna array with identical elements is taken by the product of an element pattern, E_0 and an array factor (*AF*);

$$E_{total} = E_0 \times AF \tag{1}$$

Equation 1 is known as pattern multiplication method. It is a conventional method which is used to calculate the far field pattern easily, but inaccurate. The method neglects the mutual coupling effect. This is due to the presumption that all elements have equal patterns [2]. These will lead to inaccuracy in antenna array design. Mutual coupling effect is an electromagnetic interaction between the elements in an array when they are placed in closer arrangement with each other. It will significantly affecting the radiation pattern of total array as the spacing between them becomes closer. The current of each element depends on each current excitation and the current induced from the neighboring antenna elements. These can be acoounted by using the active element pattern (AEP) method. The AEP is obtained with a single element in

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the array is excited while all others elements in that array terminated with matched loads [2-6]. AEP is investigated in detail in order to estimate the far field pattern of the antenna array. It is because the mutual coupling is considered and it is an accurate method to synthesize the far field pattern.

In addition, beam steering and null positioning are another advantages of antenna arrays. Beam steering is important in adaptive environment such as in big city in order to direct the main beam to the desired user. Null positioning on the other hand, can be placed in order to cancel the interference from other users. In addition, there is a problem to optimize the desired amplitude and phase density and one way that can be applied to find the optimum solution by using the optimization method for beam steering. Many researchers considered array factor employing Matrix Inversion and IDFT [6], single neural neuron network beamformer [7] and self adaptive differential evolution technique [8] for beam steering. However, the works do not consider mutual coupling effect. On the other hand, beam steering also requires beamforming networks (either passive or active) such as Butler [9] and Rotman [10] networks in order to provide different amplitude and phase for each element of the antenna array.

Thus, in this paper, a design of half wave dipole antenna at 2.45 GHz is used to form an array and was constructed by using Computer Simulation Technology (CST). The study involves investigation of coupling effect using the AEP. The radiation pattern of pattern multiplication method has been compared with finit5e integration technique using Matlab and CST respectively. Then, the excitation of antenna array is optimized and the beam of 3x3 antenna array has been steered to 60° using 3 techniques; Uniform, Chebyshev and Binomial distribution. The paper is organized as follows: Section 2 discusses the research method to investigate the active element pattern and its effect to the beam steering antenna array. The comparison of AEP of centre and edge fed also will be presented. Section 3 presents the result and analysis involving the active element pattern and pattern multiplication method. It also demonstrates the capability of antenna array to steer the beam i.e. to 60° using three different methods; Uniform, Chebyshev and Binomial distribution. Section 4 concludes the investigation of the active element pattern, pattern multiplication and future works of this research.

2. Research Method

Figure 1 presents the methodology of this paper. In overall, the radiation pattern of antenna arrays are governed by the mutual coupling effect among the elements. Where the amount of coupling depends on the radiation characteristics, separation between elements, number of elements and relative orientation of elements. This will be investigated further using an array of dipole antenna of NxN (where N=1, 3, 5, 7 and 9). Then, the optimization method to steer the beam using Uniform, Chebyshev and Binomial distribution has been performed for 3x3 antenna array. The simulation of the antenna array is done by using CST and MATLAB software.

2.1 Active Element Pattern

The mutual coupling happened when two or more radiating antenna are placed near to each other. The effect will increase as the distance between to elements increased. The energy has been transferred between from one element to the neighboring elements and this is called mutual coupling. Previous works calculating the total array pattern by performing pattern multiplication method. It is a conventional method which does not consider coupling effect. However, this can be mitigate using active element pattern (AEP). Active element pattern or AEP is a radiation pattern when one radiating element is driven and all the others are terminated (passive) with matching load. The far field pattern of an antenna array can be considered as the superposition of electric field radiated by every element in the array. So the total field can be calculated with following formula [3];

$$E(\theta,\emptyset) = \sum_{n-1}^{N} V_n \, g_n^u(\theta,\emptyset) \qquad (2)$$

Where $E(\theta,\emptyset)$ defines the total electric field radiated by the array, V_n is the feed voltage applied to the *n*th element and *N* is the number of voltage sources applied to the array. The set $g_n^u(\theta,\emptyset)$ includes the effect of mutual coupling and it is known as the exact active element pattern as it is calculated or measured once for each element.

