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A compact miniaturized star fractal antenna for modern wireless applications

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ABSTRACT

In this paper, six-band resonant fractal antenna architecture is proposed and fabricated. The ultimate shape is established after six iterations. The resonator is starshaped, and each iteration, a hexadecagon shape from the resonator is subtracted. The antenna is designed and calculated by the numerical simulation based on the finite element method (ANSYS HFSS) and finite integration technique (CST studio). The experimental measurements were performed by the vector network analyzer AVR ROHDE AND SCHWARZ ZVB20. The gain is 4.85 dB, and the bandwidth is 0.33 GHz. The antenna's structure allows it to work effectively in the global system for mobile communication (GSM), digital communication system (DCS), long-term evolution (LTE), WiMAX, WLAN, and C bands. The designed patch has a compact size of (75×75×1.6) mm^3 uses as a support the FR-4 substrate for wireless equipment.

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1. INTRODUCTION

Telecommunications have become trivialized in recent years. Driven by the enthusiasm of the public, reception systems have become portable and antennas have become miniaturized. The use of printed antennas has become common in radio communication systems [1]–[4].

During the last decades, the means of telecommunication have experienced unprecedented growth in the use of data thanks to the explosion of uses and the multitude of applications such as, mobile internet, smart grid, intelligent transport, smart home, e-health, and other military applications such as weather radar or surveillance radar [5]–[9]. This growth is reflected in an enormous increase in mobile data traffic every year [10]. With this in mind, we can confirm that antennas play a very deterministic role in wireless communication by sending and receiving information [11], [12]. In this sense, the antenna is the key component that determines the performance of the entire radiofrequency system. An antenna is the only element that transmits and receives radio frequency waves. Generally, it has a so-called reciprocity property, i.e., it can be used for reception and/or for emission with the same electrical and radiation characteristics [13]. On the other hand, and in view of the current economic environment requiring increasingly better performance and the importance of the antenna in radio frequency equipment, conventional antennas can no longer respond to current and future challenges. For this reason, miniature antenna technology urgently needs to be developed to overcome the demands of new wireless communication systems [14]–[16].

Nowdays, fractal technology is quickly becoming an efficient way to respond to the needs of future products. It allows us to efficiently design miniaturized antennas or integrate multiple radio communication components into a single device [15]–[17]. In new generation antennas used in mobile devices, miniaturization is required, it needs to integrate multiple devices such as cellular, wireless LAN, geographic positioning, broadcasting devices, and needs to be put in various places (such as road stations, airports, workplaces, malls, subway sites). In this case, users want to use the smallest antenna possible to facilitate the use of wireless devices [18], [19].

The concept of "fractal antenna" was first proposed in 1975 by the French mathematician B. Mandelbrot [20]. The term "Fractal" is derived from the Latin "broken". The fractal has two main characteristics: self-similarity and space-filling (i.e., the fractal dimension). Self-similarity means that the geometric size is appropriately enlarged or reduced, the entire structure does not change, and the same degree of irregularity is present at different stages. Fractal dimension refers to the use of a feature number (not necessarily an integer) to measure its irregularity, complexity, or convolution [21], [22].

In this rechearch work, the authors present a fractal antenna on an FR-4 substrate with a thickness of 1.6 mm. The proposed prototype has excellent radiation qualities and can be used in a variety of wireless communication technologies, including global system for mobile communication (GSM), digital communication system (DCS), long-term evolution (LTE), WiMAX, WLAN, and C-band. It also has a high gain and wideband in the frequency range (1-6) GHz. The study is divided into two sections. In the first section, we define different design phases of the proposed fractal antenna architecture. Also, the evolution of radiation parameters during the proposed antenna design steps is presented and discussed. In the second section, the numerical results obtained by the HFSS software, CST software, and experimental measures are presented and discussed. Finally, a comparison study was conducted to compare the results of this work with those of planar antennas previously published in the literature [23]–[28].

