Proc. of the 2nd International Conference on Electrical, Communication and Computer Engineering (ICECCE)
12-13 June 2020, Istanbul, Turkey

Performance Improvement of a Microstrip Patch Antenna by Using Electromagnetic Band Gap and Defected Ground Structures

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***Abstract*—This paper presents a compact microstrip patch antenna designs incorporated with EBG on the front side and DGS on the back side. The gain and directivity values of the microstrip patch antenna are improved about 23% while the bandwidth is broadened by the collocation of EBG on the front and periodically etched DGSs on the back of it. Thus, a novel design which provides solutions for the needs of today's wireless technology is presented.**

Keywords—microstrip patch antenna, electromagnetic band gap structures, defected ground structures

I. INTRODUCTION

The growing demand and usage of wireless communications need more compact and smaller devices and it is evident that the antennas are the most important components of these devices. Microstrip patch antennas are light weight, compact, easy to integrate and cost effective, thus the most common form of printed antennas. Unfortunately, they have some unenviable features like narrow bandwidth and surface wave excitation. Increasing the substrate thickness can be the first choose that comes to mind, but this supports the surface wave excitation that affects the antenna performance [1]. To improve the bandwidth, slotted antenna structures can be used. However, this is also worsened the radiation pattern [2]. For improving the performance of microstrip patch antennas, they can be incorporated with metamaterials [3-4]. Electromagnetic band gap (EBG) structures, a kind of metamaterial, are periodic geometries constructed by repetition of a unit cell and they are successfully used to suppress the propagation of surface waves within a certain frequency band. They can be deployed as a part of the antenna configuration, in order to improve the performance. However, the EBG unit cell has to be designed as the resonant frequency of antenna locates in band gap region of the EBG structure for a successful design.

Defected Ground Structures (DGS) can also be used to control the excitation and propagation of electromagnetic waves through the substrate layer [5]. Generally, the DGS are produced by etching a single, multiple, periodic or non-periodic slots with different geometries on the ground plane. DGS configurations have individual shapes, which depend on the geometry and size of it and enhances the performance of the device according to DGS's characteristics. The return loss level and bandwidth is improved depending on the number of periods in periodic DGSs. The DGS unit cell geometry, distance between two adjacent unit cells and the arrangement of unit cells on the ground plane are the main parameters that effect the performance of periodic DGS. Miniaturization, multiband performance, bandwidth improvement gain enhancement and impedance matching are some of the advantages of DGS on antennas and planar microwave circuits [6]. Moreover, the slots etched on the ground reduces the overall weight and size of the designed antenna.

For today's applications miniature microstrip antenna designs with DGS are very common in recent years [7-8]. There are also studies reporting that periodic defects on the ground, as an EBG structure applied on ground, enhanced the bandwidth of the patch antennas [9-10]. Furthermore, a patch antenna with improved performance by using DGS with 28 GHz operation frequency for 5G applications is presented in [11]. Also [12] presents results which especially focused on the bandwidth improvement of DGS applications.

The rest of the paper has the following sections: Section II presents design procedures of the proposed antennas with EBG and individual periodic DGSs. Section III gives the analysis results of the designed antennas obtained by a well-known electromagnetic simulation program, while the study is concluded in Section IV.

II. DESING PRINCIPLES

In this paper, six various microstrip patch antenna designs with the combination of a mushroom like EBG structure around the antenna and DGS formed as periodic ring slots or holes with different geometrical shapes in the ground plane are represented.

A. Antenna Desing with EBG Structure

A conventional microstrip patch antenna working at X-band is enhanced with mushroom like EBG structure placed in E plane. The antenna and the EBG structure are placed on a dielectric substrate with 2.5 relative permittivity and 1.524 mm height. The patch and the gap widths of the EBG structure are 3.5 mm and 1mm, respectively. The distance between the antennas radiating edge and the EBG patches is 4mm. This value is around the period of the EBG structure that is equal to the sum of the width of an EBG patch and the spacing between each patches. When the EBG structures are placed to a distance around the periodicity of the EBG unit cell optimum performance can be achieved and this placement also provides size reduction [13-14]. By this design, an antenna operating at 10 GHz with 10.1 dB gain and 10.3 dB directivity values are obtained with approximately 28% gain enhancement. Also,

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TABLE I. GEOMETRICAL SPECIFICATIONS OF THE PROPOSED DEFECTED GROUND STRUCTURES

