On the Omni-directional Radiation Pattern with Polyhedron Array

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Abstracts: A new technology which can be used to improve the omni-directional radiation pattern of polyhedron array is studied with mutual coupling compensation. Firstly, the mutual coupling between array elements is expressed in a matrix form, which can be obtained by the orthogonal method. The mutual coupling is compensated by calibrating the excitation of array elements. Then, a tetrahedron array consisting of eight dipole elements with operating frequency of 800MHz is designed and simulated in order to obtain an omni-directional pattern. In this way, the omni-directional radiation property of polyhedron array can be improved greatly. The roundness of the omni-directional pattern of 1.271dB can be obtained for the array antenna designed, with 1.5dB improved. The numerical results show that the method is accuracy and efficiency.

Key words: omni-directional antenna, polyhedron array, orthogonal method, coupling compensation

1. INTRODUCTION

The omni-directional antenna plays an important role in the wireless communication system. Arranging the elements of antenna array in different forms is an effective way to achieve omni-directional radiation. For instance, linear array, circular array, polygon array, and polyhedron array are widely used in smart antenna system[1] and other wireless communication system. All traditional means to synthesize antenna array are implemented without taking the coupling between the elements into account. But this coupling couldn't be neglected in a real system, especially when the distance between the elements less than λ, because the coupling can affect the amplitude and phase of the elements and lead to the radiation distortion. The polyhedron array proposed in this paper is an tetrahedron array in order to realize omni-directional radiation pattern, which is made up of eight half-wavelength dipole elements working at 800MHz. The mutual coupling between the array elements is compensated so that the radiation property of the array can be enhanced. A technology to compensate the mutual coupling is given in literature [2], which is based on the application of Fourier decomposition. The disadvantage of this technology is that it becomes inaccurate when the distance between the elements is less than $\lambda/2$. In the present, the mutual coupling between the elements is compensated by celebrating the excitation of the array[3], and the coupling matrix can be derived with the help of the orthogonal method[3−5]. In this way, a better omni-directional radiation pattern can be obtained with the polyhedron array.

2. COUPLING COMPENSATION BASED ON CALIBRATING THE EXCITATION OF THE ARRAY

The ideal pattern of a linear equally spaced array can be expressed as follows[6,7]:

$$F(\theta,\varphi) = f^{i}(\theta,\varphi)\cdot \sum_{n=1}^{N} I_n^d e^{j\beta(x_n\cos\varphi\sin\theta + y_n\sin\varphi\sin\theta + z_n\cos\theta)} \tag{1}$$

Where $f^{i}(\theta,\varphi)$ is the isolated element pattern, I_n^d and (x_n, y_n, z_n) are the excitation current and the position of the feed point of the n^{th} element, respectively. N is the total number of the elements of the array. A desired radiation pattern can be derived by adopting appropriate amplitude and phase of I_n^d.

However, the pattern of each element in an array will be different from $f^{i}(\theta,\varphi)$ because of the coupling affection. It is obvious that the radiation properties of an array antenna cannot be given by (1) if the coupling affection is taken into account. Under the coupling conditions, the pattern of an array can be expressed as follows[3]:

$$F(\theta,\varphi)=\sum_{n=1}^{N} I_n f_n(\theta,\varphi)\cdot e^{j\beta(x_n\cos\varphi\sin\theta+y_n\sin\varphi\sin\theta+z_n\cos\theta)} \qquad (2)$$

where I_n is the input current and $f_n(\theta,\varphi)$ is the pattern of the n^{th} element. This pattern is actually the antenna pattern when only the n^{th} element is excited and the rest elements are short-circuited. The coupling between the m^{th} and n^{th} elements can be presented by the equivalent excitation current coefficient c_{nm}. Therefore, considering the formulation of (1) and (2), $f_n(\theta,\varphi)$ is written as[3] :

$$f_n(\theta,\varphi)=\sum_{m=1}^{n} c_{nm} f^i(\theta,\varphi)\cdot e^{j\beta[(x_m-x_n)\cos\varphi\sin\theta+(y_m-y_n)\sin\varphi\sin\theta+(z_m-z_n)\cos\theta} \qquad (3)$$

The exponential term reflects the phase difference between the m^{th} and n^{th} elements.

