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DESIGN AND ANALYSIS OF COMPACT METAMATERIAL INCORPORATED MICROSTRIP PATCH ANTENNA FOR WIRELESS APPLICATION

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Abstract- In this paper a compact metamaterial incorporated microstrip patch antenna is presented. A hybrid structure, which is a combination of Boolean addition and subtraction of self-similar hexagonal geometries at different scale which is designed at the top layer of the FR-4 substrate (tan (δ) = 0.02, ε_r= 4.3, h= 1.6). A modified ground plane is also designed at bottom layer of substrate to meet resonance criteria. Also, a hybrid metamaterial parasitic element is incorporated on the ground plane for performance improvement. On energizing with the microstrip feed line the simulated antenna exhibits five resonance frequencies 1.11, 1.7, 2.18, 2.8, and 3.5 GHz. It has covered four frequency band-1(1.01- 1.25 GHz), band-2 (1.52-1.93 GHz) band-3 (2.15- 2.24 GHz) and band-4 (2.25- 3.95 GHz) for $|S_{11}| \leq -10$ dB which are suitable for several wireless communication applications.
Keywords: Hexagonal, Metamaterial, multiband antenna, S_{11} parameter, Microstrip patch.

1. INTRODUCTION

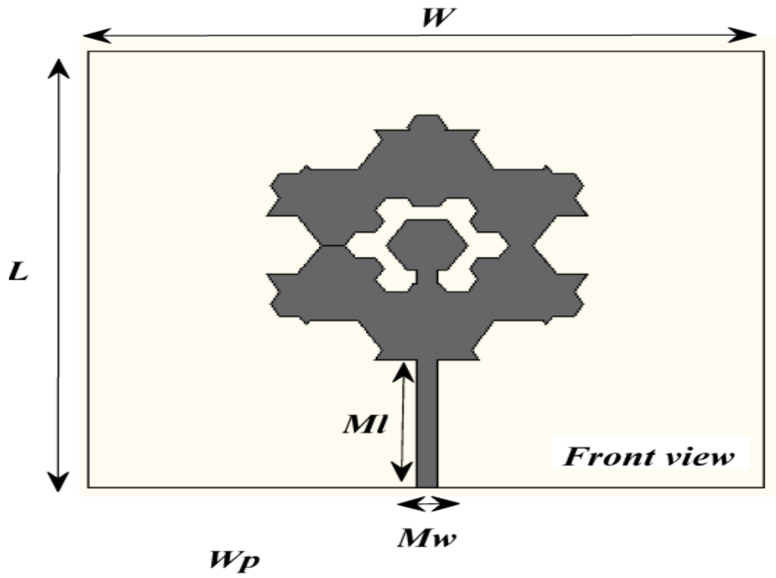
Modern wireless communication, driven by applications like high-definition streaming and online gaming, necessitates high data throughput, thus driving demand for optimized antenna performance [1]. Microstrip patch antenna design using metamaterial has emerged as a promising solution to achieve compact size, low-profile, wideband and multiband functionalities [2–3]. Mostly microstrip patch using fractal like metamaterial structures have self-similarity in shape at the different scale [4]. Using multiple reduction copy technique [5], the fractal structure can be achieved by applying multiple number of iterations. An increase of electrical length can be achieved by the space-filling property of fractal by applying on an antenna element. The extension of the resonator in designed antenna offers a reduction in resonant frequency due to more convolution and more radiating surface for current distribution. In recent years various metamaterial inspired fractal techniques for miniaturization of antennae [13-14], combined fractal geometries [7-12] and the Koch monopole fractal [6] have been applied. Also, several techniques for metamaterial-based fractal structure design have been reported to meet the demand of diversity antennas in the LTE/Wi-Fi/Wi-Max/WLAN bands [15-16]. In [17] the Koch curve like edged antenna has been implemented for MIMO fractal antenna development. Multi-band and wide band antennas are desired to support multiple wireless communication services on a device.

