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An Array with Crossed-Dipoles Elements for Controlling Side Lobes Pattern

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Abstract— This paper introduces an array with a new element structure to achieve asymmetric sidelobe pattern nulling which is a much desired feature in many applications such as communication systems, tracking radars, and imaging. The proposed element structure consists of combining two simple wire dipoles in the horizontal and vertical positions to form a crossed dipole element. The array patterns of the horizontal and vertical dipoles alone share some common radiation feature such angular null positions which are exploited to provide sidelobe nulling. By properly scaling the array pattern of the horizontal dipoles and added or subtracted its array pattern from that of the vertical dipoles, a new array pattern corresponds to the crossed dipoles elements with controlled sidelobes pattern can be obtained. The scaling factor selects which sidelobes to be cancelled. The method is equally applied to the uniformly and non-uniformly excited arrays. The proposed idea is verified by simulating an array with 10 half wavelength crossed dipoles using CST microwave studio.

Index Terms— Antenna arrays, two crossed dipole elements, asymmetric sidelobe pattern nulling.

I. INTRODUCTION

Currently antenna arrays play a very important role in enhancing the performances of many modern wireless communication systems through configuring their radiation patterns to be maximum at some desired directions and minimum at some other undesired directions. The sidelobe pattern nulling of antenna arrays can easily block the undesired signals at the antenna end. Thus, low sidelobes either on one side or both sides of the main beam and pattern nulling which they are depend on the excitation currents of the antennas are necessary for these applications. Many numerical algorithms have been proposed in the literature for optimizing the excitation currents to get the desired array patterns, for example see [1-6]. However, these optimization methods were generally difficult and complex. Thus, the authors in [7-9] investigated simpler methods for obtaining the required array patterns where they suggested formulating an appropriate auxiliary pattern from reusing two or more side elements whose sidelobes are

similar to that of the complete array pattern. Then, a required pattern nulling was obtained by subtracting the auxiliary pattern from that of the complete array pattern. These methods were simple since only two or a few number of reused array elements was made re-adjustable. In [10], scanned sub-arrays were used to generate sum and difference patterns, while in [11-12] a genetic algorithm was used to find and optimize the most active elements that could effectively contribute to generate the required nulls. On the other hand, the authors in [13-14] suggested exploring common current excitations to simplify the array feeding network while generating the required array patterns.

In all of the aforementioned methods, the type of the array elements was not investigated. The aim of this paper is mainly to present an efficient structure of the radiation elements that can produce an array with required sidelobe pattern nulling. This can be achieved, by considering two dipole elements and putting them in a crossed form configuration such that their corresponding array patterns can be added or subtracted to produce a new pattern with required sidelobe nulling .

II. PRINCIPLES OF THE TECHNIQUE

A. Conventional Array with Horizontal or Vertical Dipole Elements

Consider N dipole elements that are arranged linearly along the z -axis and positioned either horizontally toward the x -axis or vertically toward z -axis, as shown in Fig.1. The separation distance between any two adjacent dipoles is set to $d = \lambda/2$. The element excitation amplitude of n th element is denoted by a_n and its progressive phase is β . Thus, the array factor of such array in the far-field observations can be written as follows [15]:

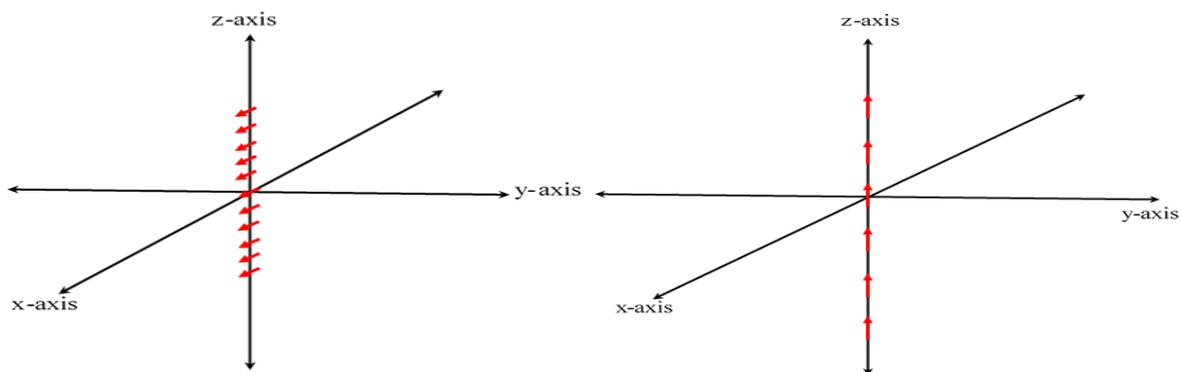


Fig.1 An array with N dipole elements positioned horizontally (left) or vertically (right) along the z -axis.