2. ANTENNA DESIGN

Authors have presented several multiband and wideband fractal antenna designs. Previous researchs are substructures of many antennas [21], [29]–[31]. Research to improve fractal antenna structures is progressing as a function of frequency, gain and radiation pattern. The suggested multiband antenna structure is illustrated in Figure 1 with a size of (75×75) mm^2. The substrate used is epoxy FR-4, characterized by a dielectric constant of ϵr=4.4 and a thickness of 1.6 mm. The patch antenna is excited by a 50 Ω microstrip line and consists of a star-shaped fractal radiator and a rectangular ground plane.

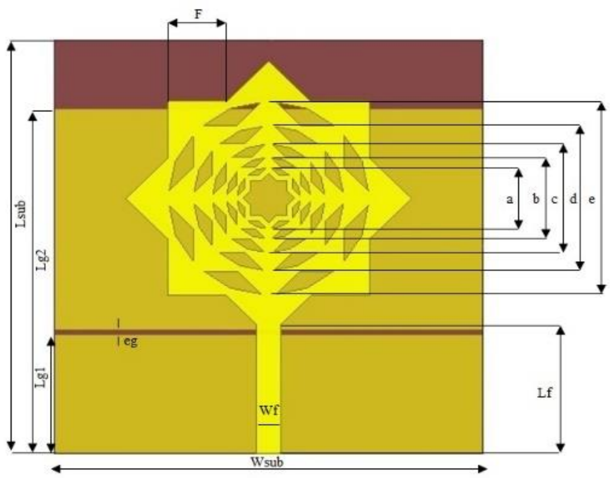

Figure 1. Parameters of the proposed fractal antenna

A radiator self-repeating geometry is suggested. After six iterations, the final shape is established. Each iteration consists of a star from which a hexadecagon has been subtracted. The relation between each iteration of the fractal antenna to the previous iteration according to Figure 1 is taken as follows: e=40 mm, d=3×e/4, c=3×d/4, b=3×c/4, and a=3×b/4. Where the parameters a, b, c, d, and e represent the diameter of iterative hexadecagons subtracted from the radiator. We note that 4/3 is the resonator size reduction factor. The final dimensions of the proposed fractal antenna are: Wsub=75 mm, Lsub=75 mm, Wf=4.95 mm, Lf=20 mm, Lg1=19.5 mm, Lg2=66 mm, and F=11.72 mm.

Figure 2 ilustrates the progression of the proposed antenna from the initor, and Figure 3 summarise the reflection coefficients of all the iterations performed. The different design stages are described below:

- The initiator antenna consists of a star-shaped radiator and a 50 Ω feed line, resonating at the frequency 3.37 GHz and 4.89 GHz with reflection coefficients of -13.04 dB and -11.91 dB.
- In the first iteration, a hexadecagon is subtracted, and replaced with a star resonator that is smaller than the initiator by a reduction factor of 4/3. This iteration yields an antenna that resonates at 1.80 GHz, 3.37 GHz, 3.88 GHz, and 4.23 GHz with a reflection coefficient of -13.78 dB, -20.6 dB, -12.01 dB, and -15.40 dB successively.
- The antenna’s second iteration allows it to operate at resonant frequencies of 1.81 GHz, 2.92 GHz, 3.37 GHz, 3.88 GHz, and 4.28 GHz with the reflection coefficients -14.58 dB, -16.28 dB, -16.89 dB, -14.28 dB, and -21.17 dB respectively.
- In the third iteration, the antenna resonates at 1.80 GHz, 2.97 GHz, 3.47 GHz, 3.93 GHz, 4.28 GHz, and 5.64 GHz with reflection coefficients of -16.90 dB, -37.70 dB, -12.99 dB, -17.54 dB, -20.30 dB, and -17.80 dB.
- The proposed fractal antenna can run correctly at the resonant frequencies of 1.76 GHz, 3.06 GHz, 3.49 GHz, 3.90 GHz, 4.29 GHz, and 5.73 GHz with reflection coefficients of -23.09 dB, -23.18 dB, -16.22 dB, -24.87 dB, -28.47 dB, and -17.05 dB respectively.

