Design and Analysis of Metafractal Antenna for Wireless Applications

Malay Ranjan Tripathy[1], **Rajesh Kumar**[1,2], **and Daniel Rönnow**[3]

[1]Department of Electronics and Communication Engineering, ASET, Amity University, Noida, India
[2]Department of Electronics and Communication Engineering, BSAITM, Faridabad, Haryana, India
[3]Department of Electronics, Mathematics and Natural Sciences, University of Gavle, Gavle, Sweden

Abstract— In this paper, a new design of metafractal antenna is proposed. The dimension of the patch is $44 \times 44\,\mathrm{mm}^2$ and the FR4 substrate is used for this. The fractal antenna with metamaterial ground plane is used for different iterations. The results show that with the increase of the number of iterations the bandwidth is increased. In the case of higher iterations for some frequency bands return loss results are improved but for other frequency bands these are degraded.

1. INTRODUCTION

Today's world is the world of compactness where all communication systems need to be of smaller sizes. The antenna size decreases as the compactness comes into play which reduces its radiation efficiency. However, radiation efficiency should be kept high, so a mid way solution is to use the fractal antenna which will reduce the size as well as will increase the radiation efficiency [1, 2]. The benefit of using fractal antenna is that it has large effective length and contours of its shape can generate a capacitance or inductance that can help to match the antenna to the circuit. With respect to the geometry, fractals have geometrical shapes which are self-similar and repeating themselves at different scales [3].

Metamaterials are artificially engineered materials that could enhance the radiated power of the antenna. The property of exhibiting negative permittivity and negative permeability can be utilized for making electrically small antenna with highly directive and reconfigurable characteristics [4, 5]. When it is used as a substrate for fractal patch antenna, a new antenna called metafractal antenna can be designed and this would increase the return loss and also the desired bandwidth of the antenna.

The paper is organized as follows. In Section 2 the metafractal antenna design and specifications are discussed. The results and discussion is done in section 3. The conclusion is outlined in the Section 4.

2. ANTENNA DESIGN

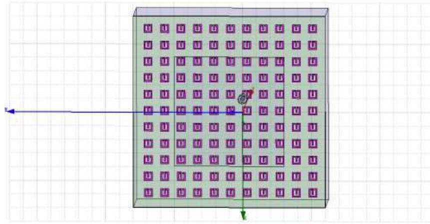
The challenge in designing an antenna is to simulate an antenna having proper return loss, linear phase and constant radiation pattern in the frequency band of operation. Also if the antenna is practically used in wireless communication systems it should satisfy the condition of light weight, planar structure and Omni-directional radiation pattern [6]. To obtain the desired characteristics the dimensions of the patch is taken as $44 \times 44\,\mathrm{mm}^2$. The metamaterial ground [7] is $70 \times 70\,\mathrm{mm}^2$; out of which the unit cell is $3 \times 3\,\mathrm{mm}^2$ size. There are 11 rows and 11 columns of unit cells which justify the dimensions of the ground. Triangle type iteration is done on the patch and a $50\,\Omega$ co-axial feed is used.

Figure 1(a) shows the metamaterial ground plane of the proposed antenna. In this case three iterations are performed on the basic patch (as shown in Figure 1(b)). The first iteration is performed with and without the metamaterial ground plane. Other iterations are performed with metamaterial structures. Ansoft HFSS software is used for this design and simulations.

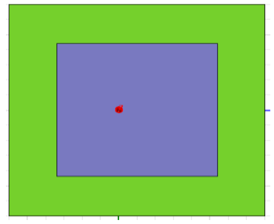
Figure 1(c) represents the metamaterial unit cell. Figure 1(d) shows the graph of the negative permittivity, negative permeability and negative refractive index [8] at different frequencies. The electromagnetic properties such as complex permeability and permittivity can be evaluated either by Drude-Lorentz method or by retrieval of S-parameters methods. The S-parameters have been extracted from HFSS, which is commercially available Finite-Element Method (FEM)-based Full wave simulator.

