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A Comparative Study of Directive Antennas from Two Different Approaches

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***Abstract*—Two different approaches have been used to design directive antennas: one is based on conventional Fabry-Perot (FP) resonators and another from flat Luneburg lenses. The former have been demonstrated to be highly directive and possess low side lobes for a limited band of frequencies. We have recently demonstrated that a new solution applying so called "transformation optics/electromagnetic", can be used to convert the conventional Luneburg lens into the same geometrical profile as those of FP resonator antennas, while maintain high directivity, low side lobe level, and an enhancement of the bandwidth of operation. In this paper, A comparative study will be presented in detail between these two approaches.**

I. INTRODUCTION

Metamaterials are artificial media, whose sub-units are of a larger scale than the molecular. For frequencies where the wavelength is larger than the lattice constant, the wave is too myopic to resolve the geometry of sub-units and sees the metamaterial as a homogeneous medium. Therefore, the macroscopic fields of the wave inside a metamaterial are averages of the microscopic fields and related to each other with macroscopic parameters ϵ and μ [1]. The geometry of the sub-units governs the macroscopic behavior of the metamaterial, allowing us to manufacture artificial media with novel and extraordinary electromagnetic properties, such as negative refraction, perfect lensing, electromagnetic cloaking and transformations [1].

Similarly to metamaterials, Electromagnetic Band Gap (EBG) media (or photonic crystals) are also artificial periodic structures [2]. However, their electromagnetic behavior is based on scattering mechanisms, since they operate for wavelengths comparable to the lattice constant of the crystal. Bragg scattering and Mie resonances give rise to stop bands, prohibiting the propagation of a wave in the crystal at a particular frequency. In contrary to metamaterials, photonic crystals cannot be homogenized and their electromagnetic properties cannot be expressed with macroscopic ϵ and μ under any circumstances [1].

Both metamaterials and EBGs have found numerous applications for antennas, as substrates or superstrates, in order to enhance the efficiency or increase the capabilities of antennas. When EBGs are, for example, implemented in antennas as a substrate, they provide in-phase reflection at the ground plane, creating low-profile antennas. Also, they can be applied to suppress surface waves on the ground plane [3], [4], and to enhance the antenna gain based on Fabry-Perot (FP) resonance [5], [6], [7].

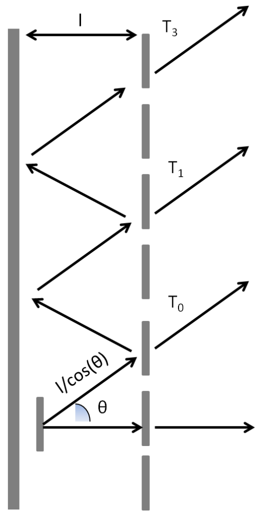

Fig. 1. A Fabry-Perot antenna configuration.

The main objective of this paper is to analyze and compare two different approaches, namely Fabry-Perot (FP) resonance and Transformation Optics/Electromagnetics [8], [9] for designing directive antennas with an aim to reduce side-lobe levels, achieve scanning capability over a wide frequency band.

II. ELECTROMAGNETIC BAND GAP ANTENNAS

In 1956, Trentini [2] proposed that a Fabry-Perot cavity, composed from a patch antenna in between a PEC (i.e. ground plane) and a partially reflecting sheet (PRS) (as shown in Fig. 1) which increases the directivity of an antenna. The antenna is placed in front of a PEC sheet, and in a distance l a Partially Reflecting Sheet (PRS), as shown on the Fig. 1. The PRS creates multiple reflections between the ground plane and the superstrate, which increases the directivity (as well as gain).

Trentini [2] calculated the power of the Fabry-Perot antenna as:

$$S(\theta) = \frac{1 - r_2^2}{1 + r_2^2 - 2r_2 \cos(\psi - \pi - \frac{4\pi}{\lambda} l \cos(\theta))} f^2(\theta)) \quad (1)$$

where r_2 is the reflection of the PRS, f is the field pattern of the patch antenna, θ inside the cosine is the phase difference between two “neighboring” rays, ψ accounts for the phase change at the reflection of the wave on the PRS, π for the phase change at the reflection on the PEC and $\frac{4\pi}{\lambda} l \cos(\theta)$ for the phase acquired due to the path difference between two rays. For instance, Fig. 2 illustrated how a periodic repetition of patches can act as PRS in order to increase the directivity of a microstrip patch antenna.

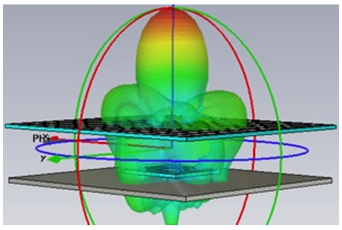

Fig. 2. Directivity for a Fabry-Perot microstrip antenna with a superstrate of square patches.

