Bandwidth Increment of Microstrip Patch Antenna Array with Opposite Double-E EBG Structure for Different Feed Positions

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Abstract

Microstrip patch antennas have been studied extensively over the past two decades because of its low profile structure, light weight and low cost. They have many advantages over conventional antennas, which makes them suitable for a wide variety of applications. However, bandwidth has been a major drawback for this type of antennas. In this paper, Opposite Double-E Electromagnetic bandgap (EBG) structure is proposed in the design so that significant improvement in bandwidth can be obtained when compared with a prototype antenna for similar feed positions. This percentage increment in bandwidth between prototype and EBG antenna is observed to be close to 50% when the feedline of the prototype antenna is placed at an optimum distance from the lower edge of the patch. It is shown that better bandwidth increment is obtained by positioning the feedline which lies below the centre of the patch width.

I. INTRODUCTION

Microstrip patch antennas have been researched extensively over the past many years because of its low profile structure, light weight, and low cost in fabrication. They are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. These low profile antennas are also useful in aircraft, satellite and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are strict constraints. Some of the principal advantages of this type of antennas are low profile nature, conformability to planar and non planar surfaces, low fabrication costs, compatibility with MMIC designs, and mechanically robust flexibility when mounted on rigid surfaces [1].

However, a major drawback of these antennas is the narrow bandwidth. There have been various efforts from researchers toward increasing its bandwidth. A possible way to increase the bandwidth is to either increase the height of the dielectric or decrease the dielectric constant. However, the first approach would make it unsuitable for low profile structures while the latter approach will make the matching circuit to the patch difficult due to excessively wide lines. Various other techniques have been proposed to increase the bandwidth of a patch antenna [2]-[4], which will not be further detailed.

In the recent past, Electromagnetic bandgap (EBG) materials have attracted much attention among researchers in the microwave and antennas communities. While generally known as photonic bandgap (PBG) structures with origin in the area of optics [5], they are now found to have a wide variety of applications in components of the microwave and millimeter wave devices, as well as in antennas [6]. In general, EBG material is a periodic structure that forbids the propagation of all electromagnetic surface waves within a particular frequency band called the bandgap. It permits an additional control of the behavior of electromagnetic waves other than conventional guiding and/or filtering structures. EBG has the potential to provide a simple and effective solution to the problems of surface and leaky waves.

Various types of EBG structures have been studied [7]-[13]. In one of the first applications by using EBG materials to antennas, a planar antenna mounted onto an EBG substrate was considered to increase the overall radiation efficiency of the device [7]. Increasing antenna directivity was studied using an EBG structure [8]. A compact spiral EBG structure was studied for microstrip antenna arrays [9]. As the spiral EBG structure is very compact and useful in wireless communications, hence it, when used on feedline, was also studied to improve the performance of a triple band slot antenna [10].

The objective of this paper is to further develop upon the idea in [10] by using a novel EBG structure on the feedline to improve the bandwidth of the antenna and compare it with the bandwidth of the prototype antenna for same feed positions. The height of the dielectric substrate and relative permittivity are reduced and the antenna is made to resonate at a single frequency. The position of the feedline is changed to various positions and the percentage increment in bandwidth for the same position of the feedline for prototype antenna and antenna with EBG structure is obtained to be close to 50% for a 2-array rectangular patch antenna. The EBG structure used in the design is a novel EBG structure defined as Opposite Double-E structure that is more compact and easier to implement than in [10].

II. DESIGN CONSIDERATIONS

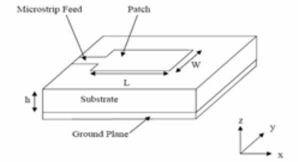


Fig. 1. Microstrip patch antenna.

A typical patch antenna is shown in Fig. 1, where $L =$ length, W = width, and h = substrate thickness. The effective dielectric constant $\varepsilon_{\mathrm{eff}}$ is slightly less than the actual dielectric constant ε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air. The equations for the design procedure are given in [1] and summarized below:

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

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

$$L_{\mathrm{eff}} = L + 2\Delta L,$$

where $\varepsilon_{\mathrm{eff}}$ 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.