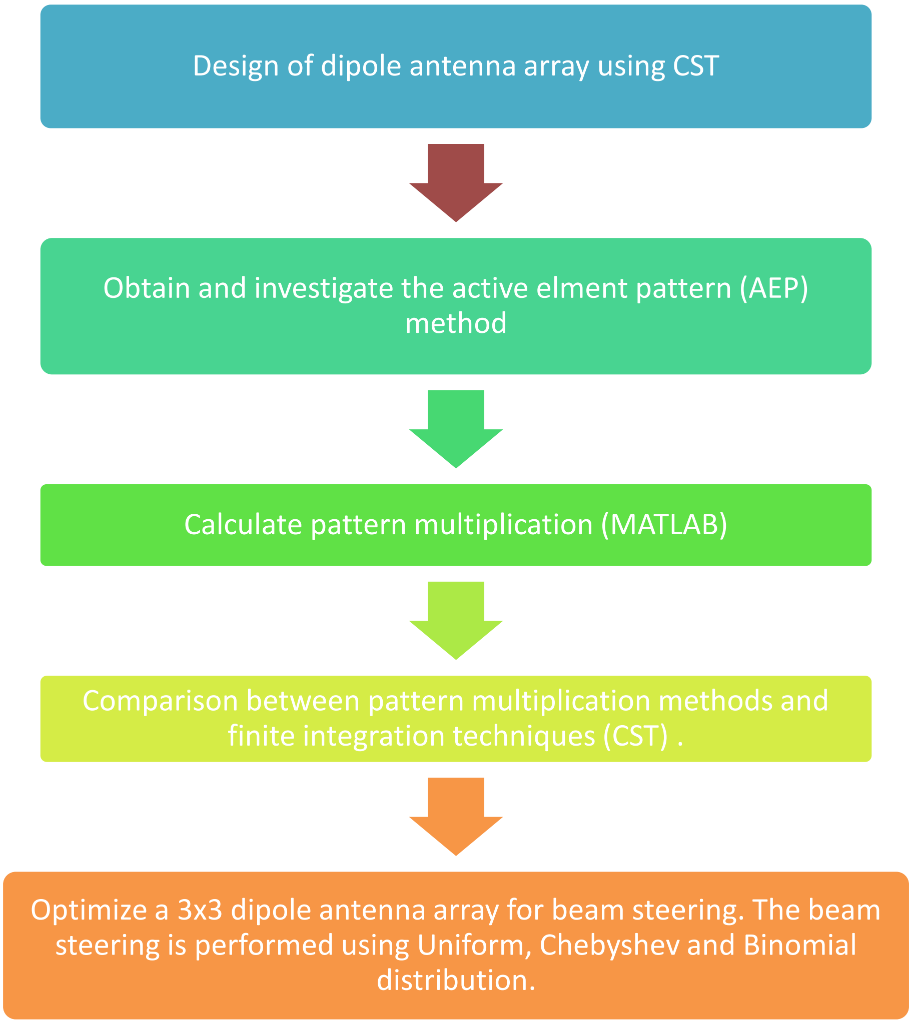


Figure 1. Research methodology

The active element pattern becomes accurate as the number of element increases by reducing the edge effect [11]. It is because the usage of the AEP by approximating it as equal for each element, then the pattem of the fully excited array can be expressed as the product of the active element factor and the array factor. In other words, the AEP replaces the element pattern (in equation (1)) and is written as:

$$E_{total} = AEP \times AF \tag{3}$$

However, the AEP is not equal between antenna elements due to the edge effects of the elements located at the end of antenna arrays. This happens due to the neighboring antenna elements which are different for each antenna especially the element which is positioned at the centre and at the edge of an array. Thus, the edge effect of AEP can be reduced by increasing the number of elements in antenna array. As a result, the ratio of the total of the edge elements will be smaller compared to the total elements of antenna. The difference of the AEP between antenna placed at the centre and at the edge elements will be analysed and compared for dipole antenna array.

