Modified Sierpenski Antenna With Metamaterial For Wireless Applications

Ishita Aggarwal, Sujata Pandey*
Amity School of Engineering and Technology, Amity University, Uttar Pradesh
*Amity Institute of Telecom Engineering and Management, Amity University Uttar Pradesh, India
Corresponding author email id: spandey@amity.edu

Abstract: This paper presents a multiband antenna based on modified sierpenski fractal structure along with metamaterials for wireless applications. Multi bands are obtained at 2.1 GHz, 5.73 GHz, 7.6 GHz and 8.4 GHz with return losses -21.49 dB, -36.36 dB, -45 dB, and -23.46 dB respectively. The dimension of the substrate used for this antenna is 52 x 60 x 1.6 mm³ and dielectric constant is 4.4 with tan δ of 0.002. The peak gain of 6.6 dB, return loss of -45 dB and VSWR of 1 are obtained at 7.6 GHz. Metamaterial unit cells are loaded on ground to improve the antenna parameters. This is a simple and compact design and has multiband features suitable for WIMAX, WLAN, C-band and X-band applications. This design is simulated by using HFSS 14.

Keywords: Microstrip antenna, Metamaterial, multiband, Sierpenski, Complementary Split ring resonator

1. INTRODUCTION

In today’s world of increasing devices, multiband antennas have an important role to play. This multiband behaviour of an antenna can be realized by using fractal structures. Fractal antennas used to be miniature in size because of its self-similar and space filling geometrical structures. Similarly metamaterials are seen to decrease the size of antenna along with improved antenna features due to its special kind of structures created on the ground, substrate and other places of antenna. The bandwidth and the gain of antenna are observed to be improved by introducing a metamaterial at the ground of antenna [1][2]. Different metamaterial structures like SRR, CSRR are reported in the literature for this purpose [3][4].

This paper presents a hybride design of antenna based on metamaterials and fractal structures. It has a contribution towards obtaining miniaturized form of multiband antenna with the increased gain and bandwidth. Use of slots at the ground plane gives noticeable change in performance of antenna. Slots on ground plane improve the antenna parameter by showing negative permeability and permeability and reducing surface waves. Metamaterial loading technique is used for enhancing the bandwidth and size reduction of antenna. Thus, the metamaterial loading and fractal structures of antenna endow the advantages of miniaturization, enhancement of bandwidth and gain.

This paper is described as follows; Section 2 outlines the antenna design and configurations, results and discussion section is presented in section 3 and conclusion is made in section 4.
2. ANTENNA DESIGN

An equilateral triangular patch antenna with side length of 40 mm is shown in the figure 1. The dimension of the substrate is 52 x 60 x 1.6 mm$^3$ with relative permittivity of 4.4 and tanδ of 0.002. The feeding technique used in this antenna is Microstrip line feeding. For calculating side length of triangular shape patch antenna, following relation is considered

$$a = \frac{2c}{3f_r \sqrt{\varepsilon_r}}$$

Where $c = 3 \times 10^8$, $\varepsilon_r$ is the permittivity of the substrate and $f_r$ is the resonance frequency.

Iteration 1 is constructed by subtracting a central inverted equilateral triangle of side 16.4 mm from the main triangle. One circular ring is added inside the central triangle having a width of 2.5 mm. After this the process of iteration 2 is carried out. Where, three equilateral triangles were created on the space available in the patch. The side of these triangles is 6.5 mm. The circular ring of width 1.1 mm is added in all three new triangles. Figures 3, 4 and 5 show the zeroth, first and second iterations of proposed antenna.

Fig 7 shows CSRR unit cell that is loaded on ground of the antenna in an array. The size of the array is 8 x 9 as shown in figure 2. The dimension of the unit cell is 3x3 mm$^2$. This has two split ring resonators. One is square split ring resonator (SSRR) and other is circular split ring resonator (CiSRR). This CiSRR is embedded in SSRR. The width of SSRR is 1 mm and the split gap is 0.5 mm. The width of CiSRR is 0.25 mm with a split gap of 0.25 mm. An array of these unit cells has

| S.no | Sides of triangle | Dimensions |
|------|------------------|------------|
| 1    | Iteration 0      | 40mm       |
| 2    | Iteration 1      | 16.4mm     |
| 3    | Iteration 2      | 6.5mm      |
been etched out from the ground. The proposed design reduces the electrical size of antenna by introducing a series of capacitances.

