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Improving Microstrip Patch Antenna Directivity using EBG Superstrate

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ABSTRACT: *Electromagnetic Band-Gap (EBG) structures are popular and efficient techniques for microwave applications. EBG structures have two main configurations, first EBG substrate and second EBG superstrate. In first case, the patch of antenna is surrounded with EBG structure that suppress the propagation of surface wave and in second case, layer of EBG structure that call EBG superstrate set above the patch of antenna to increase the directivity and to reduce the side lobes of the radiation pattern. In this paper, we study the influence of the EBG superstrate on the performances of an aperture coupled rectangular microstrip patch antenna. The return loss, radiation pattern and directivity are studied using HFSS software. The simulation results show that the gain, directivity and S11 parameter of the antenna with EBG cover are increased at X band (8-12GHz). Compared with the patch feed with the same aperture size but without superstrate, the performance of the proposed antenna is significantly improved.*

KEYWORDS : *Patch antenna; HFSS; EBG Structure; Return Loss; Gain; and Directivity.*

I. INTRODUCTION

Microstrip antennas are widely used in various applications because of low profile, low cost, lightweight and conveniently to be integrated with RF devices. However, microstrip antennas have also disadvantages such as the radiation of electromagnetic energy in different directions from radiation source (i.e. patch) witch cause the electromagnetic energy duo to the patch and feed of microstrip antenna, divide in all direction in the space that it results to reduce directivity, gain and wide radiation beam [1].BG structures are periodic structures that are composed of dielectric, metal or metallo-dielectric materials. These structures can prevent or assist wave propagation in special directions and frequencies therefore they can be used as spatial and frequency filters [2].There are several configurations of EBG structures according to their application in antenna. Two main configurations are:

a. EBG structures place on antenna substrate that by creation band gap in certain frequency range Suppress from propagation of surface wave. This configuration is defined as EBG substrate. In this configuration both of mushroom-like EBG and uniplanar EBG is used [3].
b. EBG structure place at certain distance above radiation source of antenna i.e. patch and by creation ultra-refraction phenomenon, concentrate radiation in various direction normal to EBG structure. This configuration is defined as EBG superstrate or Metamaterial superstrate and only the uniplanar EBG is used in this one [4].

In this paper, we consider the problem of enhancing the directivity of an aperture coupled microstrip patch antenna. the paper is organized as follows: Section II explains the design procedure of an aperture coupled microstrip patch antenna (ACMPA) covered by EBG structure and section III is about the simulation results achieved by using single layer and two layers EBG superstrate in addition to the analysis of a comparative performance for better understanding. Section IV gives conclusion and anticipated future work.

DESIGN OF PATCH ANTENNA WITH EBG SUPERSTRATE : An aperture coupled patch antenna eliminates the direct electrical connection between the feed and radiating conductors by employing two dielectric substrates separated by a ground plane. This allows independent optimization of both the microstrip transmission line feed and radiating patch; patch and feed line are electromagnetically coupled through an aperture made on the ground. Such a design can be well explained with the help of following diagram:

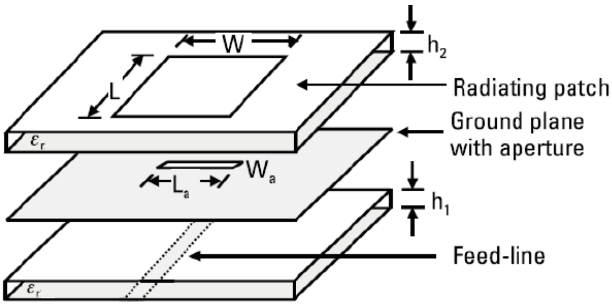

Fig. 1: Geometry of the basic aperture coupled microstrip antenna

Fig. 1 represents conventional aperture coupled microstrip patch antenna. The basic microstrip patch antenna consists of three layers. The dielectric substrate is placed between a ground plane (lower layer) and radiating metallic patch (top layer). The proposed microstrip patch antenna is realized on the Roger RT/duroid substrate with permittivity εr=2.2 and thickness (h) of substrate is 0.79 mm, the ground plane and radiating patch is made of copper. The operating frequency of antenna (fr), at which we wish to achieve the maximum directivity, is 7 GHz. The dimension of radiating patch is calculated by equations (1), (2), (3) and (4) where L, W is length and width of radiating patch [5].
Effective dielectric constant is calculated from:

$$\varepsilon eff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(1+\frac{12\mathrm{h}}{W}\right)^{-1/2} \quad (1)$$