Initiator 1st Iteration 2nd Iteration 3rd Iteration Proposed antenna

Figure 2. Fractal patch design growth from the initiator to the proposed antenna

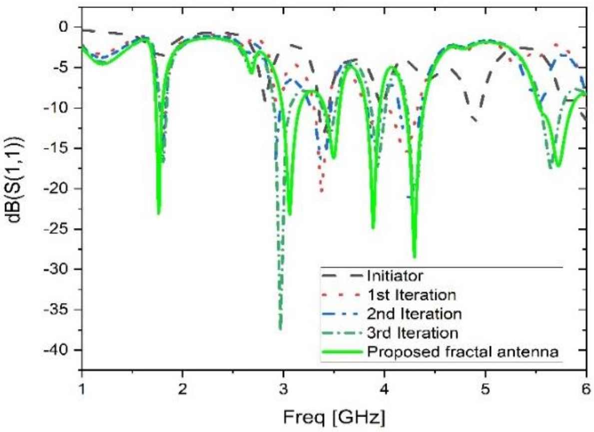

Figure 3. Reflection coefficients for antenna iterations

Table 1 lists the various characteristics that determine the antenna performance, namely bandwidth, resonant frequencies, reflection coefficients, and gain. Table 1 shows that as the number of iterations increases, the electrical parameters of the antenna, namely the resonance number, the bandwidth, the antenna adaptation, and the gain are improved. With this improvement in operating ranges and electrical characteristics, the suggested fractal antenna works effectively for global system for mobile communication GSM, DCS, LTE, m-WiMAX, WLAN, and C band applications.

Table 1. Performances obtained during the process of improvement of the fractal antenna

Iteration	N. Bands	BW [GHz]	Fr [GHz]	S_{11} (dB)	Gain (dB)
Initiator	2	0.10	3.37	-13.04	0.69
		0.11	4.89	-11.91	0.96
Antenna with the first iteration	4	0.06	1.80	-13.78	3.50
		0.15	3.37	-20.60	3.33
		0.17	3.88	-12.01	3.19
		0.29	4.23	-15.40	4.88
Antenna with the second iteration	5	0.06	1.81	-14.58	3.44
		0.08	2.92	-16.28	3.01
		0.19	3.37	-16.89	3.63
		0.14	3.88	-14.28	3.57
		0.21	4.28	-21.17	4.03
Antenna with the third iteration	6	0.07	1.80	-16.90	3.42
		0.16	2.97	-37.69	2.92
		0.13	3.47	-12.99	1.60
		0.14	3.93	-17.54	3.58
		0.16	4.28	-20.30	4.28
		0.21	5.64	-17.80	5.85
Proposed fractal antenna	6	0.07	1.76	-23.09	3.01
		0.18	3.06	-23.18	3.19
		0.15	3.49	-16.22	1.89
		0.14	3.90	-24.87	3.01
		0.18	4.29	-28.47	4.85
		0.33	5.73	-17.05	3.77

Figures 4 and 5 show respectively the effects of "Lg1" and "Lsub" on the properties of the reflection coefficient. When "Lg1" rises, the second and sixth functioning bands are canceled, while the third band is displaced (see Figure 4). On the other hand, the other three bands have stayed rather constant. When "Lg1" decreases, the sixth band of operation is canceled, while the other bands remain steady. From Figure 5, the first and sixth bands cancel out as "Lsub" is increased, but the other bands remain practically constant. The second band is added to the canceled bands when "Lsub" lowers. So, Lg1=19.5 mm and Lsub=75 mm are the best values, as shown in Figures 4 and 5.

