IJSTE - International Journal of Science Technology & Engineering | Volume 2 | Issue 10 | April 2016
ISSN (online): 2349-784X

Analysis of Spherical Dielectric Lens using Spherical Modal Expansion

Ravishankar S
Professor
Department of Electronics & Communication Engineering
R V College of Engineering, Bangalore-59, India

Mahesh A
Assistant Professor
Department of Electronics & Communication Engineering
R V College of Engineering, Bangalore-59, India

Abstract

In this paper, the analysis of spherical dielectric lens with 1x2 rectangular microstrip patch array antenna in C band (f_0= 6GHz) is carried out using spherical modal expansion(SME). First single rectangular microstrip patch antenna is designed at a resonant frequency of 6GHz, followed by 1x2 array using a Neltec substrate with dielectric constant 3.2. Later, a spherical dielectric lens antenna is designed which is at least two wavelengths greater than the microstrip patch array. A low loss and low cost Dielectric material, Polypropylene is used for lens design. Numerical computation of spherical lens with 1x2 patch array is carried out in Matlab. To validate the numerical results, Spherical lens with 1x2 patch array is simulated in EM flow solver HFSS. The numerical results and HFSS results are in good agreement. The analysis indicates that, designed spherical lens gives a maximum additional gain of 9.2dB at 6GHz.
Keywords: Dielectric lens, HFSS, Neltec, Polypropylene, RT Duroid

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 [1]. 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 [2]. Earlier techniques for the analysis of shaped dielectric lenses, employed ray tracing methods of GO and PO, that are valid only in the far field of a primary point source type of radiator. But in reality, the dielectric lens is in the near field of finite sized primary radiators oriented at different angles and at different distances from the lens centre. In this work, a new accurate analytical procedure is proposed for the radiation pattern of multiple primary radiators in the near field of a dielectric lens using Spherical Modal Expansion (SME) approach. Earlier SME approaches to solve for the field scattered by a dielectric sphere approximated the primary radiator as a far field Huygens source [6]. The lens is treated as a scatterer. Techniques for radial translation and spatial rotation of the small aperture Spherical Modal Complex Coefficients (SMCC) are utilized to align them to the phase centre of the Dielectric Lens. The SMCC of the scattered fields due to the lens are then obtained by application of boundary conditions. The analysis is flexible enough to accommodate different types of radiators and different shapes for the dielectric lens [5].

In this work, numerical analysis of radiation pattern of spherical dielectric lens with 1x2 microstrip patch array is carried out with Spherical modal expansion (SME) and to validate the numerical results, Finite Element Method (FEM) based EM flow solver HFSS is used.

II. Analysis and design

Considering fig 1, a spherical surface surrounding the array-lens combination, the task is to obtain the total field on the surface. This field is expressed as a SME and its SMCC's can be expanded anywhere else to obtain field points. The issue lies however in computing the scattered field.

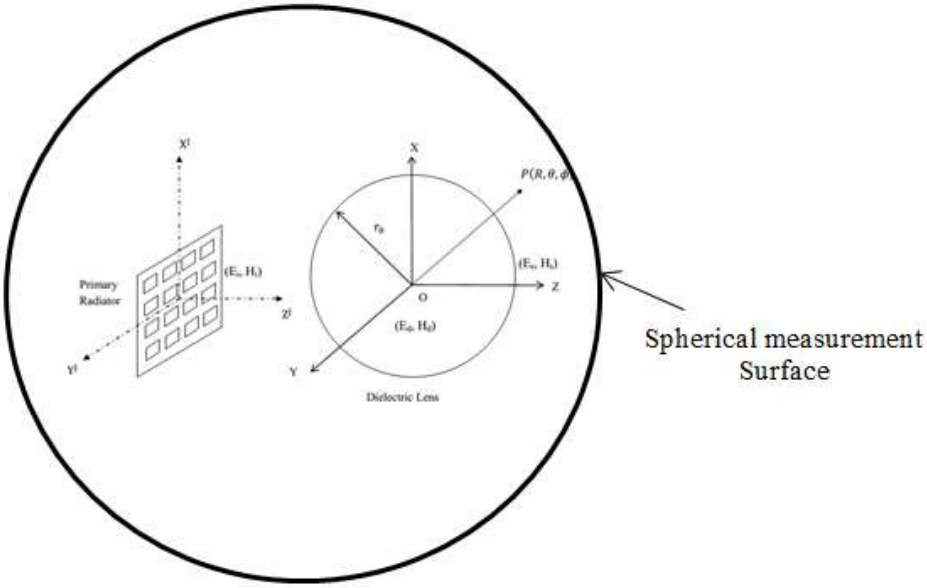

Fig. 1: Coordinate system for analysis of radiation pattern of lens array antenna

The analytical steps involved to compute the scattered field using SME as follows.