After substituting （3）to（2）, one can obtain:

$$F(\theta,\varphi)=f^i(\theta,\varphi)\cdot \sum_{n=1}^{N}(\sum_{m=1}^{N} c_{mn} I_m)e^{j\beta(x_n\cos\varphi\sin\theta+y_n\sin\varphi\sin\theta+z_n\cos\theta)} \qquad (4)$$

From Eq.（1）and（4）, it is found that

$$I_n^d=\sum_{m=1}^{N} c_{mn} I_m \qquad (5)$$

Eq. (5) can be written in matrix form as follows:

$$[I^d]=[c]^T\cdot[I] \qquad (6)$$

where T indicates the matrix transpose, and $[I^d]$ is the excitation of the uncoupled array, while $[I]$ is the corresponding excitation for the real array. Solving (6), we obtain

$$[I]=\{[c]^T\}^{-1}\cdot[I^d] \qquad (7)$$

3. COUPLING MATRIX DERIVEDBY ORTHOGONAL METHOD

It can be seen that it is necessary to find a method to get the coupling coefficient of c_{nm}. Here, we solve the coupling matrix with the help of orthogonal method. The ratio $f_n(\theta,\varphi)/f^i(\theta,\varphi)$ of (3) is expressed as a linear combination of non-orthonormal functions $\Phi_m^{(n)}(\theta,\varphi)$, where

$$\Phi_m^{(n)}(\theta,\varphi)=e^{j\beta[(x_m-x_n)\cos\varphi\sin\theta+(y_m-y_n)\sin\varphi\sin\theta+(z_m-z_n)\cos\theta]} \qquad (8)$$

Thus,

$$F_n(\theta,\phi)=\frac{f_n(\theta,\varphi)}{f^i(\theta,\phi)}=\sum_{m=1}^{N} c_{nm}\Phi_m^{(n)}(\theta,\varphi) \qquad (9)$$

Since the basis { $\Phi_m^{(n)}(\theta,\varphi)$ } is not orthogonal, an orthogonal basis $\{\Psi_i^{(n)}(\theta,\varphi)\}$ must be constructed in the following form[3,4]:

$$\Psi_i^{(n)}(\theta,\varphi)=\sum_{m=1}^{i} A_{m,n}^{(i)}\Phi_m^{(n)}(\theta,\varphi) \qquad (10)$$

In the new system of basis, the element pattern $F_n(\theta,\varphi)$ can be expressed as follows:

$$F_n(\theta,\varphi)=\sum_{i=1}^{N} B_{ni}\Psi_i^{(n)}(\theta,\varphi) \qquad (11)$$

Due to the orthogonality of $\{\Psi_i^{(n)}(\theta,\varphi)\}$, the weights B_{ni} of (11) become[4,5]

$$B_{ni}=\langle F_n,\Psi_i^{(n)}\rangle = \int_0^{2\pi} d\varphi\int_0^{\pi} F_n(\theta,\varphi)\Psi_i^{(n)*}(\theta,\varphi)\sin\theta d\theta \qquad (12)$$

By combining (9) and (11), the coefficient c_{nm} can be found from [3,4]:

$$c_{nm}=\sum_{i=m}^{N} B_{ni}C_{m,n}^{(i)} \qquad (13)$$

Matrix $[c]$ can be got by the orthogonal method described above. Then, with equation (7), the excitations when coupling coefficients are taken into account are derived.

4. NUMERICAL RESULTS

An omni-directional polyhedron array consisting of eight half-wavelength dipole elements is studied. We choose the method mentioned above to compensate the coupling of the array in order to improve its omni-directional radiation property. Fig.1 shows the structure of the polyhedron array. The total number of the half-wavelength dipole elements working at 800 MHz is eight. Each section contains two dipoles which are $\lambda/4$ far from the ground plane. The distance between the elements is $\lambda/2$. The edge length of the finite ground plane of each section is λ .

The coupling between the elements of different sections can be neglected because of the finite ground plane and the distance between elements over one wavelength. As a result, the coupling compensation of dipole elements of the same section is considered under the condition of infinite groundplane. At this time, the excitation of the two dipoles in the same section are e^{i0} and $2e^{i0}$, respectively.