The real part [5, 8] of refractive index is given by $re(n) = \frac{1}{kd}\cos^{-1}[\frac{1}{2S_{21}}(1 - S_{11}^2 + S_{21}^2)]$ and the wave impedance is $z = \sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}}$.

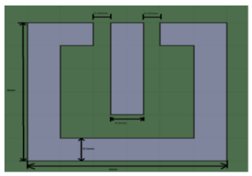
Further n and z are related to μ and ξ by the relations $\xi = \frac{n}{z}$ and $\mu = nz$.



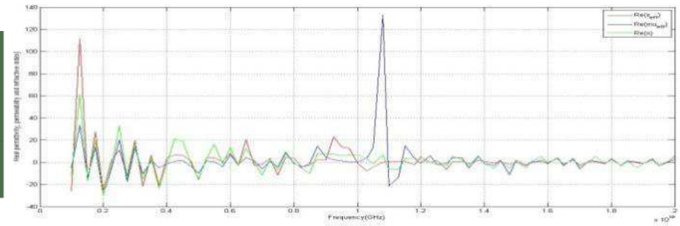
(a)



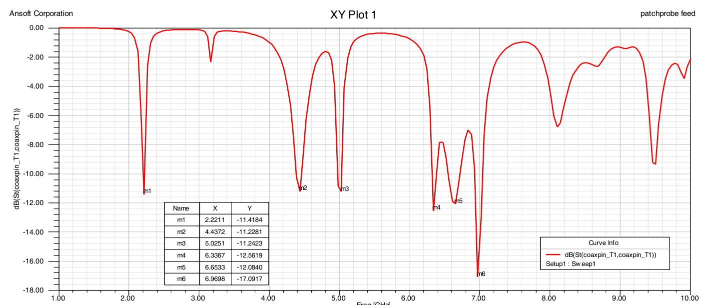
(b)



(c)



(d)

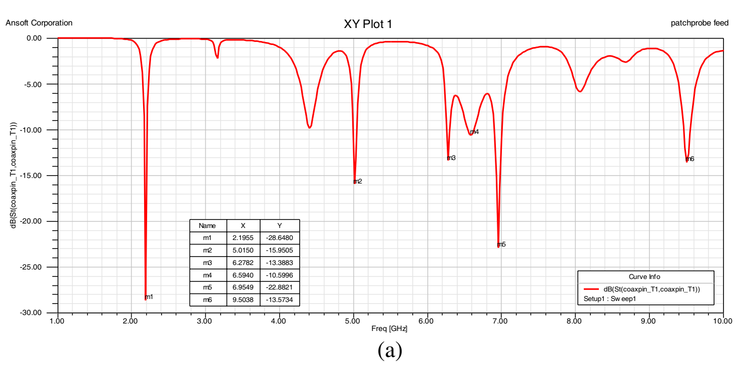


(e)

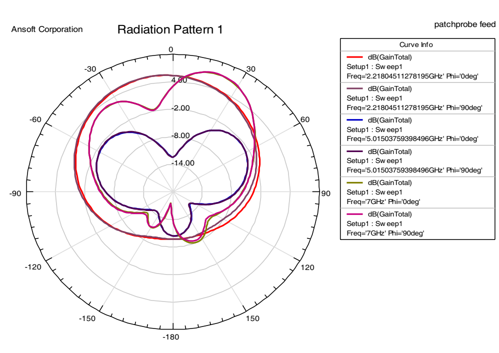
Figure 1: (a) Metamaterial unit structure as ground. (b) Basic patch. (c) Meta-material unit cell. (d) Real part of permittivity, permeability and refractive index. (e) Return loss of the Zeroth iteration without Meta-material ground.