In this research, a half-wave dipole is used as basic elements to investigate the AEP method. A dipole antenna is designed at 2.45GHz using CST. Then the antenna array is constructed by combination of the designed dipole antenna with variation of parameters. The radiation pattern of the antenna array changes due to the increase of the number of elements (N), spacing (d), and excitation phase (β) of the antenna array.

The AEP is applied to the N=1, 3, 5, 7 and 11 of linear array and N×N (N=1, 3, 5, 7, 11) of planar array that has been constructed in CST. The active element is applied to the single antenna element located at the center-fed and also to the edge-fed of an antenna array. In other words, there is only one element that active in while others are terminated with their impedance of 73ohm. The array is compared with the increased of the number of elements in row and column. Then, comparison is made based on the different between center and the edge feed of the active element pattern of the antenna array.

2.2 Comparison between AEP and Pattern Multiplication Techniques

The array pattern of dipole antenna array has been calculated using AEP and pattern multiplication method for comparison. It was reported from [12] that AEP (equation (2)) is more accurate compared to the pattern multiplication (equation (1)) due to the coupling effect accounted in AEP.

2.3 Optimization of the Pattern of Dipole Antenna Array

Later, the array performance to beam steering of the dipole antenna array has been optimized using uniform, binomial, and Dolph-Chebyshev methods. Uniform distribution refers to the equal amplitude with a progressive phase that feeding each of the elements of the antenna array [1]. Eventhough it gives the highest gain but it produces high side lobes. For binomial distribution, the amplitude of each element of antenna array has been weighted according to binomial function [1]. It provides low side lobe level but low gain.

Dolph's procedure has been performed by matching the Fourier polynomial with the terms of like degree of a Tchebyscheff polynomial [13]. This gives the optimum source amplitude distribution for a specific SLL with all side lobes of the same level. For further studies on the effect of the active element pattern, the comparison between the pattern multiplication method using MATLAB and active element pattern from CST has been performed.

3. Results and Analysis

Increasing the number of element (N) of the dipole antenna causes the width of the main lobes becomes narrower. Plus, the number of side lobes increased. The side lobes represent the power radiated or received in potentially unwanted directions. The number of side lobes is increased when the spacing (d) between elements increased. The grating lobes also stated to occur when the spacing of the element with its neighbor equal or greater than λ. Generally element spacing is kept to be smaller than 0.5λ to avoid grating lobes. However, the effect of mutual coupling is higher as the energy is transferred between elements. Meanwhile, the phase shift (β) also plays a significant role as it involves in beam steering.

3.1 Investigation of AEP on Dipole Antenna Arrays

The parameters such as the spacing (d) between elements has been decided to be 0.25λ in x and y-direction to form a planar array facing towards z-direction, as to observed coupling effect between elements. The active element pattern method has been applied by using a single element in the array which is excited while all others elements in that array terminated with its impedance which is 73ohm.

3.1.1. Effect on the Center-fed and Edge-fed Element Pattern

Figure 2 shows the assembly of the antenna array using the active element pattern technique (AEP) by changing the position of the active elements at the center and edge of the antenna array. The total number of elements is fixed to 121 elements (11x11 elements). All elements of the antenna array ports generated with reference impedance at 73ohm. It is observed in Figures 3 and 4 that the AEP is different when the active element is positioned at the center as compared at the edge. It is because due to the neighboring element of the center fed (which is surrounded by 4 elements) are differed compared to edge fed (surrounded by only 2 elements). Therefore, the edge effect will bring inaccuracy to the calculation of the unit AEP because unit AEP neglecting the edge effect. This behavior may be observed in Figure 4(b) at the pattern of AEP is cut at theta=90° due to the four neighboring elements of centre feed AEP instead of 2 neighboring elemnents of edge feed AEP.