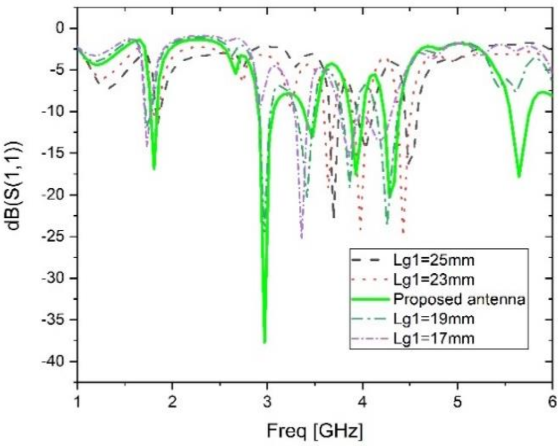

Figure 4. Influence of the ground plane slot position on the S11

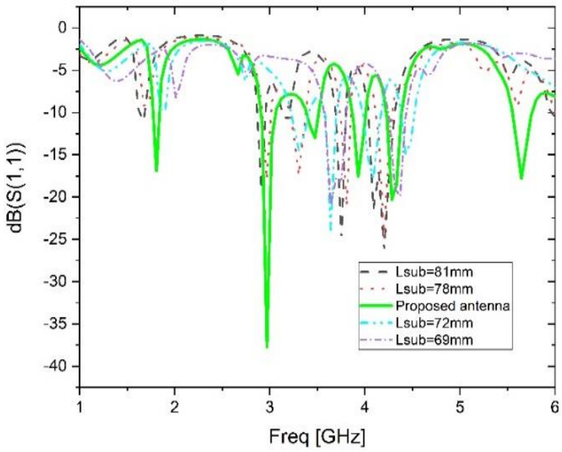

Figure 5. Effect of substrate length on the reflection coefficient

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 6 depicts the manufactured and measured prototype of the proposed antenna, which was used to test the multiband antenna properties. The reflection coefficient experimental measurement as a function of frequency is carried out using the vector network analyzer AVR Rohde and Schwarz ZVB20. The characteristics of S11 simulated by Ansys HFSS electromagnetic (EM), CST microwave studio software, and measured are shown in Figure 7.

Top side Bottom side

Figure 6. Antenna prototype manufactured

The results were plotted across a frequency range [1- 6] GHz. Figure 7 shows that the simulated and measured findings are in reasonable agreement. The small differences between the measured and simulated reflection coefficient results can be attributed to measurement conditions, features of the substrate used for manufacturing, connection leakage, and imperfect soldering. The measured return loss reveals that, over the scanned frequency range, the manufactured antenna offers six resonant bands. The first band extends from 1.73 to 1.80 GHz with a resonant frequency of 1.77 GHz. The second band, centered at 2.99 GHz, covers the frequency range of [2.96-3.03] GHz. In the third band, the antenna covers the [3.40-3.58] GHz band with a resonant frequency of 3.49 GHz. The frequency range [3.82-3.96] GHz is covered by the fourth band and the resonant frequency is 3.90 GHz. The fourth band resonates at 4.35 GHz and covers [4.25-4.44] GHz. The last operating band obtained extends from 5.63 to 5.74 GHz and resonates at 5.69 GHz. The manufactured antenna can, therefore, work effectively for GSM, DCS, LTE, m-WiMAX, WLAN, and C band applications. Table 2 summarizes the measured and simulated bandwidth and frequency bands covered by the patch proposed.

