Microstrip Antennas with EBG Structures

Nikolay Stoyanov[1], Chavdar Levchev[2] and Georgi Georgiev[3]

Abstract: **Investigations of basic characteristics of the antennas with EBG structures are made. The impacts of EBG structures in patch antenna on antenna pattern and antenna gain is analyzed. The obtained results can be used in design and investigation of antennas with reduced mutual coupling between the elements and back ward radiation.**

Keywords: **Microstrip patch antenna, EBG structures, Transmition lines, Band-gap.**

I. Introduction

Electromagnetic band-gap (EBG) materials also known as photonic crystals (PCs) or photonic band-gap (PBG) materials are a novel class of artificially fabricated structures which have the ability to control and manipulate the propagation of electromagnetic (EM) waves [1].

The ability of PCs to control the propagation of light has its origin in photonic applications. The concept of photonic band structure arises in analogy to the concept of electronic band structure [2]. Just as electron waves that travel in the periodic potential of a crystal are arranged into energy bands separated by band-gaps, one expects the analogous phenomenon to occur when EM waves propagate in a medium in which the dielectric constant varies periodically in space. EBGs are the structures which show such a phenomenon, because EBGs produce forbidden frequency gaps in which propagation is prohibited.

Electromagnetic band-gap (EBG) structures exhibit unique electromagnetic properties that have led to a wide range of applications in electromagnetic devices. In this study, electromagnetic band-gap structures are utilized to enhance the bandwidth of a patch antenna built on a thin substrate and backed by a ground plane. It is well known that placing a ground plane (a perfect electric conductor) closely behind a patch antenna to make the radiation unidirectional severely limits the antenna bandwidth. The EBG surface investigated for this antenna utilizes a periodic structure of rectangular patches. The EBG surface behaves as artificial magnetic conductor in the frequency band of operation. The novel antenna configuration is investigated theoretically using a full wave method of moment solver. Parametric study to understand the effect of geometrical and substrate parameters on antenna performance is carried out. The design details along with simulation and experimental results will be presented.

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An important application of planar EBGs is to provide magnetic ground planes for electric sources [3]. It is well known that magnetic sources radiate well when they are located on electric conducting ground planes, where as electric sources will be shorted and do not radiate when they are located on electric conducting ground planes. Even when an electric source is placed slightly above conducting ground planes, the bandwidth narrows significantly. This is a disadvantage in broadband antennas and in low profile antennas backed with a ground plane.

II. Design of the Antenna and EBG Structure

A. Patch Antenna Design

The first step is the design procedure of patch antenna without EBG structures.

The geometry of the patch antenna is shown in Fig. 1.

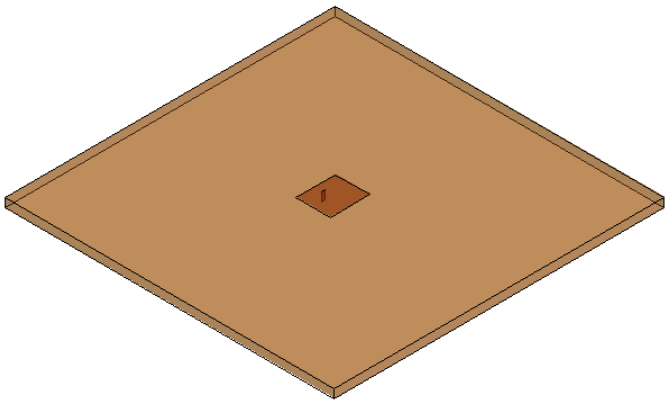


Fig. 1. Simulation model to analyze the microstrip antenna

The equations for the design procedure are given in [1] and summarized below [4]:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}, \quad (1)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)}, \quad (2)$$

$$L_{eff} = L + 2\Delta L, \quad (3)$$

where ε_{eff} denotes the relative effective dielectric constant, ε_r represents the relative dielectric constant of substrate, h stands for the height of dielectric substrate, W is the width of the patch, ΔL identifies the length increment, and L_{eff} denotes the effective length.
For efficient radiation, the width W is given by Bahl and Bhartia [5] as:

$$W = \frac{c}{2 f_0 \sqrt{\left(\frac{\varepsilon_r + 1}{2}\right)}}, \qquad (4)$$

where f_0 denotes the centre frequency.

