Sierpinski Gasket Fractals Implemented as Electromagnetic Band Gap (EBG) Structures on a Multiband Antenna for WLAN/WiMAX Applications

Praveenkumar Patil Kedar, **G. S. Karthikeya**, **Gowda N. G. Monish**, **and Bhaskar Harsha**
Antenna Research Laboratory, Department of Electronics and Communication Engineering
B.M.S. Institute of Technology & Management, Vishweshwaraya Technological University, India

Abstract— Implementation Sierpinski Gasket Fractals on Band Reject L Slot printed Patch Antenna is investigated as Electromagnetic Band-Gap (EBG) Structures. Various iterations of the fractals are performed and investigated in the frequency range from 2 GHz to 5 GHz. Initially, the gain of the patch antenna over the frequency range is measured for reference. Later, different designs of the same fractals are loaded as EBG on the antenna. The peak gain of the reference is found out to be 2.38 dB and variations from it, after loading with EBG, are studied.

1. INTRODUCTION

Over the years the need for planar antennas with desirable attributes has been growing steadily in both the military and commercial sectors. Few of these attributes include compact size, low profile, high gain, multiband or broadband and various combinations of the same [1, 2]. But it has not been possible to incorporate all of these attributes together in a single antenna. This has been a major challenge in antenna design and researchers world-wide are looking into fractals geometry for the answers.

The term fractal was first used by the mathematician Mandelbrot. It means "broken" or "fractured" and extended to geometric patterns found in nature [3]. It basically describes a family of geometries shapes that are self-similar on different scales. The original geometries were devised from the study of the ones occurring in nature. The combination of these fractal geometries and electromagnetics is now paving way for investigation of novel electromagnetic structures.

In recent years, researchers around the globe have been growing interested in fractals due to their natural occurrence and are devising ways to implement them in the current trend of antennas [4, 5]. Few of the most commonly used fractal geometries are Sierpinski Gasket, Koch Snowflake, Menger Sponge and Hilbert Curve [6–8]. The aim of this is to investigate electromagnetic properties related to these fractal geometries and, possibly, find a solution to current hurdles in antenna design and research [9]. There are mainly two active areas in fractal antenna research: (1) the study of fractal shaped antenna elements and (2) incorporation of these fractal geometries in antennas arrays.

Electromagnetic Band-Gap (EBG) Structure is an area of metamaterial antenna research in which researchers are growing interested and investigating. Loading EBG to antennas imparts, to the antennas, many properties including surface wave suppression, band rejection or increased gain [10]. But there has not been much research on fractals loaded as EBG. The amalgamation of these two areas of research is yet to be explored.

This paper has been divided into five sections. First a brief theory on EBG is stated. Next the construction details of the proposed antenna are discussed along with the investigation results and conclusion.

2. EBG STRUCTURES

Many fascinating periodic structures are found in nature. These structures, when they interact with electromagnetic waves, find many applications in filter designs, gratings, frequency selective surfaces, photonic crystals, and photonic band gaps. These structures are classified together under one broad term, namely "Electromagnetic Band Gap (EBG)" Structures. In general EBG structures can be defined as artificial periodic structures which direct the propagation of electromagnetic waves in a specified band for any combination of incident angle and polarization state [11].

Realization of EBG structures is usually done through periodic arrangement of metallic conductors and dielectric materials. According to the geometry of these structures, they can be classified, generally, under three categories: three dimensional volumetric structures, two dimensional planar structures and one dimensional transmission lines. Two dimensional structures are the ones mostly used in antenna engineering [11].

3. ANTENNA DESIGN

The dimensions of the L Slot Patch Antenna [12], which is selected as the test antenna for Fractals loaded as EBG, is given in Fig. 1. The antenna has a FR4 epoxy substrate of thickness 1.6 mm with a dielectric constant 4.4 and loss tangent of 0.02. The overall dimension of the test antenna is $35\,\text{mm} \times 30\,\text{mm} \times 1.6\,\text{mm}$. Excitation is given to the microstrip line at edge of the substrate represented by X in Fig. 1. The dimensions in the figures are as follows: $L1 = 19\,\text{mm}$; $L2 = 10\,\text{mm}$; $L3 = 15\,\text{mm}$; $L4, L8, L11 = 14\,\text{mm}$; $L5, L7 = 1.5\,\text{mm}$; $L6 = 1\,\text{mm}$; $L9 = 6\,\text{mm}$; $L10 = 7\,\text{mm}$.

