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An Array with Crossed-Dipole Elements for Controlling Sidelobes 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 is built by 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 share some common radiation features such as angular null positions which are exploited to provide the required sidelobe nulling. By properly scaling the array pattern of the horizontal dipoles and adding or subtracting its array pattern from those of the vertical dipoles, a new array pattern corresponding to the crossed dipoles elements with controlled sidelobes pattern is obtained. The proposed method is equally applied to the uniformly and nun-uniformly excited arrays. Moreover, the proposed idea is verified by simulating an array with 10 half wavelength crossed dipoles using computer simulation technology microwave studio, and the obtained results – which are compared to the theoretical Matlab findings - confidently validate the presented idea.

Keywords— Antenna arrays; Two crossed dipole elements; Asymmetric sidelobe pattern nulling.

1. INTRODUCTION

Currently antenna arrays play a very important role in enhancing the performance 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 or both sides of the main beam and pattern nulling - which depend on the excitation currents of the antennas - are necessary for these applications. Many techniques have been proposed in the literature for configuring the array radiation pattern which is controlled by the following five array design parameters: the geometrical layout of the array elements and their spacings, the excitation amplitude and phase of the individual elements and finally the pattern of the individual elements. Generally, array synthesis techniques use numerical optimization approaches to optimize the excitation amplitude and phase of the array elements to get the desired array patterns [1-6]. However, these optimization methods are generally difficult and complex. Thus, the authors in [7-9] investigated simpler methods for obtaining the required array patterns. They suggested formulating an appropriate auxiliary pattern by reusing two or more side elements, whose sidelobes are similar to those 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 few number of reused array elements were 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 generating the required nulls. On the other hand,

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the authors in [13, 14] have 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 the required sidelobe nulling.

2. PRINCIPLES OF THE TECHNIQUE

2.1. 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 crossed dipoles is set to be $d = \lambda/2$ so that the grating lobes can be prevented. Also, the mutual coupling effect between the array dipoles especially in the horizontal configuration can be reduced. Thus, the array factor of such array in the far-field observations can be written as follows [15]:

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

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

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

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

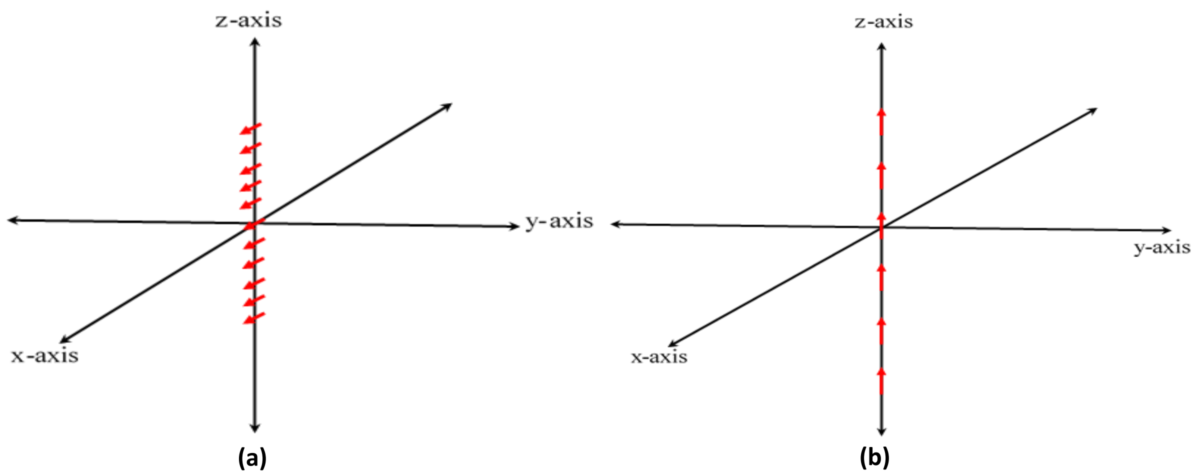


Fig. 1. An array with N dipole elements positioned: a) horizontally; or b) vertically along the z-axis.

