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Using EBG to Enhance Directivity, Efficiency, and Back Lobe Reduction of a Microstrip Patch Antenna

***Abstract**. In this work, a compact rectangular patch antenna and 2×2 microstrip antenna array with EBG structures have been integrated. Two types of EBGs were utalized, such as a mushroom-like EBG and a new designe of Triple Side Slotted of EBG (TSSEBG). These suggested EBGs have been located on the top antenna surface for eliminating unwanted surface waves. The mitigation in vias number is effective method for decreasing the fabrication process complexity, where it decreased from 164 to 46 and from 392 to 92 in case of used TSSBG instead of EBG in the rectangular antenna and array antenna respectively. The single antenna withTSSEBG demonstrate 10.5 dBi directivity, 93% efficiency, and −21 dB side lobe. At 6 GHz, the TSSEBG antenna array has a good improvement in directivity (15.5 dBi), side lobe (−28.5 dB), and efficiency (88%).*

***Streszczenie.** W tej pracy zintegrowano kompaktową prostokątną antenę płatkową i układ anten mikropaskowych 2 × 2 ze strukturami EBG. Wykorzystano dwa typy EBG, takie jak grzybopodobny EBG i nowy projekt Triple Side Slotted of EBG (TSSEBG). Te sugerowane EBG zostały umieszczone na górnej powierzchni anteny w celu wyeliminowania niepożądanych fal powierzchniowych. Zmniejszenie liczby przelotek jest skuteczną metodą na zmniejszenie złożoności procesu produkcyjnego, gdzie zmniejszyła się z 164 do 46 iz 392 do 92 w przypadku zastosowanego TSSBG zamiast EBG odpowiednio w antenie prostokątnej i antenie matrycowej. Pojedyncza antena z TSSEBG wykazuje kierunkowość 10,5 dBi, wydajność 93% i listwę boczną −21 dB. Przy 6 GHz, zestaw anten TSSEBG ma dobrą poprawę kierunkowości (15,5 dBi), listka bocznego (-28,5 dB) i wydajności (88%). (**Wykorzystanie EBG do zwiększenia kierunkowości, wydajności i redukcji tylnego płata anteny z mikropaskami**)*

Keywords: Mushroom-like EBG, Rectangular and array antenna, connecting pin vias, Enhanced a microstrip antenna, EBG
Słowa kluczowe: Grzybopodobny EBG, Prostokątna i matrycowa antena, łączące przelotki pinowe, Wzmocniona antena mikropaskowa,

Introduction

The type of microstrip patch antenna show several features, for instance the low cost, easy to fabricate and suitable to integrate with RF devices [1]. To increas the gain and directivity of single microstrip patch, antenna arrays can be used and provide diversity reception [2]. The phenomenon of the surface waves excitation is considered undesired, where the current is lost in the substrate. Therefore, antenna efficiency, gain, and directivity will be decreased. Many techniques were used to avoide the surface waves effects. Such as, adding dielectric layers over the radiating elements [3] or optimizing the shape of radiating elements [4]. A low effective dielectric constant has been achieved by drilling an air gap under the radiating elements [5]. A compact design is obtained on high dielectric constant [6]. Consequently, by increasing the substrate thickness, the reduction problem in the band width can be solved [7]. The mushroom-like EBG is one of the most important technologies of electromagnetic band-gap (EBG) [8], has been applied to avoid the bad impacts of surface waves. However, The stopband characteristics of such structure is used to improve the performance of antenna by suppressing the surface wave, and design the low profile antenna by the property of in-phase reflection[9-13].

The EBG structures have been used to enhance the radiation pattern of antenna [14-17]. The mutual coupling and side lobe levels were diminished [18,19]. The author in [19] used uniplanar EBG structure to implement a 2×2 antenna array to reduce the mutual coupling, thereby lowering the side lobe. In [20] three various 2D-EBG shapes have been designed, in the whole antenna ground plane for decreasing the back lobe and increasing the gain. Moreover, the mushroom-like EBG was appiled in antenna array to enhance the side lobe and gain [21]. Most of literatures that were done by applying the EBGs as superstrate over the antenna, which resulted in bulky antenna size. Another works also achieved to reduce the mutual coupling in MIMO antenna, or placing the EBG in the antenna ground plane by using multi layers. However, the facilities of EBG in the same substrate to enhance antenna array not much found. The EBG structure operation mechanism can be explain by the LC filter model. The electromagnetic waves are TE and TM modes, on the surface of dielectric substrate the TE mode is happened in case of the surface impedance is capacitive. While TM mode is achieved when the impedance is inductive. The uniplanar EBG (without pin vias) can extinguish the surface waves in TE modes. Meanwhile, the mushroom like EBGs have the ablity for suppressing surface waves in both modes (TE and TM)[17]. Thus, the mushroom like EBG is applied in this work

