Specific Excitation Conditions Achieved by Near Field Source in EM Analysis

Lu Liu, Xianzheng Zong, Zaiping Nie

School of Electronic Science and Engineering
University of Electronic Science and Technology of China
Chengdu, 610054, China

***Abstract*—A simple preprocessing of providing specific incident conditions for the structures that work with antenna array is proposed in this paper. In lots of electromagnetic (EM) systems, such as antenna-radome system, antenna array always works with other structures. To figure out the EM performance of these kinds of structures, specific excitation condition is needed. Based on Huygens-Fresnel and superposition principles, instead of real-world antenna array modeling, near field source is used as the excitation source. Using this method, prescribed incident conditions can be achieved easily. Numerical results show that the strategy of the proposed preprocessing has a capability of good feasibility and the EM analysis efficiency can be improved.**

Keywords—near field source, large-scale antenna array, specific excitation condition, radome

I. Introduction

Lots of large-scale antenna arrays work with other electromagnetic (EM) structures, such as antenna-radome system [1-3]. To analyze the EM performance of these kinds of systems, commercial software such as FEKO and CST are used extensively. In most situations specific excitation conditions are needed. Important far field parameters of the array like Gain, beam width and sidelobe level (SLL) are predetermined. Generally most of these commercial software can't generate the antenna array model based on those prescribed parameters automatically. However, it's complicated and inconvenient if the antenna array model is built manually, especially for non-uniform excited large-scale antenna array.

According to the Huygens-Fresnel principle, it states that every points on a wavefront is itself the source of spherical wavelets. It implies that the original source of the wavefront can be ignored and the wavefront itself is considered as a source for all further wavefronts [4-5]. In array synthesis, the well-known Taylor and Chebyshev methods [6] efficiently obtain the appropriate number of array elements and the weighting vector for equally spaced arrays that keep the critical parameters within prescribed performance bounds.

To improve the efficiency of the problem mentioned above, the near field source rather than large-scale real-world antenna array modeling is used to achieve the specific excitation conditions in this paper. Antenna synthesis methods is used to design the antenna array to keep the important parameters within bounds. Then the near field source of the large-scale array can be obtained based on the superposition principle. Image method can be included if there is ground plane. Compared with creating real-world antenna array model, the proposed method makes the EM analysis easier to work with, because the near field source can be obtained by preprocessing easily.

II. Formulation

For large-scale antenna arrays, dipoles are often used as the array elements. Take the dipole array as an example. The near field of each dipole can be expressed analytically. The near field formulas of hertz dipole can be written as

$$dE_\theta = j\eta \frac{\beta I d_z}{4\pi r}\sin\theta[1+\frac{1}{j\beta r}+\frac{1}{(j\beta r)^2}]e^{-j\beta r} \tag{1}$$

$$dE_r = \eta \frac{I d_z}{2\pi r}\cos\theta(1+\frac{1}{j\beta r})e^{-j\beta r} \tag{2}$$

$$dE_\varphi = 0 \tag{3}$$

where η represents the wave impedance. Assume that the current distribution on the half-wave dipole is sinusoidal

$$I(z) = I_m \sin[\beta(l-|z|)], -l \le z \le l \tag{4}$$

Where l is the length of the dipole and I_m is the excitation current. Then the near field of half-wave dipole can be expressed as

$$E_k = \int_{-l}^{l} dE_k \tag{5}$$

k represents θ, r or φ. Therefore, the final field formulas of element m can be written as

$$E_\theta^m = \frac{j60 I_m e^{-j\beta r_0}}{r_0}\cdot[1+\frac{1}{j\beta r_0}+\frac{1}{(j\beta r_0)^2}]\cdot\frac{\cos(\beta l\cos\theta)-\cos(\beta l)}{\sin\theta} \tag{6}$$

$$E_r^m = \frac{120 I_m \cos\theta e^{-j\beta r_0}}{r_0^2 \beta \sin\theta}\cdot(1+\frac{1}{j\beta r_0})\cdot\frac{\cos(\beta l\cos\theta)-\cos(\beta l)}{\sin\theta} \tag{7}$$

$$E_\varphi^m = 0 \tag{8}$$

where r_0 represents the distance between field point and antenna position. Based on the superposition principle, the total near field distribution of antenna array can be obtained by

$$E_k^{Array} = \sum_{m=1}^{N} E_k^m \tag{9}$$

As for antenna-radome system, usually specific antenna array radiation performance is needed as the incident condition for the radome. The prescribed performance can be achieved by antenna array synthesis methods. For low side-lobe array, Taylor synthesis can be used to design the current distribution (I_m) of the array based on the prescribed Gain, SLL and beam width. Therefore the near field of specific performance antenna array can be obtained approximately. Here, mutual coupling between each antenna elements is ignored.

