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SIMULATION OF A DISCRETE LUNEBURG LENS FED BY A CONFORMAL PRINTED ANTENNA

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INTRODUCTION

Communications and information technology stimulate a development of various antennas. Because of their simplicity, slot fed circular microstrip antennas (MA) [1] seem to be attractive. Even more attractive are MAs conformally printed on curved surfaces, such as spherical-circular MA (SCMA) because of their higher degree of freedom. However, conventional numerical methods, such as Moment-Method (MM) or FDTD need very high computer resources and do not guarantee a convergence because of ill-conditioned matrices, numerical instabilities, and vulnerability to high-Q resonances. Besides, many applications need special properties: agile scanning beam, multibeam capability, scanning in a large field of view, etc. Here, a very attractive candidate is a discrete Luneburg lens (LL) [2,3,4], which is a layered dielectric sphere. Spherical geometry of both SCMA and LL enables one to simulate them with the same method. Here, we shall use the Method of Analytical Regularization (MAR) [5-7], sometimes called semi-inversion method. Generally, it converts a first-kind singular integral or series equation to a well-conditioned second-kind Fredholm matrix equation, and therefore serves as a perfect pre-conditioner of an ill-posed problem. Then both numerical convergence and efficiency is achieved and matrix-truncation error is controlled.

ELECTROMAGNETIC MODELING

Suppose that the layer $\#i$ is characterized by its material properties ε_{ri} and μ_{ri}, outside radius r_i, and the size of corresponding PEC spherical disk, θ_i, like in Fig. 1. The used excitation is a tangential magnetic dipole (TMD). Spherical geometry offers to expand electromagnetic field in terms of vector spherical modes involving $P^1{}_n$, associated Legendre functions, with coefficients $a_n^{s,i}$ and $b_n^{s,i}$.

The first step concerns the application of so-called dual boundary conditions. This yields a set of $4N_{shell}$ coupled dual series equations (DSE): for $0 \le \theta < \theta_i, i = 1 \dots N_{shell}$, $\sigma = e, o$,

$$\Sigma_{n\ge1} \left(C_{an}^{Z} \cdot X_{an}^{\sigma} - X_{an}^{\sigma Z,feed}\right) \cdot P_n^1(\cos\theta) = \sigma(-1) \cdot C_1^{\sigma} \ \tan\theta/2$$

$$\Sigma_{n\ge1} \left(C_{bn}^{K} \cdot X_{bn}^{\sigma} - X_{bn}^{\sigma K,feed}\right) \cdot P_n^1(\cos\theta) = -C_1^{\sigma} \ \tan\theta/2,$$

and also, for $\theta_i < \theta \le \pi, i = 1 \dots N_{shell}$, $\sigma = e, o$,

$$\Sigma_{n\ge1} \left(C_{an}^{K} \cdot X_{an}^{\sigma} - X_{an}^{\sigma K,feed}\right) \cdot P_n^1(\cos\theta) = \bar{\sigma}(-1) \cdot C_2^{\sigma} \ \cot\theta/2$$

$$\Sigma_{n\ge1} \left(C_{bn}^{Z} \cdot X_{bn}^{\sigma} - X_{bn}^{\sigma Z,feed}\right) \cdot P_n^1(\cos\theta) = C_2^{\sigma} \ \cot\theta/2,$$

where X_n^{feed} are vectors corresponding to the slot feed field modal description, C_n^Z and C_n^K are matrices related to the structure without metallic elements. The unknowns are the vectors X_n, $n \ge 1$, $X_{an}^{\sigma} = [a_n^{+,2} \dots a_n^{+,Nshell+1}]^T$, $X_{bn}^{\sigma} = [b_n^{+,2} \dots b_n^{+,Nshell+1}]^T$. C_1^{σ} and C_2^{σ} correspond to auxiliary constants to be determined. $\sigma(-1) = +1$ if $\sigma = o$ and $\sigma(-1) = -1$ otherwise. Besides, the power boundedness condition determines the allowable class of the unknowns as

$$\Sigma_{n\ge1} \left\| C_{an}^{Z} \cdot X_{an}^{\sigma} \ / \ n \right\|^2 < +\infty \quad \Sigma_{n\ge1} \left\| n \cdot C_{bn}^{K} \cdot X_{bn}^{\sigma} \right\|^2 < +\infty .$$

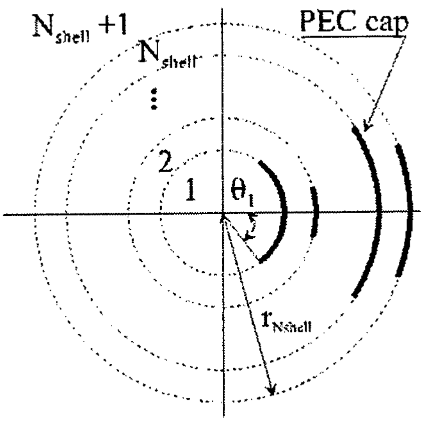

Fig. 1: Definition of the structure.

