Self-Polarizing Highly-Gain Fabry-Perot Cavity Antennas with EDR Unit Cell

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Abstract— the paper describes a novel low profile circularly polarized antenna. The antenna is a single dipole located in a cavity, substrate consists of polarized depend on electromagnetic band gap and in the superstrate uses a new unit cell with circularly polarized feature. The distinguishing feature of the design is that it incorporates the following interesting concepts simultaneously: artificial high impedance surfaces or artificial magnetic conductors, materials showing refractive indexes of less than unity (n < 1), and polarizing structures. It is excited in single-linear polarization at 45 and radiates in circular polarization. An FP antenna with a superstrate that consists of EDR (electric disk resonator) unit cell is optimized in C-band to validate the concept at 5.8 GHz. A 3-dB axial ratio bandwidth of about 1.9% is achieved with an antenna height of only 0.8λ, wide enough for most applications.

Keywords- fabry-perot antenna; PDEBG; EDR unit cell; circularly polarized; axial ratio

I. INTRODUCTION

A FPR (Fabry-Perot Resonator) 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 geometrical optics model has been applied to describe the theory of FP resonator antenna [2]. As shown in Figure 1 depending on the reflection coefficient of the PRS (partially reflective surface), \( \Gamma = \rho \exp(\jmath \phi) \), the distance between the PEC (perfect electric conductor) and the PRS, \( d \), the directivity of the antenna can be improved in an arbitrary direction \( \alpha \), by a factor of \( S \).

\[
S = \frac{1 - \rho^2}{1 + \rho^2 - 2\rho \cos(\phi - \pi - \frac{4\pi}{d} \cos \alpha)}
\]

II. DESCRIBING THE MAIN SCHEME

For a half wavelength cavity (\( d = \lambda / 2 \)), in the broadside direction (\( \alpha = 0 \)), the maximum directivity is obtained, when the reflection coefficient of the PRS is close to the short-circuit condition.

For a pure CP (circularly polarized) condition we need to provide [4-6]:

\( |E_x| = |E_y| \)
\( \angle E_x - \angle E_y = 90' \)
A. Substrate Design

The PDEBG (polarization-dependent electromagnetic band gap) ground plane that is shown in Figure 3 not only improves the radiation efficiency, but also changes the linear polarization into circular polarization [7-8]. The latter effect is similar to a meander line polarizer. The dipole is oriented along $\phi = 45^\circ$ direction. The total radiation field at the broadside direction can be approximated by the summation of the directly radiating field ($E_d$) from the dipole and the reflected field ($E_r$) from the ground plane as below:

$$E = E_d + E_r$$

$$E_d = \frac{E_0}{2} (x e^{-j\theta_x} + y e^{-j\theta_y}) + \frac{E_0}{2} (x e^{-j2\theta_x} + y e^{-j2\theta_y})$$

The PDEBG ground plane is fabricated on a RT/duroid 6002 high frequency laminate ($\varepsilon = 2.94\pm0.04$) with a 3.5mm thickness. The patch dimensions and gap widths are designed to achieve a 90° reflection phase for $x$ polarization and a -90° reflection phase for $y$ polarization. The width of the rectangular patch is 4.8 mm and the length is 7.8 mm. The gap width between adjacent patches is 1.2 mm along the $x$ direction and 0.6 mm along the $y$ direction. A finite ground plane with a size of 60 mm x 60 mm is used in the experiment, which includes 9x6 rectangular patches.

B. EBG Unit Cell

The unit cell of the proposed electric disk resonator (EDR) structure is shown in Figure 4. The dimensions of the unit cell comprising this electric metamaterial be $l_x$, $l_y$, and $l_z$ in the $x$, $y$ and $z$ directions respectively [9-10]. The metal disks at the top and bottom faces of the structure have areas $A_D$, and are connected together by a metal post with inductance $L_p$. Also shown in Figure 4, the current in the post that connects the two disks is $i_p$, and the voltage between the upper and lower disk is $v_d$. The electric resonance frequency is dependent on the leakage capacitance between the plates $C_F$ and the post inductance.
The leakage capacitance $C_F$ is first estimated based on dimensions of disks in the EDR unit cell as:

$$C_F = \frac{\varepsilon_0 A_D}{l_d} = \frac{\varepsilon_0 \pi r_c^2}{l_d}$$

(3)

