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ULTRA-WIDE BANDWIDTH MICROSTRIP MONOPOLE ANTENNA BY USING ELECTROMAGNETIC BAND-GAP STRUCTURES

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Abstract—A novel compact design for ultra-wide bandwidth (UWB) planar monopole antenna is presented in this paper. The basis for achieving the UWB operation is through using semicircular microstrip monopole antenna with modified ground plane in the form of semi circular umbrella like shape. This shape produces bandwidth ranging from 3 to 35 GHz with discontinuities from 7 GHz to 10 GHz, from 12.5 GHz to 17.5 GHz and from 22 GHz to 40 GHz. The antenna size is reduced by 27% relative to the size of conventional rectangular monopole patch antenna. Metamaterial structures are used for further antenna performance improvement. Two types of metamaterial namely EBG and DGS are studied. First, embedding metallo EBG (EMEBG) is used to eliminate ripples in the operating band and also further reducing the antenna size by more than 30% as compared to the proposed patch. The antenna design provides an impedance bandwidth of more than 33 GHz. Second, four arms spiral defected ground structure (SDGS) is used as a ground plane with four arms to further improve the antenna performance. The SAMC reduced the antenna size by more than 48% as compared to the proposed antenna patch, increased bandwidth, and decreased the cross polarization effect. Finally, embedded EBG together with SDGS ground plane are studied to take advantages of both techniques.

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1. INTRODUCTION

Planar monopole antennas have been used in wireless communication systems for a long time due to their simple structures, convenient feeding mechanisms and low fabrication cost. The low profile, light weight, and low cost of manufacturing of monopole microstrip patch antennas have made them attractive candidates for many applications [1, 2]. However, their limited impedance bandwidth needs to be further improved for ultra wide bandwidth (UWB) applications. One simple but powerful technique to increase the bandwidth is to replace the cylindrical monopole wires by the planar elements, such as rectangular (square) shapes, elliptical (circular) shapes, triangular shapes, and others.

Another way to increase the impedance bandwidth of the monopole antennas can be achieved by modifying the radiator plane shape. A novel shape of the modified radiator plane is in the form of semi circle and this shape is used in this paper to increase bandwidth [3]. Other alternative approaches for improving the bandwidth of printed circuit monopole radiators include the use of a variety of Electromagnetic Band Gap (EBG) structures such as those utilized in earlier publications [4–7].

The first part of the paper is focused on describing the new shape of monopole microstrip antenna by using semi circular radiator to achieve wide bandwidth. With the intention to overcome bandwidth limitation, a thick and relativity high permittivity substrate is used [4–7]. The second part of this paper is focused on using metamaterial techniques. Recently, metamaterial structures have been used to mimic perfect magnetic conductors (PMC) over a narrow frequency range, for use as a ground plane in a low profile antenna configuration. Especially at the 0° reflection phase in a certain frequency band, the surface shows the property of a perfect magnetic conductor (PMC) [8, 9]. First approach is embedding metalo-electromagnetic band-gap (EMEBG) to further increase the antenna bandwidth. Second approach is using four arms spiral defected ground structure (SDGS) as ground plane that minimizes the cross polarization effect of printed spiral geometry. The use of EMEBG resulted in decreasing discontinuities in the achieved bandwidth [10–12]. Final design is a combination of the two approaches as embedding four arms spiral shape in the medial of the substrate and keeps the semi circular ground. Another design is obtained by embedding square shaped EBG in the medial of substrate with four arms spiral DGS ground plane.

2. REFERENCE ANTENNA GEOMETRY AND DESIGN

A low profile monopole microstrip patch antenna is proposed as shown in Figure 1(a). The antenna has an umbrella semi circular shape, for both the radiator and the ground plane. Although similar designs were reported in several papers, variations in the design are simulated in this paper before achieving the designed shape of monopole antenna [5]. The antenna is printed on FR4 dielectric substrate with thickness approximately $0.034\lambda_{3.3\,\mathrm{GHz}}$ (3.2 mm), relative permittivity $\varepsilon_r = 4.7$ and $\tan\delta = 0.02$. The half circular patch is of radius = 12 mm and the semi circular ground plane is of radius 15 mm. The radiator is placed a distance $L_{\mathrm{feed}} = 16$ mm from one edge of the substrate. The total dimension of the substrate is $L_g \times W_g = 40 \times 40\,\mathrm{mm}^2$. The antenna is fed by microstrip line of characteristic impedance $50\,\Omega$ and $W_{\mathrm{feed}} = 3.8$ mm.

