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BANDWIDTH IMPROVEMENT OF MICROSTRIP ANTENNA ARRAY USING DUMMY EBG PATTERN ON FEEDLINE

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Abstract—Microstrip patch antennas have several advantages over conventional antennas including their low profile structure, light weight and low cost. As such, they have been widely used in a variety of applications. However, one of the major drawbacks of this antenna is the low bandwidth. In this paper, bandwidth of a dual patch antenna is improved by etching dummy EBG pattern on the feedline. Effects of different positions of the feedline on the bandwidth are also studied. A good improvement in bandwidth for the antenna with the dummy EBG pattern when compared to the reference antenna is obtained for all the feedline positions.

1. INTRODUCTION

Microstrip patch antennas have been designed and characterized extensively over the past many years because of their low profile structures, light weights, and low costs in fabrication [1–9] where various design techniques and fast solvers have been developed to enhance radiation performance (such as the bandwidth and gain). 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,

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conformability to planar and non planar surfaces, low fabrication costs, compatibility with MMIC designs, and mechanically robust flexibility when mounted on rigid surfaces [10].

In spite of many advantages, these antennas suffer from some disadvantages which include their low efficiency, low power, high Q, poor polarization purity, spurious feed radiation and very narrow bandwidth [11–17]. There have been some efforts spent using various techniques to improve the performance of such antennas for their widespread applications. As such, there has been considerable efforts spent by researchers from all over the world towards increasing its bandwidth. A possible way for increasing 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 feeding lines.

Various other techniques have been proposed to increase the bandwidth of a patch antenna [18–22]. Bandwidth of small size microstrip antennas has been improved by the use of U slot and L probe [18]. By using compound techniques [19], a new type of stacked microstrip patch antenna that increases the frequency bandwidth has also been studied. In [20], the bandwidth of an aperture coupled microstrip patch antenna has been improved by using an appropriate impedance-matching network using filter design techniques. The use of two triangular structures for microstrip patch antennas to improve the bandwidth has been studied [21]. Unbalanced structures have also been used to design patch antennas to improve bandwidth [22].

In the past, electromagnetic bandgap (EBG) materials attracted much attention among researchers in the microwave and antennas communities [23, 24]. Various EBG structures have been proposed and they have found many applications in the microwave region [25–30] which will not be further detailed. Recently, EBG structure on the feedline has also been studied to improve the performance of a triple band slot antenna [31].

The objective of this paper is to study the dual array patch antenna examined in [22] and improve its bandwidth by etching patterns that are similar in nature on the feedline. This pattern will be referred to as dummy EBG pattern because of its resemblance in certain properties and behavior to a conventional EBG structure. A good improvement in bandwidth (48.8% increase with a bandwidth of 0.381 GHz versus the reference bandwidth of 0.256 GHz) is obtained for the antenna having dummy EBG pattern on the feedline when compared to the reference antenna for all the feedline positions. The results was briefly and partially reported in a short conference paper

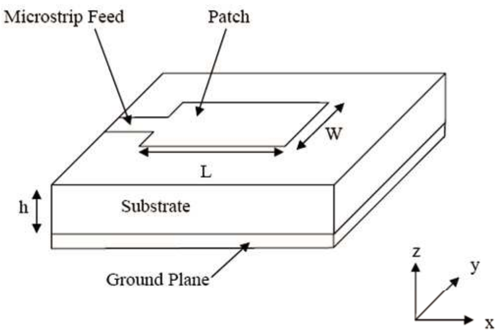


Figure 1. Microstrip patch antenna.

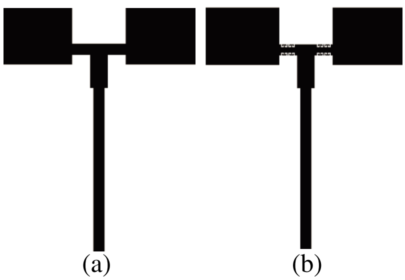


Figure 2. Rectangular patch antenna array structure. (a) Reference antenna without EBG pattern, and (b) dummy EBG pattern antenna.

presented early [32], and this present paper provides a more complete version and more comprehensive results for archival literature.