$$AF(\theta) = \sum_{n=1}^N a_n e^{j[(n-1)\psi_z]} \quad (1)$$

where a_n is the amplitude element excitation coefficients, $\psi = kd_z \cos \theta + \beta$, d_z is the spacing between elements along the z-axis $k = 2\pi/\lambda$ and λ is the wavelength in free space. Note that the array factors of these two configurations are same, only the element patterns differ. Thus, the overall array pattern (AP) for these two configurations can be obtained by multiplying the element pattern by the array factor as follows

$$AP(\theta)_{\text{Horizontal}} = \underbrace{\cos \theta}_{\text{Element Pattern}} \underbrace{\sum_{n=1}^N a_n e^{j[(n-1)kd_z \cos \theta]}}_{\text{Array Factor}} \quad (2)$$

$$AP(\theta)_{\text{Vertical}} = \underbrace{\sin \theta}_{\text{Element Pattern}} \underbrace{\sum_{n=1}^N a_n e^{j[(n-1)kd_z \cos \theta]}}_{\text{Array Factor}} \quad (3)$$

The above two array patterns are plotted for $N=20$ dipoles as shown in Fig.2.

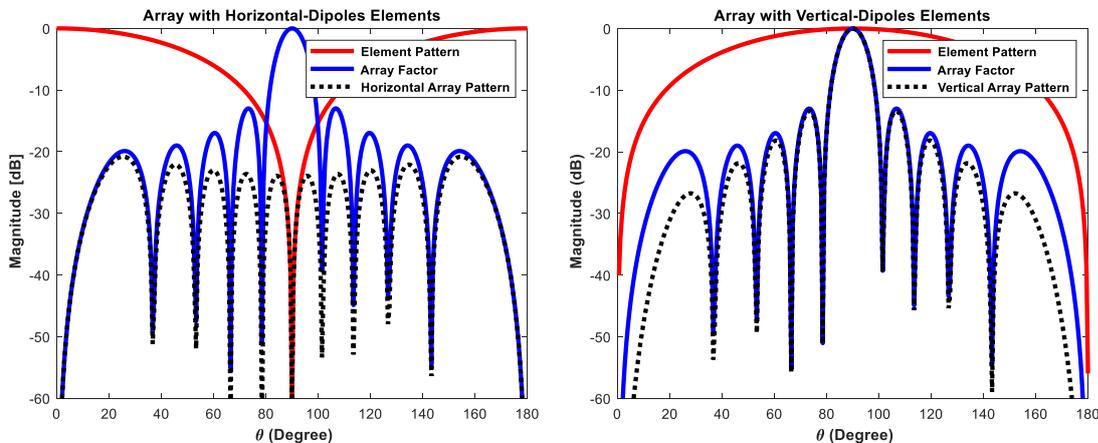


Fig.2 Array Patterns For $N=20$ dipoles positioned horizontally (left) or vertically (right) along the z-axis.

From figure 2, it can be seen that the resultant array pattern of the horizontal dipoles is in the form of sidelobes in which its nulls are exactly coincident with those of the resultant vertical array pattern. By combining these two antenna arrays with their resultant patterns of the vertical and horizontal array dipoles, one can get a new array with its elements as a two crossed dipoles.

B. An Array with Two Crossed Dipole Elements

In this section, the array elements are chosen such that the horizontal and vertical dipoles are combined to form a cross dipole for each array element. Then, the overall array pattern of the

combined arrays is the superposition of the horizontal and vertical array patterns. As mentioned the nulls of the array patterns of the horizontal and vertical dipoles are exactly coincidence. Thus, we need only to properly scale the magnitudes of the horizontal array pattern. Note that the horizontal and vertical array patterns are in-phase in one side and they are anti-phase in another side of the array pattern. Therefore, a great reduction in the sidelobe pattern can be obtained in one side and an increase in the sidelobe level in the other side. In other words, asymmetric sidelobes with the overall array pattern can be obtained. Moreover, depending on the value of scaling factor (K), a deep wide null can be also introduced in the overall array pattern. This is explained in the flowing equation:-

$$AP(\theta)_{\text{Crossed}} = K \underbrace{\cos(\theta) \sum_{n=1}^N a_n e^{j[(n-1)kd_z \cos \theta]}}_{\text{Horizontal Array Pattern}} + \underbrace{\sin(\theta) \sum_{n=1}^N a_n e^{j[(n-1)kd_z \cos \theta]}}_{\text{Vertical Array Pattern}} \quad (4)$$

By applying the above equation for $K=1$ and $N=20$, an overall array pattern for the two crossed dipole elements can be obtained as shown in Fig.3.

