Multilayered Cone-Based High Directivity Antenna Designs

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1. Introduction

As the wireless communication develops rapidly in recent years, more wireless equipment appears, and applications of circularly polarized (CP) antennas are widely used in the wireless communications [1]. Unless the antenna is used only for point-to-point communications, where the CP performance at the boresite direction is of major concern, it is desirable to design the antenna structure that radiates fields with an as wide beamwidth of a good CP as possible, which potentially provides better reception performances such as in the applications of global positioning system (GPS) where a single antenna is used to receive signals from various satellites in different angular locations. Such examples can be easily found in the satellite communications [2]. Although in many antenna designs, such as using cross-dipoles, a good CP can be obtained in the antenna's boresite direction, the polarization discrimination of TE and TM modes grows while the angle of incident waves increased[3] with respect to the antenna's boresite. That means more signal amplifications in the system are compulsory which will increase the cost accordingly. Directivity performance is a key characters for long-haul wireless signal transmission, in order to improve the efficiency of antenna and keep the polarization discrimination at a lowest level in a wide range of angular region, we introduce a compensation method using multilayer cone-based which can greatly improve the directivity of a ordinary transmitter without involve any discriminations.

The cone-based multilayered structure can be regarded as one-dimension (1D) photonic crystals. The concepts of the 1D photonic crystals were first brought forward by E. Yablonovitch and S.John[4]. Photonic crystals are periodically structured using dielectric materials that can be recognized as multilayer films. If the structures show a periodicity in the range of the wavelength of the light, interferences appear which affect the propagation of light in these materials strongly and allow the energy re-distributing in the angular space. The 1D photonic crystals have been shown a wide range of applications, such as the area of laser, glass fibers and pigments, also photonic crystal can be used in the newly emerged area of integrate optics [5] and sensing [6].

2. Theory of photonic crystals

As in the case of 1D photonic crystal, the amendment of Maxwell's equation can be expressed as: $-\partial^2 E/\partial x^2 = \varepsilon(x)\varpi^2 E/c$. (1)

Figure 1 gives a representative structure of 1D photonic crystal [7]. The width of the incident beam is assumed to be large compared with its lateral displacement such that the incident fields illuminating the structure exhibit the characteristics of local plane waves and can be characterized by TE/TM modes. The fields of incidence will experience many reflections and transmissions in the structure, which contribute significantly to the resultant reflected and transmitted beams. There are several approaches that can be used in the optical film computations. The analytical resolution is rather complex while calculating the electromagnetic field layer-by-layer within the multilayer films. We introduce a transfer matrix method that can provide a great deal of flexibility in designing interference coatings with almost any specified frequency-dependent reflectance or transmittance characteristics.

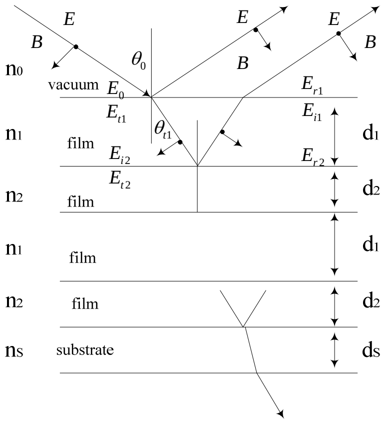

Figure 1: Reflection and transmission

The electric and magnetic fields of the incident wave must obey the boundary condition restrictions [8], that is, the tangential components of the resultant E- and B-field are continuous across the interface and their magnitudes on either side are equal. Under this restriction of the boundary condition。 We get the relation of the electric and magnetic fields between the adjacent layers of the crystal:

$$\begin{bmatrix} E_k \\ B_k \end{bmatrix} = \begin{bmatrix} \cos\delta_k & i\sin\delta_k / \gamma_k \\ i\gamma_k \sin\delta_k & \cos\delta_k \end{bmatrix} \begin{bmatrix} E_{k+1} \\ B_{k+1} \end{bmatrix} \tag{2}$$

where $\delta_k = \frac{2\pi}{\lambda} n_k d_k \cos\theta_k$, $1 \le k \le N$, and $\begin{bmatrix} E_1 \\ E_1 \end{bmatrix} = M \begin{bmatrix} E_N \\ E_N \end{bmatrix}$ (3)

where M is the compound matrix, $M = M_1 M_2 .....M_N$. We generally represent the M-matrix as the following form:

$$M = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \tag{4}$$

We define the reflection and transmission coefficients as: $r = E_{r1} / E_0$ And $t = E_{tN} / E_0$ (5)