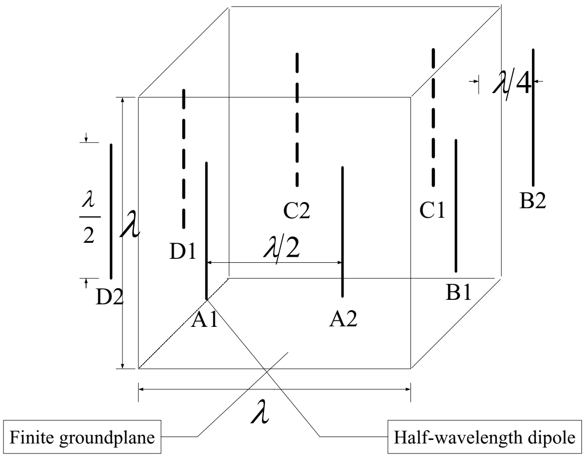

Fig.1 Structure Of The Polyhedron Array

The ideal pattern is computed by the pattern multiplication principle, while the actual one is derived by FEKO which is based on MOM. The normalized gain of the two-dipole linear array under the condition of non-coupling and coupling is shown in Fig.2. It is found that the difference between the two curves is obvious. The mutual coupling of the elements affect the pattern greatly and should been compensated in the array.

The mutual coupling compensation between the array elements is finished by calibrating the excitation of the array, and the coupling matrix is derived with the help of the orthogonal method mentioned above.

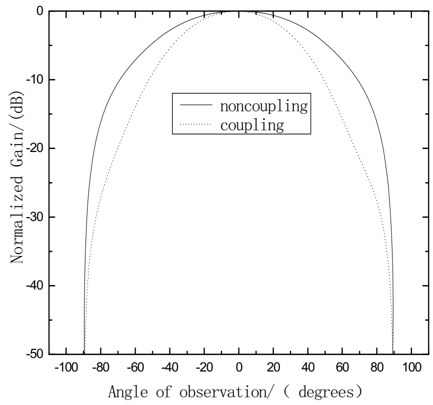

Fig.2 Normalized Gain of The Two-dipole Array under The Condition of Non-coupling and Coupling

In this case, the nonorthonormal functions $\Phi_m^{(n)}(\theta,\varphi)$ of the two-dipole array can be gotten from (8) and the constructed orthogonal basis $\{\Psi_i^{(n)}(\theta,\varphi)\}$ are derived by (10) accordingly. On the other hand, B_{ni} can be obtained from (12). Therefore, the coefficient c_{nm} can be derived from (13). Consequently, the excitation of the two-dipole array after compensation is worked out by (7). Table.1 gives the excitation of the real array with compensation, and that without compensation is also given for comparison:

TABLE.1 THE EXCITATION OF THE REAL ARRAY BEFORE AND AFTER COMPENSATION

	Excitation of element 1	Excitation of element 2
Without compensation	e^{i0}	$2e^{i0}$
With compensation	e^{i0}	$1.283\,e^{i0.2606}$

Then, a tetrahedron array is designed to realize an omni-directional pattern. The configuration of the array is shown in Fig.1. We apply the same excited coefficient as shown in Table.1 to each section of the array. Also, the ideal pattern of the tetrahedron array is computed by the pattern multiplication principle, while the actual one is derived by FEKO. Fig.3 shows the normalized gain of the omni-directional polyhedron array with and without coupling compensation. The roundness of the pattern without compensation is 2.705dB while the compensated one is 1.271dB. It is easily found that roundness of the pattern of the tetrahedron array has been improved about 1.5dB, and the maximum radiation is much nearer to the normal direction of the array plane. The result indicates that the coupling has been compensated effectively and the omni-directional radiation property of the polyhedron array is improved.

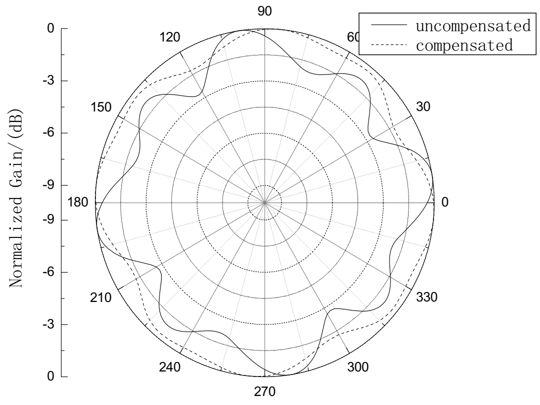

Fig.3 The Normalized Gain Of The Omni-directional Array With And Without Coupling Compensation

5. CONCLUSION

The mutual coupling compensation is always a difficulty in array synthesis. In this paper, an omnidirectional tetrahedron array operating at 800MHz is studied. The orthogonal method is used to compute the coupling matrix in this paper and the mutual coupling between the array elements is compensated by calibrating the excitation of the antenna array. The numerical results show that the omnidirectional radiation pattern can be obtained by a polyhedron array, and the roundness of the radiation pattern can be improved effectively after mutual coupling compensation.

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