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Improving the bandwidth of high gain Fabry-Perot antenna using EBG substrate

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Abstract

In this paper, design of high gain antenna with electromagnetic resonances of Fabry-Perot (FP) cavity is presented. FP Resonator antenna generally consists of primary radiator backed with a metal ground plane and a partially reflective surface (PRS). FP cavities are mainly used as energy-focusing elements to enhance the antenna directivity but at the same time leads to bandwidth reduction. This reduction of bandwidth in FP antenna is compensated by the use of EBG substrate. The proposed structure consists of SRR array that is implemented as a PRS and an EBG substrate. This antenna is designed to operate at a frequency around 10 GHz. The structure increases the gain from 6.11 dB up to about 12 dB or more and improves the bandwidth 0.82%. For validation of purposes, the antenna is designed and simulated through using of two different 3D full-wave electromagnetic simulation tools; CST Microwave Studio and Ansoft's High Frequency Structure Simulator (HFSS).

Keywords: High-Gain Antenna, Fabry-Perot Antenna, Electromagnetic Band Gap (EBG), High Impedance Surface (HIS).

INTRODUCTION

Recently various geometries have been proposed to design broadside directive antennas that combine both compactness and a single feeding point. It is known that high directivity is often achieved by array techniques, while introduction of power dividers inevitably brings in some losses in the design of feeding network, so achieving a high gain with a low-profile antenna that utilizes a single antenna element opposed to an array is always a desired design goal. For designing this kind of antennas Fabry-Perot (FP) optical concept is introduced [1-2].

This structure in comparison with antenna array techniques has some advantages such as having a simple structure [3]. This structure is based on the formation of a resonant FP cavity that consists of a radiating element placed between two metallic arrays which act as partially reflective surfaces (PRS) or between one periodic metallic array and a ground plane.

Any kind of radiation aperture can serve outside or inside the cavity as a feed [4-5]. Directivity and bandwidth are dependent on the reflection (amplitude and phase) of the PRS as well as the distance from the ground plane [6]. This technique uses PRS reflection to introduce leaky waves and beam forming effects when is placed in front of the grounded radiation aperture. A ray theory that has been proposed, showing that the directivity of the antenna increases when the reflectivity of the PRS increases [7-8]. By increasing the reflection coefficient of PRS, directivity will be improved but antenna bandwidth decreases [9].

In the structure design that has been shown in this paper, reduction of FP antenna bandwidth is compensated by using EBG substrate. This proposed FP antenna consists of a single-layer dielectric superstrate with metal SRR array and an EBG material as high impedance surface (HIS) ground plane that is shown in Fig. 1. The EBG structure utilizes the inherent properties of dielectric materials to enhance the microstrip antenna performance [10-12]. EBG materials are periodic dielectrics that produce pass-band and stop-band characteristics. The characteristics of an EBG are dependent on the shape, size, symmetry and the material used in their construction. Surface waves are reduced by using an EBG substrate which leads to increase the directivity, bandwidth and radiation efficiency. The height of the superstrate is $\lambda/2$ so it can achieve the maximum directivity.

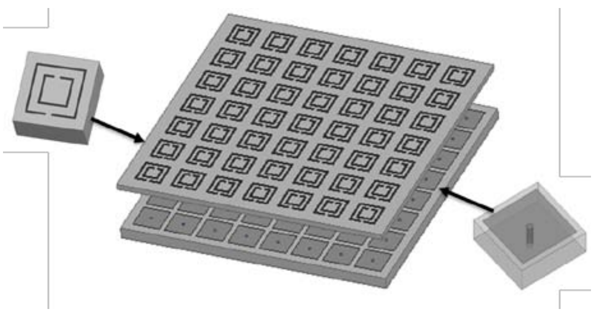


Figure 1. The FP antenna consists of a PRS superstrate and an EBG substrate.

MATERIALS AND METHODS

FP cavity antenna consists of a feeding source that placed between a PRS and an HIS ground plane. A microstrip patch is placed into the cavity as feed. Gain and bandwidth are functions of reflection coefficient in cavity FP as follow:

$$G = (1+R)/(1-R) \quad (1)$$

$$BW = \Delta f / f_0 = (\lambda / 2\pi L_r) \times (1-R)/\sqrt{R} \quad (2)$$

Where R is the reflection coefficient of PRS and L_r is the resonant length-distance between ground plane and the PRS [13]. According to equation 1 the gain increases considerably with R. However bandwidth decreases as R increases (eqn. 2).