B. EBG Substrate Design

The basic property of the prototype of periodic structures is the usage of additional equivalent resonance circuits in each element (fig. 2.). If each microstrip line is examined like an equivalent inductance and the distance between them is examined like a capacity, it is not hard to see that parallel resonance circuits are formed. On the other hand, using the upper conception, equivalent transmission line between all elements is formed (1).

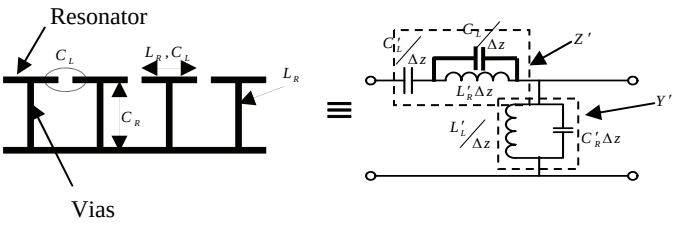


Fig. 1. Equivalent circuits of the EBG structure by using transmission line theory

The formula for the self capacitance can be presented:

$$C_1 = \frac{a\varepsilon_0(1+\varepsilon_r)}{\pi}\cosh^{-1}\left(\frac{a+g}{g}\right) \qquad (5)$$

$$L(nH) = 2.10^{-4} l\left[\ln\left(\frac{l}{W+t}\right) + 1.193 + \frac{W+t}{3l}\right]K_g \qquad (6)$$

where all dimensions are in microns and

$$K_g = 0.57 - 0.146\ln\frac{W}{h}, \qquad \frac{W}{h} > 0.05 \qquad (7)$$

The term K_g gives an estimation of the presence of a ground plane and decreases as the ground plane is brought nearer. The terms W, t, h and l are the line width, line thickness, substrate thickness and length of the section, respectively.

C. Design parameters for EBG structures

The dielectric material is selected to be FR4. The material constant is ε_r= 4.4, μ = 1, σ = 0. The center frequency for the simulations is set at f_0 = 15 GHz, which corresponds to a free space wavelength λ_0 = 20 mm. The wavelength in the waveguide is thus $\lambda g = \lambda_0/\sqrt{4.4}$ = 9.5 mm. The cell size is set at $\Delta = \lambda_0/67$ in all of the cases reported below. It is found that with this choice the resulting waveguide width $d = 0.627\lambda g$ produced desired results nearly centred about f_0. More over, this discretization value produces very accurate simulation results. This waveguide width is slightly larger than half of the center wavelength in the dielectric; hence, there should be only the fundamental symmetric mode present in the EBG structure. The metal rods are taken to be copper, which has the material properties $\varepsilon = \varepsilon_0 + i\sigma/\omega$, where σ = 5.8 × 107 *S/m*, and $\mu = \mu_0$. Thus, the loss tangent in the metal rods is $\sigma/(\omega\varepsilon_0)$ = 8.02 × 105.

III. Investigation of Mutual Coupling Suppressing of the EBG Structures

A. Experimental Model

It is well known that EBG structure use for suppressing of mutual coupling between the patches in microstrip antenna arrays. For this reason the above design EBG structures are fabricated and measured with Vector Network Analyzer. The photo of fabricated model is shown at fig. 3.