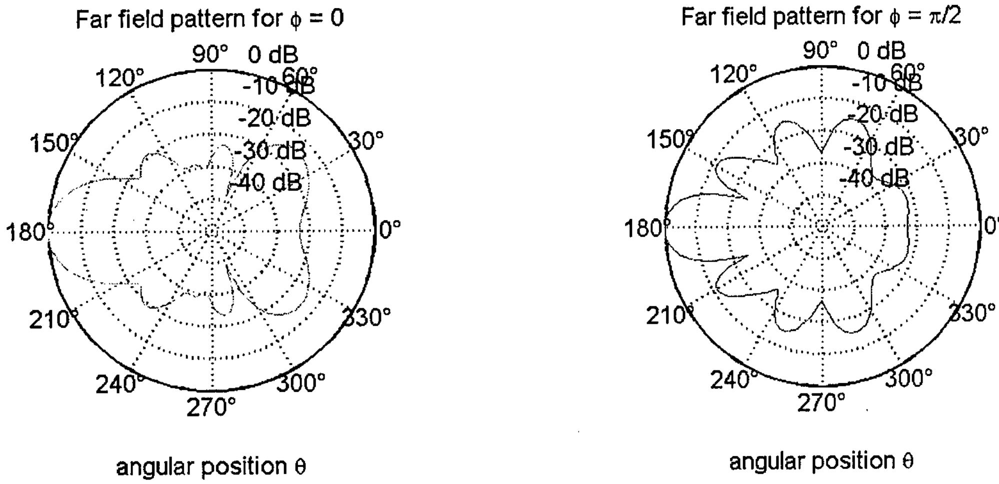

Fig. 2. Far field pattern for a SCMA fed LL with $k_o r_{outside}$ = 10.0.

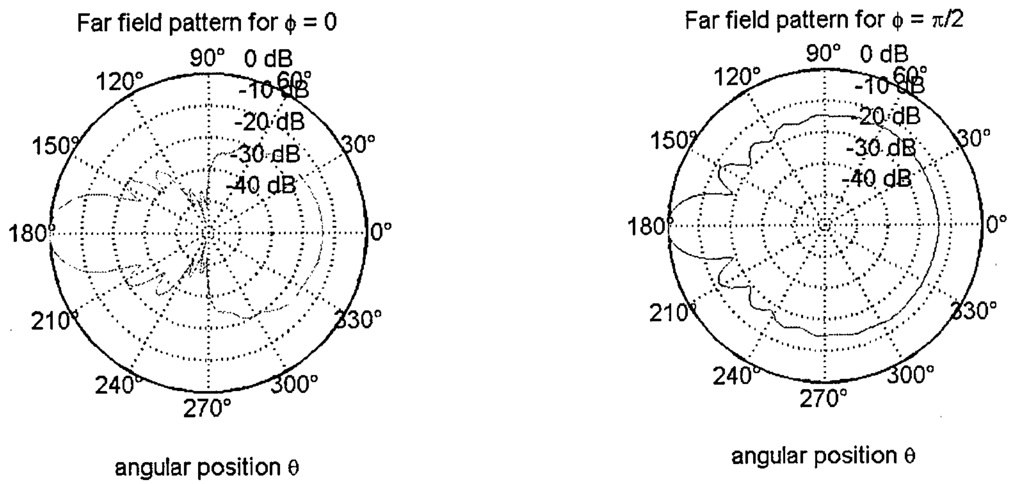

Fig. 3. Far field pattern for a TMD fed 40-layer LL with $k_o r_{lens}$ = 10.0.