The antenna performance is investigated numerically and experimentally. The simulation is done by commercial simulator HFSS version 11, while fabrications of antennas are done by using photolithographic technique. Measurements are carried out using a vector network analyzer Agilent E8364A. Using this final design [5],

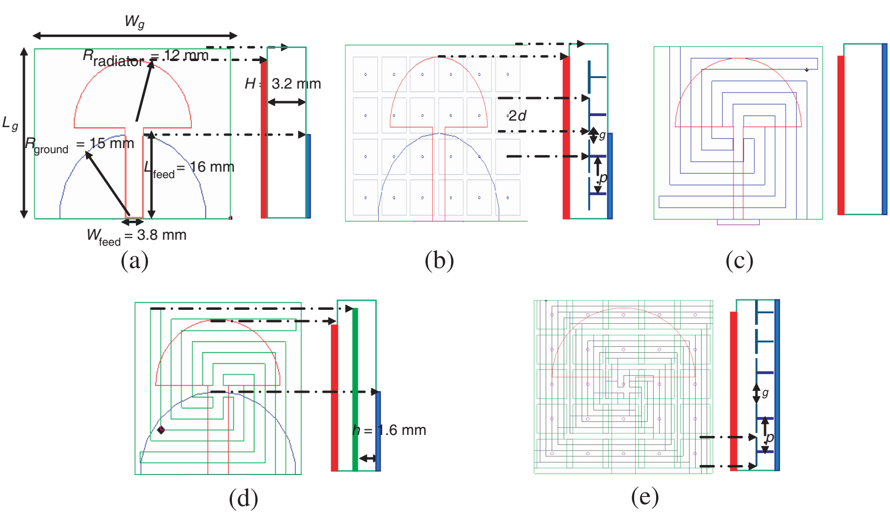


Figure 1. The prototype of the proposed antennas design. (a) Elevation and side view of proposed antenna. (b) Elevation and side view of antenna with EEBG. (c) Elevation and side view of antenna with SDGS. (d) Elevation and side view of antenna with embedded SDGS. (e) Elevation and side view of antenna with embedded EBG and SDGS ground.

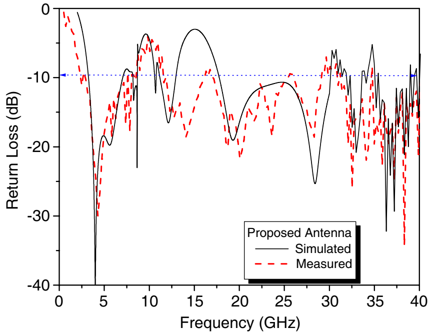


Figure 2. Simulated and measured reflection coefficient of the proposed antenna.

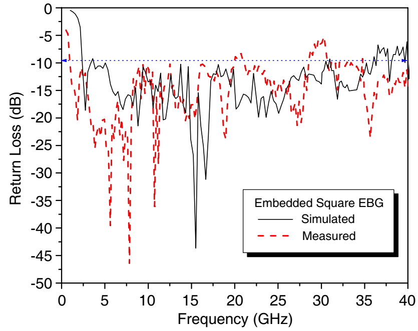


Figure 3. Comparison between measured and simulated reflection coefficient for embedded square EBG.

the antenna shows ultra wideband characteristics as shown in Figure 2, but with discontinuities in the bandwidth from 7 to 10 and 12.5 to 17.5 GHz.

3. DESIGN USING EBG

After achieving the best possible performance results from this approach, various metamaterial techniques are used as designs of EBG structures to further improve bandwidth by removing these discontinuities, enhancing gain and reducing the antenna size. Small square patches are embedded in a periodical electromagnetic band-gap structure as shown in Figure 1(b). These small patches have half square side $d = 3\,\mathrm{mm}$, periodicity with period $P = 7\,\mathrm{mm}$, and the vias have radius $= 0.25\,\mathrm{mm}$ [5]. These dimensions are used based on simulation results for optimizing the performance of the antenna system. The effect of adding EBG on the antenna performance is then examined. Simulated and measured results illustrating the performance of the square EBG structure are shown in Figure 3 with bandwidth discontinuity from 20 GHz to 21 GHz and 27 GHz to 30 GHz. There is a little difference between the simulated and measured results that may be attributed to improper soldering.