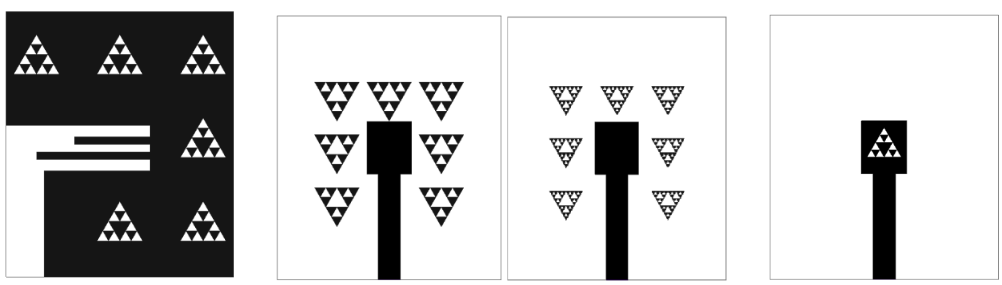
The basic fractal structure consists of a basic equilateral triangle. In the first iteration of the fractal structure, the triangle is divided into four equilateral triangles and the middle triangle is omitted. In subsequent iterations, the process is repeated for the newly formed equilateral triangles. The second and the third iteration of the fractal structure are shown in Fig. 2.

(a) (b)

Figure 1: (a) Top view. (b) Bottom view.

(a) (b)

Figure 2: (a) Second iteration fractal. (b) Third iteration fractal.



(a) (b) (c)

Figure 3: (a) Fractals loaded on the Ground Plane. (b) Fractals loaded, around the patch, on the bottom of the antenna. (c) Fractal loaded as slot on the patch.

3.1. Fractals Loaded on the Ground Plane as Slots

In this configuration, the fractals are etched out of the ground plane as slots. Parametric analysis is done and the side of the fractals is varied from 3 mm to 4.5 mm, the gap between the fractals is varied from 7 mm to 11 mm and the orientation of the fractals is changed from 0° to 180°. This is shown in Fig. 3(a).

3.2. Fractals Loaded as EBG around the Patch

Fractals are arranged around the patch on the bottom plane of the substrate and parametric analysis is done. The side of the fractals is varied from 3 mm to 4.5 mm, the gap between the fractals is varied from 7 mm to 11 mm and the orientation of the fractals is changed from 0° to 180°. The design is shown in Fig. 3(b).

3.3. Fractal Slots on the Patch

The fractal structure is etched out of the patch and parametric analysis is done. The side of the fractal is varied from 3 mm to 4.5 mm and the orientation of the fractal is varied by rotating it from 0° to 360°. This is shown in Fig. 3(c).

