Performance Improvement of Fractal Antenna with Electromagnetic Band Gap (EBG) and Defected Ground Structure for Wireless Communication

Shailendra Kumar Dhakad, Umesh Dwivedi, Sudeep Baudha and Tapesh Bhandari

Abstract This paper is aimed at developing a Sierpinski carpet fractal antenna with electromagnetic band gap (EBG) in the ground plane. This is designed using Rogers Duroid 5880 substrate, and validation of model is done using extensive simulations in CST MWS 2011. Several iterations are done and optimized to give the best result. The simulation results showed return loss of −22.25 dB at 8.592 GHz for third iteration. There is an enhancement of bandwidth by 209% from 75 MHz (conventional patch antenna) to 234.4 MHz using SCFA with EBG and directivity of 4.4 dB at resonant frequency. It shows reduction in size of antenna, and the proposed antenna size is 17.2 × 20.5 mm^2. This antenna works well in X-band communication (8–12 GHz) for ultra-wideband imaging for medical application and weather monitoring radars in satellite communication.

Keywords Sierpinski carpet fractal antenna · Return loss · Voltage standing wave ratio · EBG structures · Microstrip patch antenna

1 Introduction

Communication system is a rapidly growing field in the world right now, and Antennas are a very important part of them. These days, designing of the microstrip antennas has become a great field of research as they are light in weight, easy to manufacture, and conformable to both planar as well as non-planar surfaces.

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G. Gnanagurunathan et al. (eds.), *Optical and Microwave Technologies*,
Lecture Notes in Electrical Engineering 468,
https://doi.org/10.1007/978-981-10-7293-2_2

One popular kind of antenna is a fractal antenna. Fractal shapes generally are the geometrical shapes which repeat themselves with respect to their previous iteration design by modifying the dimension of each new iteration. They are chosen over conventional shapes for antenna design because they increase the electrical length while keeping the surface area and volume same.

Electromagnetic band gap structures help in creating a gap in the band around the operating frequency of the antenna. Popular EBG structures are mushroom-like EBG, polygonal, circular, and spiral. However, it is found that circular-shaped EBG exhibits higher directivity and gain as compared to other types of EBG structures.

In this paper, a third-iteration Sierpinski fractal antenna is designed with circular EBG. Analysis of the antenna is done using various modifications. Analyzing the results of this antenna with the number of iterations and studying the effect of EBG and non-EBG structures in the ground plane are done in the following paper. The final antenna is found to be working in the X-band radar application including single polarization, dual polarization, Synthetic Aperture Radar and also for weather monitoring by meteorological department.

2 Methodology

In this work, the third iteration of a Sierpinski fractal antenna with a circular-shaped electromagnetic band gap structure on its ground plane was analyzed. This antenna was designed using Rogers RT Duroid 5880 substrate. Table 1 shows the substrate properties.

2.1 Antenna Design

Firstly, in the zeroth iteration, a conventional rectangular patch antenna is designed with the dimension shown in Fig. 1. Table 2 shows the values of the variables used in Fig. 1. In the first iteration, a rectangle is cut from the middle of the zeroth iteration, the dimension of which is 1/3rd the dimension of the rectangle in the zeroth iteration. In the second iteration, seven more rectangles are cut from the first iteration, the dimension of each, again being 1/9th of the zeroth iteration. In the third iteration, 50 more rectangles are cut symmetrically from the second iteration, the dimensions of which are 1/27th as compared to the zeroth iteration (Fig. 2).