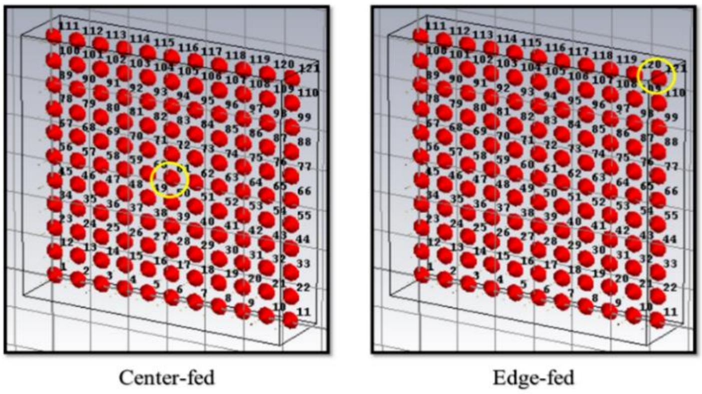


Figure 2.11x11 planar array with center-fed and edge-fed

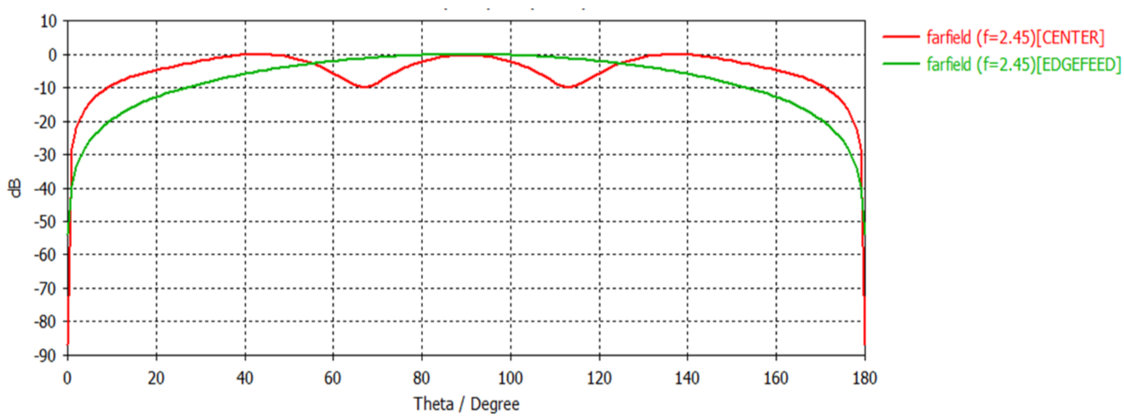


Figure 3. 2D (Cartesian plot) farfield pattern at phi=90°

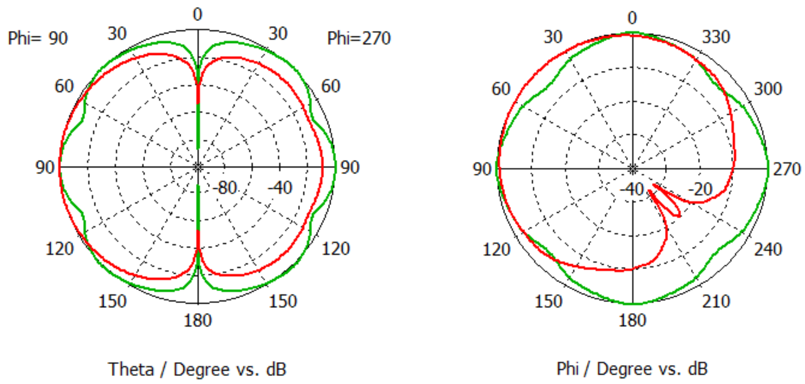


Figure 4. 2D (Polar plot) farfield pattern at (a) phi=90° and (b) theta=90° between center feed (green curve) and edge feed (red curve).

3.1.2. Effect on the Increasing Numbers of the Antenna Array

Figure 5 shows the assembled of the antenna array by applying only one element is active and others are terminated with their impedance while increasing the numbers of the elements in planar array along x and y direction, which is facing towards z-direction. In this project, an NxN (N=1, 3, 5, 7, 11) planar array, with uniform spacing is construct using CST. All elements of the antenna array ports generated with reference impedance at 73ohm. It is observed that as the number of element, N increases, the unit AEP varies and becoming more accurate as the unit AEP only can be applied by assuming an infinite number of elements, N.