A. Characterization of the Incident Fields in Terms of SMCC:

The far field equations of 1x2 rectangular microstrip patch array [5] are used to compute the SMCC's. The computed SMCC's of equations (1) and (2) are valid in the near field also.

$$\bar{E}_i(R', \theta', \phi') = \sum_n \sum_{m=-n}^{n} (a_{imn}\bar{M}'_{mn} + b_{imn}\bar{N}'_{mn}) \qquad (1)$$

$$\bar{H}_i(R', \theta', \phi') = iY_0 \sum_n \sum_{m=-n}^{n} (a_{imn}\bar{N}'_{mn} + b_{imn}\bar{M}'_{mn}) \qquad (2)$$

Where, $\bar{M}'_{mn}$ and $\bar{N}'_{mn}$ are the spherical vector wave functions defined in equation [5]
a_{imn} and b_{imn} are incident spherical modal complex coefficients.
R' is a far field distance which is constant. The elevation angle and azimuth angle are
θ' and ϕ' respectively.
The spherical modal complex coefficients a_{imn} and b_{imn} can be obtained as equation (3) and (4)

$$a_{imn} = \frac{\int_0^{2\pi}\int_0^{\pi} \bar{E}_i.\bar{M}_{mn}\, r^2 \sin\theta d\theta d\phi}{\int_0^{2\pi}\int_0^{\pi} \bar{M}_{mn}.\bar{M}_{mn}\, r^2 \sin\theta d\theta d\phi} \qquad (3)$$

$$b_{imn} = \frac{\int_0^{2\pi}\int_0^{\pi} \bar{E}_i.\bar{N}_{mn}\, r^2 \sin\theta d\theta d\phi}{\int_0^{2\pi}\int_0^{\pi} \bar{N}_{mn}.\bar{N}_{mn}\, r^2 \sin\theta d\theta d\phi} \qquad (4)$$

B. Radial Translation of The SMCC:

The SMCC's obtained in step 1 are radially translated to the phase center of the lens. This is the reference point for evaluating the fields radiated by the patch array lens combination. The field after translation is given by equation (5) and (6).

$$\bar{E}_i(R, \theta, \phi) = \sum_v \sum_{m=-v}^{v} (A_{imv}\bar{M}_{mv} + B_{imv}\bar{N}_{mv}) \qquad (5)$$

$$\bar{H}_i(R, \theta, \phi) = iY_0 \sum_v \sum_{m=-v}^{v} (B_{imv}\bar{M}_{mv} + A_{imv}\bar{N}_{mv}) \qquad (6)$$

Where $A_{imv} = \sum_n \left(a_{imn}A_{mv}^{mn} + b_{imn}B_{mv}^{mn}\right)$

$$B_{imv} = \sum_n \left(a_{imn}B_{mv}^{mn} + b_{imn}A_{mv}^{mn}\right)$$

C. *Evaluation of the Unknown Scattered Fields*

The SMCC of the fields scattered by the lens are obtained by applying the boundary conditions, which are then used to compute the scattered fields. The tangential components of fields are continuous across the boundary i.e., $E^i + E^s = E^d$.
The scattered fields are the difference between the total fields with the dielectric sphere present and the incident field given by equation (7).

$$E_s = E_T - E_i \text{ and } H_s = H_T - H_i \qquad (7)$$

The scattered fields referred to lens coordinate system can be written as equation (8) and (9).

$$E_s(R,\theta,\phi) = \sum_{n=1}^{N} (a_{sn}\overline{M}_{mn} + b_{sn}\overline{N}_{mn}) \qquad (8)$$

$$H_s(R,\theta,\phi) = -iY_0 \sum_{n=1}^{N} (a_{sn}\overline{N}_{mn} + b_{sn}\overline{M}_{mn}) \qquad (9)$$

The fields inside the dielectric sphere can be written as equations (10) and (11).

$$\overline{E}_d = \sum_{n=1}^{N} (a_{dn}\overline{M}_{mn} + b_{dn}\overline{N}_{mn}) \qquad (10)$$

$$\overline{H}_d = -iY_d \sum_{n=1}^{N} (a_{dn}\overline{N}_{mn} + b_{dn}\overline{M}_{mn}) \qquad (11)$$

D. *Evaluation of Total Field*

Once the unknown SMCC's (a_{imn}, b_{imn}) for incident field E_i and unknown SMCC (a_{sn}, b_{sn}) for scattered field E_s are known, then total field at any point in space is computed by addition of the incident and scattered fields and are easily obtained.