Substituting the expression of t, r, and M in (4) and (5) into the boundary condition, (3) can be solved for the transmission and reflection coefficients in terms of the transfer-matrix elements to give:

$$t = 2\gamma_0 / (\gamma_0 m_{11} + \gamma_0 \gamma_s m_{12} + m_{21} + \gamma_s m_{22}) \tag{6}$$

$$r = (\gamma_0 m_{11} + \gamma_0 \gamma_s m_{12} - m_{21} - \gamma_s m_{22}) / (\gamma_0 m_{11} + \gamma_0 \gamma_s m_{12} + m_{21} + \gamma_s m_{22}) \tag{7}$$

Equation (6) and (7) , together with the transfer-matrix elements, enable us to evaluate the reflective and transmissive properties of the single or multilayer film represented by the transfer matrix.

3. Experimental environment

The designed structure is carried out to check the performance and simulation was performed using HFSS 9.0. In this case, a cross-dipole antenna is employed as an example to demonstrate this concept, which can be however employed to the treatment of many other CP antennas in a similar fashion. Also in this example we design the compensating 1-D photonic crystal using the KP (Kronig-Penney) model [7], and the structure of the crystal is ranged in the ABAB alternate form as can be seen in figure 2. Based on the front-fed arrangement described in literature [9], we design the reflector of the crossed-dipole a parabolic structure so that the backward radiation of the crossed dipoles can be directed into the forward direction and thus increase the gain of the antenna. Note that a paraboloid is used because as shown in geometrical optics that if a beam of parallel rays is incident upon a parabolic reflector, the reception will converge at its focus, where thus the crossed-dipole is placed at the focus to enhance a parallel beam.

We use a glass substrate (ns=1.52) at the top of the photonic crystal and allow incidence from air (n0=1). The relative permittivity of the 4 layers below the substrate is 1.44, 1.172, 1.44, and 1.172 respectively while the relative permeability of all the layers is 1. The thickness of each layer is a quarter of the effective wavelength. All the films are assumed to be both homogeneous and isotropic.

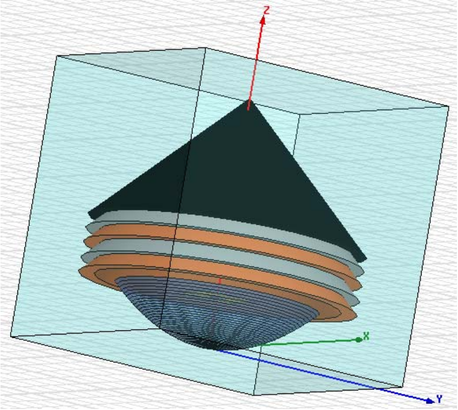

Figure 2: Multilayered cone-based compensation structure with circular polarized antennas