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

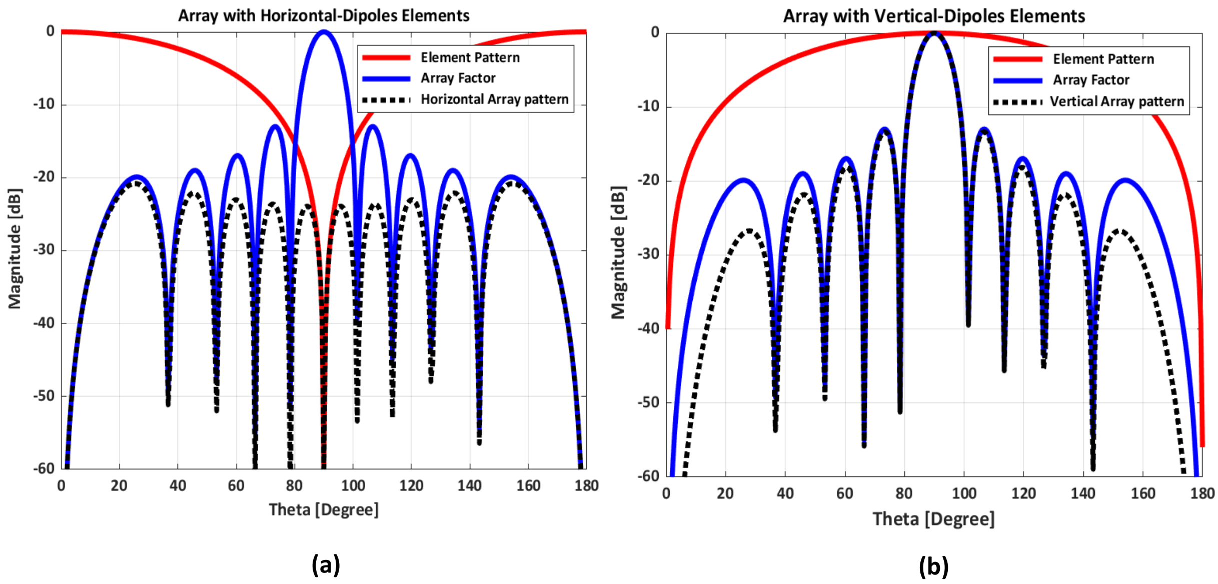


Fig. 2. Array patterns for N = 20 dipoles positioned: a) horizontally; or b) vertically along the z-axis.

From Fig. 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 identical 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 two crossed dipoles.

2.2 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 earlier, the nulls of the array patterns of the horizontal and vertical dipoles are exactly matched. 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 out-of-phase in the other 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 (SF), a deep wide null can be also introduced in the overall array pattern. This is explained in the following equation:

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

By applying the above equation for N = 20 and choosing the value of the scaling factor to be SF = 1, an overall array pattern for the two crossed dipole elements can be obtained as shown in Fig. 3(b) where the third sidelobe on the left side of the crossed array pattern has been completely suppressed.