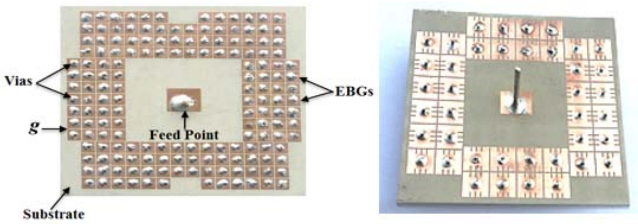
. In this work, mushroom like EBG has been used for lowering the back radiation of rectangular antenna and four elements of antenna array, using just one probe feed. Then, by swapping the mushroom like EBG by another new design of EBG which called (TSSEBG). A compact antennas (single and array) on high dielectric constant with a miniature size, simple desig, and good performance have been accomplished. At the end, the numbers of pin vias have been decreased from 164 to 46 and from 392 to 92 for the rectangular and array antennas respectively, with good efficiency, high directivity, and low side lobe level.

Enhanced the Performance of Antenna Using EBG

Mushroom like EBG structures are periodically loded in two dimensions to reduce the surface waves. This structure contains four elements named as, a ground plane, metallic patche, dielectric substrate, and connecting vias. By connecting vias, we can get the band stop advantage, at the resonant frequency of antenna. In this case the impedance is very high-rise, which leads to suppress surface waves [22]. Using the transmission line methode to calculate the mushroom-like EBG dimensions [23]. Triple Side Slot of EBG (TSSEBG) has been designed from the first propose of mushroom like EBG. Each four elements of mushroom-like EBG are replaced by one element of TSSEBG, more details in [24-30].

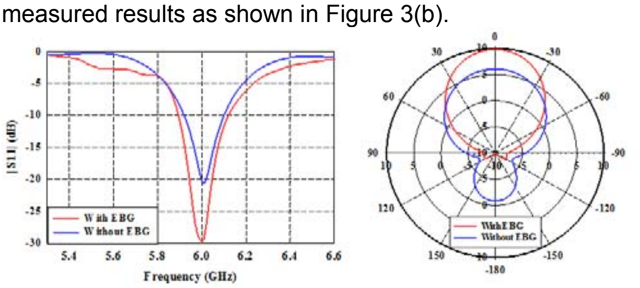
The rectangular antenna with a probe feed was bounded by the mushroom like EBG structure. The sizes of the rectangular antenna is 6.4 mm × 7.5 mm. Rogers substrate (RT/Duroid 6010) hickness is 2.74 mm, with a dielectric constant (10.2) as shown in Figure 1(a). Then, same of the rectangular antenna was surrounded by TSSEBG to minimize the difficulity in the design. The width of the TSSEBG is 5 mm; via radius is 1 mm, and the 0.3

mm is the TSSEBG gap. Rogers substrate with the same details has been used as exposed in Figure 1(b), where the sums of pin vias were reduced from (164) to (40).

