A Comparison in the Performance of Microstrip patch Antenna with and without EBG Substrate and Superstrate

Vikrant/Assistant Professor
Department of Electronics and Communications Engineering
TERII, Kurukshetra, India
vikranttoky@gmail.com

Rajesh Khanna/Professor
Department of Electronics and Communication Engineering
Thapar University, Patiala, Punjab, India
rkhanna@thapar.edu

***Abstract*--Performance of Microstrip Patch Antenna with three different configurations of substrate materials has been analyzed and presented in this paper. It is shown that the Microstrip Patch Antenna with square EBG Structure achieve a high gain and large Bandwidth as compared to conventional Microstrip Patch Antenna. Placement of EBG Superstrate from the patch of Antenna is critical so distance between antenna and Superstrate and thickness of Superstrate is optimized to achieve best performance and is obtained when EBG Superstrate is placed at half of the operating wavelength from the Patch of the Antenna. The proposed structures are simulated on CST Microwave Studio Suite.**

Keywords—CST, EBG, PBG, Superstrate, Gain, SLL

I. Introduction

Microstrip patch antennas have been an attractive choice in mobile and radio wireless communication [1]. This is because they have advantages such as low profile, conformal, low cost and robust. However, at the same time they have disadvantages of low efficiency, narrow bandwidth and surface wave losses. The solution to these problems of Microstrip patch antennas is Electromagnetic BandGap Structures (EBG) [2].

The concept of electromagnetic band-gap (EBG) structures originates from the solid-state physics and optic domain [3]. Thus the terminology, photonic band-gap (PBG) structures, was popularly used in the early days. At the initial stage of the researches, hit and trial approach was adopted to find out the band gap experimentally, this is all because of lack of theoretical predictions and mathematical formulas. Previously EBG was known as PBG because investigations of these structures were mainly on wave interactions at optical frequencies. But from past few years, continuous and dedicated work on EBG at microwave, millimeter and sub-millimeter wave frequencies [4] the name EBG Structure comes in to picture. The promising features of this EBG witnessed as a new form of structure are invented for radio frequency and microwaves applications. This new structure (EBG) can be realized in 1-D, 2-D, 3-D. This dimensionality depends upon the direction of periodicity of the structure, the structure proposed in this paper is 2-D [6].

Microstrip antennas mounted on a substrate can radiate only a small amount of its power into free space because of the power leak through the dielectric substrate. In order to increase the efficiency of the antenna, the propagation through the substrate must be prohibited. Once the surface waves of the antenna are prohibited to propagate through the surface then the antenna can radiate more towards the main beam direction and hence increase its efficiency [5].
First perforated EBG structure was proposed by Eli Yablonovitch [1]. This structure was conceptualized and manufactured was in 1991 by Eli Yablonovitch at Bell Communications Research in New Jersey. y. Yablonovitch fabricated the crystal structure by mechanically drilling holes which were millimeter in radius these holes were created into a substrate of high dielectric permittivity (perforated EBG). This structure creates a 3-D band gap. Use of this structure is not practical in few communication systems because 3-D nature of band gap reject incident energy from all directions. Instead of 3-D, 2-D EBG structure is used in Microstrip Patch Antenna design so that incident energy in the bad gap can be rejected only in one plane which is identical condition for Patch Antenna. Rejection of this energy in one plane results in improvement of operational bandwidth, gain and reduction of side lobe level (SLL) .

In this paper, three different structures are presented which are Microstrip Patch Antenna (i) with

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homogeneous substrate (ii) with EBG substrate material (iii) with EBG substrate and superstrate material. Here EBG composed of cylindrical air pockets periodically arranged in square symmetry in host material. Design is simulated in CST Microwave Studio Suite.

The centre frequency of the band-gap can be roughly determined by the formula [6].

$$f = \frac{c}{\sqrt{\varepsilon_{eff}}}\frac{1}{\lambda_g} \quad (1)$$

Where
c = velocity of light in free space
ε_{eff} = effective permittivity of substrate material
$\lambda_g = 2a$ (Bragg Condition)

For a microstrip line with etched ground plane, the effective dielectric constant ε_{eff} can be estimated as that of the line with unperturbed ground plane [6]:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \cdot \frac{1}{\sqrt{1+\frac{12d}{W}}} \quad (2)$$

Where d and W are the thickness of the substrate and the width of the line, respectively.

