Sierpinski Array with Swastik Electromagnetic Bandgap for Ku-Band Applications

Manisha Gupta1* and Vinita Mathur2

1Department of Physics, JECRC University, Jaipur - 303905, Rajasthan, India; drguptamanisha@gmail.com
2Department of Electronics and CommunicationJECRC University, Jaipur - 303905, Rajasthan, India; vinitamathur12@gmail.com

Abstract

Objectives: Novel and miniaturized array with four elements is designed in this paper. To make it applicable for multiband applications the array elements are fractured. Improvement in terms of its performance parameters like gain and bandwidth is done by introducing Electromagnetic Bandgap (EBG) structure. The antenna is applicable for satellite applications.

Methods/Analysis: A four element array using Right Isosceles Triangular Microstrip patch Antenna (RITMA) is designed first. Further two iterations are done based on Sierpinski fractal geometry. Swastik shape electromagnetic bandgap (EBG) is then introduced into the substrate. The antennas have been modeled and optimized by using the CST Microwave Studio tool. The antennas have been designed using Rogers RT 5880 substrate (\(\varepsilon_r = 2.2\)) and a substrate height of 2.5 mm and compared with FR-4 (\(\varepsilon_r = 4.4\)) and a substrate height of 1.59 mm. Comparison is also been done with structures having EBG structures and without EBG. Both antennas have been designed using inset feed. It has been found that array with EBG exhibits better results as compared with without EBG.

Findings: New Microstrip fractal patch antenna planar array with and without swastika shape EBG structure is been proposed. The antenna works in multiband where its resonances are at 7.9, 9.7, 12.0, 14.1, 16.2, and 18.5 GHz within 7-19 GHz. Bandwidth obtained is 165.7, 186.8, 444, 450, 549, 594 MHz, and Gain 7.39, 10.96, 7.39, 9.73, 10.14, 9.21dB respectively at these resonances. Both antennas shows multiband behavior but area used is less in EBG structure.

Novelty/Improvement: In this paper, an approach for multi-band antennas is proposed. First an RITMA array with four elements is designed. It is then fractured using Sierpinski fractal, on the substrate EBG structure is added to get better results. The antenna shows compact dimensions with good return loss and pattern performance to be adopted for satellite applications.

Keywords: Array, Fractal, Inset Feed, Microstrip Patch Antenna, Sierpinski Structure, Swastik Electromagnetic Bandgap

1. Introduction

Microstrip antenna has various applications in fields like telecommunication, satellite, medical and military1–3. However it has some limitations in its parameters like bandwidth, poor polarization and gain. Fractal antennas play a vital role to make an antenna applicable for multiband applications. Although fractals can be constructed using iterations; this technique is known as Iterated Function Systems (IFS)4,5. One fractal structure that has aroused particular interest is the Sierpinski gasket which, was first given by Puente6. In the progression of its fractal iteration, the structural behavior translates to a log-periodic allocation of frequency bands as given by (1), where \(\delta\) is the scale factor ratio.

\[
\delta = \frac{h_n}{h_{n+1}} = 0.5
\]

where, \(n\) represents the number of iterations and \(h\) represents the height of the patch.

Further gain and radiation pattern can be increased by amendments in substrate i.e. its material, height and tan \(\delta\). Due to surface wave generation the efficiency of the antenna starts reducing because increase of thickness of substrate. EBG structure helps in the reduction of this effect8–11. EBG structures are artificial regular objects that bypass the generation of electromagnetic waves.

*Author for correspondence
in a particular band of frequency for all angles and all polarization states. EBG structures also have the effect of size reduction of the patch which is of importance to current devices. Dimensions, periodicity, and permittivity are the features on which the bandgap structure depend\textsuperscript{12,13}. The EBG structure shapes are integrated with MPA on a ground plane; here ground is changed by a high impedance EBG layer. However fractal on patch and EBG on substrate or ground helps reduce the size of antenna considerably. EBG has some standard shapes like mushroom-like, UC-PBG, fork-like, and spiral-like\textsuperscript{14–17}.