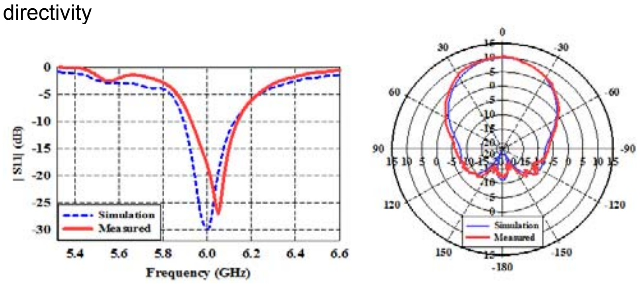


(a) (b)
Fig. 1. (a) Antenna and mushroom like EBG, (b) Antenna and TSSEBG

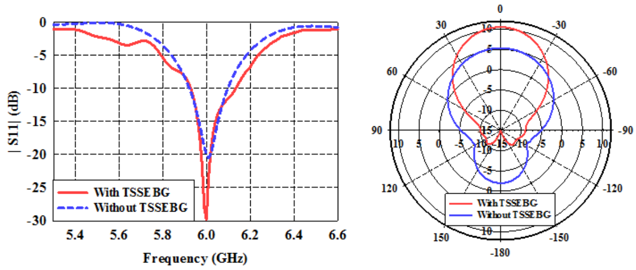
The simulated of S-11 for the antenna and mushroom-like EEG at 6 GHz comes with good resulte (−30 dB), where the resonant frequency slightly shifts to 5.97 GHz . By contrast as shown in Figure 2(a), the S-11 is −20.7 dB, and a 6.01 GHz of the reference antenna (without EBG). The side lobes have been improved from −7 dB to −17.5 dB. Additionally, better directivity was achieved by using EBG from 5.66 dBi to 10 dBi as shown in Figure 2(b). The measured value of S-11 is less than −26.5 dB at 6.05 GHz as shown in Figure 3(a). In the direction of main lobe EBG antenna, the measured directivity is 10.22 dBi. Good agreement was achieved between the simulated and measured results as shown in Figure 3(b).



(a) (b)
Fig. 2. With and without EBG (a) S11 of antenna, (b) Antenna directivity

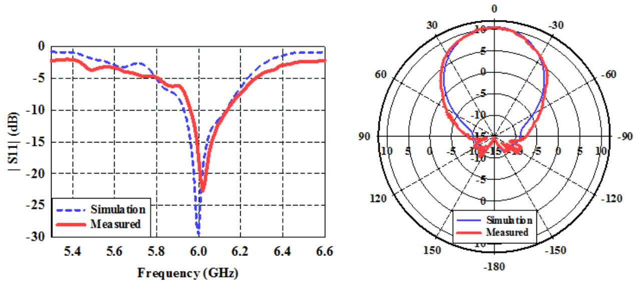


(a) (b)
Fig. 3. (a) Simulated and measured S11 using EBG, (b) Simulated and measured normalize maximum directivity.



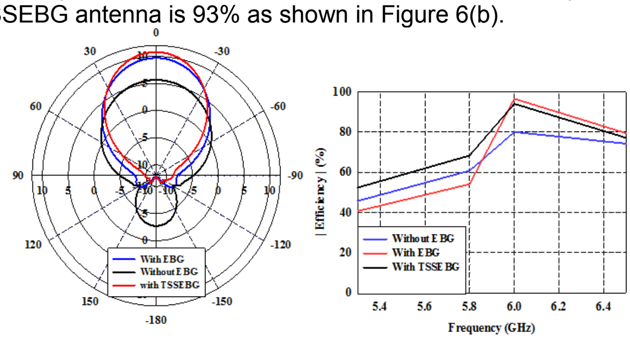
(a) (b)
Fig. 4. With and without TSSEBG (a) S11 of the antennas, (b) Antenna directivity

In the Figure 4(a), at the 6.02 GHz of resonant frequency, the S-11 of the TSSEBG antenna is −29 dB. Furthermore, the directivity is 10.6 dBi as shown in Figure 4(b). The measured resonant frequency of the compact TSSEBG antenna is 6.03 GHz with good matching of S-11 (− 22.5 dB) as exposed in Figure 5(a). Good acceptance was obtained in Figure 5(b) between the measured, and simulated outcomes of the TSSEBG antenna radiation pattern in main lobe of the direction.



(a) (b)
Fig. 5. (a) Simulated and measured S11 using TSSEBG, (b) Simulated and measured normalize maximum directivity of TSSEBG antenna.

In summary, the radiation patterns comparison of these antennas are presents in Figure 6(a). The antenna without EBG has efficiency (80%), and after applying the EBG the efficiency improved to 96%. In additional, the efficiency of TSSEBG antenna is 93% as shown in Figure 6(b).