Figure 7: New metamaterial unit cell

RESULTS AND DISCUSSION

The proposed antenna is simulated using Ansys HFSS software. The following parameters are discussed in details below:

Different iteration stages of modified sierpinski antenna with and without metamaterial were simulated to analyze the influence of fractal iterations on the performance of the antenna. Fig 8 shows the reflection coefficients of sierpinski antenna with different iterations. With the increase in the number of iterations, the resonance frequencies increase and the lowest resonance frequency decreases. These are the result of this self-similar characteristics of fractal.

For 0th iteration, triangular patch antenna, three resonance frequencies were obtained at 2.33GHz, 6.19GHz and 8.28GHz with return loss of -25dB, -22.44dB and -20.14dB respectively as shown in figure 8. For the first iteration, four resonance frequencies were obtained at 2.2GHz, 6.03GHz, 8.14GHz and 9.8GHz with return loss of -33.39dB, -29dB, -16.25dB and -19dB. For the second iteration, four resonance frequencies are obtained which are 2.2GHz, 5.95GHz, 8GHz and 9.7GHz with return loss of -22.8dB, -42.4dB, -12.9dB and 25.25dB. From the Figure 8, it can be concluded that at iteration 0 the return loss at 6.19GHz is -22.44dB whereas at iteration 2 the value has increased to -42.4dB at 5.95GHz.

Figure 8: Return loss of iteration 0 to 2
As shown in figure 9, for iteration 0 the VSWR for the resonance frequencies 2.33GHz, 6.19GHz and 8.28 GHz are 1.25, 1.42, 1.25. For the first iteration, VSWR for resonance frequencies 2.2GHz, 6.03GHz, 8.14GHz and 9.8GHz are 1.07, 0.91, 1.3 and 0.91. The VSWR for second iteration corresponding to resonance frequencies 2.2GHz, 5.95GHz, 8GHz and 9.7GHz are 1.43, 0.95, 1.5 and 0.79. From the Fig, it can be seen that at frequency 6.19 GHz, the value of VSWR is decreasing from 1.42 in iteration 0 to 0.95 in iteration 2.

![Figure 9: VSWR of iterations 0 to 2](image)

From the table 2, it can be seen that the with increase in the number of iterations, the value of return loss increases. In iteration 0, the return loss at 6.19 GHz is -22.4dB which increases to -29dB in iteration 1 and to -42.4dB in iteration 2. The value of VSWR decreases with increase in number of iterations. It can be seen that at 6.19 GHz the value of VSWR decreased to from 1.42 to 0.95 with increased number of iterations.

| Iterations | Bands | Return loss | VSWR  |
|------------|-------|-------------|-------|
| 0          | 2.33  | -25.05      | 1.25  |
|            | 6.19  | -22.4       | 1.42  |
|            | 8.28  | -20.13      | 1.25  |
| 1          | 2.2   | -33.39      | 1.07  |
|            | 6.03  | -29         | 0.91  |
|            | 8.14  | -16.25      | 1.3   |
|            | 9.8   | -19         | 0.91  |
| 2          | 2.2   | -22.8       | 1.43  |
|            | 5.95  | -42.4       | 0.95  |
|            | 8     | -12.9       | 1.5   |
|            | 9.7   | -25.25      | 0.79  |

The figure 10 shows the return loss of iteration 2 with and without metamaterial. For the second iteration, Four resonance frequencies are obtained which are 2.2, 5.95, 8, and 9.7GHz with return loss of -22.8dB, -42.4dB, -12.9dB and 25.25dB. When metamaterial is loaded at the ground the resonance frequencies obtained are 2.15GHz, 5.73GHz, 7.6GHz, 8.4GHz and 8.8GHz with return loss of -21.49dB, -36.36dB, -45dB, -23.46dB and -18.81dB. The return loss at frequency 5.95 for iteration 2 is -42.4dB which has decreased to -36.36 when
loaded with metamaterial. This shows that there has been a considerable decrease in the value of return loss of resonating frequency bands.