3. RESULTS AND DISCUSSION

The disadvantage of the patch antenna includes the narrow bandwidth and low gain [9]. The use of metamaterial technology improves the bandwidth [10, 11]. To show the effect of the metamaterial structure on the conventional patch antenna, the array of metamaterial unit cells is designed on the ground plane of the antenna. The return loss vs. frequency without and with metamaterial ground plane is shown in Figures 1(e) and 2(a). In Figure 1(e) it is seen that the antenna resonates at 2.2211 GHz, 4.4372 GHz, 5.0251 GHz, 6.3367 GHz, 6.6533 GHz and 6.9698 GHz with return loss of −11.4184 dB, −11.2281 dB, −11.2423 dB, −12.5619 dB, −12.0840 dB and −17.0917 dB respectively. Moreover, it is observed that the bandwidths at these frequencies are 0.0188 GHz, 0.0726 GHz,



(a)



(b)

Figure 2: (a) Return loss of 0th iteration with meta-material unit structure. (b) Radiation pattern of 0th iteration with Metamaterial unit structure.

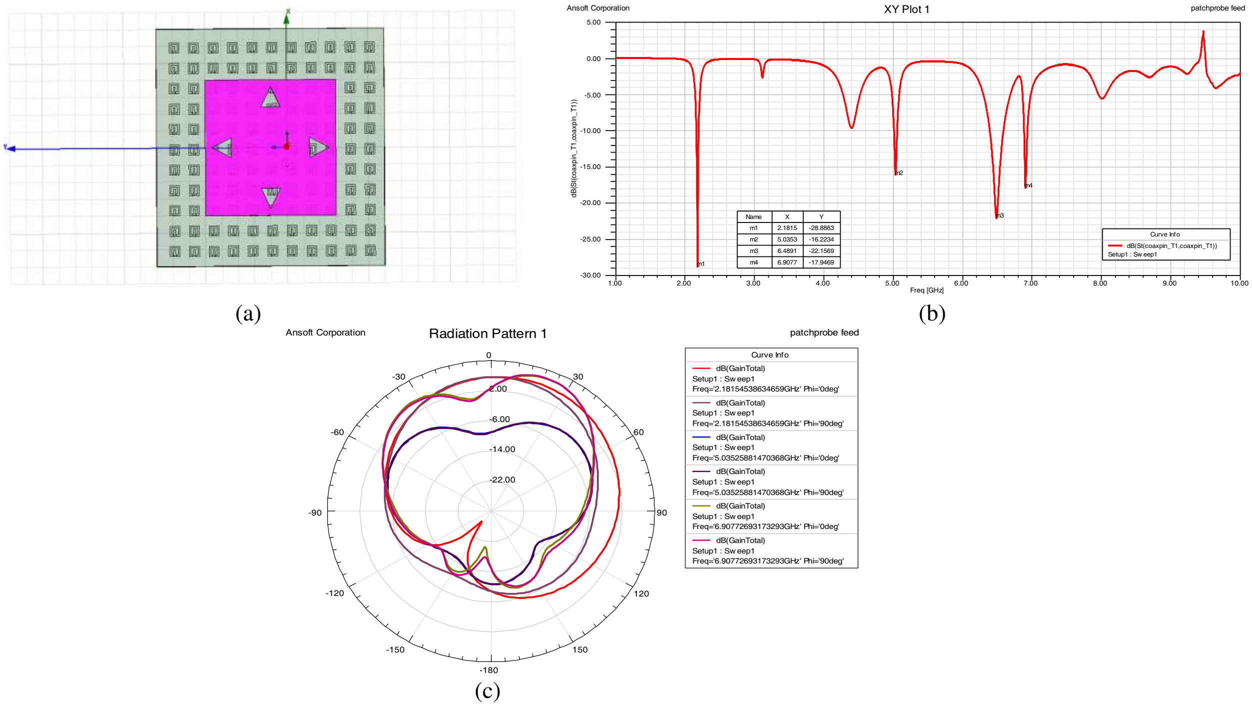


Figure 3: (a) 1st iteration with metamaterial unit structure. (b) Return loss of the 1st iteration with meta-unit structure. (c) Radiation pattern of 1st iteration.