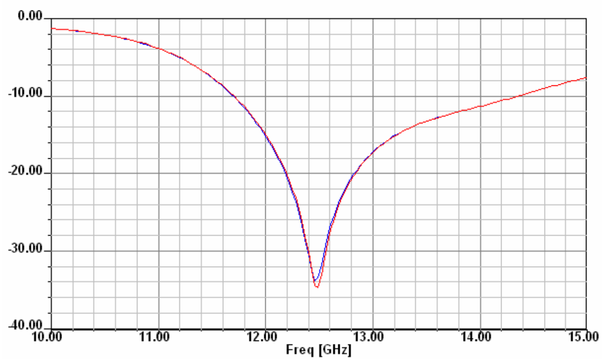

Figure 3: The reflection coefficient of the paraboloidal reflector

4. Experimental Result

The reflection coefficient of the paraboloidal reflector is shown is figure 3. We can easily check that the reflection is the least at the frequency of 12.45GHz. In this section the performance of our proposed models for deploying cone-base multilayered enhanced antennas. Figure 4 and 5 show the performance of the radiation pattern to check the directivity of the designed antenna compensation structure. Patterns in figure 4 are the scenario without cone-based structure, and figure 5 present the results of a 5 layer cone-based board. As can be shown, the directivity of the antenna grows from about 14.8dB to 16.2dB, and two boresite appears on the 45 degree azimuth angle direction. The side lobe grows due to the transmission enhanced structures.

The axial ratio (AR) performances with and without the cone-based multilayered structure are presented in figure 6 and figure 7 respectively. It is clearly that the AR performance is slightly improve after deployment of the cone-based multilayered structure especially at the direction of theta=0, the two curves denote the AR performance at direction of azimuth angle 0 degree and 90 degree.

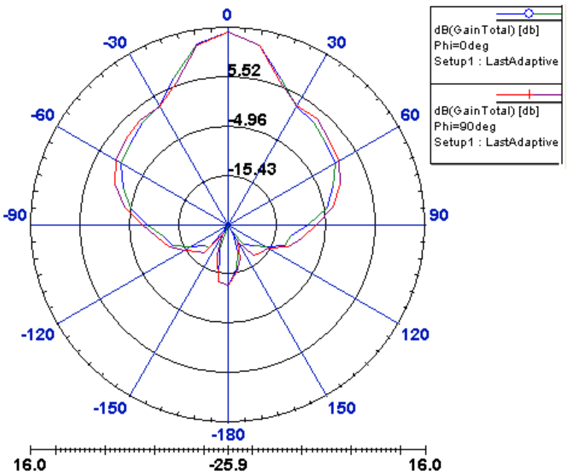

Figure 4: Radiation pattern without the multilayered cone structure

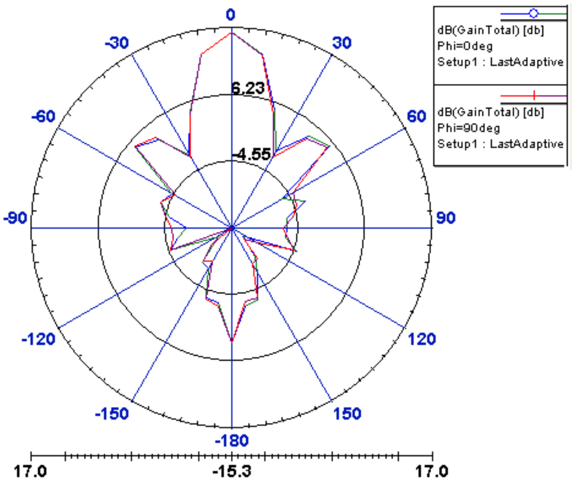

Figure 5: Radiation pattern after multilayered cone structure placement

Figure 8 presents the total gain of antenna that has a multilayered cone. From which we can see that due to a symmetric compensation structure, the pattern of 3D polar plot is isotropic, in other word, the energy eradiated by antenna is well-proportioned without any imbalance involved.