Proceeding Section of the paper consists of designing of said structures followed by the discussion of simulated results and finally the work is concluded.

II. Design and Analysis

A. Patch Antenna on Homogenous Substrate:

Antenna proposed in this paper is particularly for WLAN application operates at a frequency of 5.8GHz. The rectangular Patch Antenna having dimensions Length (L) width (W) 11.6mm and 16mm respectively. Initially this patch is integrated with homogeneous substrate material having dimension 60mm×50mm.

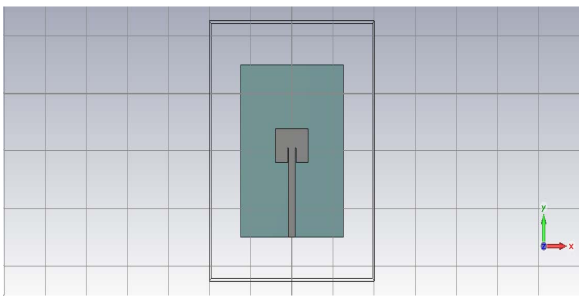

Figure 1: Geometry of Patch Antenna on Homogeneous Substrate

Since this structure is further compared with EBG Structure so simplest way to excite to the patch is with the help of Microstrip line feeding technique so the patch is excited with Microstrip line of impedance 50Ω having dimensions 31mm×3.4mm. The design discussed above is shown in the figure 1.

The basic element of EBG structure is a unit cell which is repeated periodically over substrate material with period 'a'. The schematic unit cell is shown in figure 2.

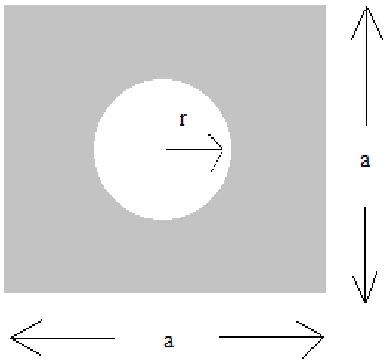

Figure 2: Schematic structure of proposed Unit Cell

B. Patch Antenna on EBG Substrate:

To design antenna on EBG substrate, very first step is to find out the band gap of the structure. Since the antenna is operated at 5.8 GHz resonating frequency so this frequency should fall in the band gap region. To design this substrate material parameters of 1D structure are chosen to be radius 'r"=4mm, periodicity factor "a"=12.6, these parameters of the 1D EBG structure is chosen in such a way that the resonating frequency falls exactly in the band gap. Parametric study has been carried out to obtain. It is worthy to mention here that r/a ratio is also important parameter in terms of finding band gap. A large value of "r/a" ratio results in wider band then a small value of "r/a" the exact BandGap. Antenna is a single port device but if requirement is to find the band gap then it is necessary to provide two port to the structure. For this purpose, *xy*- plane are assigned electric boundaries, *xz*- plane are assigned magnetic boundaries and *yz* boundaries are kept open. This perforated structure can be extended to 2-D by cascading 1-D structure in parallel. Following are the design specification for each structure proposed in this paper

Design parameters:

- Operating Frequency: 5.8GHZ
- Substrate Material: Fr4
- Dielectric Permittivity (ε_r): 4.4
- Substrate Thickness(h): 1.6mm
- No. of Unit Cell Cascaded (n): 8
- Period of unit cell(a): 12.6mm
- Radius of the Circle(r): 4mm
- Thickness of superstrate: 21.58mm (~λ/2)
- Gap between Patch and superstrate: 25.28mm

2-D EBG is designed according to the designed specification mentioned above whereas the Patch of the Antenna have the same dimensions as in the case of homogeneous substrate. Figure 3 shows the integration of Patch with EBG.