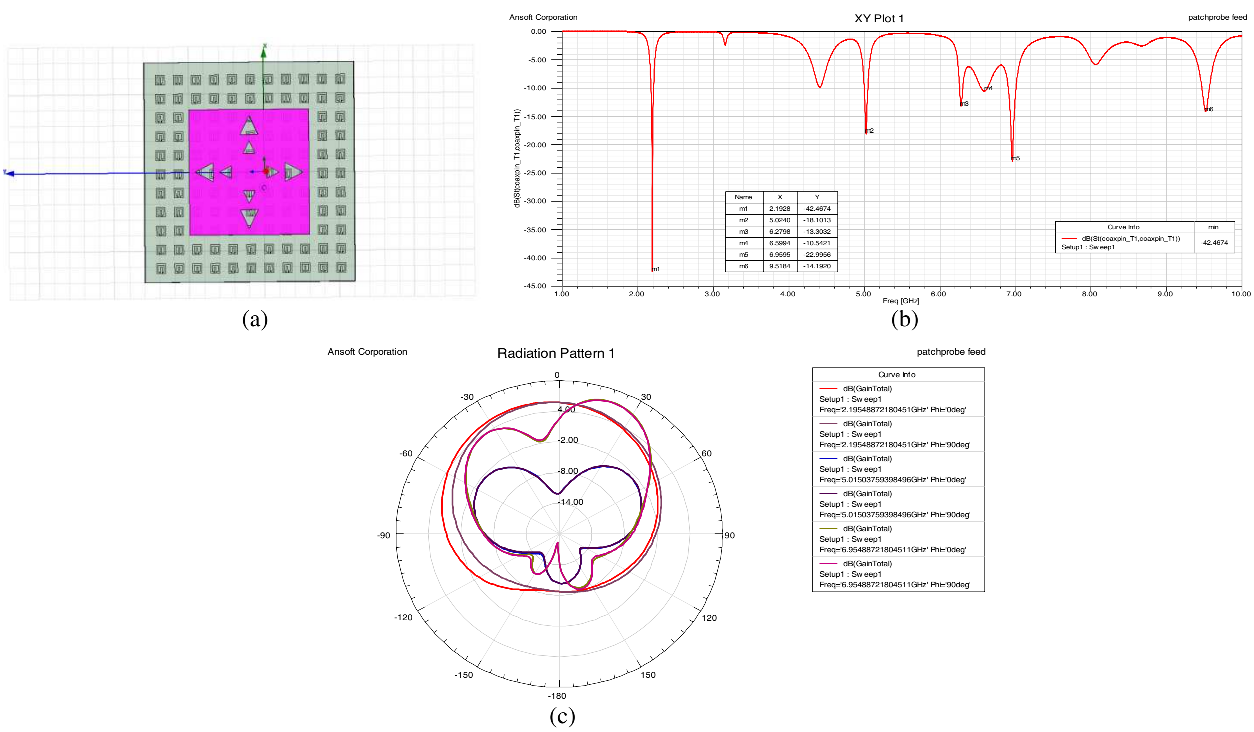


Figure 4: (a) 2nd iteration with meta-material material unit structure. (b) Return loss of the 2nd iteration with meta-unit structure. (c) Radiation pattern of 2nd iteration.

0.0582 GHz, 0.064 GHz, 0.1675 GHz and 0.1122 GHz respectively. The graph shows 6 resonant frequencies with highest return loss of −17.0917 dB.