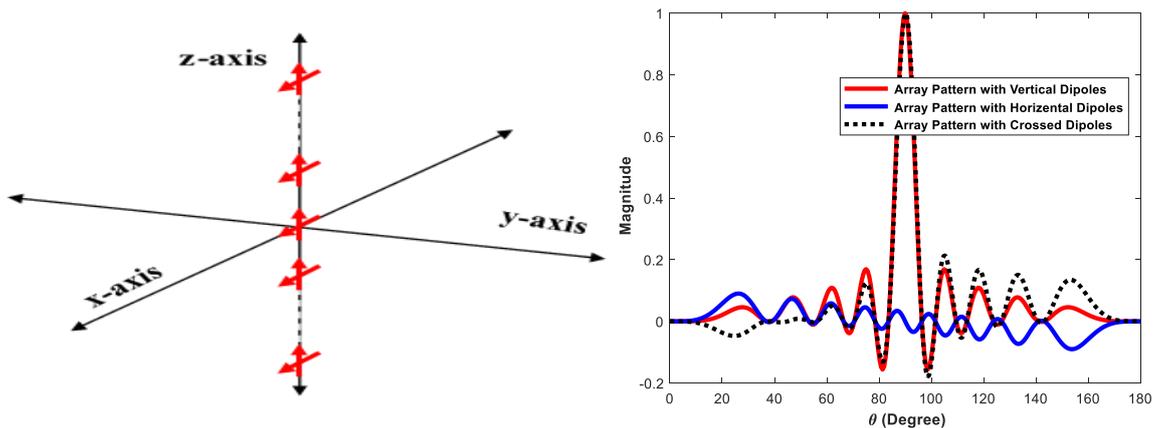


Fig.3 Structure of the proposed array (left), and its Overall Array Pattern for $K=1$ and $N=20$.

III. SIMULATION RESULTS

To demonstrate the possibilities of the proposed method in generating the required pattern nulling, three various cases are presented where the first case is related to the uniformly excited arrays, while the other two cases are related to the non-uniformly excited arrays such as Dolph, and Taylor. In all cases, an array with 10 crossed-dipole elements along the z -axis is considered. Moreover, the inter-element spacing between any two successive crossed-dipole elements is chosen to be 0.5λ . For Dolph excited arrays, the desired SLL was set to -26 dB, while for Taylor excited arrays they are set to $SLL = -20$ dB, and $nbar = 4$. The scaling factor was variable for each case to get best match in the sidelobe regions of the horizontal and vertical array patterns.

In the first case, the scaling factor was set to $K=1$ such that the third sidelobe can be cancelled. The array patterns according to (4) were obtained as shown in Fig. 4. Further, table I shows the performance measures in terms of directivity, both peak and average sidelobes, and the beamwidths of the tested arrays. It can be seen that the third sidelobes on the left side on the main beam in the uniform, Taylor, and Dolph array patterns with crossed-dipole elements are cancelled. Moreover, many of the other sidelobes on the left side were reduced down with compared to that of the vertical dipole array pattern.

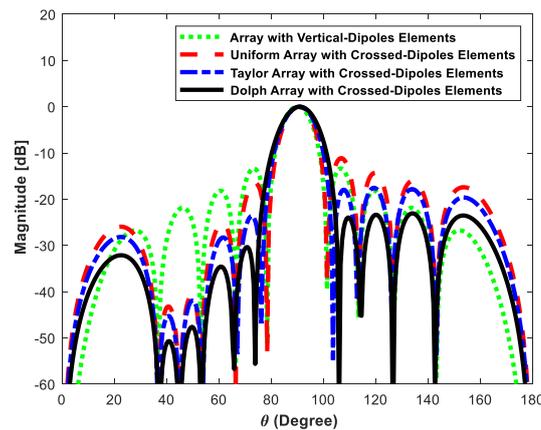


Fig.4 Array Patterns for $K=1$.