Ring Structures								**Hole Structures**			
Circular ring		***Square ring***		***Hexagonal ring***		***Rhombic ring***		***Circular hole***		***Square hole***	
Outer diameter	3.5	Outer edge width	3.750	Outer diagonal width	3.5	Outer diagonal width	3.30	Circular hole diameter	4.0	Square hole edge width	3.5
Inner diameter	3.00	Inner edge width	2.500	Inner diagonal width	3.0	Inner diagonal width	0.670				
Ring width	0.25	Ring width	0.625	Ring width	0.25	Ring width	1.315	Gap width	0.5	Gap width	1.0
Gap width	1	Gap width	0.750	Gap width	1.0 in x 1.47 in y	Gap width	1.20				

All dimensions are given in mm.

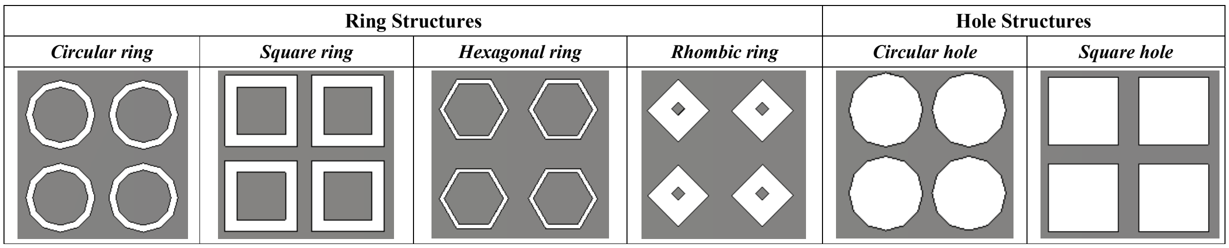
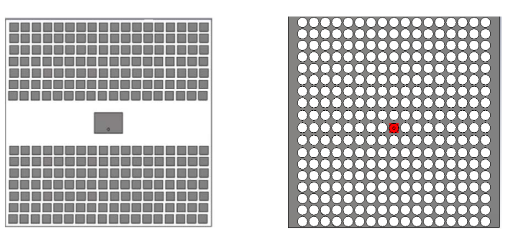


Fig. 1. 2x2 arrays of the used six different shapes on the grounds of the proposed antennas.

the significant decrease in side lobe levels shows that the EBG structure is successfully suppresses the surface waves. But the impedance bandwidth is decreased approximately 48% because of the close spacing between the antenna and the surrounding EBG.

B. DGS Specifications

Different shapes etched on the ground of a microstrip antenna have been reported that provides better performance such as size reduction, bandwidth and gain enhancement [15]. Furthermore, periodically defected ground structures have similar microwave properties as EBG structures. The designs constructed by periodic circular, square, hexagonal, rhombic rings and circular and square holes on the ground plane of the antenna with EBG are simulated and investigated in this study. The geometrical specifications of the unit cells belong to six different DGS models used in this study are given in Table I. Furthermore, for explaining the designs more clearly the small parts of the designed DGSs including 2x2 arrays of the used six different shapes on the grounds are shown in Fig. 1. The given DGS unit cells are placed to the whole ground structures by taking care of the pins of the mushroom like EBGs on the front side do not come to the empty areas during the design procedures. The front sides of the all presented designs in this study are common, but the back sides are constructed by periodically locating the introduced six different shapes. One of the proposed antennas which has circular hole structured DGS on the back side is shown with its front view and back view in Fig. 2.



(a) (b)

Fig. 2. Configuration of the proposed antenna (a) front view – antenna and EBG structure, (b) back view – DGS with circular holes.

III. RESULTS AND DISCUSSIONS

All of the structures designed in this study were designed and simulated by CST-MW. The return loss, impedance bandwidth, gain and directivity values were obtained and listed in Table II for the designs that are examined in this study. The return loss results were given for the antenna designs with EBG structure on the front side and four different ring slotted DGS and two different hole structured DGS designs on the back side in Fig. 3 and Fig. 4, respectively.

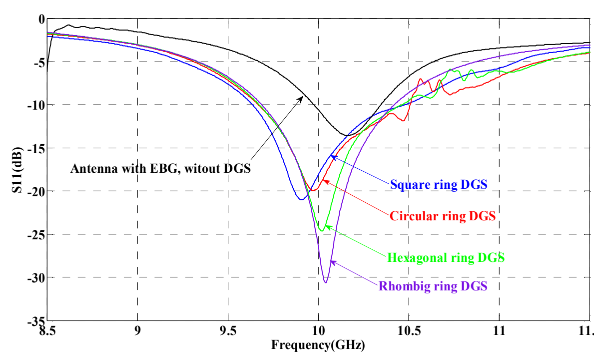


Fig. 3. The obtained return loss characteristics for proposed antenna designs with EBG and four different ring slotted DGSs.