4. RESULTS AND DISCUSSION

4.1. Fractals Loaded on the Ground Plane

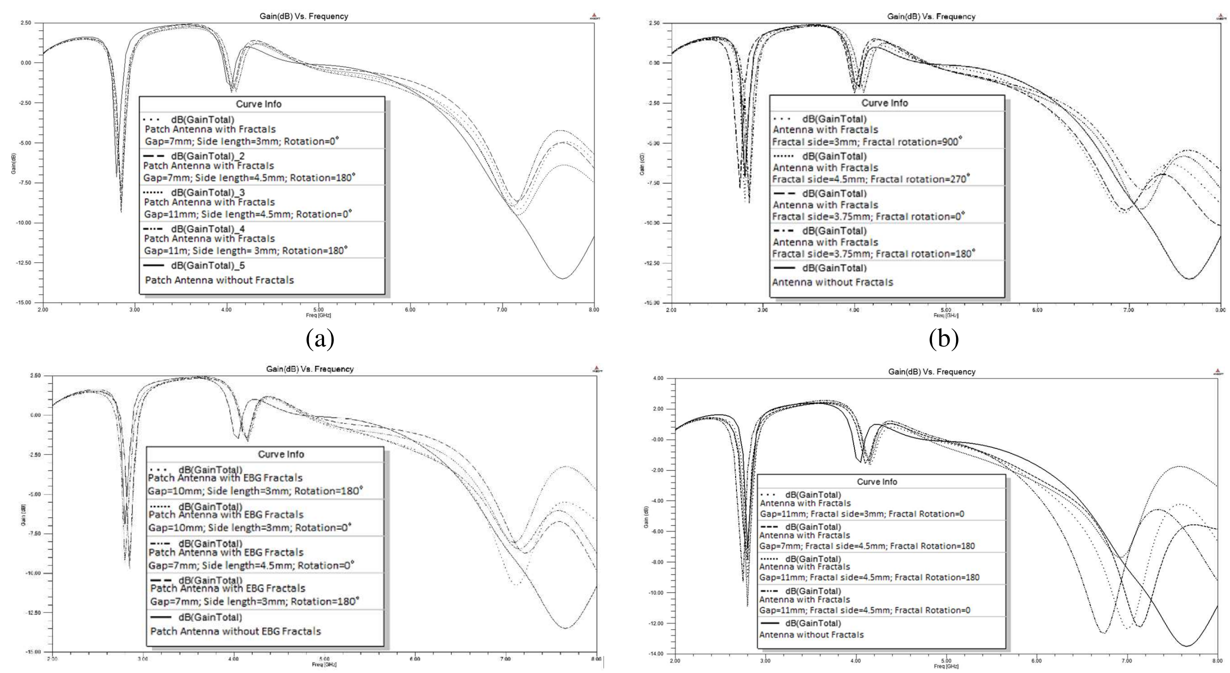
The second iteration fractal is analyzed in this design. It is observed that there is no considerable change in the peak gain of the antenna. After the Parametric analysis, the peak gain is found to be 2.42 dB at 3.6 GHz frequency. This can be seen in Fig. 4(a).

4.2. Fractal Slots on the Patch

The second iteration fractal is analyzed in this design. It is observed that there is no considerable change in the peak gain of the antenna. After the Parametric analysis, the peak gain is found to be 2.40 dB at 3.5 GHz frequency. This can be seen in Fig. 4(b).

4.3. Fractals Loaded as EBG around the Patch

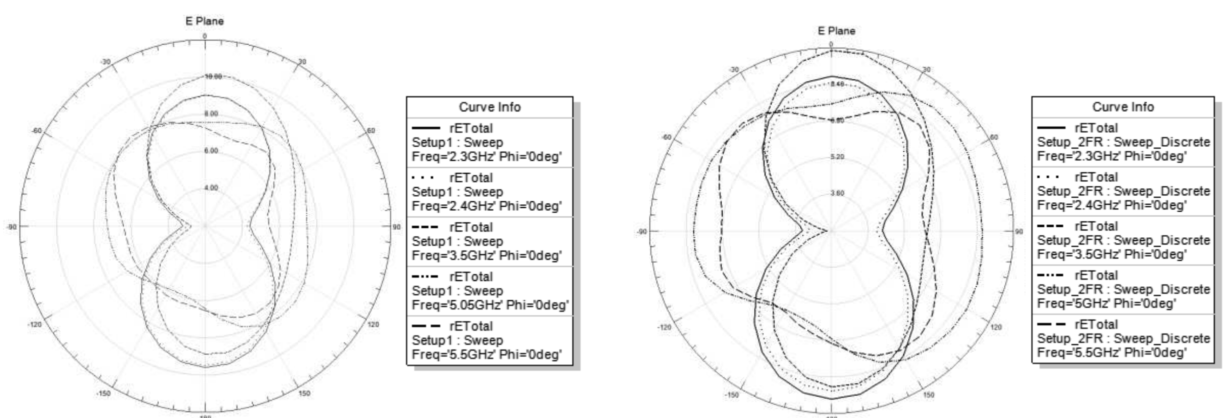
The third and second iteration of the fractal structures are analyzed in this design and it is observed that there is no considerable change in the peak gain of the antenna. After the parametric analysis, it is found that the peak gain of the second iteration fractal loaded design is 2.55 dB and the



