Design a Novel Structure of Circular Polarization Antenna Using Reflective Meta Surface

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Abstract— A new configuration of a high gain circular-polarization Fabry–Perot (FP) cavity antenna is presented. It is excited in single-linear polarization at 45 degree and radiates in circular polarization. It consists of a polarizing partially reflective surface (used to ensure the polarization conversion) and a PDEBG (polarization dependent electromagnetic band gap) ground plane. Unit cells that are used in this superstrate are SRs (spiral resonators) that enable a greater miniaturization rate. SRs are shown to be useful to reduce the electrical dimensions of the resonant inclusions when synthesizing artificial metamaterials. In this paper we present a FP/EBG (electromagnetic band gap) antenna operating around 5.8GHz. Results of simulation are shown proposed antenna has the advantages of high gain, and a wide boresight axial ratio over the operating frequency bandwidth.

Keywords- circularly polarization; dipole antenna; EBG; partially reflective surface; spiral resonator

I. INTRODUCTION

Modern satellite communication systems often demand low-profile, wide bandwidth, high gain, and circular polarization antennas. To increase the antenna gain, array antennas are widely used. However, designing an array antenna is a complex process due to the complicated feeding networks needed to generate both the CP (circularly polarization) behavior and high gain, and such networks cause low efficiency in high-gain antennas. As another approach to obtain high-gain behavior, electromagnetic band gap (EBG) resonator antennas, FPC (Fabry–Perot cavity) antennas have also been proposed. In this paper, a method is proposed for designing a high gain circular polarization antenna with single-layer PRS. This PRS is a single dielectric layer with periodic spiral resonator on one surface to provide a close-to-optimal reflection phase. An important topic in EBG research is to miniaturize the cell size of the EBG unit. As a FPR antenna generally consists of a primary radiator backed with a metal ground plate and a partially reflective covered plate [1]. When the spacing between these two plates is about integer times of half wavelength, the forward radiation can be enhanced remarkably by means of in-phase bouncing.

A primary source and a Fabry-Perot Cavity which is highly frequency the number of iterations increases, the equivalent inductance increases, resulting in a lower resonant frequency. Using a similar idea, a larger equivalent inductance can also be realized with an increasing number of spiral turns. In this design, a linearly polarized dipole antenna is located on top of a polarization-dependent EBG (PDEBG) ground plane. Dipole has a 45 degrees difference with x axis [2]. This ground plane has a substrate (Rogers RT duroid 6002, εr = 2.94) that are located a 9×6 array on it. The high gain property is achieved by using metamaterial unit cells while conversion of the incident LP wave exciting the cavity into a CP wave front radiated in free space for circular polarization is obtained by acting of superstrate same resonance conditions for x- and y-polarizations prepared by PDEBG ground plane. In addition, the acting both of substrate and PRS caused that we have a wide broadsight axial ratio (≈ 60) at 5.8 GHz and a 3-dB axial-ratio bandwidth of about 5% is achieved with an antenna height of only 1.1λ. Simulation results show a maximum gain of 9.4 dB with a minimum AR level of around 3 dB with 12% wideband.

II. ANTENNA GEOMETRY AND DESIGN THEORY

Figure 1 shows the multiple reflections and transmission of the cavity in order to demonstrate the concept of our proposed

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1 Linearly polarized  
2 Circularly polarized  
3 Axial ratio

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A Fabry-Perot cavity is mainly formed by a radiating element between a complete reflecting screen (PEC), and a partially reflecting surface. A broadside directive radiation pattern results when the distance between the ground plane and PRS causes the waves emanating from PRS in phase in normal direction. If reflection coefficient of the PRS is $\Gamma = \rho e^{j\psi}$ and $f(\alpha)$ is the normalized field pattern of feed antenna, then normalized electric field $E$ and power $S$ at an angle $\alpha$ to the normal are given by

$$E = \left| \frac{1 - \rho^2}{1 + \rho^2 - 2\rho \cos(\phi)} \right| f(\alpha)$$

$$S = \left| \frac{1 - \rho^2}{1 + \rho^2 - 2\rho \cos(\phi)} \right|^2 f^2(\alpha)$$

$$\phi = \phi - \pi - \frac{4\pi \lambda}{d} \cos \alpha$$

The distance between the PEC and the PRS, $d$, the directivity of the antenna can be improved in an arbitrary direction $\alpha$, by a factor of $S$. For a half wavelength cavity ($d = \lambda/2$), in the broadside direction ($\alpha = 0$), the maximum directivity is obtained, from (2), when the reflection coefficient of the PRS is close to the short-circuit condition.