Table 1 Properties of the substrate

Properties	Value
Relative permittivity, ε_r	2.2
Thickness	0.38 mm

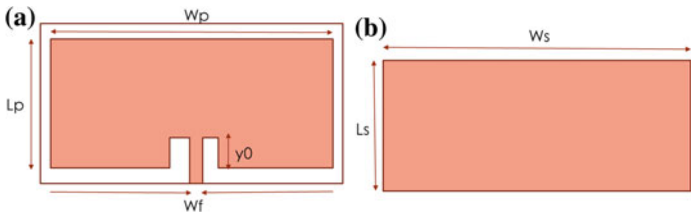

Fig. 1 Patch antenna **a** Front view. **b** Back view

Table 2 Proposed antenna design parameters

L_p	L_s	W_p	W_s	W_f	Y_o	r/a
17.27	19.6	20.5	22.5	1.18	5	0.5

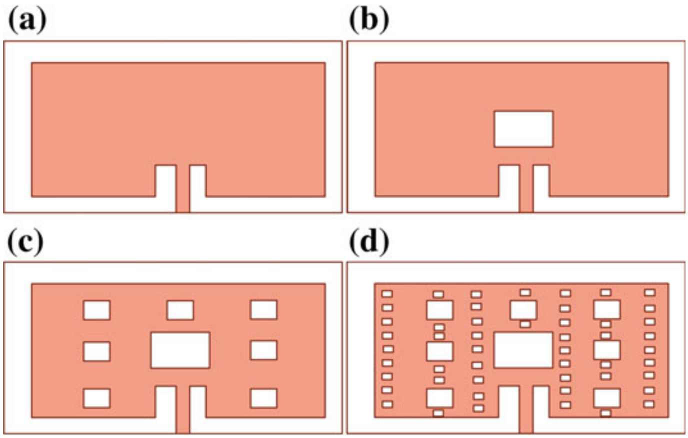

Fig. 2 **a** Zeroth iteration. **b** First iteration. **c** Second iteration. **d** Third iteration

The antenna was designed using equations [1] to calculate dimensions and resonant frequency.

(1) Effective dielectric constant for $E_r = 2.2$

$$\varepsilon_{r,\text{effective}} = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left[1 + 12\frac{\text{thickness}}{\text{Width}}\right]^{\frac{-1}{2}}$$

where ‘thickness’ is the thickness of substrate and ‘width’ is the width of the patch antenna. Due to fringing, effective length is more than physical length. The effective length is L_n

$$L_n = L + 2\delta L$$

While δL is given by

$$\frac{\delta L}{h} = 0.412 \frac{\left(\in_{r,\text{effective}} + 0.3\right)\left(\frac{\text{width}}{\text{thickness}} + 0.264\right)}{\left(\in_{r,\text{effective}} - 0.258\right)\left(\frac{\text{width}}{\text{thickness}} + 0.8\right)}$$

The actual length L can be calculated using following formula

$$L = \frac{1}{2f_r\sqrt{\in_{r,\text{effective}}\ \mu_o\ \in_o}} - 2\,\Delta L$$

Width W is given by $W = \frac{c}{2f}\sqrt{\frac{2}{\in_r + 1}}$, where c is the speed of light and f is the frequency.

In the Sierpinski antenna design different iterations, we use iteration function system (IFS) using self-affine transformation matrix. The scale factor of length of each side.

$L_n = L/3^n$ and number of patches with each iteration are $N = 8^n$.

The antennas are designed with and without EBG structures. Electromagnetic band gap structures give positive or negative effect on antenna radiation at some frequencies. It increases the selectivity of antenna and increases the directivity at particular frequency and suppresses unwanted radiations. Several designs can be used, and particularly circular-shaped EBGs are used in ground plane. The radius of these circular shaped EBG is denoted by r, and the distance between them is given by 0.45 * r (Fig. 3).

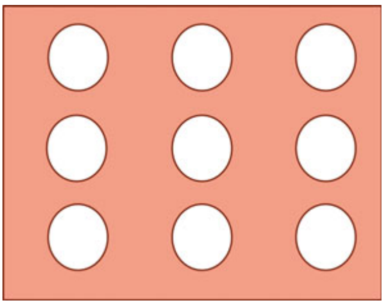

Fig. 3 EBG structure in ground plane

3 Results and Discussions

3.1 Analysis with Respect to Number of Iterations and EBG Structure in Ground Plane

The following Fig. 4 shows the return loss plot of conventional patch antenna. From the graph, we infer that the conventional patch antenna resonates at 9.204 GHz with a bandwidth of 75.7 MHz.

After applying the EBG structure in the ground plane, the resonant frequency is now found to be 9.708 GHz and the bandwidth reduced to 40.6 MHz. Figure 5 shows the return loss plot for the conventional patch antenna with and without EBG structure in the ground plane.