2. DESIGN CONSIDERATIONS

A typical patch antenna is shown in Fig. 1, where L denotes length, W stands for width, and h represents substrate thickness. Using the design equations given in [10] and [33], a 8 mm $\times$ 6.3 mm dual patch antenna operating at a single frequency of about 14.8 GHz with a substrate thickness of 0.381 mm and $\epsilon_r = 2.33$ is designed. This antenna will be used as a reference for comparison of various results.

The structure of the rectangular patch antenna array is shown in Fig. 2, where Fig. 2(a) shows one of the many designed antenna array without dummy EBG pattern while Fig. 2(b) shows the antenna array with the dummy EBG pattern. In the rest of paper Figs. 2(a) and 2(b) will be referred to as the reference antenna and dummy EBG pattern antenna respectively and these terms will be used interchangeably.

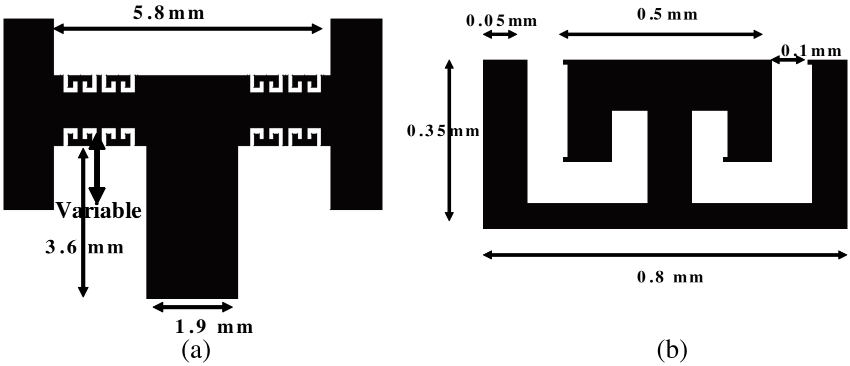


Figure 3. Magnified view of the feedline for dummy EBG pattern antenna. (a) Magnified view of feedline, and (b) magnified view of EBG pattern.

Figure 3 depicts the magnified view of the feedline for the dummy EBG pattern antenna, where Fig. 3(a) shows the magnified view of the feedline with 8 dummy EBG pattern and Fig. 3(b) shows the single element of the EBG pattern used for design, simulation and measurement. Physically, the implementation of EBG structures will suppress the local surface waves (or currents) to focus the current distribution and to better-match the impedance (because of the smaller patterned resonant elements and their different combinations). Therefore, the sizes at resonances will have to change according to the corresponding operating wavelength. The etched patterns of the feeding lines will also affect the performance. In this paper, we will not discuss on the patterns of the EBG structures due to the limited length.

Similarly, dummy EBG pattern antenna is also designed by etching a 2-by-4 array of similar patterns on the feedline connecting the two patches of the dual patch antenna. The EBG-array pattern is built on a 0.381 mm thick substrate with the relative permittivity of 2.33. The period of the proposed pattern is 0.8 mm, which is operating at a frequency of about 14.8 GHz. As such, the period of this pattern is about 4% of wavelength at the stopband frequency, which satisfies the conventional definition for an EBG structure [25, 26]. The dimensions of the dummy EBG pattern have been shown in Fig. 3(a). Variations of the reference antenna and the dummy EBG pattern antenna are then designed by changing the feedline positions connecting the twin patches of the antenna. The variable distances of the feedline are highlighted in Fig. 3(a).

The software used for the simulation is the Zeland's IE3D. The highest operating frequency used is 18 GHz with cells/wavelength ratio as 20 for a better and higher accuracy. The edge cell width to wavelength is chosen to be 0.1, in accordance with the design experiences.