Width of metallic patch:

$$\mathrm{W} = \frac{\mathrm{c}}{2fr\sqrt{\frac{2}{\varepsilon r+1}}} \quad (2)$$

Length of metallic patch:

$$\mathrm{L} = \mathrm{L}_{\mathrm{eff}}\text{-}2\Delta\mathrm{L} \quad (3)$$

Calculation of length extension

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon eff+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon eff-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

The patch dimension (W × L) has been calculated as(11.86mm×9.15mm)and for ground plane dimension has been calculated as (Wg = 60 mm, Lg = 45 mm)[6].

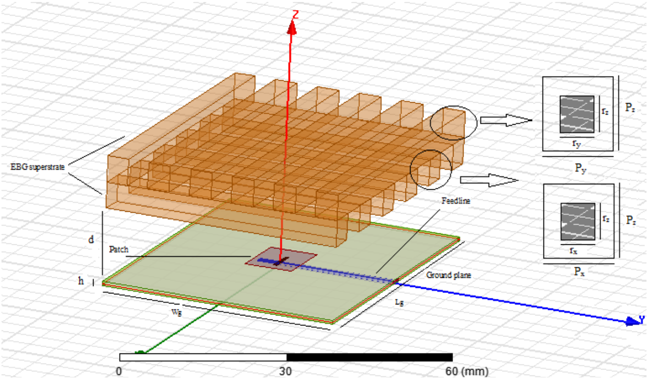

Fig. 2: Geometry of the EBG patch antenna

EBG structure places above the patch of antenna for concentrating of radiation energy normal to itself.Fig. 2 shows configuration of microstrip antenna with EBG superstrate. The EBG material iscomposed of two layers, the first layer has a rectangular lattice (Px=12.7 mm, Pz= rZ), and the dielectric rods have a rectangular cross section (rx= 4mm, rz= 5mm), for the second layer it has a rectangular lattice (Py=15.72 mm, Pz= rZ), and the dielectric rods have a rectangular cross section (ry= 5mm, rz= 5mm). The cover has sex layers of rods in the x-direction, and sex layers in the y-direction (see Fig 2). The length of the rods (in the x and y direction)is chosen to be the same as the dimension of the ground plane. The distance between the substrate and the cover is chosen to be d = 14 mm.

The dielectric material is taken to have a dielectric constant ε_r= 9.2 which corresponds to the dielectric constant of the "Rogers TMM 10 (tm)" in the microwave frequency range. Adjustment of first superstrate layer is the most important stage in antenna design and it is about one third of operation wavelength ($\lambda/3$) above ground plane which cause to gain increase. The second layer, improve beam shaping and directivity. The distance of second layer from first layer is taken almost zero.

Below, we will present the simulation results in terms ofthe computed radiation patterns, return loss and directivity of the proposed antenna. We use HFSS, which is 3D High Frequency Structure Simulator software [7].

II. SIMULATION RESULTS AND DISCUSSION

Now-a-days, it is a common practice to evaluate the systemperformances through computer simulation before the realtime implementation. A simulator *"Ansoft HFSS"* based onfinite element method (FEM) has been used to calculate return loss, radiation pattern and directivity. Thissimulator also helps to reduce the fabrication cost because only the antenna with the best performance would be fabricated [8].

Reflection characteristics : The reflection characteristic of the antenna design for high directivity operation is shown in Fig. 3. For comparison the results are also presented for the aperture coupled feeding patch antenna without the EBG superstrate.