4. DESIGN USING SPIRAL DGS

Printed DGS spiral geometry is often used to reduce antenna size and minimize cross polarization. There have been however various SDGS surfaces such as mushroom-like EBG structure [6], Hilbert-Curve, Jerusalem Crosses, dipole and slot arrays proposed for integration with antenna designs. In particular, the Hilbert-Curve inclusion focuses on the compactness of the surface. In addition, when plane wave illuminate on an EBG surface, the reflection phase continuously changes from 180° to −180° with increasing frequency. Especially at the 0° reflection phase in a certain frequency band, the surface shows the property of a perfect magnetic conductor (PMC). The PMC material does not exist in nature, but an artificial magnetic conductor (AMC) can be realized from the property of the EBG structure [4]. In this paper, printed spiral geometries are investigated as shown in Figure 1(c). Four arms spiral DGS has behavior like as AMC, it has an axial symmetry which means that periodic structure in the azimuth plane. The SDGS arms are considered to be periodical structure in the $\pm x$ and $\pm y$ directions [13, 14]. The operation principle of the DGS surface can be simply explained by an equivalent LC circuit theory. To increase the value of the inductor, a single spiral is placed on top of the substrate to replace the conventional ground plane. The parameters of the substrate remain the same as the reference conventional monopole. The width of the spiral is 1 mm $= 0.011\lambda_{3.3\,\mathrm{GHz}}$ with gap = 1 mm and splits from the center and rotates in clockwise direction. The four arms spiral is used in the ground plane as in Figure 1(c) to improve the performance such as decreasing antenna size, reducing bandwidth discontinuity and increasing antenna gain. The performance of spiral shapes were studied and redesigned by

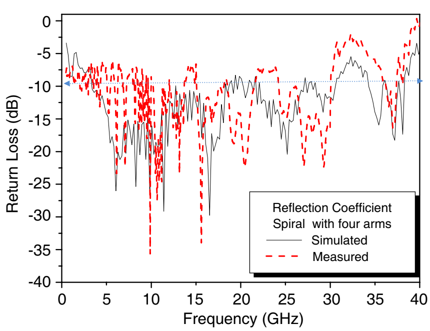


Figure 4. Comparison between simulated and measured reflection coefficient of spiral with four arms as a ground plane.

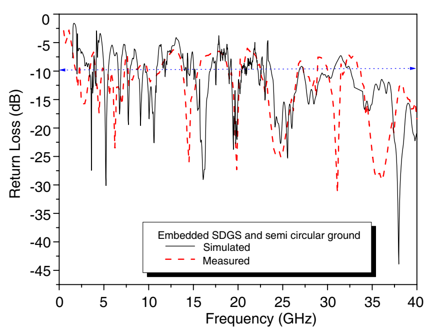


Figure 5. Comparison between simulated and measured reflection coefficient of embedded spiral with four arms and modified ground plane.

calculating reflection coefficient. The resonant frequency decreases as the number of spiral turns increases. The antenna reflection coefficient is shown in Figure 4. The first resonant frequency is 49.45% lower than the reference geometry in Figure 2. In contrast to the previous designs, if this spiral shape is rotated 90°, it can exactly recover itself. Therefore, this symmetrical condition guarantees the same scattering response to the x- and y-polarized incident waves. As a result, no cross polarization is observed with this structure. Therefore, with this design the compactness of geometry is achieved without increasing the cross polarization level. This significant reduction in size for a single element leads to an attractive design feature for many wireless communication applications.

5. DESIGN USING COMBINATION OF EBG AND DGS

Finally, a combination of EMEBG and SDGS to take advantages of both approaches was studied, by embedding SDGS with four arms at height 1.6 mm from the modified semi circular ground plane as shown in Figure 1(d). The four spiral arms width equal to 2 mm and separation between arms equal to 2 mm. Another way to improve the antenna performance is using embedded square shape EBG and keep the same previous dimensions as in Section 3, with four arms spiral

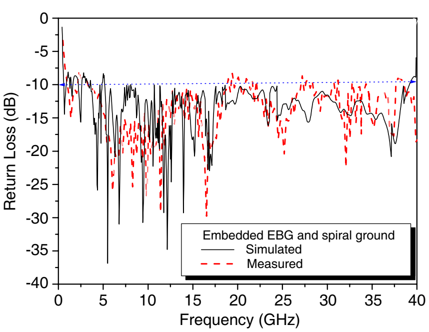
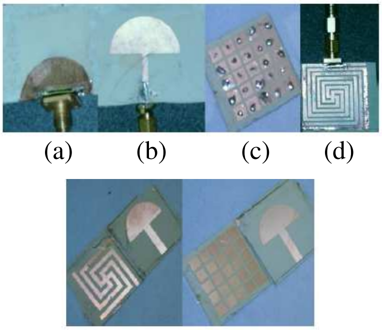


Figure 6. Comparison between simulated and measured reflection coefficient of embedded square EBG and four arms SDGS ground plane.



(a) (b) (c) (d)

(e) (f)

Figure 7. The fabricated proposed antenna (a) modified ground plane, (b) semi circular radiator, (b) embedded square EBG, (d) four arms SDGS, (e) embedded SDGS and (f) embedded square with four arms SDGS.

DGS ground plane as shown in Figure 1(e) with spiral arm width 2 mm and separation 1 mm.