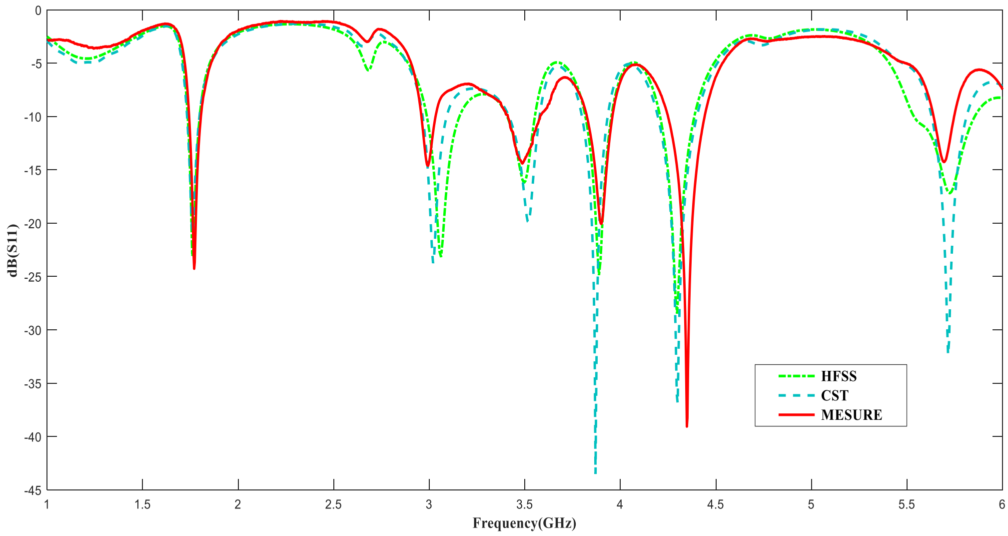

Figure 7. Reflection coefficient S11 for suggested fractal antenna

Table 2. Measured and simulated bandwidth and frequency bands covered by the patch proposed

	Bandwidth (GHz)	Covered Bands
HFSS results	[1.73-1.80], [2.98-3.16], [3.40-3.55], [3.81-3.95], [4.21,4.39], [5.53-5.86]	GSM, DCS, LTE, m-WiMAX, WLAN, and C band
CST results	[1.73-1.80], [2.96-3.09], [3.40-3.57], [3.80-3.93], [4.20-4.40], [5.63-5.81]	
Measures	[1.73-1.80], [2.96-3.03], [3.40-3.58], [3.82.3.96], [4.25.4.44], [5.63-5.74]	

Using the HFSS simulator, the fractal antenna radiation pattern in both planes E and H is presented in Figure 8 at resonant frequencies of 1.77 GHz, 2.99 GHz, 3.49 GHz, 3.90 GHz, 4.35 GHz, and 5.69 GHz. For the first five frequencies, we notice that the radiation pattern in the H plane is unidirectional or almost unidirectional. At the resonance frequency of 5.69 GHz, a small distortion is observed due to the action of high frequencies on the substrate FR4. On the other hand, the E plane radiation pattern maintains the directionality of the five resonant frequencies.