Total field of the array lens is reconstructed on the spherical surface surrounding the lens array.
The total field of the array-lens is expressed as equation (12).

$$E^T = E^i + E^s \qquad (12)$$

The scattered field E^s has SME expansion and unknown SMCC. To obtain the scattered SMCC's boundary conditions are applied on the surface of the spherical lens.

The rectangular microstrip patch antenna, 1x2 patch array is designed using equations given in [4]. The far field equations for a rectangular microstrip antenna in E and H plane are given in [4]. The lens antennas designed in this paper have dimensions greater than two wavelengths compared to primary radiator. The shape of the lens antenna is designed based on the mathematical equations of [8].

III. RESULTS AND DISCUSSION

The structure of spherical lens illuminated by 1x2 patch array is shown fig2. The radiation pattern of spherical lens antenna is numerically computed using equations (1) to (12) and compared with HFSS simulation results is shown in fig 3 and 4 in E plane and H plane respectively. The results are in good agreement.

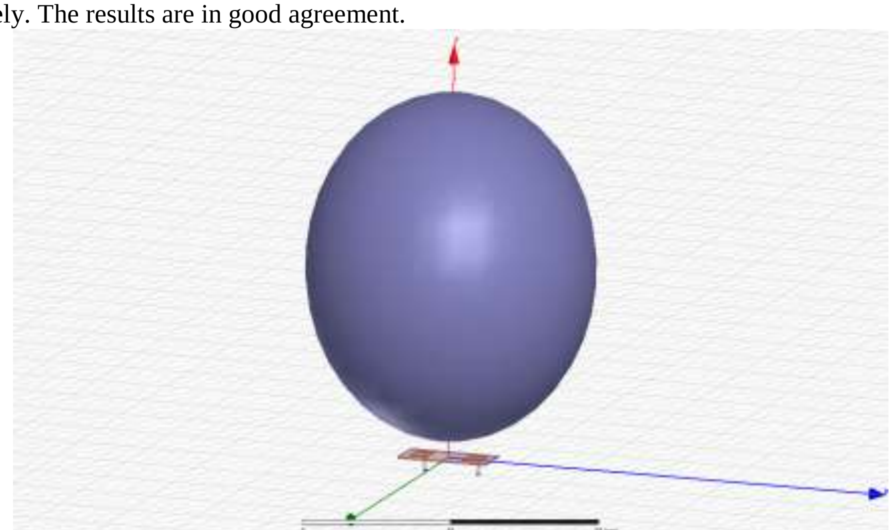

Fig. 2: Structure of a spherical lens with 1x2 patch array

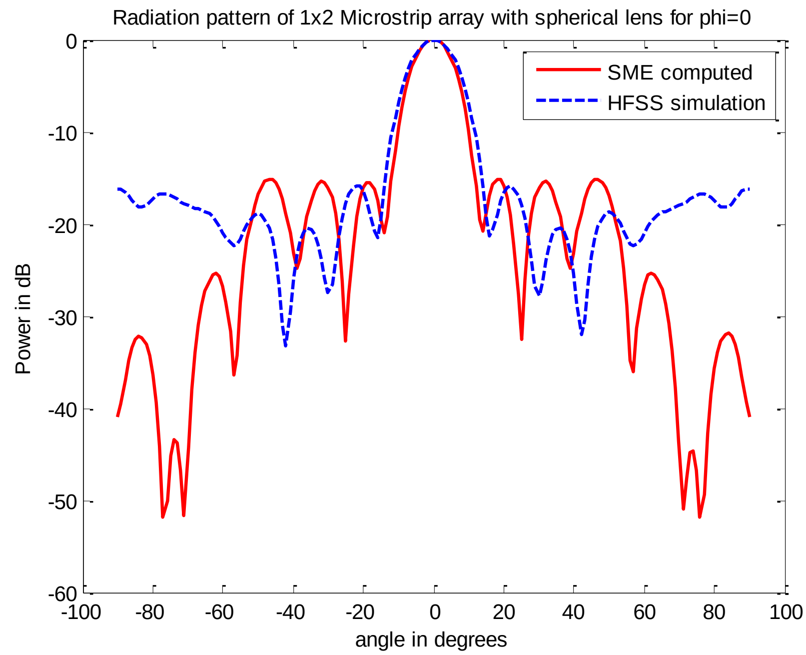

Fig. 3: Radiation Pattern of a 1x2 patch array with lens at phi=0

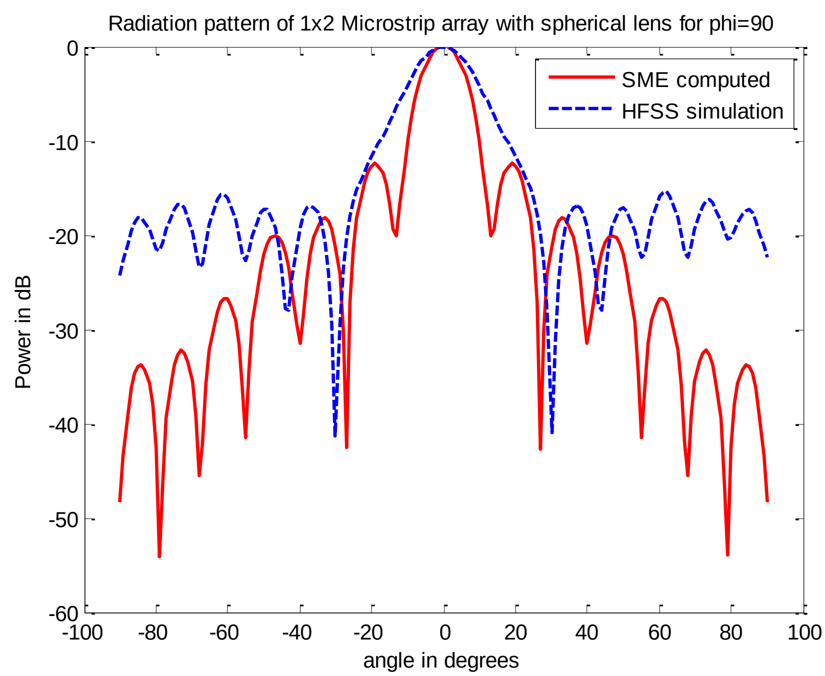

Fig. 4: Radiation Pattern of a 1x2 patch array with lens at phi=90

IV. CONCLUSION

In this paper, design and analysis of a 1x2 patch array with spherical dielectric lens is carried out in C band. Low loss substrate is used for designing patch antenna array. Return loss of -25 dB and below is obtained for single patch and 1x2 patch array. A spherical dielectric lens is