$C_{SR} = C_0 - \frac{1}{4(\omega + s)} \frac{N^2}{N^2 + 1} \sum_{n=1}^{N-1} [1 - (n + \frac{1}{2})(\omega + s)]$  \hspace{1cm} (4)

Also in this case, $C_{SR}$ since is the distributed capacitance between adjacent turns. Let us consider now the total inductance of the SR. A very simple formula for can be easily derived considering the self-inductance of a single turn with an average total length given by (5):

$$L_{SR} = \frac{\mu_0}{2\pi} \left[ \sum_{n=1}^{N} l_n \right] \left( \frac{1}{2} + \ln \left( \frac{l_{avg}}{2\alpha} \right) \right)$$

$$l_{avg} = \frac{1}{N} \sum_{n=1}^{N} l_n = \frac{4IN - [2N(1 + N) - 3] (s + w)}{N}$$

The final expression of $L_{SR}$ is:

$$L_{SR} = \frac{\mu_0}{2\pi} \left( \sum_{n=1}^{N} l_n \right) \left( \frac{1}{2} + \ln \left( \frac{l_{avg}}{2\alpha} \right) \right)$$

![Fig. 1. Structure of Fabry-Perot](image1)

![Fig. 2. The geometry of the spiral resonator unit cell](image2)

A single spiral is placed on top of a grounded superstrate as shown in Figure 5. The thickness of the superstrate is 1mm (0.019$\lambda$) and the relative permittivity of the substrate 4.4 (FR4-epoxy) and a tangential loss of 0.019. The periodicity of the unit cell is 7.8mm (0.15$\lambda$). The width of the spiral is 0.517mm (0.01$\lambda$) and the gap between metal strips is also 0.517mm (0.01$\lambda$) [5].

![Fig. 3. Simulation of the S11 and S21 coefficients of the SRR unit cell](image3)
The aforementioned EBG surfaces consist of symmetric square units. Thus, the reflection phase for a normally incident plane wave is independent of its polarization state. These substrates have different design. To locate metal patches on the dielectric substrate can obtain suitable radiation pattern and also changes the linear polarization into circular polarization. It is an isotropic structure for normal incidence. The latter effect is similar to a meander-line polarizer. Figure 4 shows the geometry of a horizontal dipole near a ground plane. When the dipole is located very close to the ground plane, 2kd is close to zero. Thus, the radiation field becomes (7):

$$E = \frac{E_0}{2}(x.e^{-jkz} + y.e^{-jkz}) + \frac{E_0}{2}(x.e^{-jkz-2jkd} + j\theta_y)$$

If the ground plane is a perfect electric conductor (PEC), $\theta_x = \theta_y = 180^\circ$. The reflected field has the opposite sign to the incident fields. Thus, the total radiating field in (7) is zero. If the ground plane is a perfect magnetic conductor (PMC), $\theta_x = \theta_y = 0^\circ$. The dipole still radiates linearly polarized waves. In order to obtain a circular polarization, different reflection phases $\theta_x$ and $\theta_y$ are needed. When a PDEBG surface with reflection phases of $\theta_x = 90^\circ$ and $\theta_y = -90^\circ$ is used as the ground plane, the total field becomes:

$$E = \frac{E_0}{2}e^{-jkz}[(x + y) + j(x - y)]$$

III. SIMULATION RESULTS

The simulation results of $S_{11}$ coefficient and the radiation pattern of the Fabry-Perot cavity antenna at the resonance are shown in Figures 6 and 7. As shown in Figure 6, the resonance of the Fabry-Perot antenna is at 5.8GHz corresponding to a return loss of $|S_{11}| = -14$dB. The radiation patterns of structure shown in Figure 7, exhibit a maximum directivity of 9.4 dB. The radiation patterns (Figure 8) measured at 5.74 GHz (minimum AR) show low side lobes (-2 dB).
The simulated boresight axial ratio of the proposed antenna is plotted as a function of Teta in Figure 9. It can be observed that the AR (axial ratio) in broadside direction is -3dB, worse than the convention circularly polarized dipole antenna, but the beamwidth where the AR is lower than 3dB bandwidths for the RHCP and LHCP antennas are 50 (-25 to 25) and 120 (-60 to 60), respectively.

The axial ratio of the structure is also shown in Figure 10. This graph is plotted in terms of frequency. The simulated 3 dB axial ratio bandwidths for the RHCP and LHCP antennas are 5.17% (5.46 GHz to 5.75 GHz) and 5.17% (5.46 GHz to 5.75 GHz), respectively.

IV. CONCLUSIONS

In this work we presented the design of an FP/EBG Antenna with a Metamaterial PRS operating around 5.8GHz. The simulation results show a directivity of 9.4dB which is 4dB more than that of the original dipole antenna which excites the FP antenna. The use of PDEBG ground instead of a simple ground plane made it possible to satisfy the resonance condition for both orthogonal polarization components, and a properly designed polarizing FSS has been used for the conversion of linear to circular polarization.

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REFERENCES


^ Right hand circular polarization
^ Left hand circular polarization