Multi-band operation with a high degree of miniaturization becomes more challenging to achieve together. Incorporating metamaterial Sierpinskiezed Koch-like sided multi-fractal [18] and Koch-like sided Sierpinski gasket [19] have been designed to meet multi-band characteristics from complex designed antenna structure for the several band of frequency. Such fractal structure provides long length to current flow in limited space using self-similarity and space filling properties. Integration of parasitic element with antenna substrate [20] and slot insertion [21] has been reported for enhancement of antenna characteristics. Therefore, in this paper, a metamaterial inspired planar antenna as a radiating element for the multiband operation is presented. It is a combination of hybrid structure iterated using Sierpinski carpet method. The proposed antenna covers GSM 900 and 1800MHZ/UTMS/Wi-bro/Bluetooth/Wi-Fi/ISM/WLAN wireless communication bands with near omni- directional radiation patterns. Here a modified ground plane is used with metamaterial parasitic structure. A parametric study is performed to analysis the effect of hexagonal Sierpinskiezed structure and parasitic ground plane on operating frequency and S_{11} parameter etc.

2. PHYSICAL DESIGN OF THE ANTENNA

The physical design of the hexagonal shaped quad band hybrid microstrip patch antenna (L × W) has been depicted in fig. 2.1 which is fabricated on FR-4 substrate with relative permittivity ε_{sub}=4.3 and thickness of 1.6mm.

Front view of the antenna shows the 50Ω micro-strip feed line ($M_l \times M_w$) which is integrated with slotted radiating patch. A modified ground with parameters L_{g1}, W_{g1}, L_{g2} and W_{g2} has been printed on back side of the substrate. Small symmetrical rectangular slots (4.5×3) mm^2 are clipped on top edge of the ground plane while another symmetrical rectangular shaped slot ($L_{g2} \times W_{g2}$) has been truncated on bottom edge of the ground plane.



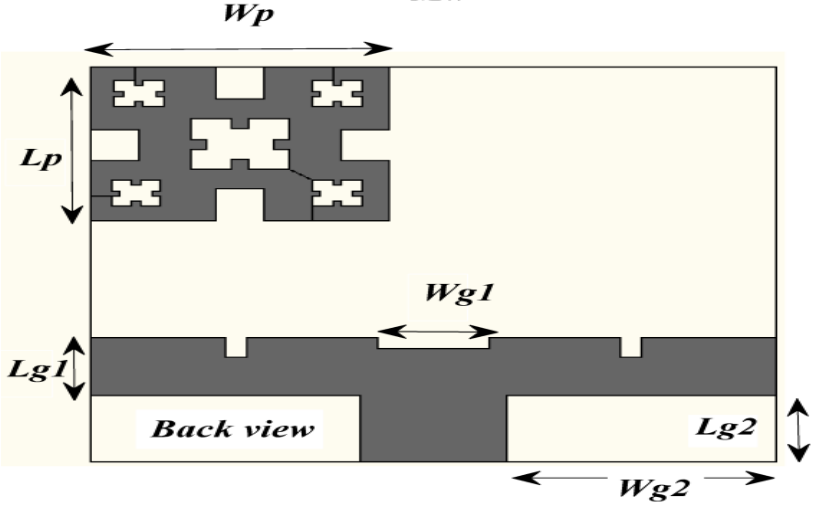


Fig. 2.1 Geometry of the hexagonal shaped microstrip patch antenna

For impedance matching, another rectangular shaped slot (2.5 × 16) mm^2 has been embedded on top edge of the ground plane. A hybrid fractal shaped parasitic element of the dimensions ($L_p \times W_p$) has been attached at top left of the ground plane.

Table-2.1 Optimized dimension of proposed antenna

Parameter	Dimension	Parameter	Dimension
M_l	25mm	W	97mm
M_w	3mm	L_{g2}	14mm
L_{g1}	13mm	W_{g2}	39mm
W_{g1}	16mm	L_p	33.5mm
R	27mm	W_p	42mm
L	90mm		

3. EVOLUTION OF THE PROPOSED ANTENNA

The evolution of metamaterial based hexagonal shaped antenna has displayed in figure 3.1. In all iteration the geometry of ground plane is same except final iteration. In iteration 0, the structure contains a hexagonal patch with radius 27 mm, feed line parasitic element and defected ground plane. After simulation using CST Microwave studio, the antenna 1 (iteration 0) exhibits two resonating bands 1.175-1.34 GHz and 1.698-1.812 GHz. To improve the performance of the antenna 1, the hexagonal shaped slot with radius 7 mm is truncated at each corner of the radiating elements. Figure 3.2 reveals that the antenna 2 (iteration 1) exhibits two frequency band (1.044-2.124 GHz, 2.718-