Where $r_c$ is the radius of disks and $l_d$ is the distance between the two disks. The inductance of the post $L_p$ can be approximated using the equation for inductance of a straight wire at high frequencies:

$$L_p = 2 \times 10^{-7} \frac{l_d}{r_p} \ln \left( \frac{2l_d}{r_p} \right) - 1$$

(4)

With values of $r_c = 8.0$ mm, $r_p = 0.4$ mm, and $l_d = 4.5$ mm, the leakage capacitance given by (3) is $C_F = 3.95 \times 10^{-13}$ F and the post inductance given by (4) is $L_p = 1.9 \times 10^{-9}$ H. The estimated resonant frequency for these values is $\omega = (C_F L_p)^{-0.5} \approx 3.6 \times 10^9$ rad/s or 5.8 GHz, and is likely to be a high estimate since fringing capacitances at the sharp edges of the disk are not included.

The EDR unit cell was simulated in HFSS inside a rectangular C-band WR-90 waveguide (4-8GHz) to characterize its resonance. Scattering parameters of the simulated EDR unit cell are shown in Figure 5. From the magnitudes of the reflection and transmission coefficients, it can be observed that the unit cell has a resonance at 5.7 GHz, in moderate agreement with the fringe-corrected prediction of 5.8 GHz.

The FP antenna is excited by a primary source of dipole type. This dipole antenna (Fig. 3) is designed to operate at 5.8GHz frequency. The dipole is located on a Rogers RT substrate with $\varepsilon_r = 2.2$, a thickness $d = 3.6$mm. The size of the patch is $7.8 \times 4.8$mm² and that of the ground plane is $60 \times 60$mm². The length of dipole is 23.4mm, and it is located 7.5mm at the top of the ground. The dipole is fed by a 50Ω SMA connector. The simulation results of $S_{11}$ coefficient, and gain in E-plan and H-plan 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 measured ~10 dB bandwidth for both the RHCP¹ and LHCP² antennas is about 7.1% (5.3 GHz to 5.7 GHz). The Radiation Pattern of structure shown in Fig. 8, exhibit a maximum directivity of 10.7 dB and F/B also achieve 11.2dB.

A maximum gain value of 10.7dB at 5.2GHz has been measured over a 1 dB bandwidth of about 3.5% (5.56 GHz to 5.76 GHz) for both the RHCP and LHCP antennas. It is worth noting that the proposed antenna simultaneously produces high-gain and CP behavior by using a simple dipole antenna [11-13]. Both gain curves for LHCP and RHCP antennas are nearly identical, owing to the symmetry of the superstrate for x-polarization and y-polarization of the incident wave.

**Fig. 7. Radiation patterns of the dipole antenna with EDR metamaterial and PDEBG ground plane**

¹ Left hand circular polarization
² Right hand circular polarization
The axial ratio of the structure is also shown in Figure 8. It can be observed that the 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 is 60(-30 to 30). This range of AR is obtained for 5.8GHz in \( \theta = 0 \) for E-Plane and H-Plane. In Figure 9 shows AR to frequency. This range is about 3.5% (5.56-5.76).

![Fig. 8. Axial ratio for the structure in Fig. 2 axial ratio in Phi=90° and 0° plane](image)

![Fig. 9. Abbreviations and acronym simulations boresight axial ratios for the proposed antenna](image)

**IV. CONCLUSION**

In this paper, a novel Fabry-Perot resonator antenna with circularly polarized structure has been proposed, and the principle of polarized variability has been analyzed and also verified by simulation. The mechanism of polarized variability is quite simpler than a traditional antenna with complex feed network, and most important is that which can be integrated with antenna. This Fabry-Perot resonator antenna presents good features of polarization transform, higher gain, and has potential significance for engineering application.

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**REFERENCES**


\(^3\) Axial ratio