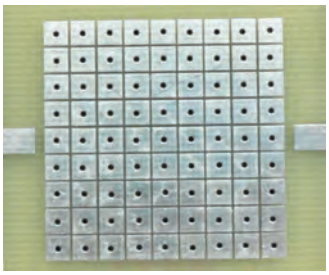
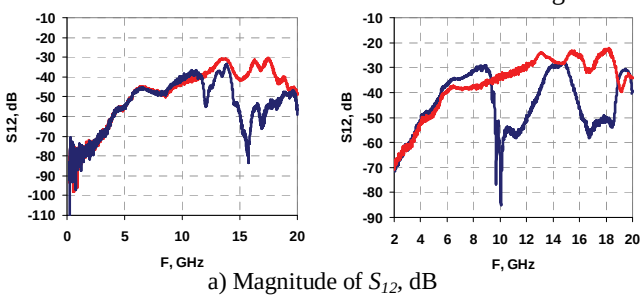


Fig.3. Experimental model for investigation of the mutual coupling between the patches in microstrip antenna array

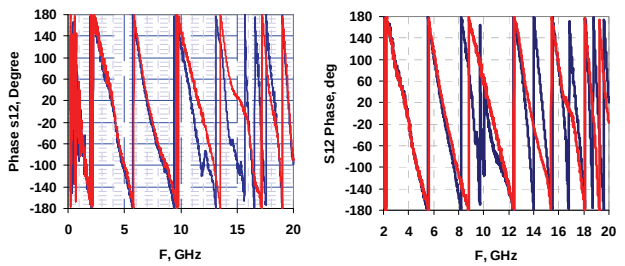
The dimensions of the microstrip elements 3 x 3 mm, the distance between them is 0,3 mm. The diameters of metalized vias are 0.8 mm. The fabricated structures are with substrate high are h=1 mm and h=1,5 mm.

B. Experimental Results

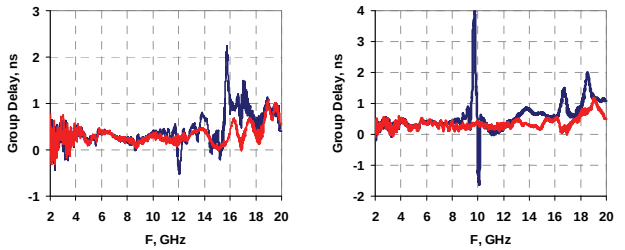
The results from the measurements are shown at fig. 4.



a) Magnitude of S_{12}, dB



b) Phase of S_{12}, degree



c) Group delay, *ns*

Fig.4. Experimental results from the fabricated EBG

The received results shows that in the thicker dielectric substrates is realized stronger suppressing of the mutual coupling between the elements in forbidden frequency band. The group delay is equivalent of the velocity at the phase variation for fixed frequency. For example in the thicker substrate (h = 1.5 mm) for 10 GHz the group delay has both values - positive and negative (left-hand materials / right hand materials boundary). For the both maximum values have high surface impedance. This characteristic of the group delay is abnormal and it could not be derived with classical electrical filters. This is that because in the EBG structures have a specific distribution of the electromagnetic field. High surface impedance can be seen in the other structure (h = 1.5 mm) above 15 GHz also.

IV. Investigation of The Microstrip Antenna with EBG Substrate

A. Microstrip Antenna with surrounded EBG structure

In this part is investigated a microstrip antenna with surrounded EBG structure (fig. 5). The basic parameters are derived from the calculations and simulations in the previous parts. The patch antenna is designed for forbidden band of the EBG structures.

The thickness of the substrate is 1 mm with a relative permittivity of 4.4. The substrate is backed by a ground plane with dimensions of 37 x 37 mm. The patch is probe-fed and has dimensions of L = 3.85 mm, W = 4.4 mm. The location of the probes is shown in Fig. 1 and Fig. The distance between the EBG surface and the patch is 3.36 mm. The voltage standing wave ratio (VSWR) of the antenna is compared with a normal patch antenna fabricated on the same substrate. Conventionality, EBG lattice is placed around the patch antenna in coplanar position to suppress the surface wave. Researches have verified that EBG structures can still exhibit band-gap feature beneath microstrip antenna [6]. The dimensions of EBG structures are the same like the measured structures in the previous parts for h=1 mm.