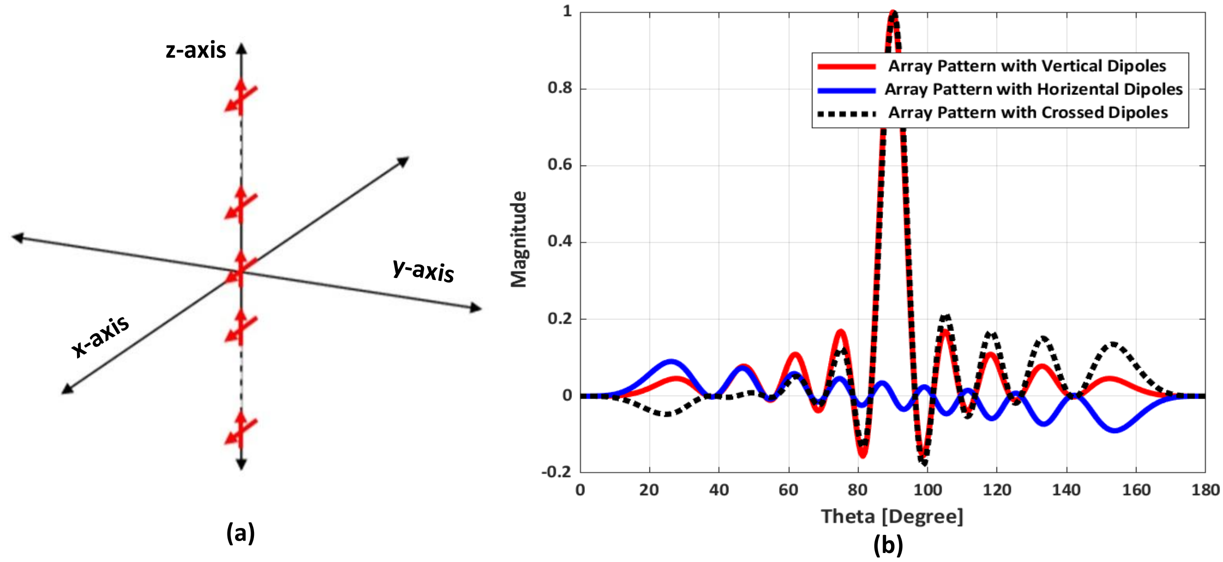


Fig. 3. The proposed array: a) its structure; b) its overall array pattern for SF = 1 and N = 20.

3. 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. It is well-known that the Dolph-Chebyshev distribution [15] produces an array with equally sidelobes, while the Taylor distribution controls the decay of the sidelobes by selecting a proper value for the design parameter nbar. 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 side lobe level (SLL) was set to −26 dB, while for Taylor excited arrays they are set to −20 dB, and nbar = 4 (here, the parameter nbar represents the number of approximately constant-level sidelobes next to the mainlobe). The scaling factor was variable for each case to get the best match in the sidelobe regions of the horizontal and vertical array patterns.

In the first case, SF was set to unity, such that the patterns of the horizontal and vertical arrays are identical and in-phase in the third sidelobe region. Consequently, the third sidelobe on the left side of the crossed array pattern can be cancelled according to Eq. (4). The obtained array patterns are shown in Fig. 4. Further, Table 1 shows the performance measures in terms of directivity, both peak and average sidelobes, the first null-to-null beamwidth (FNBW) and the half power beam width (HPBW) of the simulated arrays. It can be seen that the third sidelobes on the left side of the main beam - in each of the uniform, Taylor and Dolph array patterns with crossed-dipole elements - are almost cancelled. Moreover, many of the other sidelobes on the left side were also reduced down, compared to that of the vertical dipole array pattern.

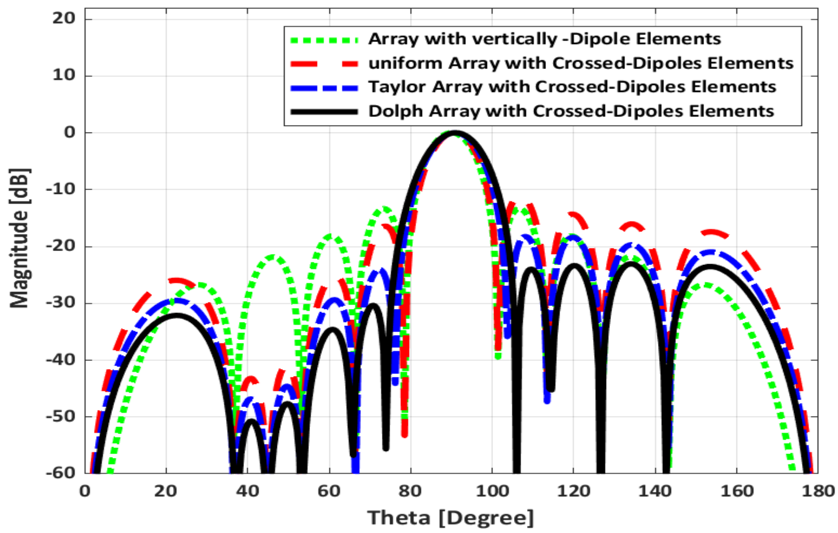


Fig. 4. Array patterns for *SF* = 1.

