Analysis Shaped Dielectric Lens Antennas using Hybrid method

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Abstract – In this paper hybrid method of analysis of shaped dielectric lens with microstrip patch array is presented. Hybrid method combines the advantage of spherical modal expansion (SME) and geometrical optics (GO). First, SME is used to find the near fields using known far field expressions for the primary source. After obtaining spherical complex modal coefficients (SMCC), each mode is treated as a plane wave radiating through a shaped dielectric lens and analysed using GO. The far field at any point on a spherical surface surrounding the lens is the sum of individual modal contributions, which are then easily transformed to far field using a SME. This hybrid method is independent of lens geometry and computationally faster compared to any electromagnetic simulation software. As expected the prediction accuracy is between that of an exact SME technique and an EM flow solver. Results have been presented for an array with spherical lens.

Keywords*- Neltec, HFSS, Sphere, Polypropylene, FEKO.*

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I. INTRODUCTION

Shaped Dielectric Lenses perform the task of collimation and shaping, along with physically small feed antennas, to obtain multiple and shaped beams in a fixed set of directions. Lenses are inherently broadband, easy to fabricate, have lower dimensional tolerances cost effective and provide a covering radome for the primary radiators that are embedded inside or placed behind the lens[1-3]. To illuminate the lens, microstrip patch array is used. Microstrip patch antennas have several advantages and applications [4] in wireless communication. In this work, analysis of shaped dielectric lenses illuminated by microstrip array is carried out using Hybrid method.

Analysis of the radiation pattern of shaped dielectric lens antennas include modal analysis, Ray tracing methods based on GO and employingElectromagnetic simulation tools such as HFSS, FEKO and CST microwave studio etc. GO methods of computing the field involves far field approximation of the primary source.

A modal expansion is most accurate as since it removes such approximations and considers the fields completely surrounding the source. An accurate FEM based analysis using an EM flow solver is discussed in [5] but is computationally very intensive, since it is dependent on the number of cells over finite sized geometries.

In the developed hybrid method, primary source is expressed as a SME. The principal component of these orthogonal modes act as collocated sources that are then ray traced through the lens onto a spherical surface completely surrounding the antenna. The summed modal contributions at any point are the total fields and can be transformed to the far field using SME. The analysis is discussed in next section.

II. HYBRID METHOD OF ANALYSIS

In this section fields of shaped dielectric lens array antenna using a new hybrid method which combines the advantages of both Spherical Modal Expansion (SME) and Geometrical Optics (GO) is presented. Here a shaped dielectric lens of maximum thickness 'T' and dielectric constant ϵ_r located at a focal point from the source is shown in figure1. The source consists of an array of primary radiators arranged in a planar configuration. However source can be of any arbitrary orientation. Apart from the refractive index of the material, also well-defined is the curvature of the lens that is circularly symmetric and not necessarily spherical.

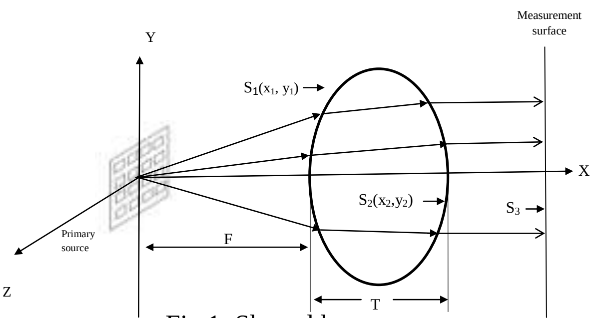

Fig 1: Shaped lens array geometry

The procedure for determining the radiation pattern of an array in the presence of a shaped dielectric lens is described as follows.