3. *S*-PARAMETERS AND BANDWIDTHS

To gain an insight into the effects of feedline position and the EBG pattern used on the antenna performance, we compared antenna performance of reference antenna and dummy EBG pattern antenna as shown in Figs. 2(a) and 2(b), respectively. The S_{11}-parameter and bandwidth values (with respect to -10 dB line) are obtained and compared for many different feed positions of the feedline connecting the twin patches. For illustration purpose, 4 best cases have been shown in this paper. Measurement results are then obtained for the case where we obtain a maximum percentage improvement in bandwidth when the bandwidth of the EBG pattern antenna is compared with that of the reference antenna for the same feedline distance. Also, the current distribution, radiation pattern and other antenna parameters are found. These will be shown in subsequent sections.

The S_{11}-parameters versus frequency (in GHz) are obtained for the reference antenna and the dummy EBG pattern antenna for different feed positions, as shown in Fig. 4. Different feed position distances are considered; and for the illustration purpose in this paper only 4 best cases have been shown Fig. 4 subsequently.

S_{11}-parameters for the reference antenna and the dummy EBG pattern antenna when feedline is positioned at a distance of (a) 1.0 mm, (b) 1.1 mm, (c) 4.05 mm, and (d) 4.1 mm measured from the bottom of the patch is obtained in Fig. 4. For these four cases, the bandwidths of the reference antenna and dummy EBG pattern antenna are found to be (a) 0.2682 GHz and 0.3987 GHz, (b) 0.3551 GHz and 0.3849 GHz, (c) 0.4399 GHz and 0.4643 GHz, and (d) 0.4289 GHz and 0.4575 GHz, respectively. In addition, we have obtained the results of the S_{11}-parameter and bandwidths for another case, where the feedline is shifted to a distance of 1.05 mm measured from the bottom of the twin patch. It is found that the bandwidths of the reference and dummy EBG pattern antenna are 0.3199 GHz and 0.3932 GHz, respectively. During this procedure, we have to tune a matching circuit to obtain consistent resonant frequency for each case so that the comparison is fair and reasonable.

The S_{11}-parameters for the reference antenna and the four dummy EBG pattern antennas obtained from Figs. 4(a) to 4(d) and another case are tabulated in Table 1. According to the antenna design theory,

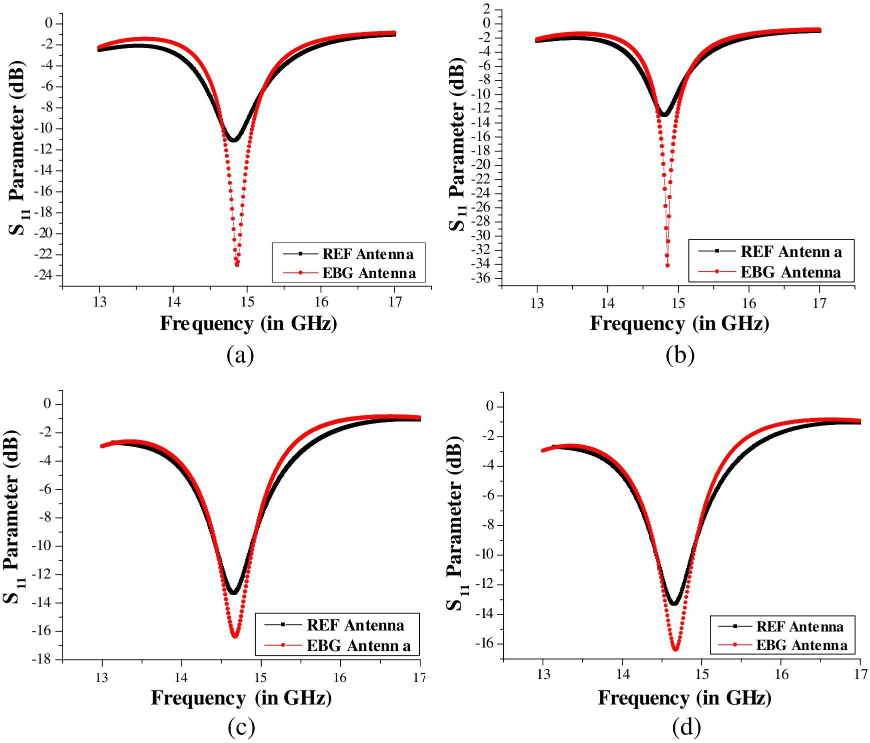


Figure 4. S_{11}-parameter comparison of reference antenna with dummy EBG pattern antennas for 4 different cases (4 feed positions) versus frequency (in GHz). Feedline positions of (a) 1.0 mm, (b) 1.1 mm, (c) 4.05 mm, and (d) 4.1 mm all measured, respectively, from bottom of patch are considered.

it is not good to locate the feedline in the centre position, so we will not discuss on it. It is apparent that the peak valley of the S_{11}-parameter can be further dropped to -23 dB and even further to -34 dB.