After the first iteration, the resonant frequency without EBG is 8.988 GHz and the bandwidth for the same increased to 169.9 MHz. After applying the EBG structure to this antenna, the resonant frequency was found to be 8.604 GHz and the bandwidth further increased to 206.6 MHz. Figure 6 shows the return loss plot for conventional patch antenna, first iteration and first iteration with EBG with the same frequency axis.

Figure 7 shows the conventional patch antenna, second iteration and second iteration with EBG with the same frequency axis. We infer from the figure that second iteration without EBG has a resonant frequency of 9.036 GHz and a bandwidth of 212.3 MHz. After applying the EBG, the resonant frequency is decreased to 8.604 GHz and bandwidth reduced to 165.6 MHz.

Finally, Fig. 8 shows the conventional patch antenna along with third iteration without EBG and third iteration with EBG. We see that the resonant frequency for third iteration is 9.036 GHz and the bandwidth increased to 220.7 MHz. After

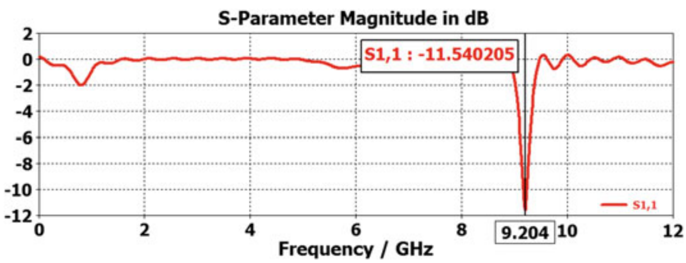

Fig. 4 Return loss plot for conventional patch antenna

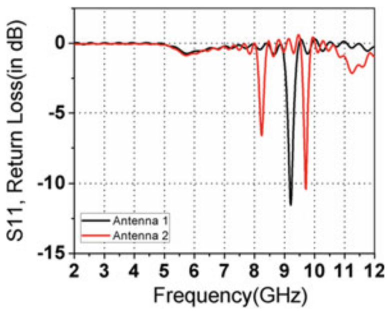

Fig. 5 Antenna 1 represents conventional patch antenna and antenna 2 represents conventional patch antenna with EBG

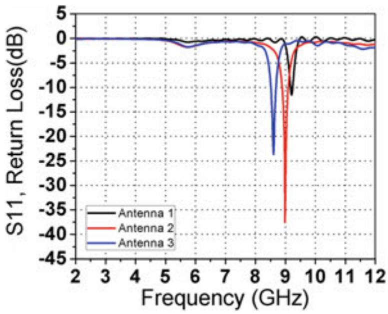

Fig. 6 Antenna 1 represents conventional patch antenna, antenna 2 represents first iteration without EBG and antenna 3 represents first iteration with EBG

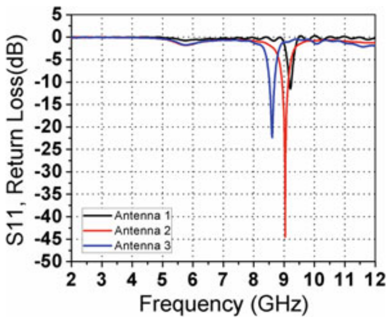

Fig. 7 Antenna 1 represents conventional patch antenna, antenna 2 represents second iteration without EBG and antenna 3 represents second iteration with EBG

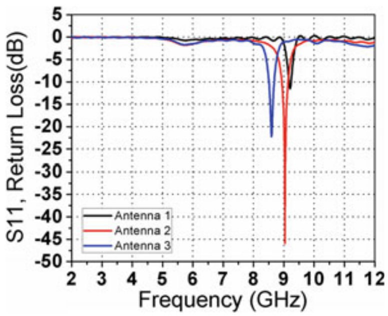

Fig. 8 Antenna 1 represents conventional patch antenna, antenna 2 represents third iteration without EBG and antenna 3 represents third iteration with EBG

applying the EBG in third iteration, we find that the resonant frequency decreased to 8.592 GHz and bandwidth increased drastically to 234.4 MHz. We see that there is an increment of 209.6433% in the bandwidth as compared to conventional patch antenna.

To summarize and tabulate all the results as the number of iterations increase, we compare the parameters such as resonant frequency, radiation efficiency at resonant frequency, total efficiency at resonant frequency, directivity at resonant frequency, and bandwidth. This work is done in Table 3.