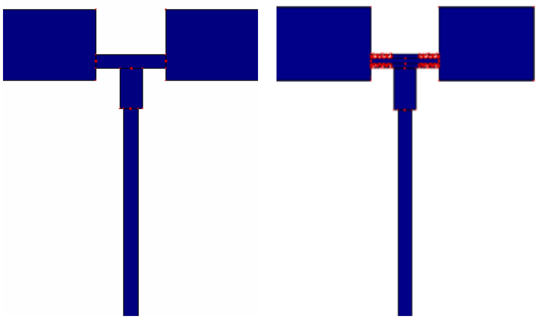
For efficient radiation, the width W is given by Bahl and Bhartia [11] as:

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

where f_0 denotes the centre frequency.

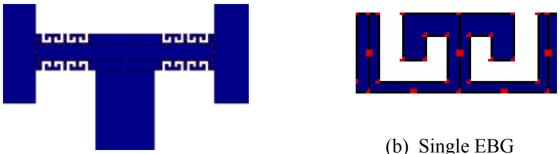
Using the above method, a 8 mm × 6.3 mm rectangular patch antenna operating at a single frequency of 14.8 GHz with a substrate thickness of 0.381 mm and $\varepsilon_r = 2.33$ is designed. An array of 8 EBG structure is also designed on the feedline, 4 on each extreme of the feedline. The etched distance of the EBG is 0.1 mm on the dielectric substrate.

The structure of the rectangular patch antenna array is shown in Fig. 2, where Fig. 2(a) shows the antenna array without EBG structure while Fig. 2(b) shows the antenna array with EBG structure. Fig. 3 depicts the magnified view of the feedline, where Fig. 3(a) illustrates the feedline with EBG structure, while Fig 3(b) shows a single element of the EBG structure used in the design and simulation.



(a) Without EBG structure (b) With EBG structure

Fig. 2. Rectangular patch antenna array structure.



(a) Feedline with EBG

(b) Single EBG element

Fig. 3. Magnified view of the feedline and a single EBG structure element.

The software used is Zeland's IE3D. The highest operating frequency used is 16 GHz with cells/wavelength ration as 20 for better and higher accuracy. The edge cell width to wavelength is put to be 0.1, in accordance with the design experiences.

III. SIMULATION RESULTS

A. S_{11} parameter for antenna without EBG for different positions of feedline

To gain insight into the effects of the physical parameters on the antenna performance, we considered two cases as shown in Figs. 2(a) and 2(b), respectively. We will also be making comparison of the S-parameter results between the two cases.

The position of the feedline is changed with respect to the lower edge of the patch on the 2-patch antenna array. The S_{11} parameter values versus frequency (in GHz) are obtained for feed positions at distances of 1.0 mm, 1.05 mm, and 1.1 mm measured from the bottom of the patch which lie at a distance less than half of the patch width are shown in Fig. 4. Similarly, S_{11} parameter values for feedline that lies above the centre of patch width at distances of 4.0 mm, 4.05 mm, and 4.1 mm are shown in Fig. 5.

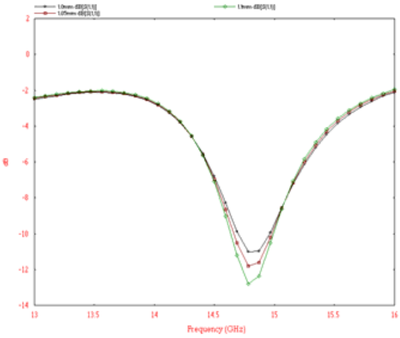


Fig. 4. The S_{11}-parameter versus frequency in GHz for different feedline positions (without EBG structure) which lie below the half width of the patch (1.0 mm, 1.05 mm and 1.1 mm from bottom of the twin patches).

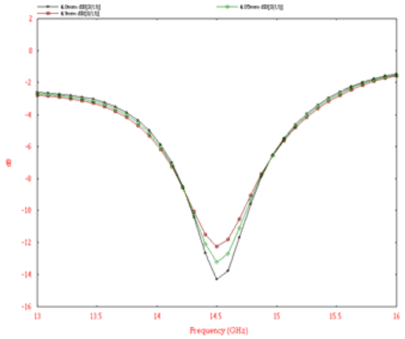


Fig. 5. S_{11}-parameter versus frequency in GHz for different feedline positions (without EBG structure) which lie above the half width of the patch (4.0 mm, 4.05 mm, and 4.1 mm from bottom; or equivalently 1.1 mm, 1.05 mm, and 1.0 mm from top; respectively).