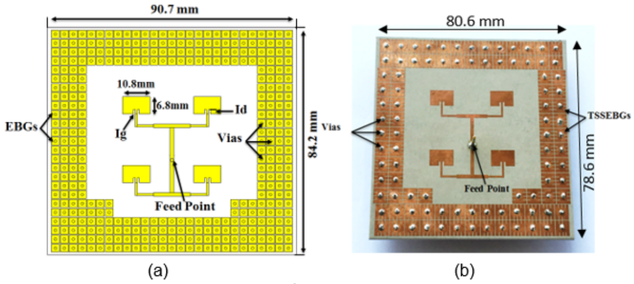


(a) (b)
Fig. 6. Enhanced antenna performance using EBG and TSSEBG (a) Directivity, (b) Efficiency

Enhanced the Performance of Antenna Array by Using EBG

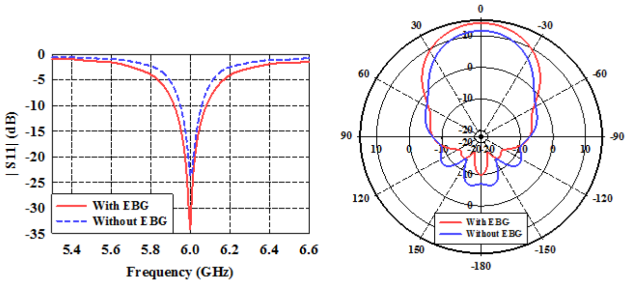
Array antenna was designed to operate at 6 GHz. The substrate thickness is 2.74 mm. To reduce the antenna size, the dielectric constant (εr) is 10.2. Moreover, the dimension of radiating elements are 6.82 mm × 10.82 mm. The distance between the centre of rectangular antenna is 26.8 mm. Then, the four patches were individually connected using transmission line (70 Ω) impedance. Another transmission line with 50 Ω has been used to connected the elements together. The adjustments of insert distance (Id) and the insert gap (Ig) are 2.1mm and 0.7 mm respectively, to improve the return loss and impedance. As shown in Figure 7(a) the pin vias are used to connect the antenna ground plane to the square patches of EBGs. The numbers of vias were decreased from 392 to 92 when we replaced the mushroom-like EBG by TSSEBG. The space between the TSSEBG patches (g) is 0.3 mm as shown in Figure 7(b).

The simulated S-parameters (S-11) were performed to explane the antenna performance. At 6 GHz the S11 of antenna array is less than −32 dB. While, the S-11 is −23 dB without using mushroom like EBG as exposed in Figure 8(a). The back lobe of the reference antenna is −17.89 dB. The antenna radiation pattern with EB0G exhibits a good lessening in the side lobe around −24 dB. The directivity in the main lobe direction (14.2 dBi) is the better compared with the array antenna without EBG (11.66 dBi) as exhibited in Figure 8(b).



(a) (b)

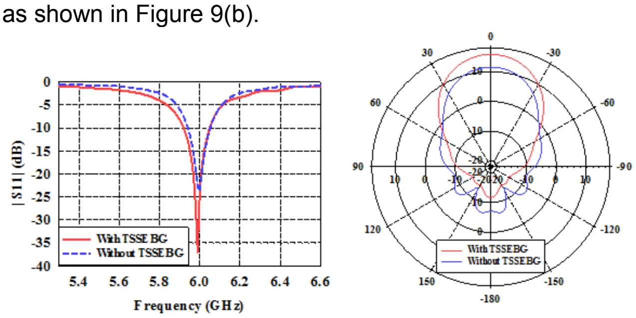
Fig. 7. (a) Mushroom like EBG structures and array antenna, (b) TSSEBG and array antenna



(a) (b)

Fig. 8. With and without EBG (a) S11 of the array antenna, (b) Array antenna directiviy

At 6 GHz The simulated S-parameters were performed for the array antenna using two columns of TSSEBG, where the S-11 is less than −36 dB. While the S-1 is less than −23 dB at the antenna without using TSSEBG, as exhibited in Figure 9(a). The pattern of the antenna with TSSEBG showed optimal lowering in the back lobe of −28.55 dB at 0° main lobe direction. This feature will generate enhanced directivity, which equal to 15.5 dBi. Meanwhile, array antenna without TSSEBG has directivity equal to 11.65 dBi as shown in Figure 9(b).