3.2 Proposed Antenna

The return loss plot for the final antenna after third iteration and EBG is shown in Fig. 9. The resonant frequency for the same is 8.592 GHz.

The voltage standing wave ratio (VSWR) plot shows good matching at frequency 8.592 GHz and is shown in Fig. 10.

The plot for directivity (3D, radiation efficiency) vs frequency is shown in Fig. 11.

The plot for gain (in dB) with respect to frequency is given in Fig. 12.

The plot for polar directivity (2D) at resonant frequency (8.592 GHz) with respect to phi is shown in Fig. 13.

Figure 14 represents the directivity of the proposed antenna. We see that the directivity is 4.595 dB at the resonant frequency which is much higher as compared to that of conventional patch antenna, i.e., 4.034 dB.

Figure 15 shows the gain (IEEE) pattern of the proposed antenna. We see that the gain at the resonant frequency is 4.064 dB which is very large as compared to that of conventional patch antenna, i.e., 1.443 dB.

After performing the analysis on the antenna by changing the number of iterations, it is clear that antenna improves its performance as we increase the number of iterations. The operational frequency of the antenna is found to be lowered when the number of iterations is increased. Also, it is found that EBG is responsible for the increment in bandwidth from 75 MHz to 234 MHz. The same trend is followed in radiation efficiency, directivity and gain. Hence, the proposed antenna is the most optimal antenna among all of them.

Table 3 Performance analysis

	Conventional Patch	Conventional patch with EBG	First iteration	First iteration with EBG	Second iteration	Second iteration with EBG	Third iteration	Third iteration with EBG
Return loss resonant frequency (GHz)	9.204	9.708	8.988	8.604	9.036	8.604	9.036	8.592
Radiation efficiency at resonant frequency (%)	55.07	31.16	93.6	89.38	93.39	89.53	93.08	88.49
Total efficiency at resonant frequency (%)	51.21	28.31	93.58	89	93.39	89.01	93.08	87.96
Directivity at resonant frequency (%)	4.034	4.712	4.025	4.584	4.009	4.588	3.994	4.595
Bandwidth (MHz)	75.7	40.6	169.9	206.8	212.3	165.6	220.7	234.4