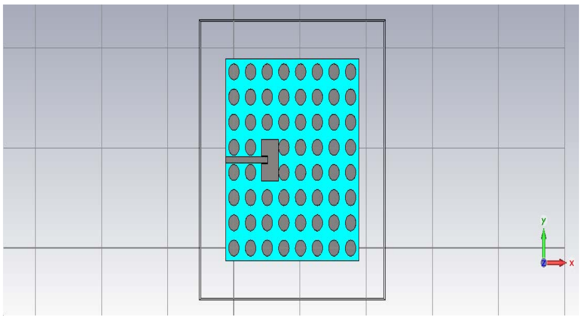

Figure 3: Structural view of Patch Antenna with EBG Substrate Material

C. Patch Antenna on EBG Substrate and Superstrate:

This section highlights the effect of EBG superstrate material on a patch antenna. The antenna structure consists of a patch, EBG substrate, EBG Superstrate and ground plane. The EBG Superstrate is suspended in air nearly at λ/2 spacing from the patch. Geometrical configurations of EBG substrate and superstrate are same except of thickness. When the EBG material is used as superstrate, it gets illuminated by the fields radiated from the patch of antenna, and almost all of the dielectric elements of the superstrate are excited so that the field distribution on its surface is quite uniform. Now this superstrate works as a aperture antenna, the size of its aperture becomes large and this result in the drastic improvement of gain of the antenna and up to some extent bandwidth is also improved. Apart from this reduction in the SLL is also observed.

theoretically maximum improvement in the performance of the antenna can be achieved when the thickness of the superstrate was chosen to be equal to the distance between the substrate and superstrate which has been taken equal to the half of operational wavelength (λ/2=25.86mm) but structure presented in this paper is optimized in term of thickness and gap between the superstrate and patch. Figure 4 shows the proposed structure.

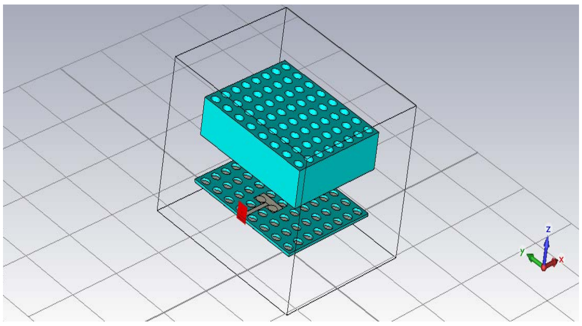

Figure 4: Structure view of Patch Antenna with EBG Substrate and EBG Superstrate

III. Result and Discussion

The S parameter of proposed structure has been obtained by simulation on CST Microwave studio. By observing the return loss, it is clear that this Antenna is resonating at 5.8GHz frequency. The impedance bandwidth for this antenna is 141MHz ranging from 5.73GHz to 5.87GHz measured at -10 dB return loss which cover WLAN standard. Figure 5 shows the simulates S-parameter for antenna. Since presence of EBG structure does not affect the resonant frequency so S-parameters obtained from rest of the 2 structures are same and are not shown.

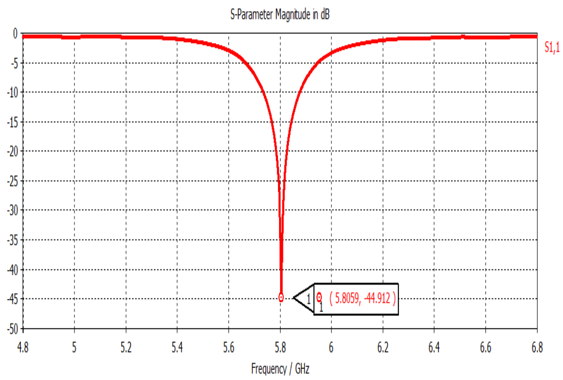

Figure 5 : Simulated S-parameter (S_{11})

The simulated radiation patterns of proposed Antenna are shown in the figure 6. It has been observed that the gain on antenna on homogeneous substrate is 6.4dB in the direction of its maximum radiation having beam width of 115.8^0 and side lobe level amplitude -10.4 dB.