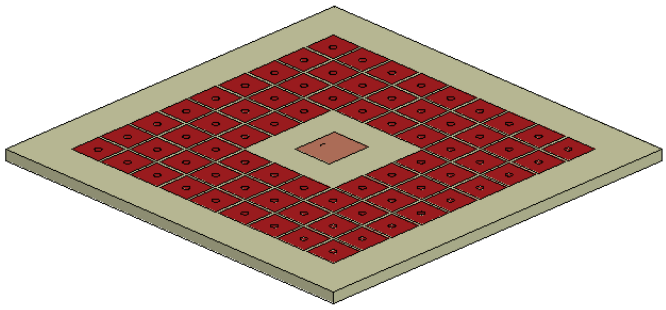
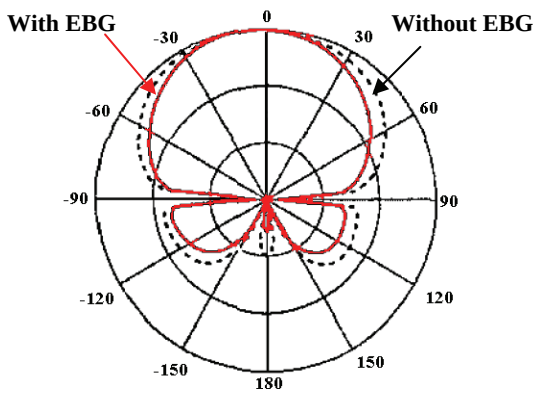


Fig.5. Simulation model to analyze the microstrip antenna with band-gap structure

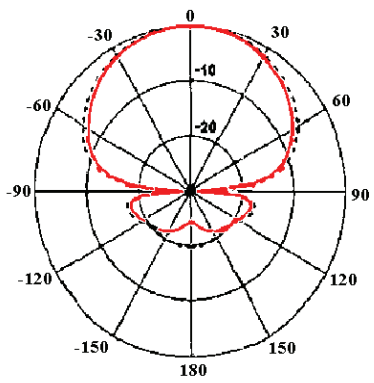
B. Radiation Pattern

The method of moment is applied to simulate the antenna properties. The EBG lattice beneath the patch caused a shift in the resonant frequency of the antenna, as shown in Fig. 6. This change in the resonant frequency can be adjusted by elevating the patch and leaving a larger gap between the antenna and the EBG surface.

Fig. 6 shows the E- and H-plane radiation patterns of the EBG patch and the reference patch without EBG (fig.1). The patterns are normalized to the maximum radiation of respective antennas. By applying the EEG structure, the gain of the patch is increased from 6.52 dB to 7.05 dB, and the radiation pattern of the E-plane is improved. In the E-plane pattern, first, side lobs is reduced by 2.16dB and the main-side lobe ratio is increased by 2.69dB. This phenomenon is not distinct in case of H-plane patterns since no surface wave is excited and propagates in that direction. Nevertheless, both Fig. 6(a) and (b) show the decrease of the back radiation due to the presence of the EBG structures. An enhancement of 4.62dB in the front-to-back ratio is observed.



a)



b)

Fig. 6. Radiation pattern of the patch antenna with and without EBG (a) E-pane (b) H-plane

V. Conclusion

The existence of the EBG structure has some effects on the input matches of the antenna, resulting in the frequency shift. Generally, the coplanar placement of EBG lattice will cause the antenna to work on a higher frequency. This phenomenon has been observed in the literature [1]-[3]. However, the measurement results depicted in Fig. 6 show a descent in the operational frequency with stacked EBG utilization. This is probably due to another effect of the EBG structure, namely parasitic loading. In the usual case of coplanar placement the band-gap feature plays a dominant role and the parasitic loading is insignificant. While inserting the EBG lattice beneath the patch, the parasitic loading becomes more distinct and lowers the operational frequency.

References

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