Microstrip Patch Antenna Design

A rectangular microstrip patch antenna with Rogers RT/duroid5870(tm) substrate has been designed and simulated at 10.2 GHz as the cavity FP feed. In this antenna, the substrate has a thickness h=2 mm and a permittivity ε_r=2.2. The length and width of patch are L=W=8.74 mm. The length and width of ground plane are L_g=W_g=52 mm. The antenna is fed by a coaxial Probe. Feed point is located where 50 ohm resistance occurs [14].

The designed microstrip antenna has a fractional bandwidth (-10 dB) of 7.78%, which ranges from 9.88 GHz to 10.68 GHz and The maximum gain is 6.11 dB at the center frequency of 10.2 GHz.

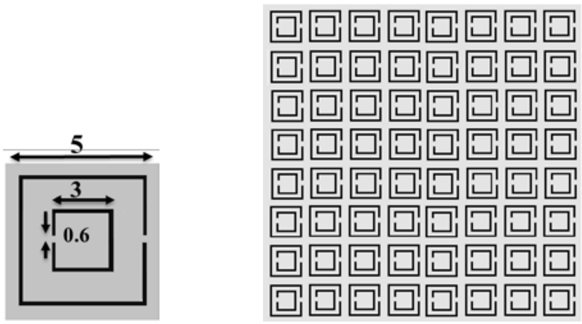
Design of PRS Superstrate

PRS is a Frequency Selective Surface (FSS) realized by a periodic distribution of metallic elements printed on a dielectric slab. It can entirely reflect almost incident waves.

By insertion of a source (i.e., a patch antenna) between the ground plane and the PRS, a high directive antenna can be obtained. Therefore, parasitic patches (PPs) on a dielectric as PRS are fabricated to enhance the reflection coefficient and the directivity [15-17]. An 8×8 SRR array is implemented as a PRS [18].

The SRR unit cell is formed of two metallic rings printed on the dielectric substrate. The SRR array is designed on a square dielectric same as the antenna's substrate. Fig. 2 shows the SRR unit cell geometrical dimensions and the PRS.

The simulated results of return loss and radiation pattern of the microstrip antenna with PRS superstrate are shown in Fig. 3 and Fig. 4, respectively. The antenna has a bandwidth of 4.28%, between 9.82 GHz and 10.25 GHz and the maximum gain is about 10.3 dB at 10.2 GHz.



(a) (b)

Figure 2. (a) SRR unit cell dimensions and (b) The 8×8 SRR array that is implemented as PRS. (Unit: mm)

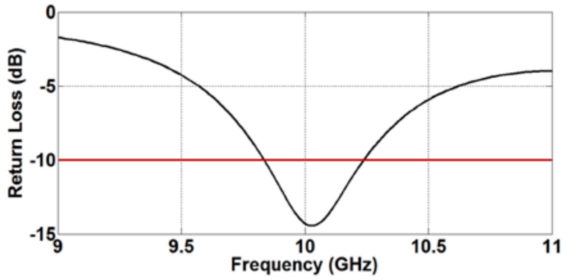


Figure 3. Simulated return loss of the FP antenna.

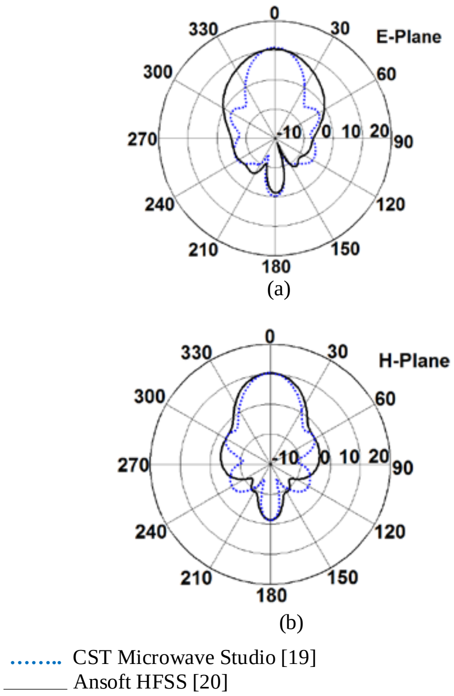


Figure 4. Simulated radiation pattern of FP antenna gain (a) E-Plane and (b) H-Plane. (CST & HFSS)