It is interesting to see that when the feedline is close to the top edge of the twin-patch array, the bandwidth is, in the absence of EBG structure, wider. Later on, we will find that this conclusion is reversed when an EBG structure is implemented. For comparison purpose, Table I shows quantitatively S_{11} parameter values for different positions of the feedline without EBG structure as measured from the bottom of the patch.

TABLE I
S_{11} PARAMETER VALUES AT CENTRAL FREQUENCY FOR DIFFERENT POSITIONS OF FEEDLINE WITHOUT EBG STRUCTURE

Feedline distance (from the bottom of the patch)	S_{11} Parameter
1.0 mm	-11.01 dB
1.05 mm	-11.83 dB
1.1 mm	-12.83 dB
1.4 mm	-30.53 dB
4.0 mm	-14.29 dB
4.05 mm	-13.21 dB
4.1 mm	-12.28 dB

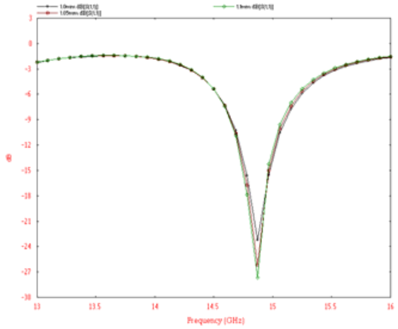


Fig. 6. S_{11}-parameter versus frequency in GHz for different feedline positions (with EBG structure) which lie below the half width of the patch (1.0 mm, 1.05 mm, 1.1 mm from bottom).

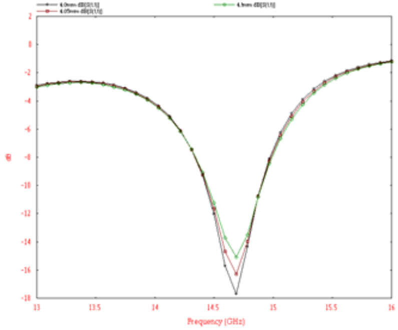


Fig. 7. S_{11}-parameter versus frequency in GHz for different feedline positions (with EBG structure) which lie above the half width of the patch (4.0 mm, 4.05 mm, and 4.1 mm from bottom; or equivalently 1.1 mm, 1.05 mm, and 1.0 mm from top; respectively).

B. S_{11} parameter for antenna with EBG for different positions of feedline

Similar to the discussions in the previous subsection, effects of positions of feedline with EBG are also looked into in this subsection. The S_{11} parameter values obtained for feed various positions which lie below the half width of the patch are shown in Fig. 6 while that which lie above it is shown in Fig. 7. Now, this time, we find that when the feedline is implemented toward the bottom edge, the bandwidth is much wider. This observation in the presence of EBG structure is just opposite to the previous case in the absence of EBG structure.

Table II shows quantitatively S_{11} parameter values again for different positions of the feedline but with EBG structure as measured from the bottom of the patch.

TABLE II
S_{11} PARAMETER VALUES AT CENTRAL FREQUENCY FOR DIFFERENT POSITIONS OF FEEDLINE WITH EBG STRUCTURE

Feedline distance (from the bottom of the patch)	S_{11} Parameter
1.0 mm	-23.27 dB
1.05 mm	-26.19 dB
1.1 mm	-27.68 dB
1.4 mm	-14.82 dB
4.0 mm	-17.71 dB
4.05 mm	-16.31 dB
4.1 mm	-15.13 dB

C. Comparison of bandwidth of the two types of structures and radiation pattern

The major drawback of a microstrip patch antenna as discussed earlier is the narrow bandwidth. Bandwidths of the antennas with EBG structure and without EBG structure are obtained and compared for various positions of the feedline. We find that a significant improvement in bandwidth can be achieved by using EBG structures on the feedline.

To gain a quantitative description of variation of the bandwidth versus the feedline positions, Table III shows the comparison of the bandwidth of the two structures.