We started by fabricating the embedded four arms spiral with modified semi circular ground to reduce the antenna size since it is much easier in fabrication. The results are shown in Figure 5. Another improvement was obtained by using embedded square shapes integrated with four arms spiral ground plane. The reflection coefficient is shown in Figure 6. The bandwidth is extended from 0.5 GHz to 40 GHz and about 8.5 dBi average antenna gain. The various shapes of fabricated antennas are shown in Figure 7. The E plane and H-plane radiation patterns of the final proposed antenna are shown in Figure 8 at two different frequencies. Table 1 summarizes all pervious results to explain how these techniques affect on antenna performance. Figure 9 shows the variation of antenna gain versus frequency without and with EBG structure. This figure indicates that

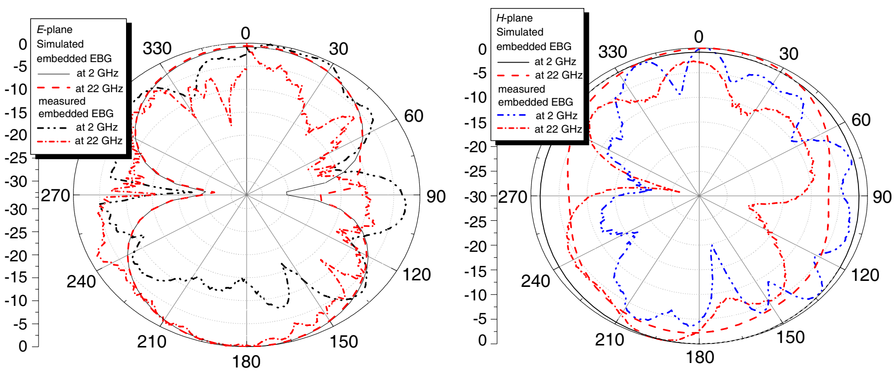


Figure 8. Comparison between measured and simulated E-plane and H-plane radiation patterns of embedded EBG with four arms spiral ground plane at two different frequencies.

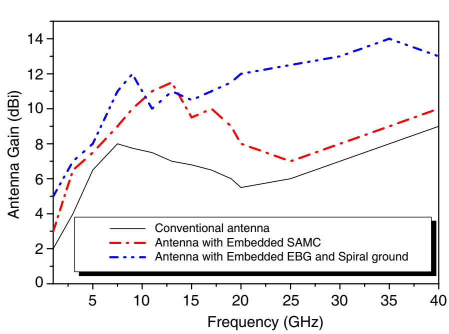


Figure 9. The antenna gain response over frequency band.

the antenna gain with EBG is better than without EBG. Second, the antenna with embedded EBG and spiral ground plane gives higher gain at all the frequency band than others.

Table 1. Effect of the embedded EBG on antenna characteristics.

Antenna Performance	**Proposed Antenna without EBG**	**Antenna with Embed square EBG**	**Antenna with SDGS as ground**
Discontinuities in Bandwidth	from 7 to 10 GHz & 15 to 17 GHz & 22 to 26 GHz, 27 to 40 GHz	from 20 to 21 GHz & 26 to 29 GHz	from 12 to 15 GHz & 21 to 25 GHz & 30 to 34 GHz & 38 to 40 GHz
F_0	3.5 GHz	2.5 GHz	1.75 GHz
Average Efficiency	0.75	0.8	0.85
Average Gain	4.5 dBi	7 dBi	7 dBi
Size reduction	27% from conventional rectangular monopole	28% from proposed antenna	50% proposed antenna
Antenna Performance	**Antenna with embedded SDGS**	**Antenna with EBG and SDGS as ground**	-
Discontinuities in Bandwidth	3 to 4 GHz & 12 to 14 GHz & 17 to 18 GHz & 21 to 23 GHz	17 to 19 GHz & 20 to 22 GHz and 33 to 34 GHz	-
F_0	1.8 GHz	1.25 GHz	-
Average Efficiency	0.8	0.86	-
Average Gain	8 dBi	8.5 dBi	-
Size reduction	48% proposed antenna	64% proposed antenna	-

6. CONCLUSION

In this paper a novel shape of half circular planar monopole radiator and ground plane was simulated and the obtained performance was evaluated. The use of metamaterial structure such as embedded EBG structures of periodical square patches were also introduced and analyzed. It is shown that, the microstrip antenna bandwidth performance was improved by using embedded square EBG from 1 GHz up to more than 35 GHz with radiation efficiency of $\eta \approx 0.7$ and an increase in the average antenna gain to 8 dBi. Using SAMC as ground plane, an ultra-wide bandwidth from 1 GHz up to 30 GHz with efficiency $\eta = 0.85$ is achieved. The best simulated antenna shape gain is studied at different frequencies. The average gain is about 7 dBi. Finally, using both approaches namely using embedded four arms spiral defected ground structure shape to reduce the antenna size and using embedded square EBG integrated with four arms spiral ground plane for further improvement bandwidth, reduction in antenna size reached to 65% and gain. The average gain is about 8.57 dBi. The measured radiation patterns (E-plane and H-plane) are approximately omni-direction throughout the entire band with different iterations and design variations.

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