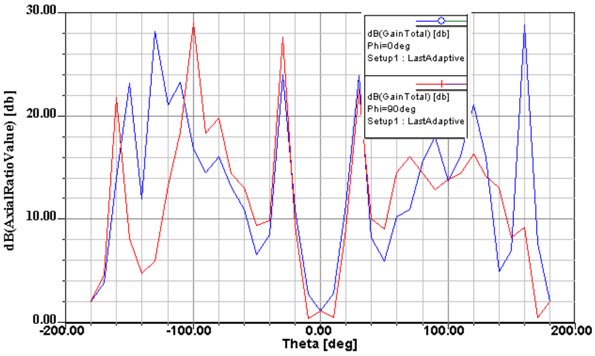

Figure 6: AR performance without the multilayered cone structure

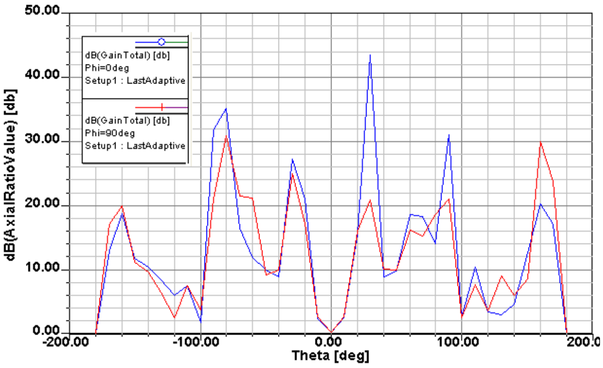

Figure 7: AR performance after multilayered cone structure placement

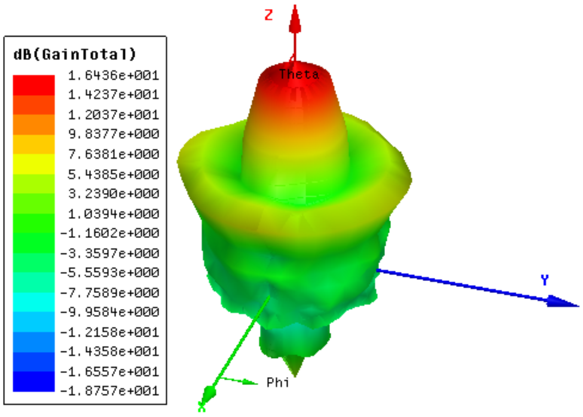

Figure 8: The far-field of the 3D polar plot with multilayered cone-based structure

5. Conclusion

In this paper, a multilayered cone compensation structure is designed to improve the directivity of wireless transmitters. The CP performance is not crippled by the extra object. The isotropic structure can also well provide uniform energy distribution. The results verify that the new proposed compensation structure can outperform the tradition transmitter, and can be widely deployed and utilized in future wireless communication.

Acknowledgments

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References

[1] A.Wang, W.V.T.Ruscht, “Considerations on designing single- and dual-reflector antennas for efficient narrow pulse radiation”, Antennas and Propagation Society International Symposium, 1994. AP-S. Digest. vol.1, pp.62-65, Jun 1994

[2] Y.Rahmat-Samii, D.-W.Duan, D.V.Giri, L.F.Libelo, “Canonical examples of reflector antennas for high-power microwave applications”, IEEE Transactions on Electromagnetic Compatibility, vol.34, no.3, Part 1, pp.197-205, Aug 1992.

[3] David M.Pozar, *Microwave Engineering*, third edition, WILEY.

[4] John Wilson, John Hawkes, *Optoelectronics*, 3rd, Prentice Hall Europe, 1998.

[5] Mumcu, G. Sertel, K. Volakis, J.L. Vitebskiy, I. Figotin, A. RF propagation in finite thickness unidirectional magnetic photonic crystals. Vol.53, No.12, pp.4026-4034, 2005.

[6] Stanislav Konorov, Aleksei Zheltikov, and Michael Scalora. Photonic-crystal fiber as a multifunctional optical sensor and sample collector, Optics Express, Vol.13, No.9, pp.3454-3459.

[7] Frank L. Pedrotti, S.J. Leno S. Pedrotti, *Introduction to optics*, second edition, Prentice Hall

[8] Constantine A.Balanis, Antenna theory, third edition, WILEY

[9] Y.Serizawa, K.Takeshita, E.Ohba.,“Antenna-reflector combination operating in the Fresnel region at microwave and millimeter-wave bands”, IEEE Trans on Antennas, vol.42, no.11, pp.1562-1565, Nov 1994.