TABLE III
BANDWIDTH (BW) COMPARISON

Feedline distance (from the bottom of the patch)	Antenna without EBG (Prototype Antenna) (BW in GHz)	Antenna with EBG (BW in GHz)	Percentage change in BW referenced to Antenna without EBG
1.0 mm	0.2685	0.4021	49.7%
1.05 mm	0.3217	0.3951	22.8%
1.1 mm	0.3608	0.3901	8.1%
4.05 mm	0.4536	0.4714	3.9%
4.1 mm	0.4199	0.4639	10.5%

Although, the bandwidth of prototype antenna when the feedline is near the top edge of the patch is larger than when it is near the bottom edge of the patch and hence placing the feedline closer to the top edge should be the preferred location, there are certain conditions and situations that arise in a given complicated circuitry which forces the feedline to be placed near the lower edge of the patch because of circuit constraints. However, we still require a wide bandwidth.

For such cases when the feedline has to be positioned near the bottom edge of the patch, we can improve the bandwidth by positioning feedline at a distance of about 1.0 mm from the bottom of the edge and by implementing EBG structures on it. This way, we can improve its bandwidth by upto 50% as shown in Table III. Besides, if there is no constraint on the positioning of the feedline, we observe that by implementing the EBG structure, the bandwidth is improved significantly from 3% to 22% for a given feed position.

Also, we observe that the sensitivity of the bandwidth to the position of the feedline is improved when the EBG structure is implemented. Thus, the bandwidth of the antenna with the EBG structure is not highly dependant on the placement of the feedline and we can have a significant improvement in bandwidth for any given feed positions.

Considering that we have to place the feedline at a distance of 1.0 mm from the bottom of the patch, radiation patterns are obtained for the feedlines without EBG and with EBG, respectively. The patterns in the planes of $\phi = 0$ and $\phi = 90$ degrees are shown in Fig. 8 and Fig. 9, respectively.

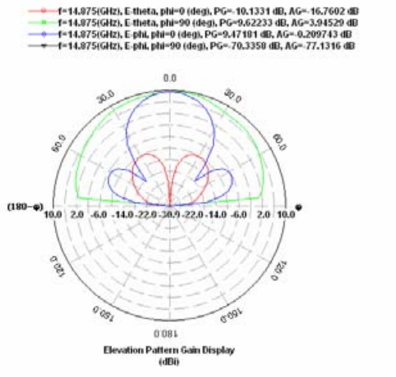


Fig. 8. Radiation pattern of E_θ and E_ϕ-components in the planes of $\phi = 0$ and $\phi = 90$ degrees for feedline without EBG structure.

From the comparison, it is found that the radiation patterns are same for the two types of feedline structures at a distance of 1.0 mm from the bottom of the patch. Physically, this is understood because the radiation is due to the twin patches which do not change for the feedline. However, there is a vast improvement in the bandwidth property of the antenna.

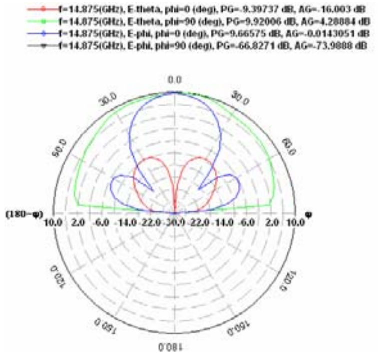


Fig. 9. Radiation pattern of E_θ and E_ϕ-components in the planes of $\phi = 0$ and $\phi = 90$ degrees for feedline with EBG structure.

IV. CONCLUSION

It has been shown that the sensitivity of the bandwidth to the position of the feedline is improved by using EBG structures on the feedline. The bandwidth is improved for the antenna with EBG structure when compared to the prototype antenna for the same feed position. Under certain circuit constraints, when the circuitry demands the feedline to be positioned near the lower edge of the patch, we can have a bandwidth improvement by upto 50% by placing the feedline at an optimum distance of about 1.0 mm and then by implementing the EBG structure on the feedline. However, the design can be easily extended for the frequency normalized structures and the patch antenna of required specifications can be then designed systematically and the present work does not present a single design, instead a class of optimum designs using the EBG structures.

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