placed at several distances from the patch array to obtain better collimation. It is observed from the above results that 1x2 patch array with spherical lens at 6GHz gives maximum gain. The designed lens antenna with microstrip array is very useful for high gain applications.

REFERENCES

[1] Carlos A Fernandes, ―Shaped dielectric lenses for Wireless Millimeter-Wave Communicatiobs‖, IEEE Antennas and Propagation Magazine, vol 41, No 5, pp 141-150, October 1999.
[2] Leandro Fernandes, ―Developing a system concept & Technologies for Mobile Broadband Communications IEEE Personal Communications Magazine, pp 54-59, Feb 1995.
[3] Carlos A Fernandes, Jose G Fernandes, Performance of Lens Antennas in Wireless Indoor Millimeter Wave Applications, IEEE Transactions on Microwave theory and Techniques, vol 47, No 6, pp 732-736, June 1999.
[4] Constantine A Balanis, Antenna Theory - Analysis and Design, 2nd Edn, Singapore: John Wiley and Sons: 2002, Chapters 6 and 12.
[5] S.Ravishankar and M.S. Narasimhan, "Multiple Scattering of EM Waves by Dielectric Spheres located in the near field of a source of Radiation," IEEE Transactions on Antennas and Propagation, vol AP-35, No 4, pp 399-405, April 1987.
[6] M. Taguchi, M. Masuda, H. Shimoda, and K. Tanaka, "Analysis of Arbitrarily Shaped Dielectric Lens Antenna," IEEE International Symposium on Antennas and Propagation Digest, 2, July 3- 8, 2005, pp. 769-772.
[7] Y T Lo and S W Lee, "Antenna Handbook", Van Nostrand Reinhold Publishers, 1993, Vol-2, Chapter 16.
[8] William F Croswell, J S Chattejee, V Bradford Mason, Radiation from a homogeneous sphere mounted on a waveguide aperture, IEEE Transactions on Antennas and Propagation, vol AP-23, No 5, pp 647-656, Sept 1975.