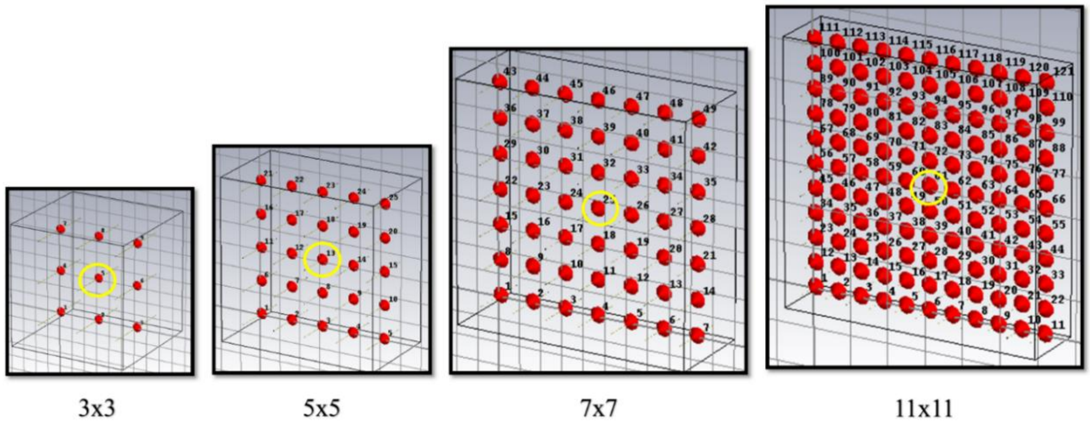


Figure 5. NxN planar array, with uniform spacing, where one element is active and others are terminated

Figure 6 shows the results on the radiation pattern obtained from CST simulation on the changes of the number of elements in planar array. It is observed that there are a few differences as number of elements increased. The similarity among them are pretty high as the number of the elements increased. It is because by activating just one element the antenna works as single antenna and produce omnidirectional pattern. As result of the increase of the number of elements in planar array, the angular separation of half points of radiation pattern which is the half power beam width (HPBW) is decrease and increased highest side lobe level.

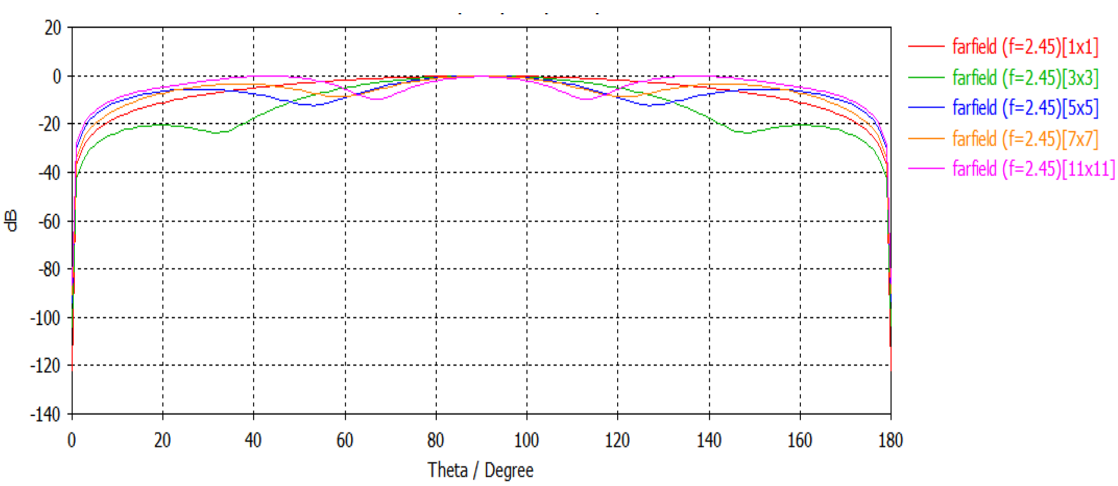


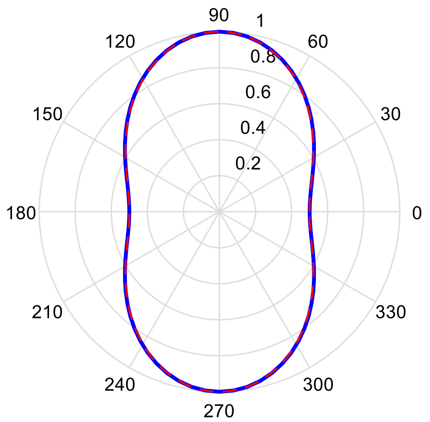
Figure 6. Radiation pattern of NxN antenna array