4.026 GHz) with four resonating frequencies. In iteration 2, a composite slot has been created which is the combination of a hexagonal slot with radius 9 mm and 6 small hexagons with radius 3mm. Antenna 3 (iteration 2) covers three frequency bands with four resonating frequencies which is shown in table 2.1. In next step six semi hexagons with radius 3 mm are Boolean added on the periphery of radiating element which improves the value of return loss at resonating frequency 3.5 GHz. In iteration 4, a hexagonal element with radius 6 mm, which is located at center, has been attached with radiating element with the help of small strip with size (3×3) mm^2. The S_{11} characteristic of the iteration covers the four frequency bands (1.026-1.33 GHz, 1.452-1.878 GHz, 2.154-2.298 GHz and 2.57-3.864 GHz) and also exhibits four resonating frequencies. In final step, the parasitic element is Minkowskized then Sierpinskiezed. The proposed antenna (iteration 5) shows five resonating frequencies as well as covers four frequency bands. Table 2 shows the covered frequency bands, resonating frequencies and their return loss of all iterations.

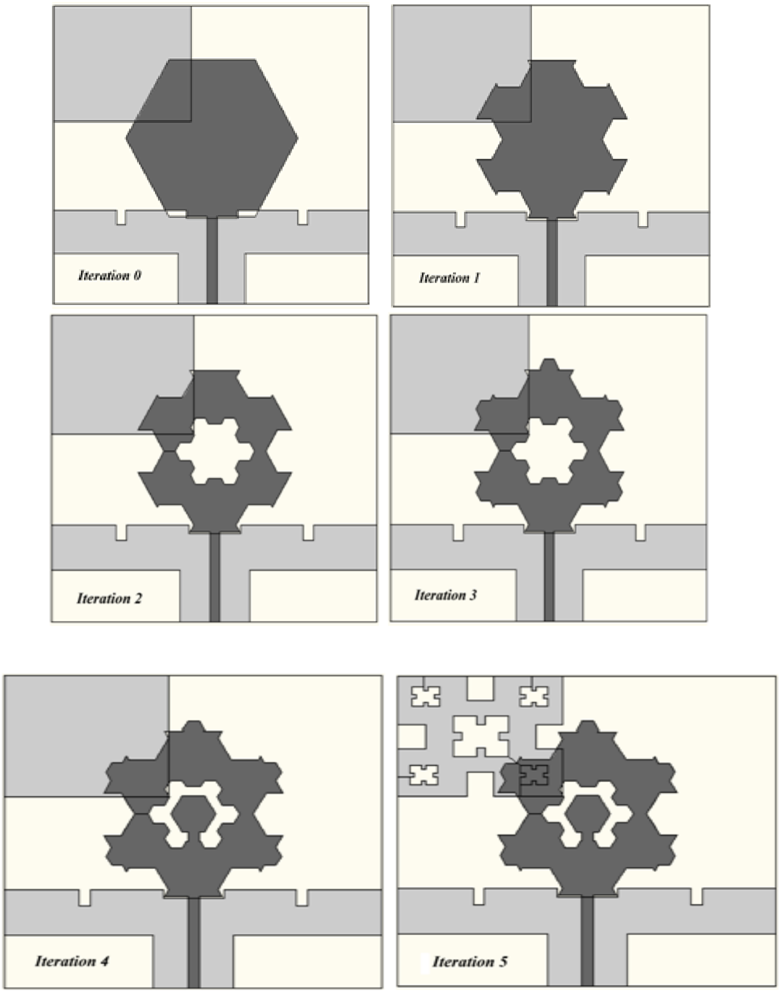


Fig. 3.1 Evolution of hexagonal shaped microstrip patch antenna

Table-2.1 Covered resonating band and resonating frequencies

Iteration No.	Band in GHz	Resonant Frequency in GHz	Return Loss in dB
0th	1.175-1.34	1.257	-13.1
	1.698-1.812	1.752	-11.77
1st	1.044-2.124	1.169	-17.73
		1.668	-19.797
	2.718-4.026	3.112	-33.312
		3.6532	-28.5
2nd	1.032-1.332	1.15	-17
	1.47-1.968	1.67	-18.422

	2.72-4.026	3.05	-36.174
		3.63	-30.48
3rd	1.026-1.362	1.16	-17.33
	1.41-1.97	1.665	-22.13
	2.61-3.822	2.88	-19.46
		3.51	-39.65
4th	1.026-1.33	1.147	-17.401
	1.452-1.878	1.674	-20.6
	2.154-2.298	2.19	-17.187
	2.57-3.864	2.92	-24.13
		3.52	-48.32
5th	1.01-1.25	1.11	-17.98
	1.5175-1.93	1.72	-34.5
	2.15-2.24	2.18	-19.26
	2.25-3.954	2.8	-40.82
		3.5	-25.23