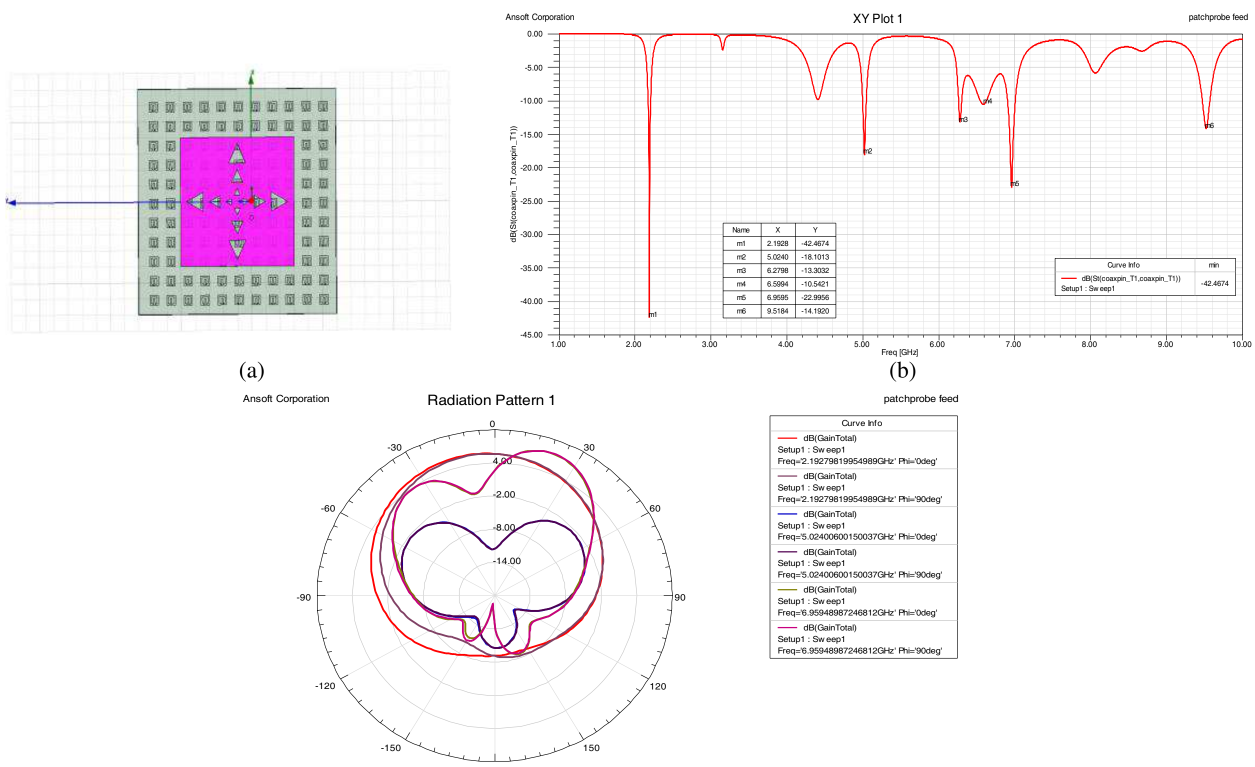
Figure 2 shows the zeroth iteration with metamaterial. In this case, the antenna resonates at 2.2180 GHz, 4.4511 GHz, 5.0150 GHz, 6.3684 GHz, 6.6617 GHz, 7.0 GHz and 9.5263 GHz with return loss of −19.1638 dB, −11.3149 dB, −21.9155 dB, −12.7089 dB, −12.4178 dB, −18.2945 dB and

-15.3294 dB respectively. Also, the bandwidths are observed as 0.04 GHz, 0.0773 GHz, 0.0554 GHz, 0.054 GHz, 0.1675 GHz, 0.1088 GHz and 0.105 GHz respectively. The numbers of bands are increased from 6 to 7 in comparison to the case of without metamaterial. Moreover, as high as -21.9155 dB return loss is obtained from band 3.

Figure 3(a) shows the first iteration with metamaterial unit structure. Figure 3(b) shows the plot of return loss vs. frequency. It is seen that there are four resonant frequencies with maximum return loss of -28.8863 dB. The resonant frequencies are 2.1815 GHz, 5.0353 GHz, 6.4891 GHz and 6.9077 GHz with return loss of -28.8863 dB, -16.2234 dB, -22.1569 dB and -17.9469 dB respectively. The bandwidths are observed as 0.0331 GHz, 0.0461 GHz, 0.1975 GHz and 0.0488 GHz respectively at these frequencies.