As the results show, by adding PRS to microstrip antenna, the gain is enhanced about 4.19 dB (from 6.11 dB to 10.3 dB) and the bandwidth is reduced from 7.78% to 4.28%. This reduction is the main disadvantage of FP antenna.

Design of EBG Substrate

To construct the ground plane of antenna, a mushroom-like EBG is used. The mushroom-like EBG known as HIS is initially proposed by Sievenpiper [21], which is made of metal patches, dielectric substrate, and via connected with patches and ground plane.

The mushroom-like EBG has a frequency band gap and a very high impedance surface characteristics, which is generally called in-phase reflection band. These conventional mushroom-like EBG can be used in antenna design to suppress the propagating of surface waves [22-24].

Mushroom-like EBG unit cell has been shown in two different dimensions in Fig. 5. There are four main parameters that affect the performance of mushroom-like EBG structures. The parameters are rectangle width (w), gap width (g), substrates thickness (h) and substrates permittivity (ε_r). Also, the vertical via radius (r) has a trivial effect because it is very thin compared to the operating wavelength. The parameters that affect the performance of EBG structures are directly dependent on the operating wavelength of the patch antenna. The following formulas are used for designing the EBG structures according to reflection phase of structure [25].

$$W = 0.12\lambda, g = 0.02, h = 0.04\lambda, \varepsilon_r = 2.20, r = 0.005\lambda \quad (3)$$

Since the designed FP antenna operates in frequency of 10.2 GHz, Optimized parameters of the EBG unit cell structure are patch width, gap width, via radius and substrate thickness that are respectively w=5.2 mm, g=1 mm, r=0.26 mm and h=2 mm.

Fig. 6 shows the reflection phase of mushroom-like EBG unit cell. It shows that electromagnetic band gap is between 8 GHz to 12 GHz where the reflection phase of EBG structure changes from 90° to -90°.

The microstrip antenna substrate uses three rows of EBG structures around its patch as shown in Fig. 7.

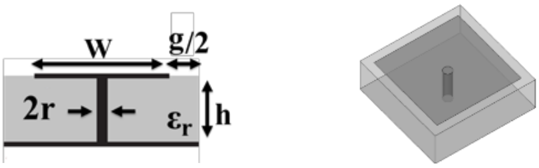


Figure 5. Mushroom-like EBG Unit Cell Parameters.

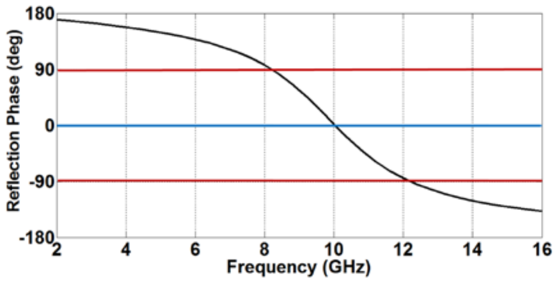


Figure 6. Reflection phase of mushroom-like EBG unit cell

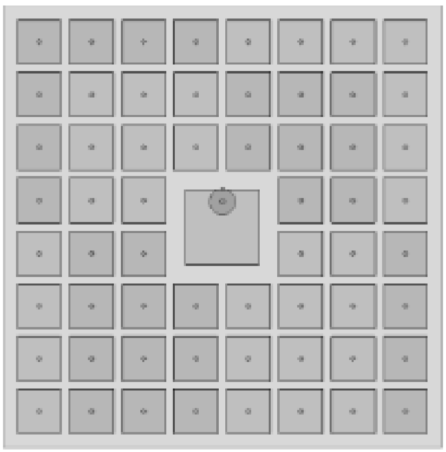


Figure 7. Microstrip antenna substrate with three rows of mushroom-like EBG

RESULTS and DISSCUTION

Fig. 8 shows the simulated return loss of the proposed FP antenna structure that consists of a PRS and an EBG substrate. The simulated return loss bandwidth from 9.93 to 10.83 GHz is about 8.6%.