Fig 10 Return loss curve with and without metamaterial

The VSWR for second iteration corresponding to resonance frequencies 2.2GHz, 5.95GHz, 8GHz and 9.7GHz are 1.43, 0.95, 1.5 and 0.79. When the antenna is loaded with metamaterial, at resonating frequencies 2.15GHz, 5.73GHz, 7.6GHz, 8.4GHz and 8.8GHz, the VSWR obtained are 1.3, 1.2, 1, 1.2 and 0.28. At 5.95GHz, the value of VSWR is 0.95 which has increased to 1.2 after loading the ground. This shows that there is an increase in the value of VSWR with loading of metamaterial.

Fig 11 VSWR curve with and without metamaterial

Fig 12 and Fig 13 shows the gain vs frequency curve of antenna with and without metamaterial. At resonating frequencies 2.2GHz, 5.9GHz, 8GHz, and 9.7GHz, the value of gain obtained are -1.4dB, 4.4dB, 6dB, 6.3dB. When CSRR is loaded on the ground, at resonance frequencies 2.15GHz, 5.73GHz, 7.6GHz, 8.4GHz and 8.8GHz, the values of gain obtained are 0.1dB, 4dB, 6.6dB, 7.3dB and 6dB. It can be seen that at 2.2GHz the value of gain has increased from -1.4dB to 0.1 dB. This shows that the value of gain increases when CSRR is etched from the ground.
Figure 12: Gain vs Frequency curve of iteration 2

Figure 13: Gain vs Frequency curve of proposed antenna with metamaterial

Figure 14 shows the omnidirectional radiation pattern is obtained when the proposed antenna is simulated at $\phi=0^\circ$ and $\phi=90^\circ$ at 2.1GHz frequency. The gain obtained at 2.1GHz is 0.1dB.

Figure 14 Simulated the radiation pattern of proposed antenna(E &H plane) at 2.1GHz.

Figure 15 shows the current distribution on the patch and ground of proposed antenna at 2.4GHz.

Figure 15 Simulated current distribution of proposed antenna at 2.4GHz on patch and ground.

According to the table 3, The measured frequency bandwidth obtained for iteration 2 is 100MHz(2.15 to 2.25GHz), 141MHz(5.879 to 6.02GHz), 100MHz(7.9 to 8) and 240MHz(9.57
to 9.81GHz). When the iteration 2 is loaded with metamaterial, there is a noticeable change in the bandwidth of antenna. At resonating frequencies 2.15GHz, 5.73GHz, 7.6GHz, 8.4GHz and 8.8GHz, the bandwidth achieved is 110 MHz, 150MHz, 200MHz, 190MHz and 430MHz. This shows that there has been an increase in bandwidth and gain of antenna when CSRR is loaded.

Table 3 Comparison of antenna with and without metamaterial loading.

| Sn o | Antenna without metamaterial | Proposed Antenna |
|------|-------------------------------|-----------------|
|      | Bandwidth | Return loss | VSWR | Gain | Bandwidth | Return loss | VSWR | Gain | Bandwidth | Applications |
| 1    | 2.2        | -22.8       | 1.43 | -1.4 | 100M Hz   | 2.15        | -21.49 | 1.3  | 0.1  | 110M Hz   | L band      |
| 2    | 5.9        | -42.4       | 0.95 | 4.4  | 141M Hz   | 5.73        | -36.36 | 1.2  | 4    | 150M Hz   | WLAN/WMax  |
| 3    | 8          | -12.9       | 1.5  | 6    | 100M Hz   | 7.6         | -45     | 1    | 6.6  | 200M Hz   | C band      |
| 4    | 9.7        | -25.25      | 0.79 | 6.3  | 240M Hz   | 8.4         | -23.46  | 1.2  | 7.3  | 190M Hz   | X band      |
| 5    | 8.8        | -18.81      | 0.2  | 8    | 430M Hz   |              |         |      |      | 430M Hz   | WPAN        |

In addition, the CSRR in the ground plane plays a very important role to the performance of antenna, as the capacitance introduces by the gap can offset apart of capacitance of antenna and helps in improving the impedance matching.