MAR TREATMENT

Mentioned above DSEs are collectively the 1st kind equation which can be written as $CX = Y$ in terms of operators. Unfortunately, C is not directly invertible and its numerical inversion is not convergent. According to [6,7], C can be cut in such a way that $C = (C_1 + C_2)\cdot C_0$, with C_1^{-1} a known operator. Then, the 1st kind problem becomes the 2nd kind problem $Z + A\cdot Z = Z_0$, where $Z_0 = C_1^{-1}\cdot Y$, $Z = C_0\cdot X$ and also $A = C_1^{-1}\cdot C_2$. A is a Fredholm operator provided that $||A||_{L^2} < +\infty$. In our problem, MAR technique is easily applied thanks to some simple variable changes: $\Omega_a(I-G_{an})\cdot Z_{an}^{\sigma} = n(n+1)C_{an}^{Z}\cdot X_{an}^{\sigma}$, and $(2n+1)\Omega_b(I-G_{bn})\cdot Z_{bn}^{\sigma} = n(n+1)C_{bn}^{K}\cdot X_{bn}^{\sigma}$, for $0 \le \theta < \theta_i, i = 1\ldots N_{shell}$, with Ω_a and Ω_b two constant matrices, and, $(2n+1)Z_{an}^{\sigma} = n(n+1)C_{an}^{Z}\cdot X_{an}^{\sigma}$, and $Z_{bn}^{\sigma} = n(n+1)C_{bn}^{Z}\cdot X_{bn}^{\sigma}$, for $\theta_i < \theta \le \pi, i = 1\ldots N_{shell}$. By the use of the Mehler-Dirichlet expressions, the set of $4N_{shell}$ coupled linear equations reduces to a set of 2nd kind equations:

$$Z_m^{\sigma} + \sum_{n\ge1} A_{m,n}\cdot Z_n^{\sigma} = Z_m^{\sigma,feed}, \ \forall m \ge 1.$$

By collecting the unknowns into a double infinite vector $Z^{\sigma} = [Z_{a0}^{\sigma T}, Z_{b0}^{\sigma T}, Z_{a1}^{\sigma T}, Z_{b1}^{\sigma T}, Z_{a2}^{\sigma T}, Z_{b2}^{\sigma T}, \ldots]^T$, and also $Z_0^{\sigma} = [Z_{a0}^{feed\ T}, Z_{b0}^{feed\ T}, Z_{a1}^{feed\ T}, Z_{b1}^{feed\ T}, Z_{a2}^{feed\ T}, Z_{b2}^{feed\ T}, \ldots]^T$, and by defining an infinite matrix A having $(2N_{shell}+2) \times (2N_{shell}+2)$ infinite blocks composed of the $A_{m,n}$ matrices, the whole set of the 2nd kind can be written as $Z^{\sigma} + A\cdot Z^{\sigma} = Z_0^{\sigma}$. Each $A_{m,n}$ is a product of two terms, $A_{m,n} = A^s_n\cdot A^d_{m,n}$, where A^s_n depend on the shells characteristics $(r_i, \varepsilon_{ri}, \mu_{ri}, i = 1\ldots N_{shell})$ and $A^d_{m,n}$ on the disk ones $(\theta_i, i = 1\ldots N_{shell})$. Moreover, A^s_n behave as $O(1/n)$, and $A^d_{m,n}$ as $O(1/(n-m))$ if $m \ne n$, and like $O(1)$ otherwise. As a consequence, A is compact as $||Z_0|| < +\infty$ that ensures the existence of unique solution, which can be approached as closely as wanted thanks to point-wise convergence.

RESULTS

In order to ensure a 3-digits accuracy in solving the matrix all the computations were done with $N = 120$. Figs. 2 and 3 present far field patterns of LL fed by SCMA+TMD and a simple TMD feeds, respectively. Here, the patch is the inner (smaller: $\theta_{inside} = 1.3°$)) conductor, and the ground surface is formed by the outer (larger) metallic cap $(\theta_{outside} = 3.0°)$. The focusing effect is clearly seen, as well as the shadowing by SCMA. MAR technique is a very powerful and economic method to study complete SCMA-LL radiation problem. It enables one to highlight with controlled accuracy the effects of finite ground size, curvature, several types of resonances connected with SCMA, ground and coating, and LL focusing, etc.

REFERENCES

[1] M. Pozar, *A Review of Aperture Coupled Microstrip Antennas: History, Operation, Development and Applications*, University of Massachusetts Press, 1996.

[2] R.K. Luneburg, *The Mathematical Theory of Optics*, University of California Press, 1944.

[3] H. Mieras, Radiation Pattern Computation of a Spherical Lens Using Mie Series, *IEEE Trans. Antennas Propagat.*, vol. AP-30, no. 6, 1982.

[4] Y. Rahmat-Samii, *et al*, Luneburg Lens Antennas Revisited: Design, Optimization, and Measurements, *AP 2000 Symposium Proceedings*, 5A7, Davos, 2000.

[5] S.S. Vinogradov, Reflectivity of a spherical shield, *Radiophysics Quantum Electronics*, vol. 26, no 1, pp. 78-88, 1983.

[6] S.S. Vinogradov, A.V. Sulima, Calculation of the absorption cross-section of a partially shielded dielectric sphere, *Radiophysics Quantum Electronics*, v. 26, no 10, pp. 927-931, 1983.

[7] A.I. Nosich, The Method of Analytical Regularization in wave-scattering and eigenvalue problems, *IEEE Antennas Propagat. Magazine*, vol. 43, no 3, pp. 34-49, 1999.