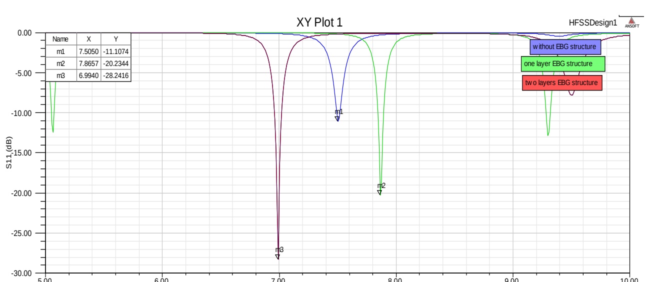

Fig. 3. Reflection coefficients of the source antenna with and without EBG structure

The return loss should be minimal at the resonance frequency for better performance; it can be seen that the reflection behavior of the unloaded antenna (without EBG superstrate) shows high resonance over the X band. After the feed antenna is loaded with one layer superstrate, it can be seen that the reflection losses were minimized (-20.23 dB at 7.86 GHz), however the operation frequency is still far from the desired. Adding a second layer helps to further minimize the reflection losses, the results of the frequency response of the S_{11} parameter show that the double-layer EBG superstrate provides a good impedance matching (S_{11} = -28.24 dB) with the source antenna that was initially designed with an air medium above it at a frequency of 7 GHz exactly.

Directivity : Fig. 4 shows the results of directivity as a function of frequency for the double layer EBG superstratebased antenna, a single layer EBG superstrate based antenna and the feed antenna. It can be seen that the antenna design using double layer EBG superstrate provides much better performance than that of the other two antenna configurations in term of directivity. The firstlayer has important role in this enhancement [9].

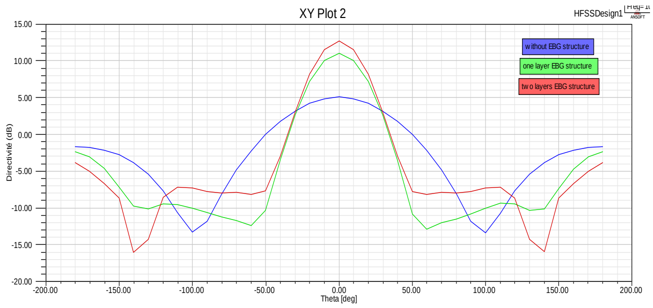

Fig. 4. Results of directivity of an antenna with single layer and double-layer EBG superstrate as well as that of the source antenna

To obtain an optimum response for directivity the air gap between the superstrate and the ground plane was varied to produce the final characteristic of directivity as shown in Figure4. The corresponding value is 14 mm. A maximum directivity of 11.78 dB is obtained at the frequency of 7GHz. Therefore it is important to control the air gap thickness in order to obtain a better performance from the antenna.

The maximum directivity of an aperture antenna is [10]:

$$D_{\max} = \frac{4\pi A}{\lambda^2} \tag{5}$$

Where A is the area of the aperture. Since A ≈ 60 × 45 mm^2 and λ = 37.5 mm in the present configuration, one has D_{max}= 13.8 dB. The directivity of our designed EBG antenna (11.78 dB) is close to the maximum directivity (13.8dB). That is physically possible for this size of antenna.

Radiation pattern and 3dB beamwidth : In figures (5 and 6)3-D radiation pattern of the antenna without EBG superstrate and antenna with two layers EBG superstrate is shown. It is clear from these figures that directivity has been improved by 6.71dB and total efficiency of Antenna increased from 36% to 85%.