In this paper Sierpinski fractal shape has been taken as basic element and a four element array is formed. To reduce the coupling and improve the performance of antenna swastika shape periodic EBG structure is formed on substrate. At higher frequency range i.e. Ku band (12-18 GHz) which is the portion of electromagnetic spectrum in the microwave range.

Section II discusses the antenna structure and design; Section III shows the effect of key parameters taken Section IV analyzes the results and effect of different iterations and EBG on array.

2. Antenna Structure and Design

A planar array using right isosceles triangular microstrip patch antenna (RITMA) is first designed but to make it operable in multiband it is been fractured. Standard fractal design taken is Sierpinski fractal as it occupies less area and space.

Using the cavity model, and assuming perfect magnetic side walls, the generalized resonant frequency of right angled isosceles triangular patch is given by equation (2) whereas of low dielectric constant and considering fringing fields is given by\textsuperscript{18}.

\[
f_{m,n} = \frac{c}{2a} \sqrt{\frac{m^2 + n^2}{\varepsilon_r}}
\]  (2)

where, \(c\) is the velocity of light, \(m\) and \(n\) are integers (mode indices), \(\varepsilon_r\) is the substrate relative permittivity, and \(a\) is the side of triangle.

The log-periodic behavior of the antennas is clearly declared when the frequency at each band is considered. Except for the first band, the resonant frequencies for the Sierpinski antenna can be evaluated as in equation (3)\textsuperscript{19}.

\[
f_r = 0.152 \frac{c}{h} \cos (\frac{\alpha}{2}) (\delta^n)
\]  (3)

where, \(h\) height of the monopole; \(\alpha\) flare angle; \(n\) band number.

The swastika type EBG designed on substrate in this paper is made by adding a discontinuation in the cross hair type EBG. Its equivalent circuit\textsuperscript{20} is as shown in Figure 1(a). The swastika type EBG is made on the same substrate as the antenna. The swastika EBG has good transmission output and better bandwidth than the two EBGs (Mushroom and Cross hair).

A Sierpinski fractal array with two iterations and 4 elements in planar form as 2’2 is designed and with 4’4 swastika shape EBG structure. Distance between patches is 20mm Structure of array is as shown in Figure 1 (b). Table 1. Shows the design parameters used for designing array.

![Figure 1](image-url)
increase in the dielectric constant of the material used in substrate will reduce the length of the patch. This method reduces the narrow impedance bandwidth of the patch antenna. As observed from Figure 3 return loss of antenna with EBG structure and using Rogers RT Duroid \( (\varepsilon_r = 2.2) \) as material shows multiband behavior with better values of return loss however if FR-4 is used as material and EBG structure is not formed then only at 11.1GHz it gives better value of -50dB and at all other frequencies the values are less. So although Rogers is costly but as it gives good results and good bandwidth so it is mostly preferred.

3.2 Effect of Substrate Thickness

Figure 4 shows the return loss with variation in substrate thickness with EBG structure. Substrate taken is Rogers RT Duroid 5880 on which this variation is done. From Figure 4 it is observed that with thickness as 2.5mm it gives better values of return loss at all resonant frequencies. As can be observed from Figure 4 that taking the thickness as 1mm of the substrate, antenna is not operational.

Table 1. Design parameters

| Antenna Part | Parameters | Values |
|--------------|------------|--------|
| Substrate    | Material   | Rogers RT Duroid 5880 |
|              | Permittivity (\( \varepsilon_r \)) | 2.2 |
|              | Dimensions (L’W’) | 90’90 mm² |
|              | Thickness   | 2.5 mm |
| Patch        | Length of base of patch (a) | 2.5 mm |
|              | Distance between patches | 20 mm |
|              | Length of main feed (L) | 35 mm |
|              | Width of main feed (W) | 6 mm |
|              | Length of feed between patches (L2) | 20 mm |
|              | Width of feed between patches (W2) | 5 mm |
| Feed         | Length of small feed | 6 mm |
|              | Width of small feed | 5 mm |
|              | Length of main feed | 10.5 mm |
|              | Width of main feed | 12 mm |
| Quarter Wave feed | Length (d) | 10 mm |
| Swastik EBG Structure | Width (c) | 10 mm |