Table 1. Performance measures for SF = 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, SF was set to 1.767. The resultants array patterns are exhibited in Fig. 5, and their performance measures are shown in Table 2. It can be seen that the second sidelobes are cancelled. Moreover, many of the other sidelobes on the left side were reduced down, compared to that of the vertical dipole array pattern.

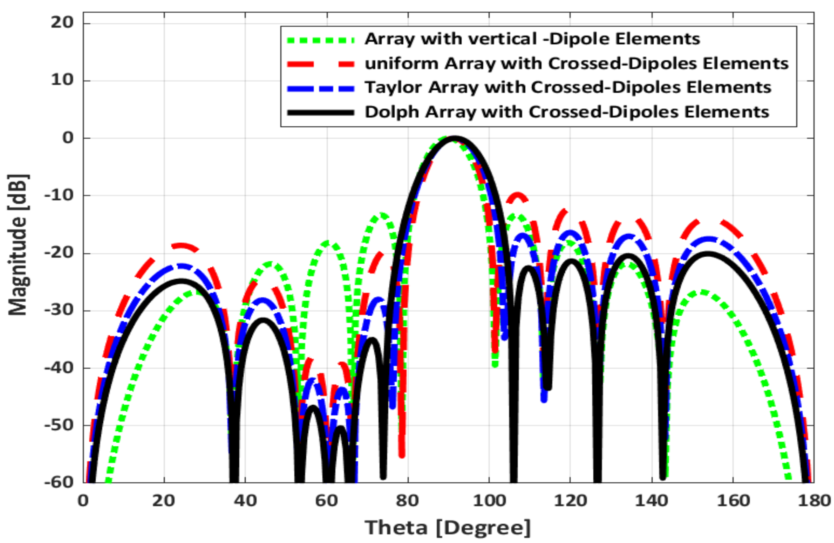


Fig. 5. Array Patterns for *SF* = 1.767.

Table 2. Performance measures for SF = 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, SF was chosen to be 3.3, such that the first sidelobe in the proposed array was almost cancelled. The resultants array patterns are shown in Fig. 6, and their performance measures are shown in Table 3.

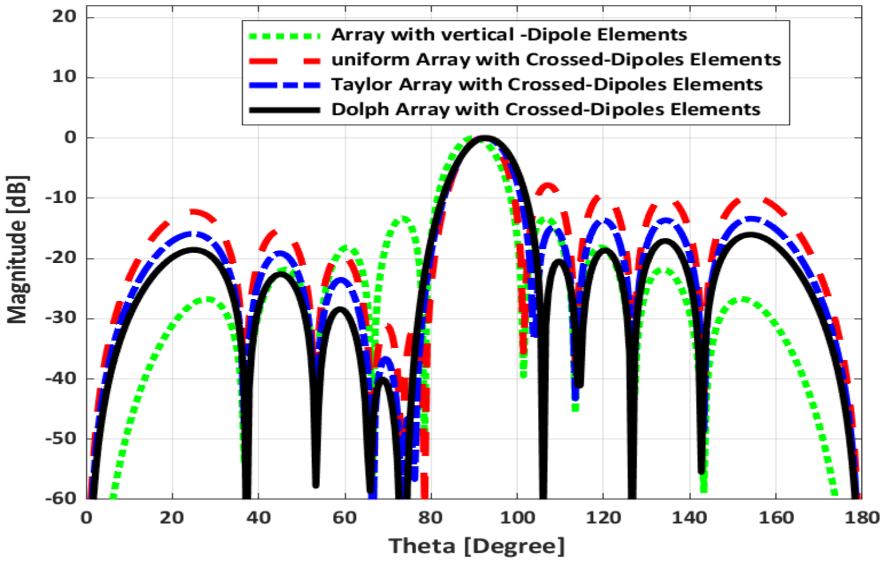


Fig. 6. Array patterns for *SF* = 3.3.