Figures 4(a) and (b) represent the second iteration and plot of return losses vs. frequency respectively. In this case, the antenna resonates at 2.1955 GHz, 5.0150 GHz, 6.2782 GHz, 6.5940 GHz, 6.9549 GHz and 9.5038 GHz with return loss of -28.6480 dB, -15.9505 dB, -13.3883 dB, -10.5996 dB, -22.8821 dB and -13.5734 dB respectively. Whereas, bandwidths are seen as 0.0411 GHz, 0.0525 GHz, 0.0439 GHz, 0.0867 GHz, 0.1052 GHz and 0.0917 GHz respectively.

Figure 5(a) shows the final iteration done on the patch antenna. Figure 5(b) represents the plot of return loss vs. frequency. In this case, the antenna resonates at 2.1928 GHz, 5.0240 GHz, 6.2798 GHz, 6.5994 GHz, 6.9595 GHz and 9.5184 GHz with return loss of -42.4674 dB, -18.1013 dB, -13.3032 dB, -10.5421 dB, -22.9956 dB, and -14.1920 dB respectively. But the bandwidths are seen as 0.0345 GHz, 0.0482 GHz, 0.042 GHz, 0.0866 GHz, 0.1027 GHz and 0.0995 GHz at these frequencies.



(a) (b) (c)

Figure 5: (a) 3rd iteration with meta-material unit structure. (b) Return loss of the 3rd iteration with meta-material unit structure. (c) Radiation pattern of 3rd iteration.

4. CONCLUSION

In the proposed design of the metafractal antenna, the metamaterial unit cell shows negative refractive index at multiple frequencies. Due to this metamaterial property the antenna shows the remarkable characteristics around 2 GHz band. Applying fractals to the patch, antenna shows miniaturization with multi-band properties. The maximum return loss is achieved at higher iteration. The results show the application of the proposed antenna in different wireless applications.

REFERENCES

1. Jahromi, M., "Novel Wideband planar fractal monopole antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 56, 3844–3849, 2008.
2. Romeu, J. and J. Soler, "Generalized sierpinski fractal multiband antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 49, 1237–1239, 2001.
3. Puente, C., J. Romeu, R. Pous, and A. Cardama, "On the behavior of the Sierpinski multiband fractal antenna," *IEEE Transaction on Antennas and Propagation*, Vol. 46, 517–524, 1996.
4. Chen, J., W. Chen, J. Yen, L. Chen, and C. Wang "Comparative analysis of split-ring resonators for tunable negative permeability metamaterial based on anisotropic dielectric substrates," *Progress In Electromagnetics Research M*, Vol. 10, 25–38, 2009.
5. Smith, D., D. Vier, Th. Koschny, and C. Soukoulis, "Electromagnetic parameter retrieval from inhomogeneous metamaterials," *Physical Review E*, Vol. 71, 1–11, 2005.
6. Nouri, A. and G. Dadashzadeh, "A compact UBW band-notched printed monopole antenna with defected ground structure," *IEEE Antennnas and Wireless Propagation Letters*, Vol. 10, 1178–1181, 2011.
7. Shambavi, K. and Z. C. Alex, "Design of printed multistrip monopole antenna for UWB applications," *Microwave and Optical Technology Letters*, Vol. 53, No. 8, 1570–1572, Aug. 2011.
8. Ye, J., Q. Cao, and W. Tam, "Design and analysis of a miniature metamaterial microstrip patch antenna," *International Workshop on Antenna Technology (iWAT-2011), IEEE Explore*, 290–293, 2011.
9. Cho, Y., K. Kim, D. Choi, S. Lee, and S. Park, "A miniature UWB planar monopole antenna with 5-GHz band-rejection filter and the time-domain characteristics," *IEEE Transactions on Antennas Propagation*, Vol. 54, 1453–60, 2006.
10. Kufa, M. and Z. Raida, "Design of filtenna with fractal defected ground structure," *7th European Conference on Antennas and Propagation*, 1278–1280, 2013.
11. Zarghooni, B. and T. Denidni, "New fractal metamaterial unit cell for microwave applications," *8th European conference on Antennas and Propagation*, 978–979, 2014.