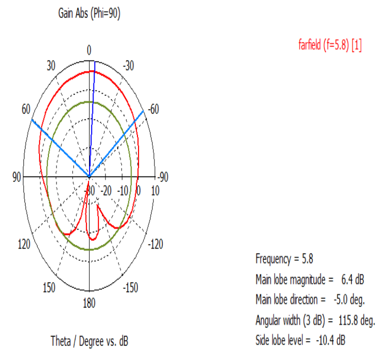

Figure 6 (a): polar plot of gain of antenna on homogeneous substrate

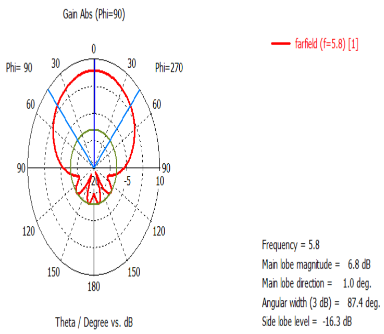

Figure 6 (a): polar plot of gain of antenna on EBG substrate Material

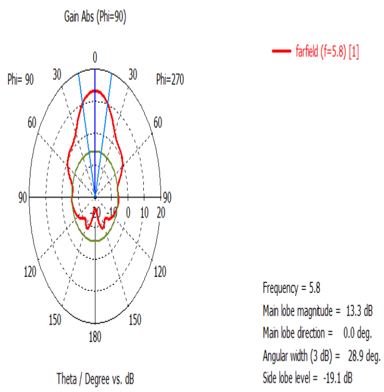

Figure 6 (a): polar plot of gain of antenna with EBG substrate and superstrate

When EBG material is used as a substrate material then gain has been improved to 6.8dB and a drastic reduction of nearly 6dB in the amplitude of side lobe level is observed. In addition to this improvement of 34MHz in the impedance bandwidth is also observed. Maximum improvement in the performance of the antenna is noticed when it is integrated with both EBG substrate as well as superstrate. A parametric study on the thickness and the gap between patch and superstrate has been done to optimize the antenna.

In first step, the gap between patch and superstrate is kept constant (25.28mm) and thickness of the superstrate is varied. In second step, the thickness of the superstrate is kept constant (21.588mm) and gap between patch and superstrate is varied. The gain of the Patch Antenna has been drastically improved from 6.8 dB to 13.3 dB. Reduction in side lobe from -16.3db to -19.1dB is also observed from the polar plot. For a frequency below 5.8 GHz, the EBG prohibits the electromagnetic waves to propagate through the EBG-superstrate and thus, the gain and directivity decreases. On the other hand, when the frequency increases well above 5.8 GHz, the propagating electromagnetic field in the superstrate has a component parallel to the upper surface and this decreases the gain and directivity. In addition to this bandwidth of antenna is now 183MHz which is improved from the previous two cases.

A. Comparison

Three patch Antenna Structures can be compared in terms of their gain, SLL and bandwidth. It has been observed from the simulated results that bandwidth for the conventional patch antenna is 141 MHz which is 2.4% of the center frequency whereas the bandwidth for the patch antenna with EBG Structure is 175MHz which is 2.9% of the center frequency, for the patch antenna with EBG Substrate and superstrate is 183MHz which is 3.2% of the center frequency. There is significant improvement in the bandwidth from 2.4% to 2.9% and then to 3.2% is noticed. Gain of the conventional patch antenna is 6.4dbi with a side lobe level (SLL) of -10.4dB at operating frequency whereas it is 6.8dB with EBG Structure and side lobe level is -16.4dbB. In case of superstrate it is 13.3 with a SLL of -19.1dB. A drastic improvement in gain and reduction in SLL is also observed. Table 1 shows the comparison of three different geometries proposed

TABLE 1 Comparison Table of Patch Antenna with and without EBG

Parameter	Patch Antenna		
	Without EBG	**With EBG Substrate**	**With EBG Substrate and Superstrate**
Bandwidth	141MHz (2.4%)	175MHz (2.9%)	183MHz (3.2%)
Gain	6.4dB	6.8dB	13.3dB
SLL	-10.4dB	-16.3dB	-19.1dB

IV. Conclusion

Comparison of Three different configurations of Microstrip Patch Antenna (on homogeneous substrate, with EBG substrate, with EBG substrate and superstrate) for a single frequency (5.8GHz) covering the band of WLAN is presented in this paper. Various parameters for comparison has been calculated with the help of CST Microwave Studio Suite. From the comparison it is concluded that performance of the Patch Antenna is improved drastically when integrated with EBG Substrate as well as with superstrate.

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