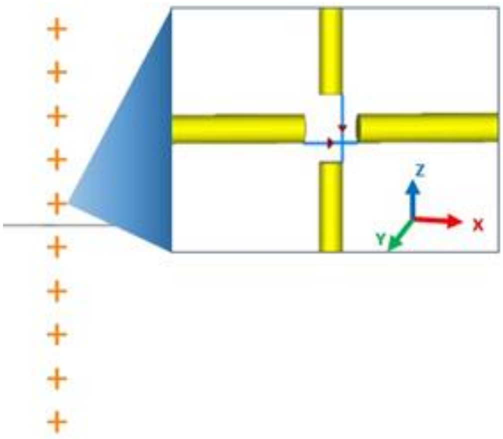
Table 3. Performance measures for SF = 3.3.

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 computer simulation technology (CST) microwave studio - is done for 10 crossed-dipoles elements array with discrete ports as shown in Fig. 7(a). The return loss response is shown in Fig. 7(b). Table 4 shows the design parameters of the proposed crossed-dipoles elements in detail.

Table 4. Design parameters of the proposed crossed-dipoles elements array

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



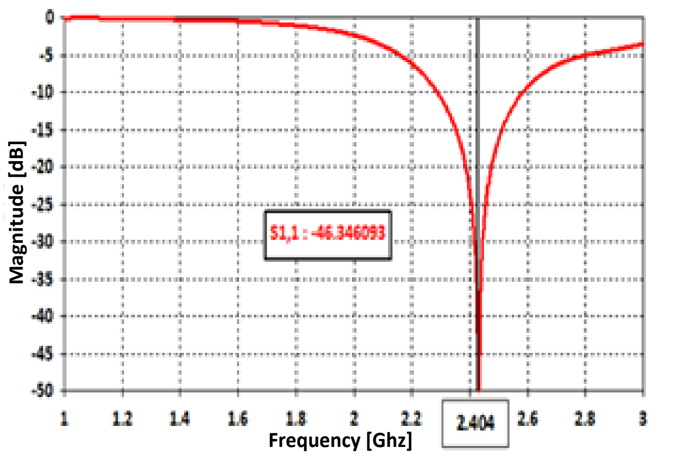


Fig. 7. The designed array: a) its structure; b) its S- Parameter at a frequency of 2.4 GHz.

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 -46.3 dB at a frequency of 2.404 GHz and the bandwidth was found to be around 261 MHz, which is suitable for many wireless applications.

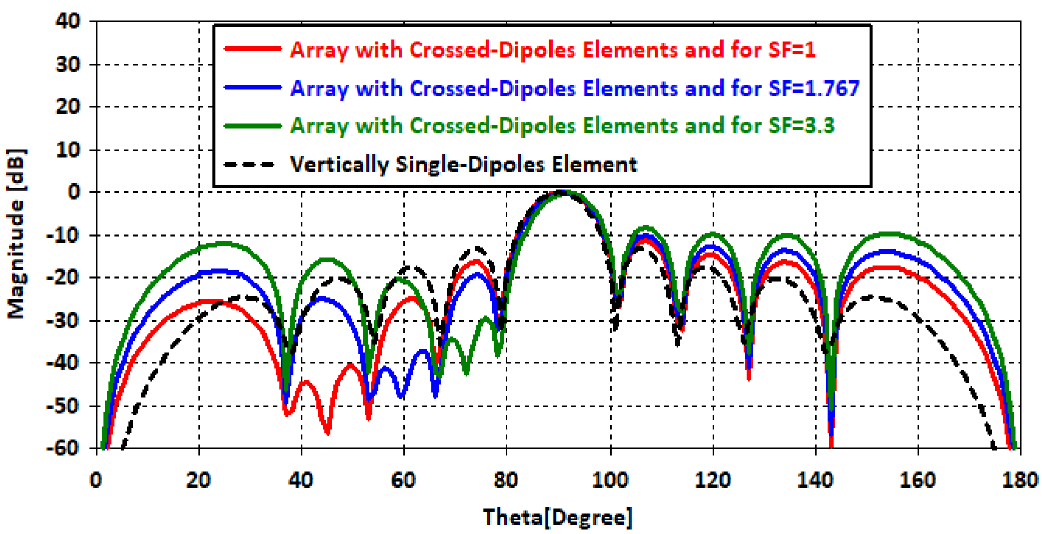


Fig. 8. CST results of the designed array for various values of the SF.

4. 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 selected 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, 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.

It worth mentioning that the proposed array can be further extended to include the circular polarization.

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