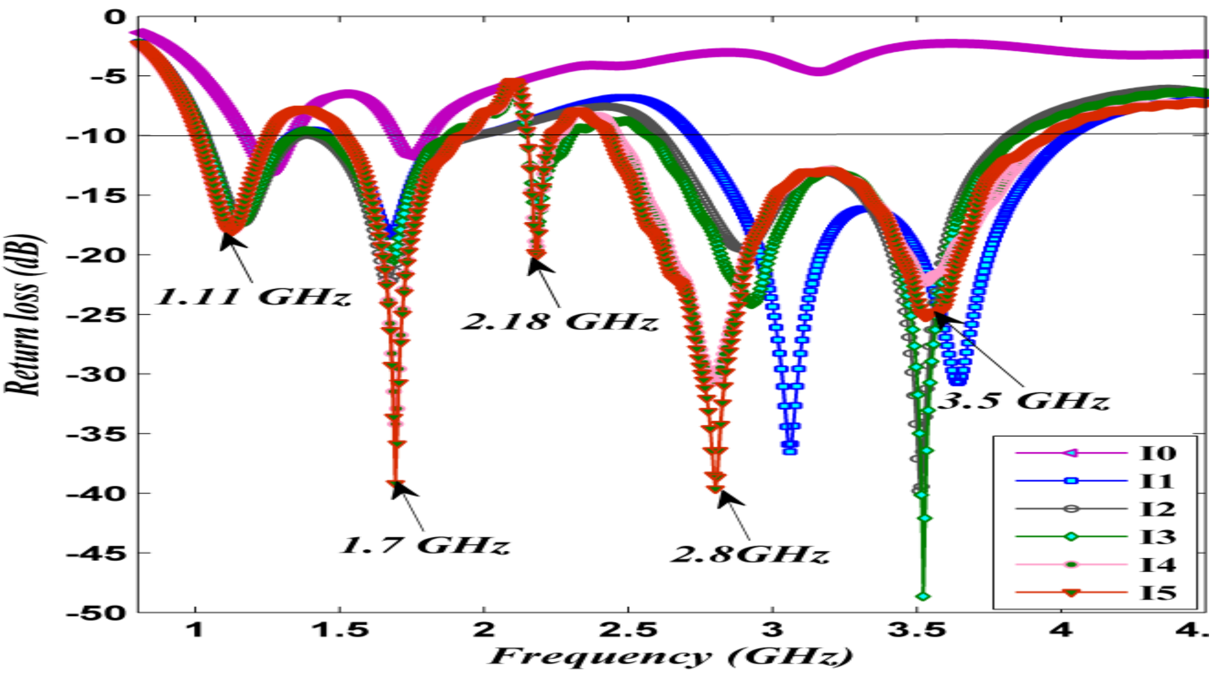


Fig. 3.2 Frequency responses of simulated antennas for various iterations

CONCLUSION

A novel hexagonal shaped hybrid fractal antenna has been simulated in this communication. The simulated antenna exhibits resonance at frequencies 1.11, 1.7, 2.18, 2.8, and 3.5 GHz. It has covered four bands of frequency band-1(1.01- 1.25 GHz), band 2 (1.52-1.93 GHz), band-3 (2.15- 2.24 GHz) and band-4 (2.25- 3.95 GHz) for $|S_{11}| \leq -10$ dB, which are suitable for several wireless communication applications (i.e. GSM 900 MHz, Wi-Fi 802.11y and WLAN 802.11b/g/a).

REFERENCES

[1] G. J. Foschini and M. J. Gans, “On limits of wireless communications in a fading environment when using multiple antennas,” Wireless Personal Communication. vol. 6, pp.311–335, 1998.

[2] D. H. Werner and R. Mittra, “Frontiers in Electromagnetics.” New York, NY, USA: Wiley/IEEE Press, 1999.

[3] D. H. Werner and S. Ganguly, “An overview of fractal antenna engineering research,” IEEE Antennas Propagation Magazine, vol. 45, no. 1, pp. 38–57, 2003.

ISSN Number: 2454-2024(Online)

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[4] K. Falconer, Fractal Geometry: Mathematical Foundation and Application. New York, NY, USA: Wiley, 1990.