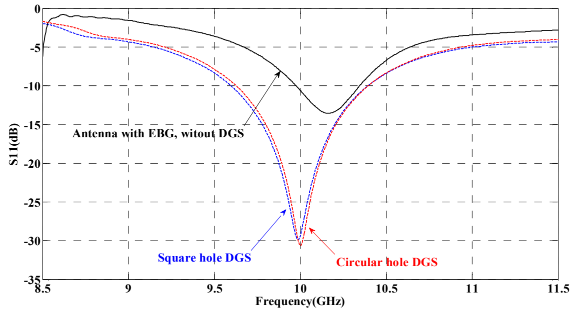


Fig. 4. The obtained return loss characteristics for proposed antenna designs with EBG and two different hole structured DGSs.

TABLE II. OBTAINED GAIN, DIRECTIVITY AND BANDWIDTH VALUES

	Gain (dB)	Directivity (dB)	Bandwidth (GHz)	Increase in Bandwidth (GHz)
Antenna without DGS				
Antenna without EBG & DGS	7.91	8.08	0.72	-
Antenna with EBG without DGS	10.1	10.3	0.37	-
Antenna with EBG & four different ring slotted DGS				
Circular ring	8.89	9.07	0.84	0.47
Square ring	10.7	10.9	0.845	0.475
Hexagonal ring	7.53	7.7	0.79	0.42
Rhombic ring	7.99	8.18	0.737	0.367
Antenna with EBG & two different hole structured DGS				
Circular hole	9.64	9.79	0.77	0.40
Square hole	9.65	9.79	0.797	0.427

When the results of the compact EBG design were investigated, it was observed that the EBG structure was improved the antenna performance in the cost of bandwidth reduction. However, all of the proposed DGS designs were successfully overcome this drawback and enhanced the bandwidth. Additionally, much better return loss values were obtained. The ring slotted DGSs gave better results when compared to hole structured ones in terms of bandwidth enhancement. The bandwidth can be increased up to 475MHz, besides keeping improved gain and directivity values.

But, when far field radiation patterns were investigated, the expected increases in side lobe levels were arisen. When the ground is not defected, made by complete conducting material, it acts as an object that reflects the electromagnetic waves and generates directional radiation patterns. The defects in the ground improves the bandwidth in the cost of increments in the side lobes in the radiation pattern. The usage of the ring slotted DGS geometries in the ground plane downgrades the gain and the directivity values, while increasing the bandwidth. But they are still approximately 11% better than the conventional antenna. However, the square ring slotted DGS gives better results.

On the other hand, when periodic circular holes or square holes were used in the ground plane as DGS, the obtained gain and directivity values are 9.64 dB, 9.79 dB and 9.65dB, 9.79 dB respectively. This indicates approximately 22% improvement that is still satisfactory. The comparison of the radiation patterns is given in Fig. 5.

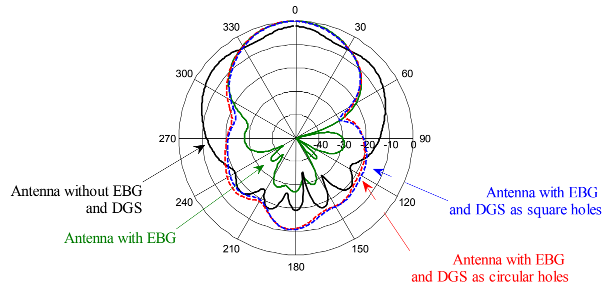


Fig. 5. Far field radiation patterns for antenna without EBG and DGS, with EBG.

IV. CONCLUSIONS

In conclusion, compact microstrip patch antenna designs were proposed with enhanced properties in this study. The EBG structure which was placed around the microstrip antenna with a distance about the periodicity of the EBG structure successfully suppresses the surface waves and improves the gain. Furthermore, the presented six different DGS forms etched on the back side enhanced the bandwidth and impedance match, besides reducing the overall weight of the antenna.Thus, the antenna design with EBG and DGS yields much better antenna performance than that of the conventional microstrip antenna.

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