Table 2 tabulates the comparison of bandwidths between reference antenna and dummy EBG pattern antenna for the five mentioned cases. From Table 2, we observe that as we change the position of the feedline and the corresponding matching circuit from the lower edge towards the upper edge of the twin patch, the bandwidth of the reference antenna is improved without the use of the dummy EBG pattern. On the other hand, for the antenna with the dummy EBG pattern, there is not much variation in the bandwidth. The sensitivity of bandwidth to the change of feedline position is reduced by using the dummy EBG pattern. However, our main concern is to compare the

Table 1. S_{11} parameters measured at the central frequency.

Feedline Distance (Measured From Bottom of twin Patch)	Reference Antenna	Dummy EBG Pattern Antenna
1.0 mm	−11.15 dB	−23.03 dB
1.05 mm	−11.94 dB	−26.76 dB
1.1 mm	−12.92 dB	−34.17 dB
4.05 mm	−13.42 dB	−15.18 dB
4.1 mm	−12.44 dB	−16.39 dB

Table 2. Bandwidth (BW) comparison for reference and dummy EBG pattern antenna for 5 different cases (different feedline positions).

Case No.	Feedline distance from the bottom of the patch	Reference (BW)	Dummy EBG pattern antenna (BW)	BW % change referenced to antenna without EBG pattern
1	1.00 mm	0.2682	0.3987	48.7%
2	1.05 mm	0.3199	0.3932	22.9%
3	1.10 mm	0.3551	0.3849	8.4%
4	4.05 mm	0.4399	0.4643	5.5%
5	4.10 mm	0.4289	0.4575	6.7%

reference antenna and the dummy EBG pattern antenna for the same feedline position. From Table 2, we see that for all the different cases where an additional case is considered, the bandwidth is improved very much from 5.5%, through 22.9%, to 48.7%.

Patch antennas are usually a part of a complicated circuitry and circuit constraints can force the feedline to be placed near the lower edge of the patch. In such a case, placing feedline closer to the lower edge of the patch yields a lower bandwidth. However, by etching patterns that behave like EBG structures onto the feedline, a good improvement in bandwidth can be obtained. This provides more diversity to the structure and circuit. From Table 2, we observe that when the feedline is placed closer to the lower edge of the patch, the percentage improvement is much greater in comparison when the feedline is placed closer to the upper edge of the patch. This shows that feedline plays an important role in the percentage improvement in bandwidth when the bandwidth of the dummy EBG pattern antenna is compared to the reference antenna for the same feedline position.

3.1. Fabrications and Measurements

The best increment in bandwidth is obtained when feedline is at a distance of 1.0 mm measured from the bottom of the twin patch. The reference antenna and the dummy EBG pattern antenna are then fabricated for this feedline position and measurement results are obtained. The fabricated antenna is shown in Fig. 5, where Figs. 5(a) and 5(b) depict the reference antenna and the dummy EBG pattern antenna, respectively. The S_{11}-parameter versus frequency (in GHz) was obtained by measurement is shown in Fig. 6 and Table 3 tabulates the S_{11}-parameters and bandwidth values for the two antennas.

From Table 3, we find that the percentage increment in bandwidth for the dummy EBG pattern antenna when compared to the reference antenna when the feedline is positioned at a distance of 1.0 mm from the bottom of the patch is approximately 48.8%. The measurement and simulation results are found to be in good agreement.