Table 2. Comparison results of different iterations at resonant frequencies (GHz)

| Resonant Frequency (GHz) | Zero Iteration | 1st iteration | 2nd iteration | 2nd iteration with EBG |
|--------------------------|----------------|---------------|---------------|------------------------|
| 7.92                     | -25.1          | -15.78        | -19.44        | -16.94                 |
| 9.70                     | -11.10         | -19.45        | -13.632       | -10.71                 |
| 12.05                    | -12.39         | -12.35        | -19.56        | -25.32                 |
| 14.10                    | -19.77         | -19.83        | -15.76        | -17.64                 |
| 16.25                    | -19.14         | -23.06        | -19.61        | -30.79                 |
| 18.5                     | -26.78         | -25.69        | -18.29        | -22.81                 |

3. Effect of Key Parameters

3.1 Effect of Substrate Material

The resonant frequency of the aerial is inversely proportional to substrate material i.e. \( \sqrt{\varepsilon_r} \); thus, with
at higher frequencies and bandwidth observed is also very less. However gradually increasing the thickness and observing the results the best value observed is at 2.5mm.

3.3. Effect of Feed Width Variation

Figure 5 shows the variation of feed width with respect to frequency. As analyzed from the figure keeping the width as 6mm maximum return loss is observed.

4. Results and Discussions

Keeping these parameters constant further results are observed of EBG structure. Figure 6 shows the phase plot of the structure. It can be observed that at higher frequencies it is not symmetrical as seen at frequencies below 12GHz.

Radiation patterns of the proposed antenna are simulated in E and H planes and shown in Figure 7. As can be observed from the Figure the side lobes are suppressed. Figure 7 (a) shows the pattern in E-plane and (b) shows in H-plane. At higher frequencies pattern is more directional. The patterns are at different resonant frequencies of return loss.

Figure 8 shows the plot between impedance and frequency for Ku band. Both real and imaginary part of impedance is shown. It can be observed from the graph that the real part is high because of the resonance characteristics. Figure 9 shows the Gain vs. Frequency plot with and without EBG. As seen with increasing frequency there is marginal increase in gain of array but results of EBG are better than that without EBG. Figure 10 the graph of radiation efficiency vs. frequency of EBG and
without EBG structure. Radiation efficiency is the ratio between realized gain and directivity.

Figure 11 shows the group delay graph with EBG structure. Figure 12 shows the axial ratio of the patch antenna.

Table 3 shows a comparison between all output parameters with and without EBG structure.

Figure 12. Axial ratio of array with EBG structure.
### Table 3. Comparison values of without EBG and EBG structures

|                      | Without EBG | EBG       |
|----------------------|-------------|-----------|
| **Resonant Frequency (GHz)** | 7.6, 9.4, 11.8, 13.90, 15.85, 18.23 | 7.9, 9.7, 11.99, 14.23, 16.23, 18.55 |
| **Bandwidth (MHz)**    | 147.7, 340, 448, 503, 558, 590    | 165.7, 186.8, 444, 450, 549, 594    |
| **Gain (dB)**          | 10.47, 9.29, 7.73, 9.54, 9.24, 8.49 | 7.39, 10.96, 7.93, 9.73, 10.14, 9.21 |
| **Directivity (dBi)**  | 9.99, 8.74, 7.13, 8.89, 8.73, 8.04 | 6.66, 10.38, 7.23, 9.04, 9.51, 8.65 |
| **VSWR**               | 1.26, 1.85, 1.25, 1.42, 1.26, 1.32 | 1.34, 1.82, 1.23, 1.45, 1.08, 1.16 |

### 5. Conclusion

New Microstrip planar patch antenna array is designed for Ku-band to make it applicable for satellite purpose. To further improve its performance and make it applicable for multiband the patch is fractured by Sierpinski fractal structure, two iterations are been done that reduces the area of the array. Comparison is been done with variations in feed thickness, feed width and with and without EBG structure. It is been analyzed that adding fractal on patch and EBG on substrate improves its output in terms of bandwidth and gain.