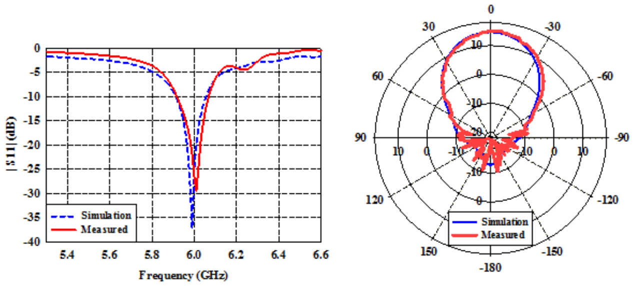


(a) (b)

Fig. 9. With and without TSSEBG (a) S11 of the array antenna, (b) Array antenna directiviy

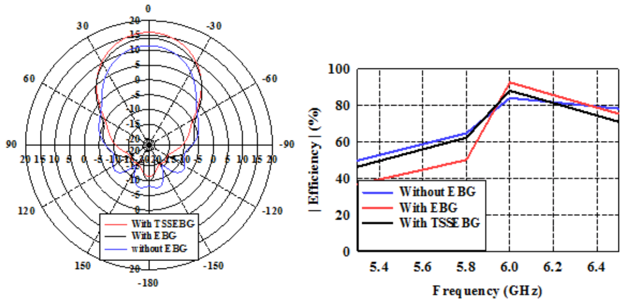
The comparison process in terms of return loss between the simulated and measured results of the array antenna which surrounded by TSSEBG is shown in Figure 10(a). A little shift in the frequency band (i.e. 6.015 GHz) for the measured result has been obtained, and the S-11 is −29 dB. The optimal reduction in the measurement process has been achieved in the TSSEBG array antenna, where the side lobe is −28.5. This feature will help to enhance antenna array directivity. In the main lobe direction, the measured directivity is 15.7 dBi as shown in Figure 10(b). A slight discrepancy between the measured and simulated results due to the fabrication and tolerances.

The pattern of the antenna with and without TSSEBG and mushroom-like EBG as shown in Figure 11(a). Largest back radiation was found in the antenna without EBG. The good radiation properties for the mushroom-like EBG structure is presented [31-33]. The pattern of the TSSEBG antenna is the better due to its back radiation is the lowest and the front radiation is the highest. Reference antenna array has efficiency equal to 84%. The efficiency enhanced to 88% when TSSEBG has been used. Meanwhile, the efficiency of 91.5% was achieved in case of using the mushroom-like EBG as shown in Figure 11(b). In Table 1, the results were illustrated the antenna performance using TSSEBG and EBG.



(a) (b)

Fig. 10. (a) Simulated and measured S11 using TSSEBG with array antenna, (b) Simulated and measured normalize maximum directivity of TSSEBG array antenna



(a) (b)

Fig. 11. (a) Enhanced antenna directivity by using mushroom like-EBG and TSSEBG, (b) Efficiency enhancement by using mushroom like-EBG and TSS-EBG

Table 1. Summary of antennas performance with and without EBG or TSSEBG

Antenna	Antenna Size(mm)	Side lobe (dB)	Directivity (dBi)	Efficiency (%)
Sigle antenna	46 x 46	-7	5.66	80
Single antenna with EBG	52 x 51	-17.45	10.1	96
Single antenna with TSS-EBG	45 x 47	-21	10.5	93
Antenna Array	82 x 76	-18	11.7	83.8
Antenna Array with EBG	85 x 91	-24.45	14.3	91.55
Antenna Array with TSS-EBG	79 x81	-28.55	15.55	88.23

Conclusion

In this work, a compact rectangular patch antenna and 2×2 microstrip antenna array with EBG structures have been combined to enhance the antenna efficiency, directivity, and side lobe. Above the antenna substrate and individually, the mushroom-like EBG and TSSEBG were proposed. To reduce the complexity, the mushroom-like EBG have been replaced by TSSEBG which resulted in decreasing the number of vias. Obviously, the new design of TSSEBG is preferable than mushroom-like EBG in terms of, number of connecting vias, side lobe reduction, and antenna radiation pattern. Table 1 is illustrated the summarize results for the compact rectangular antenna and array antenna performance. These antenna structures have a great eventuality for use in satellite application.

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