3.2 Comparison between AEP and Pattern Multiplication Techniques

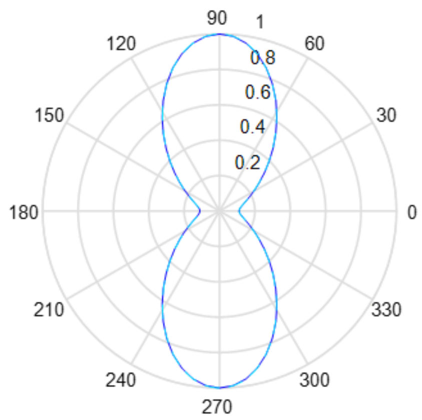
Table 1 shows the comparison of the 2D radiation pattern result from pattern multiplication using MATLAB and active element pattern from CST. The linear array by increasing the number of elements is used, the spacing of the element between used is 0.25λ.

As the result, the simulation using CST has include the active element pattern while the pattern multiplication has been performed using MATLAB to obtain the total field. It is observed that there are minimal difference especially at the side lobe levels. This is because, the AEP method includes the mutual coupling between the elements which increase the accuracy of the farfield pattern.

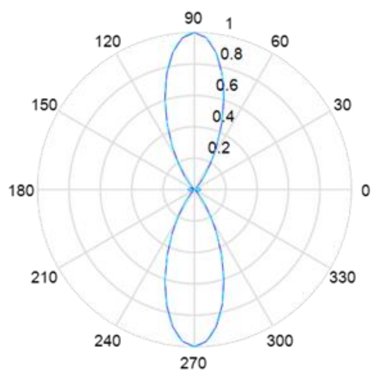
Table 1. Comparison on 2D radiation pattern at theta=90° and spacing is 0.25λ



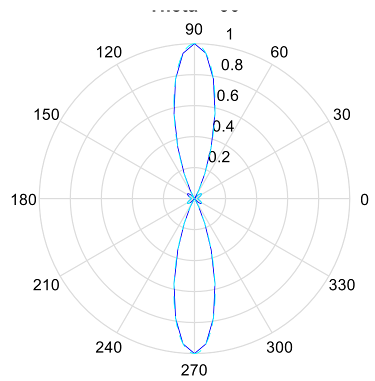
Number of element=2. The pattern multiplication method is shown using blue line and CST is shown in red line.



Number of element=3. The pattern multiplication method is shown using blue line and CST is shown in cyan line.



Number of element=5. The pattern multiplication method is shown using blue line and CST is shown in cyan line.



Number of element=7. The pattern multiplication method is shown using blue line and CST is shown in cyan line.

3.3 Optimization of the Pattern of Dipole Antenna Array

The beam steering is important in adaptive environment such as in big city in order to direct the main beam to the desired user. In addition, there is a problem to optimize the desired amplitude and phase density and one way that can be applied to find the optimum solution by using the optimization method for beam steering. The comparison of three optimization methods which are uniform distribution, binomial and Chebyshev has been performed using CST. The dipole antenna array of 3x3 elements are chosen with fixed parameters. The excitation of the array is positioning at theta scan of 90° and phi of 60° and relative side lobe level is -20dB respectively. It is observed that the beams have been successfully steered towards 60° using the optimization techniques; 1) uniform distribution, 2) Chebyshev and 3) Binomial.

Table 2 illustrated the radiation pattern results of the three techniques. In addition, Table 3 summarized the performance of the optimization method using Uniform distribution, Chebyshev and Binomial in CST. From those three distribution on 3x3 array, uniform distribution yields the lowest directivity with the highest side lobe levels. Binomial distribution leads to lowest side lobe level with the highest directivity which is the most desirable compared to the other two techniques. On the other hand, Chebyshev providing an intermediate values of directivity and side lobe levels.