In addition to the above parameters measured, we also

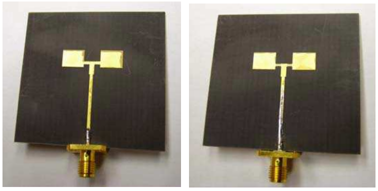


Figure 5. Fabricated antenna structures. (a) Reference antenna, and (b) EBG patterned antenna.

Table 3. Measurement results for antenna structures when feedline is at a distance of 1.0 mm measured from the bottom of the twin patch.

Antenna performance	Reference antenna	Dummy EBG pattern antenna
S_{11} Parameter	-16.5 dB	-20.8 dB
Bandwidth	0.256 GHz	0.381 GHz

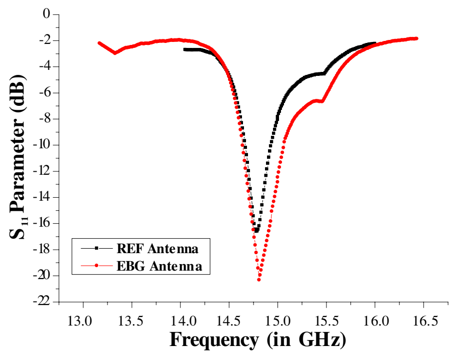


Figure 6. S11-parameter versus frequency (in GHz) obtained by measurement for reference antenna and dummy EBG pattern antenna for feedline position 1.0 mm measured from the bottom of the twin patch.

Table 4. Other important antenna parameters.

Antenna performance	Reference antenna	Dummy EBG pattern antenna
Radiation efficiency	88.58%	88.95%
Antenna efficiency	81.71%	87.11%
Linear gain	9.71 dBi	9.94 dBi

measured (or indirectly calculated) the other important antenna parameters [10, 33], namely, radiation efficiency, antenna efficiency, and linear gain; and they have been tabulated in Table 4 respectively for the reference and the dummy EBG pattern antennas. From Table 4, we see that the dummy EBG pattern antenna maintains the same radiation efficiency as the reference antenna, but have better antenna efficiency and linear gain.

4. RADIATION EFFECTS

4.1. Current Distributions

Current distributions are obtained for the reference antenna and the dummy EBG pattern antenna for the feedline position that gives the best increment in bandwidth, i.e., feedline at a distance of 1.0 mm measured from the bottom of the patch. The currents are shown in Figs. 7(a) and 7(b), respectively.

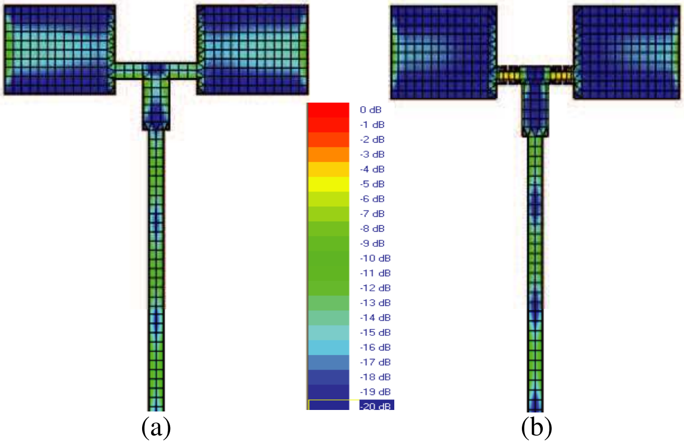


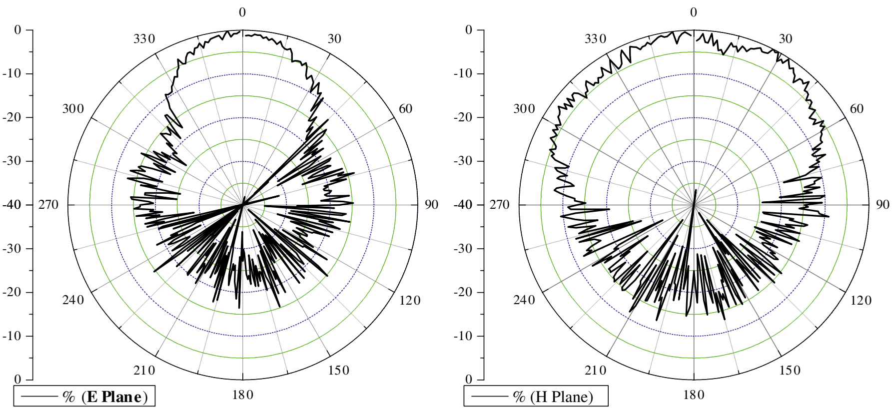
Figure 7. Current distribution for reference antenna and dummy EBG pattern antenna when feedline is at a distance of 1.0 mm measured from bottom of twin patch. (a) Current distribution for reference antenna and (b) current distribution for dummy EBG pattern antenna.