1. The primary radiator is characterized by a spherical modal expansion. Here the unknown spherical modal complex coefficients (SMCC's) a_{mn} and b_{mn} of the primary radiator are determined from the far fields on a surface where the fields are known. Using these coefficients the primary radiator is represented as sum of spherical modes.

$$E(r,\theta,\phi) = -\sum_m \sum_n A_{mn} M_{mn}(r,\theta,\phi) + B_{mn} N_{mn}(r,\theta,\phi) \quad (1)$$

$$H(r,\theta,\phi) = -\frac{k}{j\omega\mu}\sum_m \sum_n B_{mn} M_{mn}(r,\theta,\phi) + A_{mn} N_{mn}(r,\theta,\phi) \quad (2)$$

Where, A_{mn} and B_{mn} are SMCC's. Spherical vector wave functions $\overline{M}_{mn}$ and $\overline{N}_{mn}$ are defined in [6]. The orthogonality of spherical vector wave functions is defined in [6].

The spherical modal complex coefficients are determined by procedure as described in [7] as

$$A_{mn} = \frac{\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} \mathrm{E}(\mathrm{r},\theta,\phi).\overline{\mathrm{M}}_{\mathrm{mn}}\ \sin\theta \ {}^{\sin}_{\cos} \mathrm{m}\phi\ \mathrm{d}\theta\ \mathrm{d}\phi}{\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} \overline{\mathrm{M}}_{\mathrm{mn}}.\overline{\mathrm{M}}_{\mathrm{mn}}\ \sin\theta\ \mathrm{d}\theta\ \mathrm{d}\phi} \tag{3}$$

$$B_{mn} = \frac{\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} \mathrm{E}(\mathrm{r},\theta,\phi).\overline{\mathrm{N}}_{\mathrm{mn}}\ \sin\theta \ {}^{\cos}_{\sin} \mathrm{m}\phi\ \mathrm{d}\theta\ \mathrm{d}\phi}{\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} \overline{\mathrm{N}}_{\mathrm{mn}}.\overline{\mathrm{N}}_{\mathrm{mn}}\ \sin\theta\ \mathrm{d}\theta\ \mathrm{d}\phi} \tag{4}$$

2. The plane wave component is extracted from each spherical mode. The principal component of these spherical modes act as N collocated primary plane wave sources. For linear polarization being considered, azimuth index m becomes 1 in equation 3 and 4.

$$\overline{\mathrm{E}}_{\mathrm{i}} = \sum_{n=1}^{N}\left[A_{1n}\frac{\mathrm{P}_{\mathrm{n}}^{1}(\cos\theta)}{\sin\theta}\mathrm{h}_{n}^{2}(\mathrm{kr})\sin\phi\ \overline{\theta} + \mathrm{B}_{1n}\frac{\partial P_{n}^{1}(cos\theta)}{\partial\theta}\mathrm{h}_{n}^{2}(\mathrm{kr})\sin\phi\ \overline{\phi}\right] \tag{5}$$

$\mathrm{h}_n^2(\mathrm{kr})$ is a Spherical Hankel function and $\mathrm{P}_{\mathrm{n}}^{\mathrm{m}}(\cos\theta)$ is associated Legendre function defined in [6].

3. The field at any point on the measurement surface is the sum of plane wave contributions corresponding to SME.

$$\overline{\mathrm{E}}_m = \sum_{n=1}^{N}\frac{e^{-jkr}}{r}\left[A_n\frac{\mathrm{P}_{\mathrm{n}}^{1}(\cos\theta)}{\sin\theta}\overline{\theta} + \mathrm{B}_n\frac{\partial P_{n}^{1}(cos\theta)}{\partial\theta}\overline{\phi}\right]\sin\phi \tag{6}$$

4. The field on the measurement surface is now used to compute a new set of spherical modal complex coefficients (SMCC's) which are valid everywhere for the total radiating system.

$$a_{ns} = \frac{\int_0^{2\pi}\int_0^{\pi}\overline{\mathrm{E}}_{\mathrm{m}}.\overline{\mathrm{M}}_{1\mathrm{n}}\sin\phi\ \mathrm{r}^2\sin\theta\mathrm{d}\theta\mathrm{d}\phi}{\int_0^{2\pi}\int_0^{\pi} M_{1n}.M_{1n}\ \sin\theta\ \mathrm{d}\theta\ \mathrm{d}\phi} \tag{7}$$

$$b_{ns} = \frac{\int_0^{2\pi}\int_0^{\pi}\overline{\mathrm{E}}_{\mathrm{m}}.\overline{\mathrm{N}}_{1\mathrm{n}}\cos\phi\ \mathrm{r}^2\sin\theta\mathrm{d}\theta\mathrm{d}\phi}{\int_0^{2\pi}\int_0^{\pi} N_{1n}.N_{1n}\ \sin\theta\ \mathrm{d}\theta\ \mathrm{d}\phi} \tag{8}$$

This procedure is independent of lens geometry.