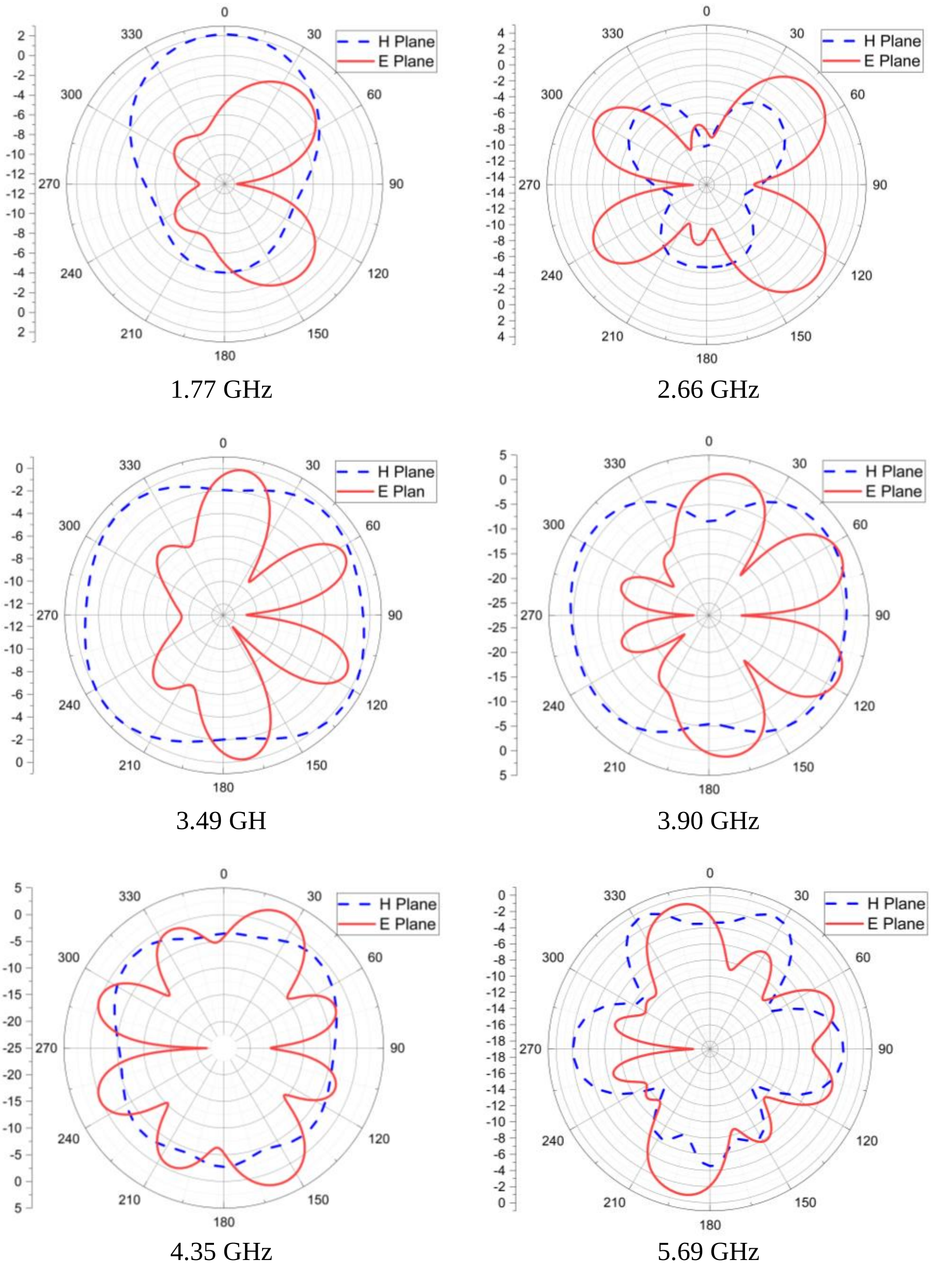

Figure 8. Far-fields at different frequency

The antennas shown in [23]–[28] are utilized as a reference to compare the performance of the proposed fractal patch (dimension, bandwidth, gain) to that of mono-band dual-band and multiband antennas (made using different approaches) published in the literature. Table 3 summarizes the comparison analysis conducted between the features of the multiband patch and those of the antennas proposed in the literature. The resonator reported by [23] has a very complex geometry, a large size, and a low bandwith. For the antenna presented in [24] although it is characterized by high gain, it has a large size and a low bandwidth.

Table 3. Comparison of the proposed antenna performance to that of other existing antennas in the literature

Ref	Size mm^3	Type of substrate	No of op. Bands	Impedance bandwidth (GHz)	Gain (dB)	Remarks
[23]	108x88x1.6	FR4	4	0.03, 0.1, 0.05, 0.8	3.23 to 5.95	Large size, low BW, and structure is complicated
[24]	110x110x6.6	FR4 (3 layers)	2	0.02,0.17	0.8 to 5.9	Large size, low BW
[25]	56×59×1.6	FR4	3	0.02, 0.07, 0.09	1.63 to 3.23	Low BW, and low gain
[26]	100x100x3.18	Taconic CER-10	1	0.045	2.56 (without FDGS) 5.38 (with FDGS)	Large size, complex structure, high dielectric constant
[27]	95x60x0.8	FR4	2	0.22, 1.32	0.76, 4.50	Large size, low gain
[28]	150x150x4	Jean fabric	2	0.2, 0.12	-	Large size, low BW
This work	75x75x1.6	FR4	6	0.07,0.18, 0.15, 0.14, 0.18, 0.33	3.01, 3.19, 1.89, 3.01, 4.85, 3.77	Compact structure, good bandwidth, and gain

Ullah *et al*. [25] has a compact size but it is characterized by a low gain and a narrow bandwidth. The antenna in [24] is characterised by large size, complex structure, and high dielectric constant. While the work of [27] have a large size and a low gain. The others present an antenna with large size and low bandwith [28]. The designed antenna is smaller than most similar antennas reported in the literature with a multiband and wideband operation and delivers a high gain of 4.85 dB, as may be deduced from the proposed references. This performance makes the proposed antenna more suitable for the integration of wireless communication circuits.