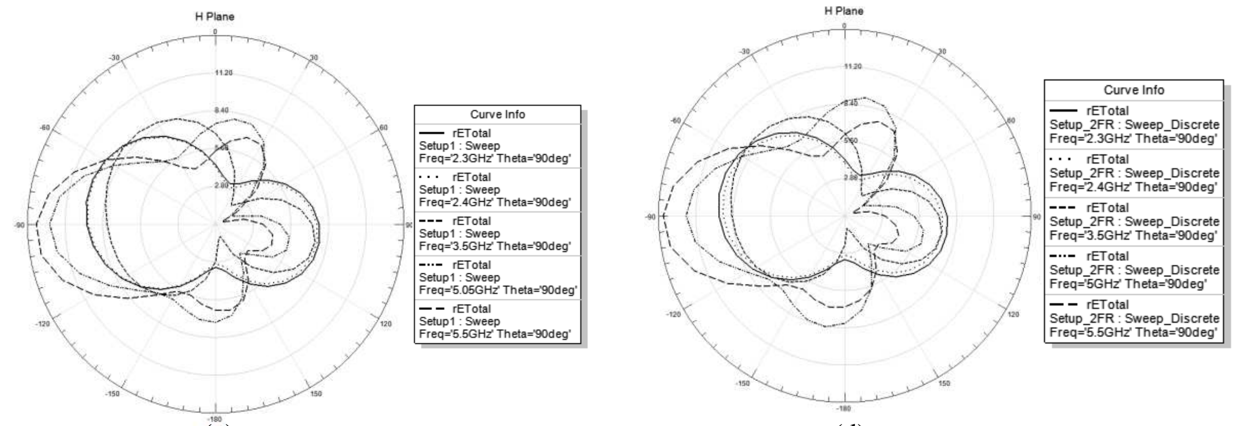
(a) (b)

(c) (d)

Figure 4: Gain (dB) versus Frequency graph. (a) Second Iteration fractals loaded as EBG slots on the top plane. (b) Second iteration fractals loaded as EBG, on the patch, on the bottom plane. (c) Third iteration fractals loaded as EBG, around the patch, on the bottom plane. (d) Second iteration fractals loaded as EBG, around the patch, on the bottom plane.

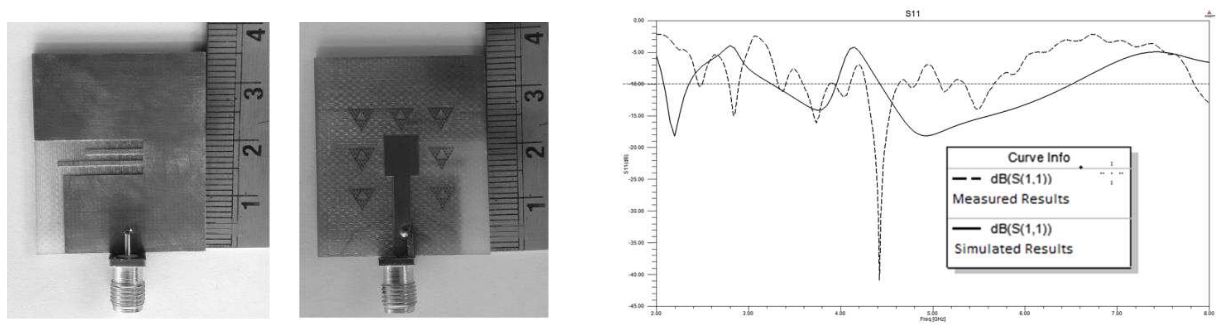


(a) (b)



(c) (d)

Figure 5: E plane radiation pattern of the patch antenna. (a) Without fractals. (b) With Fractals. H plane radiation pattern of the patch antenna. (c) Without Fractals. (d) With fractals.



(a) (b)

Figure 6: (a) Fabricated antenna top and bottom view as shown in Fig. 1. (b) S_{11} Graph of simulated results versus measured results of the fabricated antenna.

peak gain of the third iteration fractal loaded design is 2.51 dB. This can be seen in Fig. 4(c) and Fig. 4(d). The radiation pattern of the design with peak gain for third iteration fractals is plotted in Fig. 5(b) and Fig. 5(d).