However, this method neglects the fact that the rays are incident on PRS with different angles and that r_2 and ψ are different for various angles of incidence. This is the reason that Trentini’s formula cannot predict the level of side lobes observed experimentally. If the transmission and power pattern of the antenna is derived, taking into account these facts, it is possible to predict the appearance of side lobes and therefore derive a strategy to suppress them.

III. LUNEBURG LENS

Another possibility to achieve directive antennas is to use lenses. Luneburg lens is a variable refractive-index spherical structure that can be applied to focus a plane wave; or to transform the wave from a point source to a plane wave. The required dielectric constant for achieving a Luneburg lens must satisfy the following equation [10], [8], [9]:

$$\epsilon_r = 2 - \left(\frac{r}{R}\right)^2 \quad (2)$$

assuming that the lens is magnetically inactive (i.e. $\mu = 1$), where $r = \sqrt{x^2 + y^2}$ is the position in spherical coordinates from the center of the lens, and R the radius which defines the size of the lens. This permittivity is plotted in Fig. 3(a) and it varies from $\epsilon(r = 0) = 2$ to $\epsilon(r = R) = 1$.

The properties of this lens were simulated with an in-house FDTD code ([11], [12], [13]). When a point source is placed on the circumference of the cylindrical lens, the wave produced by the point source is transformed after the lens into a plane wave, as shown in Fig. 3(b), and by simply moving the point source on the circumference of the cylindrical Luneburg lens, the direction of the plane wave changes as it is illustrated in Fig. 3(c).

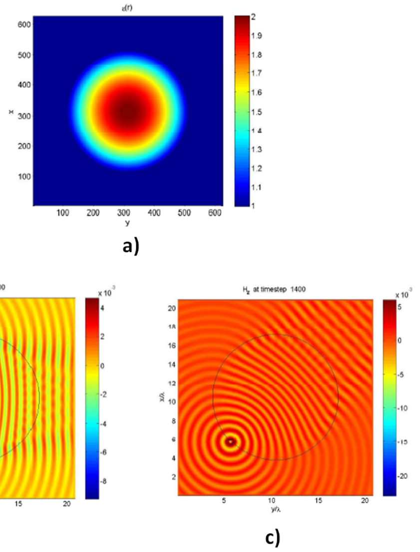

Fig. 3. Luneburg lens: ϵ_r distribution for lens, (b) field distribution when a point source ia excited at (-R,0) and (c) at ((-Rcos(π/4),-Rcos(π/4)).)

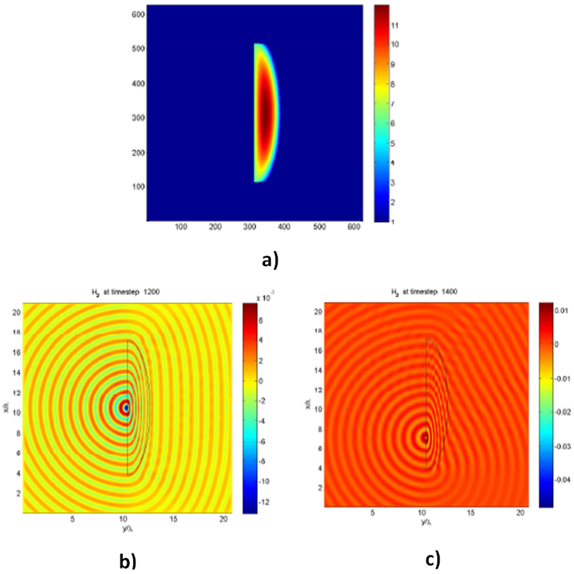

Fig. 4. Slim hemi-cylindrical Luneburg lens: ϵ_r distribution for transformed lens, (b) field distribution when a point source ia excited at (0,0) and (c) at (0,-0.5R)

By the use of transformation optics/electromagnetics [14], [15], this Luneburg lens can be converted into a flat lens, that has the same properties as the original one. This represents an advantage for practical implementations, being this design comparable to planar PRS structures. The dielectric distribution of a proposed Luneburg lens (after transformation) is illustrated in Fig. 4 (a), and its remaining focusing properties are illustrated in Fig. 4 (c-d).

IV. CONCLUSIONS

In summary, two different techniques to increase the directivity of antennas have been compared and discussed. Both techniques can be used to preserve the flat profile of antenna structures with a simple feed, and to produce directive radiations. However, the configuration with flat Luneburg lens can be used to steer the antenna beam while maintain low side lobe levels within a broadband of operation. Detailed results will be shown at the conference in due course.

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