### 6. References

1. Munir ME, Farooq U. Multiband microstrip patch antenna using DGS for L-band, S-band, C-band and mobile applications. 2016 13th International Conference on Modern Problems of Radio Engineering, Telecommunications and Computer Science (TCSET), Lviv; 2016 Feb 23–26. p.198–201.
2. Richitha M, Kumar VS, Dwivedi RP. High performance broadband polarizer for Ka band applications. Indian Journal of Science and Technology. 2015 Aug; 8(19):1–5. DOI: 10.17485/ijst/2015/v8i19/76225.
3. Nisha ASA. Hybrid coupled feed circularly polarized patch antenna for military applications. Indian Journal of Science and Technology. 2015 Nov; 8(29):1–4. DOI: 10.17485/ijst/2015/v8i29/63684.
4. Gianvittorio JP, Samii YR. Fractal antennas: a novel antenna miniaturization technique, and applications. IEEE Antennas Propagation Magazine. 2002; 44(1):20–36.
5. Mezaal YS. New compact microstrip patch antennas: Design and simulation results. Indian Journal of Science and Technology. 2016 March; 9(12):1–6. DOI: 10.17485/ijst/2016/v9i12/85950.
6. Werner DH, Ganguly S. An overview of fractal antenna engineering research. IEEE Antennas Propagation Magazine. 2003 Mar; 45(1):38–57.
7. Puente C, Romeu J, Pous R, Garcia X, Benítez F. Fractal multiband antenna based on the Sierpinski gasket. IEE Electronic Letter. 1996 Jan; 32(1):1–2.
8. Song CTP, Hall PS, Shiraz HG. Shorted fractal Sierpinski monopole antenna. IEEE Transactions on Antennas and Propagation. 2004 Oct; 52(10):2564–70.
9. Sievenpiper D, Lijun Z, Broas RFJ, Alexopolous NG, Yablonovitch E. High impedance electromagnetic surfaces with a forbidden frequency band. IEEE Transactions on Microwave Theory and Techniques. 1999 Nov; 47(11):2059–74.
10. Li Y, Fan M, Chen F, She J, Feng Z. A novel compact Electromagnetic-Bandgap (EBG) structure and its applications for microwave circuits. IEEE Transactions on Microwave Theory and Techniques. 2005 Jan; 53(1):183–90.
11. Madhav BTP, Sanikommu M, Pranoo MNVS, Manikanta KSN, Kumar BS. CPW fed antenna for wideband applications based on tapered ground and EBG structure. Indian Journal of Science and Technology. 2015 May; 8(9):1–9. DOI: 10.17485/ijst/2015/v8i9/53392.
12. Garg TK, Gupta SC, Pattnaik SS. Metamaterial loaded frequency tunable electrically small planar patch antenna. IEEE Transactions on Microwave Theory and Techniques. 2002 Sep; 50(9):1285–90.
13. Coccioli R, Yang FR, Ma KP, Itoh T. Aperture-coupled patch antenna on UC-PBG substrate. IEEE Transactions on Microwave Theory and Techniques. 1999 Nov; 47(11):2059–74.
14. Zheng QR, Lin BQ, Fu YQ, Yuan NC. Characteristics and applications of a novel compact spiral Electromagnetic Band-Gap (EBG) structure. Journal of Electromagnetic Waves and Applications. 2007 Apr; 21(2):1991–213.
15. Cheng HR, Song QY. Design of a novel EBG structure and its application in fractal microstrip antenna. Progress in Electromagnetics Research C. 2009; 11:81–90.
18. Gupta M, Mathur V. Analysis of Right angled Isosceles Triangular Microstrippatch Antenna (RITMA) for UWB application. IEICE Communication Express. 2016 Jan; 5(1):13–18.
19. Song CTP, Hall PS, Shiraz HG. Perturbed Sierpinski multiband fractal antenna with improved feeding technique. IEEE Transactions on Antennas and Propagation. 2003 May; 51(5):1011–17.
20. Kushwaha N, Kumar R. Study of different shape Electromagnetic Gap (EBG) structures for single and dual band applications. Journal of Microwaves, Optoelectronics and Electromagnetics Applications. 2014 June; 13(1).
21. Gupta M, Mathur V. Design of compact triangular patch antenna for WiMaX applications. 2016 International Conference on Recent Cognizance in Wireless Communication and Image Processing; 2016 April 29. p. 791–5.