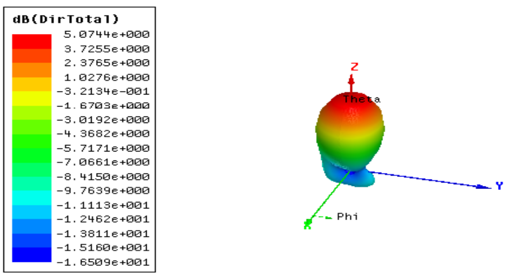

Fig. 5. 3D-Radiation pattern of microstrip antenna without EBG superstrate showing directivity of 5.07 dB

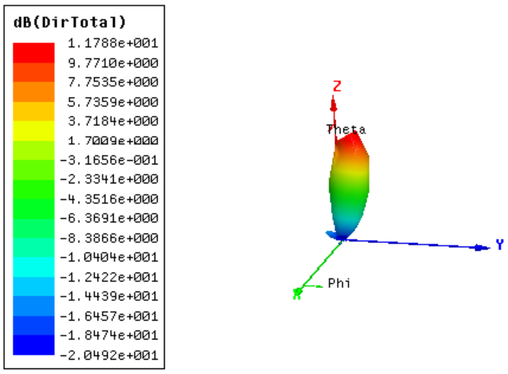

Fig. 6.3D-Radiation pattern of microstrip antenna with two layers EBG superstrate showing directivity of 11.78 dB

Fig. 7 displays Radiation pattern for the double layer EBG superstratebased antenna, a single layer EBG superstrate based antenna and the feed antenna.

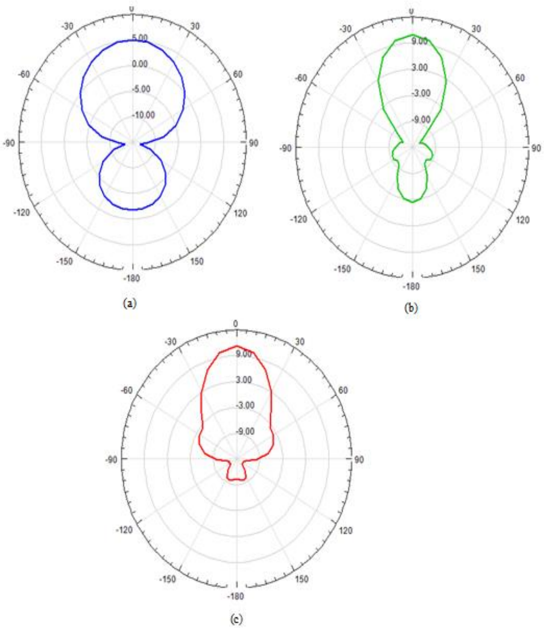

Fig. 7. Radiation pattern of (a) simple microstrip antenna (b) antenna with one layer EBG structure (c) antenna with two layersEBG structure

The results for the beamwidth are 75°, 34° and 30° at the frequency of 7.5 GHz, 7.86 GHz and 7 GHz for the simple antenna (a), antenna with one layer EBG superstrate (b) and antenna with two layers EBG superstrate respectively.It is obvious the use of two layers EBG superstrate, cause the increase of directivity of the antenna, the new antenna provides a narrower beamwidth (30° at E-plane) along the forward direction.A summary of the designed antennas is given in Table I. The table reveals that the designed antenna with two layers EBG superstrate had the best results in terms of frequency, return loss, directivity and beamwidth as those of antenna with one layer superstrate and antenna without the superstrate.

Table I. Comparison Forreturn Loss, Directivity And Beamwidth

Antenna	Freq	Return loss	Directivity	Beamwidth
Without EBG superstrate	7.5 GHz	-11.1 dB	5.07 dB	75°
with one layer EBG superstrate	7.86 GHz	-20.23 dB	10.97 dB	34°
with two layers EBG superstrate	7 GHz	-28.24 dB	11.78 dB	30°

III. CONCLUSION

In this paper, aperture coupled microstrip patch antenna with EBG superstrate has been studied. The main impetus for studying this antenna structure with EBG superstrate was the desire to realize increased directivity without using complex structures such as SRR (Split Ring Resonator) superstrate. The directivity characteristics of the composite structure have been investigated by using HFSS software, which has been found to be a useful tool for designing antennas of this type. Finally, it was found that both the directivity level, beamwith as well as reflection coefficient could be further enhanced by using EBG superstrate with two layers, rather than one. A very important need is to verify more of the simulation results with experimental measurements which will be reported in future work.

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