Table 2. Comparison on beam steering techniques using Uniform Distribution, Chebyshev and Binomial when the beam is steered towards theta=90° and phi=60°.

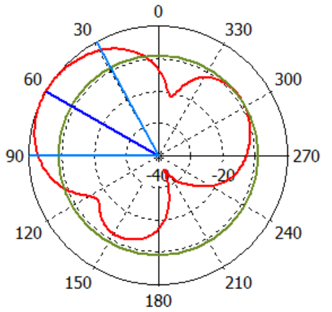
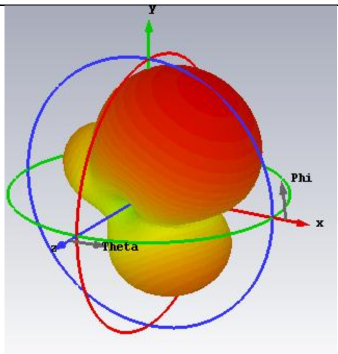
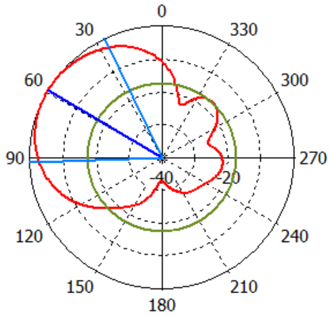
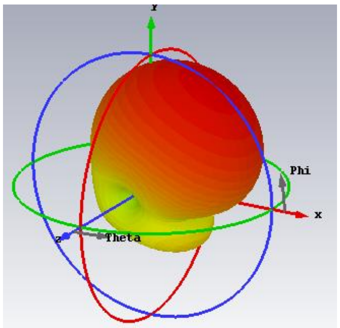
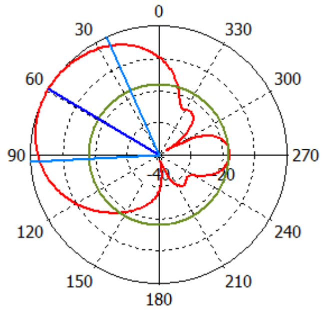
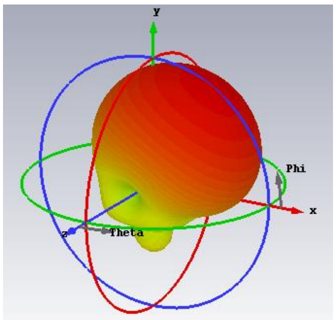
Method	2D Radiation Pattern	3D Radiation Pattern
Uniform Distribution		
Chebyshev		
Binomial		

Table 3: Performance of beamsteering techniques (Uniform, Chebyshev and Binomial distribution) of 3x3 dipole array when the beam is steered towards theta=90° and phi=60°.

Method	Half power beam width (HPBW)	Highest side lobe levels (dB)	Directivity
Uniform Distribution	61.4°	-9.1 dB	3.007 dB
Chebyshev	66.2°	-17.3 dB	8.604 dB
Binomial	69.0°	-18.0 dB	9.788 dB

4. Conclusion

The radiation pattern of the antenna array changes due to the variation of parameters. Next, the active element pattern is obtained using one active element while others terminated.

Then as comparison, the active element pattern is feasible at center-fed rather than edge-fed of the active element pattern of the antenna array. In addition, the comparison has been made between pattern multiplication using MATLAB and active element pattern using Computer Simulation Technology (CST). Lastly, the array performance of beam steering for the dipole antenna array have been optimized using Uniform, Binomial, and Dolph-Chebyshev methods. Whereas, uniform amplitude array which is also known as uniform distribution has the smallest half power beam width (HPBW) followed by Chebyshev and Binomial array. On the other hand, binomial distribution has the smallest side lobes level followed by Chebyshev and Uniform distribution. The highest directivity of the 3x3 dipole array has been leads by Binomial, Chebyshev and Uniform distribution.

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