5. Using the new set of SMCC's, the total field is reconstructed in the far field.

$$\mathrm{E}_{\mathrm{t}}(\mathrm{r},\theta,\phi) = -\sum_{\mathrm{m}}\sum_{\mathrm{n}} a_{ns}\mathrm{M}_{1\mathrm{n}}(\mathrm{r},\theta,\phi) + b_{ns}\mathrm{N}_{1\mathrm{n}}(\mathrm{r},\theta,\phi) \tag{9}$$

The numerical computed results and HFSS simulation results are discussed in next section.

III. Results and Discussion

The hybrid method of analysis developed in equations (1) to (9) is numerically computed in Matlab. To validate the numerical results, spherical lens antenna with microstrip patch array is simulated in EM flow solver HFSS software. The results are presented at 6GHz for 1x2 patch array illuminating a spherical lens.

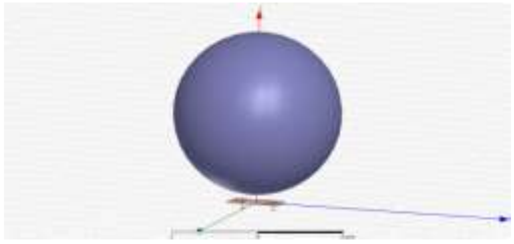

Fig2: Structure of 1x2 patch array with Spherical lens

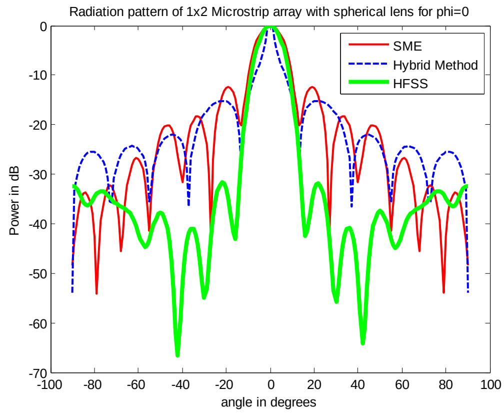

Fig3: Radiation pattern of 1x2 Patch array with Spherical lens at 6GHz for phi=0

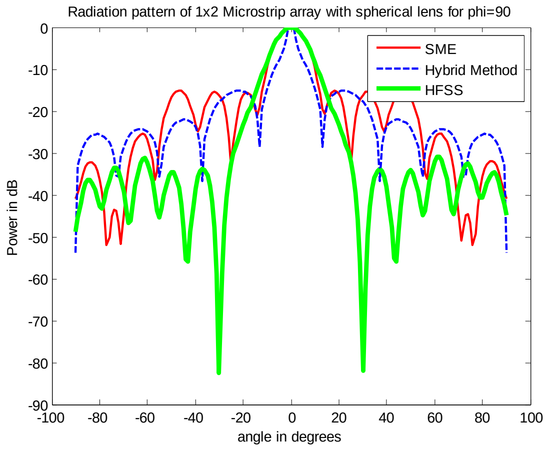

Fig4: Radiation pattern of 1x2 Patch array with Spherical lens at 6GHz for phi=90

IV. Conclusion

The results of the developed hybrid method and SME results are in agreement as compared with finite element based HFSS. Computation time required by the hybrid method is a fraction of an EM solver HFSS. In comparison, the accuracy of the hybrid method is between that of a closed form SME and HFSS. The developed hybrid method is independent of lens geometry and can be applied to other non-spherical geometries.

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