By comparison of Fig. 7(b) with Fig. 7(a), we observe that with the dummy EBG designed, the feedline current does not spread out, instead the current in the feedline is focused to supply the energy to the two radiating patches as expected; the magnitude of current distribution decreases significantly at and near the dummy EBG pattern; and to keep the radiation efficiency, the dummy EBG structure itself stores strong energy to supply to the radiators.

4.2. Radiation Patterns

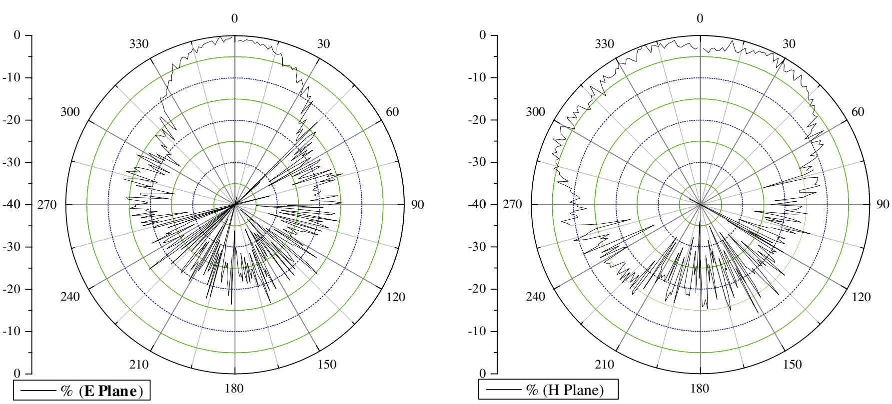
Radiation patterns by measurement are obtained for reference antenna and dummy EBG pattern antenna for the feedline position 1.0 mm. Fig. 8 shows the radiation pattern for reference antenna when feedline is at distance of 1.0 mm, where Fig. 8(a) shows the E-plane pattern and Fig. 8(b) shows the H-plane pattern. Similarly, Fig. 9 shows the radiation pattern for the dummy EBG pattern antenna, where Fig. 9(a) illustrates the E-plane pattern and Fig. 9(b) depicts the H-plane pattern. The spikes in the pattern are because of the induced noise.

From Figs. 8 and 9, we observe that the corresponding E-plane and H-plane radiation patterns of reference antenna and EBG pattern antenna respectively do not significantly change much. This is expected as the dummy EBG pattern is etched on the feedline and



(a) (b)

Figure 8. Radiation pattern for reference antenna from measurement. (a) E-plane pattern, and (b) H-plane pattern.



(a) (b)

Figure 9. Radiation pattern for dummy EBG pattern antenna from measurement. (a) E-plane pattern, and (b) H-plane pattern.

radiation is due to the twin patches which do not change for the two antennas.

5. CONCLUDING REMARKS

In this paper, the bandwidth of a dual patch microstrip antenna has been improved by using dummy EBG pattern on the feedline. Effects of changing position of the feedline connecting the two patches are also studied. It has been shown that the best increment in bandwidth can be obtained when feedline is closer to the lower edge of the patch. For our designed antenna, this distance is 1.0 mm, which gives a bandwidth increment of up to 48%. The overall gain and antenna efficiency are improved by using the EBG pattern on the feedline. Current distribution and radiation patterns are also obtained. This design can be easily extended for the frequency normalized structures and the patch antenna of required specifications can be then designed systematically.

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