Simulated result of the proposed antenna return loss shows that bandwidth has increased to 8.6% which this is 4.32% wider than bandwidth of FP antenna without EBG structure and is 0.82% wider than primary microstrip antenna bandwidth.

The antenna radiation patterns of gain at the center frequency of 10.3 GHz at E-plane and H-plane are plotted in Fig. 9 (CST& HFSS).

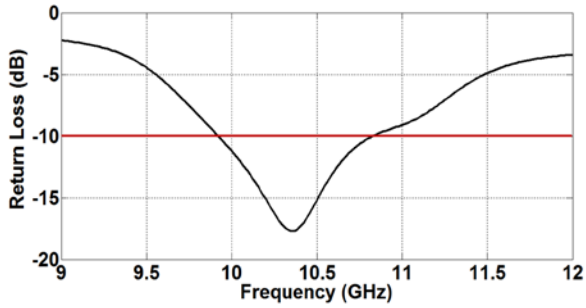


Figure 8. Simulated return loss of the proposed FP antenna with EBG substrate.

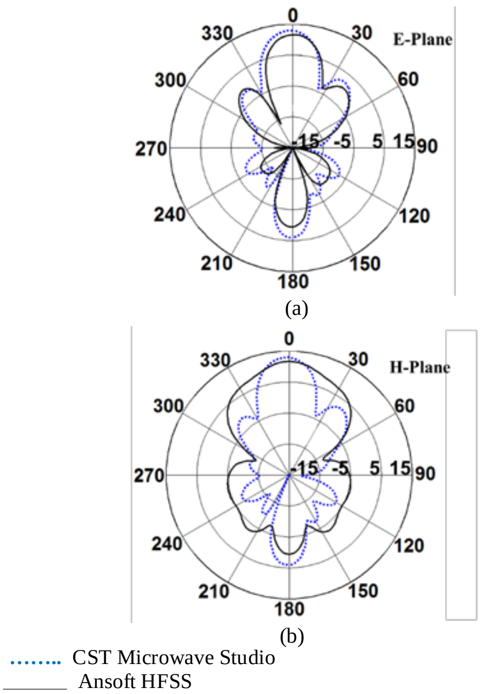


Figure 9. Simulated radiation pattern of proposed FP antenna gain with EBG substrate (a) E-Plane and (b) H-Plane. (CST & HFSS)

Simulation results show that the maximum gain is 12.3dB in CST and 11.8 dB in HFSS. That is approximately 1.7 dB higher than gain of FP antenna without EBG structure and 5.89 dB higher than the gain of primary microstrip antenna.

Table I summarizes the performance of FP antenna with\without EBG ground plane in terms of bandwidth and gain. In FP antenna without EBG, the gain is enhanced about 4.19 dB and bandwidth is reduced about 3.5%. By adding EBG structure, antenna bandwidth and the gain are increased about 4.32% and 1.7 dB respectively. The simulation results that obtained by CST microwave studio and HFSS simulators show a good agreement.

Table I. Comparison of resonance frequency, bandwidth and gain of three structures of antenna.

Antenna	f_0 *(GHZ)*	*BW%*	*Gain(dB)*
Microstrip antenna	10.2	7.78	6.11
Microstrip antenna with PRS	10.2	4.28	10.3
Microstrip antenna with PRS and EBG substrate	10.3	8.6	12

CONCLUSION

The purpose of this paper is to propose a structure to enhance the bandwidth of a high gain FP antenna. The cavity FP antenna consists of a PRS superstrate and EBG substrate. A microstrip patch antenna is placed into the cavity as feed. The gain of primary microstrip antenna is increased by adding PRS suprestrate but antenna bandwidth is decreased, which is the main disadvantage of FP antenna. EBG substrate is used to compensate the FP antenna bandwidth reduction and to obtained more antenna gain. As a result, the gain of final structure is about 12 dB and bandwidth about 8.6%.

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