[5] H. Peitgen, H. Jurgens, and D. Saupe, Chaos and Fractals: New Frontiers of Science. Berlin, Germany: Springer-Verlag, 1992.

[6] C. P. Baliarda, J. Romeu, and A. Cardama, “The Koch monopole: A small fractal antenna,” IEEE Trans. Antennas Propagation, vol. 48, pp. 1773–1781, 2000.

[7] S. R. Best, “On the performance properties of Koch fractal and other bent wire monopole,” IEEE Trans. Antennas Propagation, vol. 51, no. 6, pp. 1292–1300, 2003.

[8] S. Oraizi and H. Hedayati, “Miniaturized UWB monopole microstrip antenna design by the combination of Giuseppe Piano and Sierpinski carpet fractals,” IEEE Antennas Wireless Propagation Letter, vol. 10, pp. 67–70, 2011.

[9] Sanar Ahmed Shehab, A. Z. Yonis, “Performance Analysis of Frequency Synthesizers under Wireless Local Area Network IEEE 802.11 at 5 GHz Band,” 2025 IEEE 9th International Conference on Software Engineering & Computer Systems (ICSECS), Pekan, Pahang, Malaysia, 2025, pp. 640-645, doi: 10.1109/ICSECS65227.2025.11279099.

[10] Y. K. Choukiker and S. K. Behera, “Design of wideband fractal antenna with combination of fractal geometries,” in Proc. IEEE 8th Int. Conf. on Information, Communications, and Signal Processing (ICICS 2011), Singapore, pp. 1–4 Dec. 13–16, 2011.

[11] W.-L. Chen, G. M. Wang, and C. X. Zhang, “Small-size microstrip patch antennas combining Koch and Sierpinski fractal-shapes,” IEEE Antennas Wireless Propagation Letter, vol. 7, pp. 738–741, 2008.

[12] L. Lizzi and G. Oliveri, “Hybrid design of a fractal-shaped GSM/UMTS antenna,” J. Electromagnetic Waves Application, vol. 24, no. 5, pp. 707–719, Mar. 2010.

[13] Hareetaa Mallani, Archana Agrawal, Ritesh Kumar Saraswat, “Implementation of Fractal Metamaterial Inspired Antenna for Multi-Standard Wireless Applications,” Progress in Electromagnetics Research B, Vol. 108, 121-137, 2024.

[14] E. I. Voronova; A. A. Yelizarov;S. V. Bashkevich; V. N. Karavashkina; M. A. Mashkova, “Simulation of a Fractal Peano Antenna with a Metamaterial Surface,” International Conference on Systems of Signal Synchronization, Generating and Processing in Telecommunications (SYNCHROINFO), Vyborg, Russian Federation, 2024, pp. 1-4,.

[15] C. H. See, R. A. Abd Alhameed, Z. Z. Abidin, N. J. McEwan, and P. S. Excell, “Wideband printed MIMO/diversity monopole antenna for Wi-Fi/WiMAX applications,” IEEE Trans. Antennas Propagation, vol. 60, no. 4, pp. 2028–2035, April 2012.

[16] J. Guterman, A. A. Moreira, and C. Peixeiro, “Microstrip fractal antennas for multi standard terminals,” IEEE Antennas Wireless Propagation Letter, vol. 3, no. 1, pp. 351–354, Dec. 2004.

[17] Y. K. Choukiker, S. K. Behera, and S. K. Sharma, “Hybrid fractal planar monopole antenna with MIMO implementation covering multiband wireless communications for handheld devices,” presented at the IEEE Int. Symp. On Antennas and Propagation, Florida, USA, Jul. 7–12, 2013.

[18] D. Li, J. Mao, “Sierpinskized Koch-like sided multi fractal dipole antenna,” Progress in Electromagnetic Research, Vol.130, pp. 207-224, 2012.

[19] D. T. Li, J. Mao, “Koch-like sided Sierpinski gasket multi fractal dipole antenna,” Progress in Electromagnetic Research, Vol.126, pp. 399-427, 2012.

[20] K. C. Lin, C. H. Lin, Y. C. Lin, "Simple printed multiband antenna with novel parasitic-element design for multi standard mobile phone applications", IEEE Trans. Antennas Propagation., vol. 61, no. 1, pp. 488-491, Jan. 2013.

[21] L. Desclos, “Size reduction of patch by means of slots insertion,” Microwave Opt. Technol. Letter, vol. 25, no. 2, pp. 111–113, Feb. 2000.