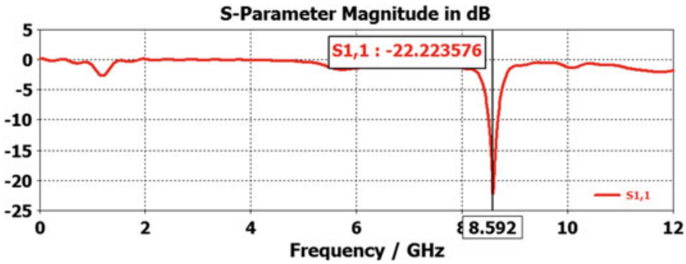

Fig. 9 Return loss plot of the proposed antenna

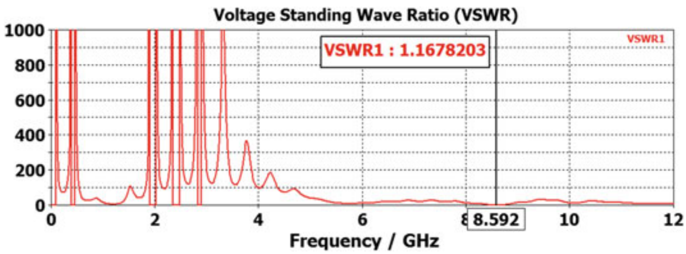

Fig. 10 VSWR plot of the proposed antenna

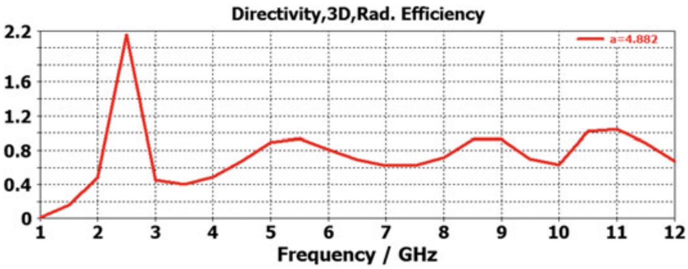

Fig. 11 Directivity versus frequency

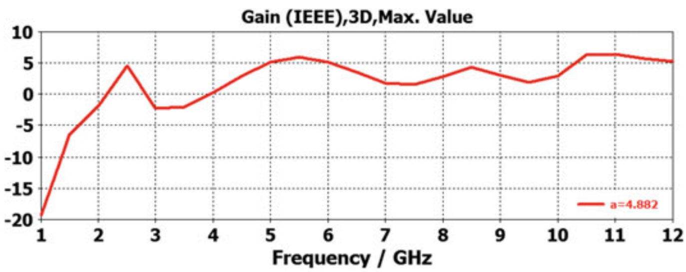

Fig. 12 Gain versus frequency curve

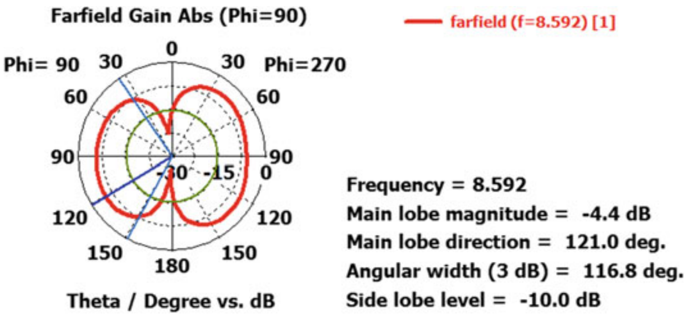

Fig. 13 Polar directivity (2D) at resonant frequency 8.59 GHz

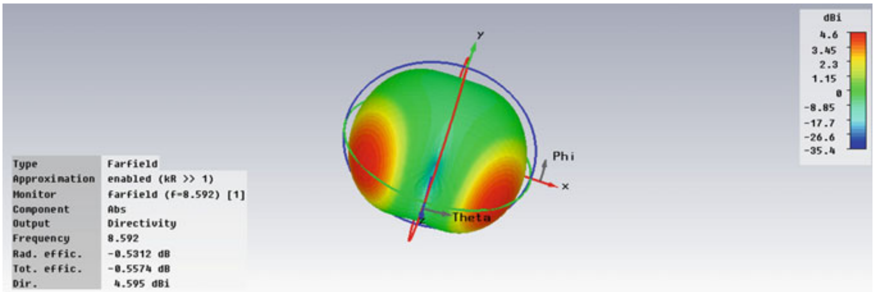

Fig. 14 Directivity pattern of the proposed antenna

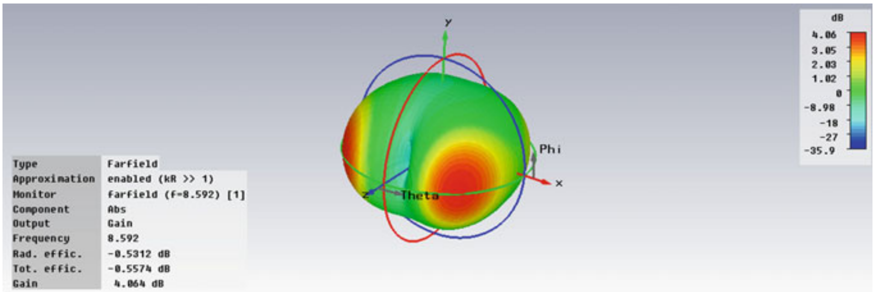

Fig. 15 Gain (IEEE) radiation pattern of the proposed antenna

4 Conclusion

The proposed antenna shows better results in terms of return loss, bandwidth, radiation efficiency, and directivity. The analysis of the antenna with respect to number of iterations and changing ground plane is done extensively, and the results are verified by CST Microwave Studio 2011. The geometry lowers the frequency of operation and increases the bandwidth with good axial ratio which is well suited for X-band applications including high-imaging radars and ultra-wideband (UWB) biomedical applications.

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Optical And Microwave Technologies
Select Proceedings of ICNETS2, Volume IV
Gnanagurunathan, G.; Sangeetha, R.G.; Kiran, K.U.
(Eds.)
2018, X, 316 p. 284 illus., 215 illus. in color., Hardcover
ISBN: 978-981-10-7292-5