Table I Performance Measures for $K=1$

The Method	Directivity [dB]	Peak SLL-left [dB]	Peak SLL-right [dB]	FNBW [Deg.]	HPBW [Deg.]	Average-SLL [dB]
Uniformly Excited Array with Vertical-Dipole Elements	10.13	-13.3	-13.3	22.8	10	-13.07
Uniformly Excited Array with Crossed-Dipole Elements	10.06	-16.4	-11.1	22.8	11.4	-12.1
Dolph Excited Array with Crossed-Dipole Elements	9.59	-30.4	-23.8	32	13.8	-10.47
Taylor Excited Array with Crossed-Dipole Elements	9.89	-32.7	-18	27.4	12.6	-10.7

In the second case, the scaling factor was set to $K=1.767$ and the resultants array patterns are as shown in Fig. 5 and their performance measures as shown in Table II. It can be seen that the second sidelobes are cancelled. Moreover, many of the other sidelobes on the left side were reduced down with compared to that of the vertical dipole array pattern.

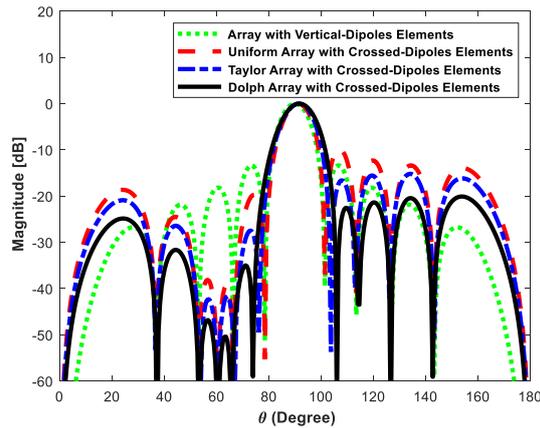


Fig.5 Array Patterns for $K=1.767$.

Table II Performance Measures for $K=1.767$

The Method	Directivity [dB]	Peak SLL-left [dB]	Peak SLL-right [dB]	FNBW [Deg.]	HPBW [Deg.]	Average-SLL [dB]
Uniformly Excited Array with Vertical-Dipole Elements	10.13	-13.3	-13.3	22.8	10	-13.07
Uniformly Excited Array with Crossed-Dipole Elements	9.91	-19.7	-9.8	22.8	11.8	-11.58
Dolph Excited Array with Crossed-Dipole Elements	9.64	-27.45	-22.5	32	15	-10.13
Taylor Excited Array with Crossed-Dipole Elements	9.86	-35	-16.6	27.4	13.8	-10.8

In the third case, the scaling factor was chosen, $K=3.3$, such that the first sidelobe in the proposed array can be cancelled. The resultant array patterns are as shown in Fig. 6 and their performance measures as shown in Table III.

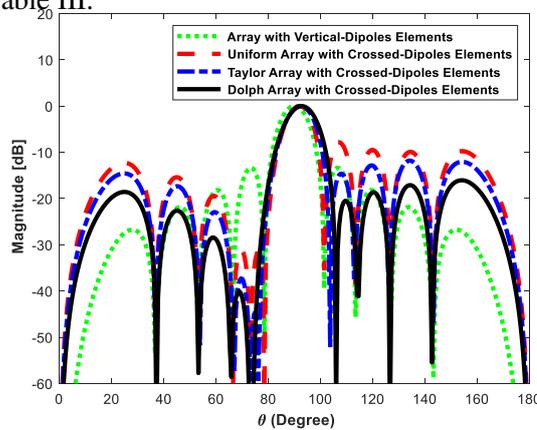


Fig.6 Array Patterns for $K=3.3$.

Table III Performance Measures for K=3.3

The Method	Directivity [dB]	Peak SLL-left [dB]	Peak SLL-right [dB]	FNBW [Deg.]	HPBW [Deg.]	Average-SLL [dB]
Uniformly Excited Array with Vertical-Dipole Elements	10.13	-13.3	-13.3	22.8	10	-13.07
Uniformly Excited Array with Crossed-Dipole Elements	9.45	-31.3	-7.8	22.8	13	-10.94
Dolph Excited Array with Crossed-Dipole Elements	9.77	-40	-20.5	32	11.5	-9.66
Taylor Excited Array with Crossed-Dipole Elements	9.74	-37.3	-14.6	27.4	10.5	-10.4

Finally, in order to consider the effects of element type, feeding position, mutual coupling, scattering and many other effects, full simulation using CST is done for 10 crossed-dipoles elements array with discrete ports as shown in Fig.7(left). The return loss curve has been shown in this figure (see Fig.7 right). Table IV shows the details of design parameters of the proposed crossed-dipoles elements.