CONCLUSION
A compact multiband antenna has been designed and simulated. The proposed antenna is using FR4 substrate with permittivity 4.4. The proposed multiband antenna is useful for applications like WIFI, WLAN, WMAX with gain up to 6.6dB has been obtained with a very good return loss of -45dB and VSWR of 1. By loading the metamaterial at ground (CSRR), improvement in the gain and bandwidth of the antenna has been shown. This antenna is resonating at 2.1GHz, 5.73GHz and 7.6GHz and 8.4GHz and 8.8GHz. Therefore, proposed antenna is feasible for use as a low cost multiband antenna for wireless applications.

REFERENCES
1. B.-I. Wu, W. Wang, J. Pacheco, X. Chen, T. Grzegorczyk and J. A. Kong, “A study of using metamaterials as antenna substrate to enhance gain,” Progress In Electromagnetics Research, PIER 51, 295–328, 2005.
2. M.M. Islam, M.T. Islam, M. Samsuzzaman and M.R.I. Faruque, “Compact metamaterial antenna for UWB applications,” ELECTRONICS LETTERS, Vol. 51, No. 16, pp. 1222–1224, 2015.
3. B. D. Bala, M. K. A Rahim, N.A Murad, and R. Dewan “Wideband Metamaterial Antenna Employing SRR Loading for WiMAX and WLAN Operations” 2014 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE) 8 - 10 December, 2014 at Johor Bahru, Johor, Malaysia.

4. Cheng Zhu, Member, Tong Li, Ke Li, Zi-Jian Su, Xin Wang, Hui-Qing Zhai “Electrically Small Metamaterial-Inspired Tri-Band” Antennas and Wireless Propagation Letters, IEEE (Volume:14 ), pp. 1738-1741, April 2015.

5. J.D.BaenaJ.Bonache,F.Martin,R.M. Sillero,F.Falcone,T.Lopetegi,MiguelA.G.Laso,J.Garcfa-Farcfa,M.F.Portillo and M.Sorolla, “Equivalent circuit models for split ring resonator and complementary split ring resonator coupled to planar transmission, (Volume:53 , Issue: 4 ),pp.1451 – 1461, April 2005.

6. M.M. Islam, M.T. Islam, M. Samsuzzaman and M.R.I. Faruque, “Compact metamaterial antenna for UWB applications,” ELECTRONICS LETTERS, Vol. 51, No. 16, pp. 1222–1224, 2015.

7. J.Romeu; J.Soler, "Generalized Sierpinski fractal multiband antenna” ,Volume: 49, Issue: 8,pp1237 – 1239.

8. WojciechJ.Krzysztofik, "Modified Sierpinski Fractal Monopole for ISM-Bands and set Application"Year: Volume 57, Issue: 3606 – 615, 2009.

9. Joan Gemio; Josep Parron Granados; Jordi Soler Castany, "Dual-Band Antenna With Fractal-Based Ground Plane for WLAN Applications,”IEEE Antennas and Wireless Propagation LettersVolume: 8, 748 – 751 2009.

Introducing the authors

Ishita Aggarwal received her B.Tech degree from MDU, Rohtak in 2009. She is working as an assistant professor in MVJ college of Engineering. Currently, she is pursuing her Ph.D from Amity University, Noida. She is interested in Antenna system design. She has published 5 papers in national conferences.

Sujata Pandey is a Professor at Amity University, Uttar Pradesh in the Electronics and Telecommunications Engineering Department. She did her PhD in Electronics from Delhi University, South Campus. Her research includes modelling, designing and simulation of different field effect and high electron mobility transistor architectures along with novel techniques in computer architecture, energy harvesting etc.