III. Numerical Results

A. *Near field distriution for 2×2 dipole array*

To verify the accuracy of the proposed model. A 2×2 uniformly excited dipole array with ground plane, as shown in Fig.1, is analyzed. This array works at 15GHz. Element spacing is 10.3mm. The near field distribution obtained from the proposed method is compared with that from full wave method (Method of Moment, MOM). Electric field distribution obtained from proposed method and full wave model are shown in Fig.2(a) and (b) respectively. The distance between near field aperture and array is 0.5 wavelength. Results show that this approach has a high accuracy, although the mutual coupling is ignored.

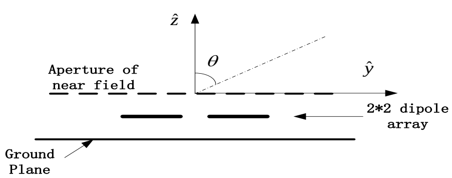
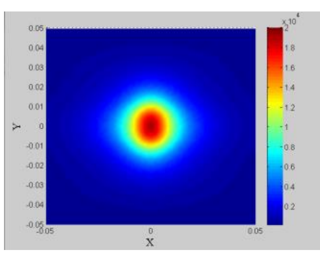
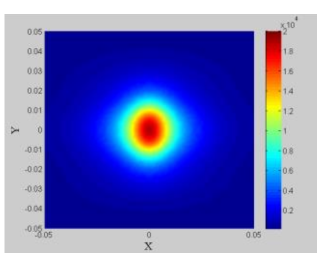


Fig.1. Near field aperture of 2*2 dipole array with ground plane.



(a)



(b)

Fig.2. Near field distribution. The units of both X and Y axis are meters. (a) Electric field distribution obtained from the proposed method. (b) Electric field distribution obtained from full wave model.

B. *Large-scale low SLL antenna array*

As the second example, a large-scale low SLL antenna array is analyzed. For an antenna-radome system, the prescribed parameters Gain is 30dB, SLL is -30dB and the upper limit of beam width is 7 degrees. Taylor synthesis method is used to design the two-dimensional array element number and weighting vector. Near field source files can be obtained based on superposition principle. The near field aperture is half-wavelength above the antenna array and the expansion distance is one-wavelength. Far field performances calculated by commercial software FEKO and CST based on the near field source obtained from the proposed preprocessing are shown in Fig.3. We can see that all the critical parameters satisfy the design requirements and targets. Therefore, near field source can be used instead of real-word antenna array modeling to achieve specific excitation conditions for other EM structures, such as radome. This method also works for phased array and monopulse antenna.

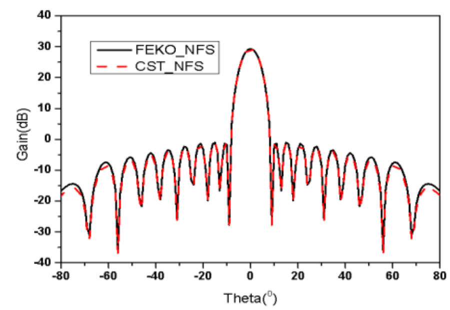


Fig.3. Far field performances obtained from FEKO and CST based on the proposed preprocessing. NFS represents near field source.

IV. Conclution

A preprocessing method to achieve specific excitation conditions is proposed in this paper. Instead of real-world antenna array modeling, near field source is used. Because the near field source can be obtained easily, the EM analysis efficiency can be improved, especially for large-scale and non-uniform excited antenna array. From the simulation results, we can see that worked with commercial software the strategy of the proposed preprocessing has a capability of good feasibility and the accuracy is acceptable.

Acknowledgment

This work is supported by the Natural Science Foundation of China (NSFC) under Projects No. 61231001.

References

[1] Hu, Bing, et al. "More accurate hybrid PO-MoM analysis for an electrically large antenna-radome structure." Progress In Electromagnetics Research 92 (2009): 255-265.

[2] Kozakoff, Dennis J. Analysis of radome-enclosed antennas. Artech House, 2010.

[3] Nair, Raveendranath U., and Rakesh M. Jha. "Electromagnetic design and performance analysis of airborne radomes: Trends and perspectives [antenna applications corner]." IEEE Antennas and Propagation Magazine 56.4 (2014): 276-298.

[4] Baker, Bevan B., and Edward Thomas Copson. The mathematical theory of Huygens' principle. Vol. 329. American Mathematical Soc., 2003.

[5] Lindell, Ismo V. "Huygens' principle in electromagnetics." IEE Proceedings-Science, Measurement and Technology 143.2 (1996): 103-105.

[6] Ballanis, Constantine A. "Antenna theory analysis and design." John Willey and Son's Inc., New York (1997).