5. CONCLUSION

A novel approach of Sierpinski Gasket Fractals to be loaded as EBG is presented. Before introducing the EBG structures the gain of the antenna is measured to 2.38 dB. A peak gain of 2.55 dB is obtained after introducing the fractal structures in the antenna in various proposed designs. There is not considerable increase in gain in the WLAN/WiMAX frequency range. However, the variations in gain increase after 5 GHz frequency for most of the designs.

ACKNOWLEDGMENT

Firstly, we would like to thank the nature and Dr. Benoit B. Mandelbrot for inspiring us to do research on fractal inspired structures. Secondly, we would like to thank Dr. Hari Prasad S. A. (Head of Department, Department of Electronics and Communication Engineering, B.M.S. Institute of Technology & Management) for his continued encouragement and support for our research. Finally we would like to thank Anritsu India Pvt Ltd and Entuple Technologies Pvt Ltd for helping us with fabrication and testing of the antenna.

REFERENCES

1. Stutzman, W. L. and G. A. Thiele, *Antenna Theory and Design*, John Wiley & Sons, 2012.
2. Wong, K.-L., *Compact and Broadband Microstrip Antennas*, Vol. 168, John Wiley & Sons, 2004.
3. Mandelbrot, B. B., *The Fractal Geometry of Nature*, Macmillan, 1983.

4. Werner, D. H., R. L. Haupt, and P. L. Werner, "Fractal antenna engineering: The theory and design of fractal antenna arrays," *IEEE Antennas and Propagation Magazine*, Vol. 41, No. 5, 37–58, 1999.
5. Werner, D. H. and S. Ganguly, "An overview of fractal antenna engineering research," *IEEE Antennas and Propagation Magazine*, Vol. 45, No. 1, 38–57, 2003.
6. Puente-Baliarda, C., et al., "On the behavior of the Sierpinski multiband fractal antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 46, No. 4, 517–524, 1998.
7. Baliarda, C. P., J. Romeu, and A. Cardama, "The Koch monopole: A small fractal antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 48, No. 11, 1773–1781, 2000.
8. Vinoy, K. J., et al., "Resonant frequency of Hilbert curve fractal antennas," *IEEE Antennas and Propagation Society International Symposium, 2001*, 2001.
9. Balanis, C. A., *Antenna Theory: Analysis and Design*, John Wiley & Sons, 2012.
10. Rahmat-Samii, Y. and H. Mosallaei, "Electromagnetic band-gap structures: Classification, characterization, and applications," *Eleventh International Conference on Antennas and Propagation, 2001. (IEE Conf. Publ. No. 480)*, Vol. 2, IET, 2001.
11. Yang, F. and Y. Rahmat-Samii, *Electromagnetic Band Gap Structures in Antenna Engineering*, Cambridge University Press, Cambridge, UK, 2009.
12. Chen, W.-S. and K.-Y. Ku, "Band-rejected design of the printed open slot antenna for WLAN/WiMAX operation," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 4, 1163–1169, 2008.
13. Karthikeya, G. S., S. Kaundinya, and S. A. Hariprasad, "Dual band hexagonal microstrip antenna loaded with hexagonal and cylindrical EBG," *2014 IEEE Fifth International Conference on Communications and Electronics (ICCE)*, IEEE, 2014.
14. Pozar, D. M., *Microwave Engineering*, John Wiley & Sons, 2009.
15. Boyle, A. P., et al., "Comparative analysis of regulatory information and circuits across distant species," *Nature*, Vol. 512, No. 7515, 453–456, 2014.
16. Gujral, M., J. L.-W. Li, T. Yuan, and C.-W. Qiu, "Bandwidth improvement of microstrip antenna array using dummy EBG pattern on feedline," *Progress In Electromagnetics Research*, Vol. 127, 79–92, 2012.
17. Boutejdar, A., A. A. Ibrahim, and E. P. Burte, "A compact multiple band-notched planer antenna with enhanced bandwidth using parasitic strip lumped capacitors and DGS-technique," *TELKOMNIKA Indonesian Journal of Electrical Engineering*, Vol. 13, No. 2, 2015.