Table IV Design Parameters

Resonant Frequency (fr).	2.4 GHz.
Wavelength (λ).	124.91 mm.
Length of the dipole (L).	$L = \lambda/2 = 62.455$ mm (Copper annealed).
The feeding gap(G).	$G=L/100=0.6245$ mm (Air).
Radius of the dipole (R)	$R=\lambda/1000=0.1249$ mm
Impedance	73(Ohm)

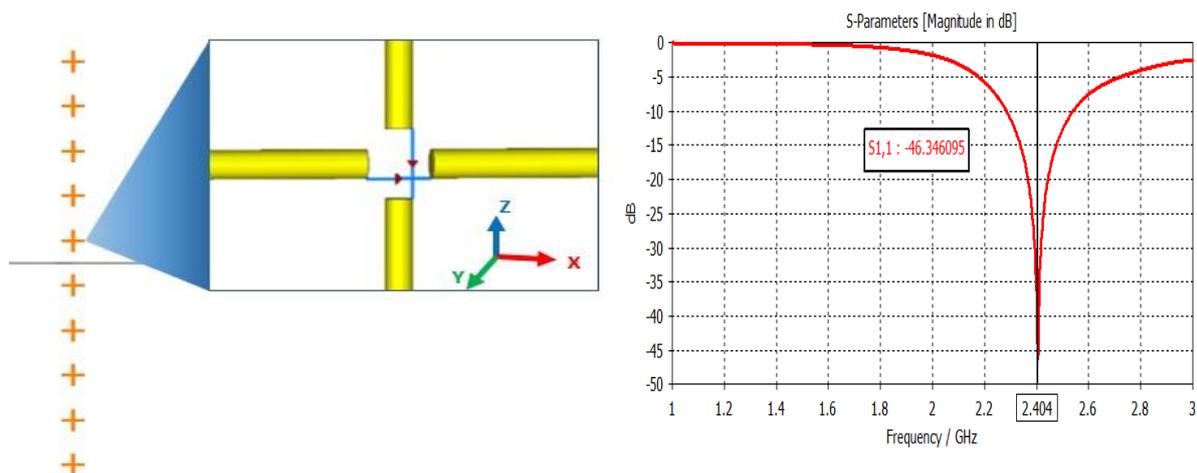


Fig.7 Structure of the Designed Array (left) and its S Parameter at F=2.4 GHz.

Fig.8 shows the results of the designed array. The CST results are found satisfactory and in good agreement with the theoretical Matlab findings. The return loss value was at -46.3 dB at frequency 2.404 GHz and the bandwidth was found to be around 261 MHz, which is suitable for many wireless applications.

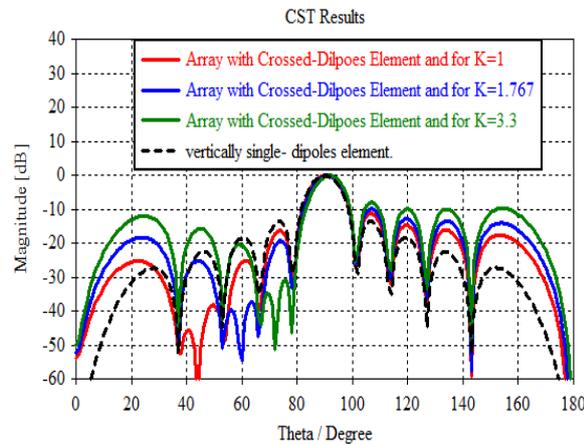


Fig.8 CST Results for Various Values of Scaling Factor, K .

IV. CONCLUSIONS

From the presented results, it can be found that the proposed array is capable to provide a required pattern with controlled nulls that depend on the selecting value of the scaling factor. The method is equally applicable to both uniformly and non-uniformly excited arrays. For all considered arrays, the differences between sidelobe levels on both sides of the main beam were more than -20 dB. Moreover, the directivity of the proposed array was found to be slightly reduced with compared to that of the conventional array with single-dipole elements. Finally, an array with the proposed crossed-dipole elements was designed and simulated using CST microwave studio and its results were compared to the theoretical Matlab findings, which confidently validated the presented idea.

The proposed array can be further extended to include the circular polarization.

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