4. CONCLUSION

It is obvious to conclude that fractal antennas perform better than conventional patch antennas. The proposed fractal antenna operates at six frequencies and can be used for various wireless applications such as GSM, DCS, LTE, m-WiMAX, WLAN, and C-band. A study of the different iterations has been developed to increase the number of resonant frequencies, bandwidth, antenna adaptation, and gain. The proposed fractal antenna has been designed to have a better match around the frequencies of 1.77 GHz, 2.99 GHz, 3.49 GHz, 3.90 GHz, 4.35 GHz, and 5.69 GHz with a high gain that can reach 4.85 dB. Although the simulated performance shows a great improvement in results, the results of the manufactured antenna show a small degradation which can be attributed to the circumstances of manufacture and measurement. The fractal antenna made in this work presents an excellent candidate for modern wireless applications. This will open the way for the design of fractal antennas with other fractal geometries suited to the desired needs.

REFERENCES

[1] A. El Fatimi, S. Bri, and A. Saadi, "UWB antenna with circular patch for early breast cancer detection," *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 17, no. 5, pp. 2370–2377, Oct. 2019, doi: 10.12928/TELKOMNIKA.v17i5.12757.

[2] I. H. Nejdi, Y. Rhazi, M. A. Lafkih, and S. Bri, "A high gain reconfigurable frequency antenna multiband for wireless communications," *2020 International Symposium on Advanced Electrical and Communication Technologies (ISAECT)*, Nov. 2020, doi: 10.1109/ISAECT50560.2020.9523654.

[3] S. Palanisamy, B. Thangaraju, O. I. Khalaf, Y. Alotaibi, S. Alghamdi, and F. Alassery, "A novel approach of design and analysis of a hexagonal fractal antenna array (Hfaa) for next-generation wireless communication," *Energies*, vol. 14, no. 19, p. 6204, Sep. 2021, doi: 10.3390/en14196204.

[4] R. Kumar, R. Sinha, A. Choubey, and S. K. Mahto, "A quadrilateral shaped fractal slot planar antenna for ultra-wide band applications," *Australian Journal of Electrical and Electronics Engineering*, pp. 1–13, Jan. 2022, doi: 10.1080/1448837X.2021.2024317.

[5] T. A. Elwi, "Remotely controlled reconfigurable antenna for modern 5G networks applications," *Microwave and Optical Technology Letters*, vol. 63, no. 8, pp. 2018–2023, Jun. 2021, doi: 10.1002/mop.32505.

[6] I. H. Nejdi, Y. Rhazi, M. A. Lafkih, and S. Bri, "Designing multiband multilayered microstrip antenna for UMTS, ISM, Communication Satellite, HiperLAN and C-Band," *2018 International Symposium on Advanced Electrical and Communication Technologies (ISAECT)*, Nov. 2019, doi: 10.1109/ISAECT.2018.8618728.

[7] A. El Fatimi, S. Bri, and A. Saadi, "A new frequency reconfigurable antenna using proximity fed technique for wireless applications," *International Journal of Electronics and Telecommunications*, vol. 65, no. 2, pp. 181–187, 2019, doi: 10.24425/ijet.2019.126299.

[8] G. Dileep, "A survey on smart grid technologies and applications," *Renewable Energy*, vol. 146, pp. 2589–2625, Feb. 2020, doi: 10.1016/j.renene.2019.08.092.

[9] H. Lee, J. Tak, and J. Choi, "Wearable antenna integrated into military berets for indoor/outdoor positioning system," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 1919–1922, 2017, doi: 10.1109/LAWP.2017.2688400.

[10] A. Z. M. Imran, M. L. Hakim, M. R. Ahmed, M. T. Islam, and E. Hossain, "Design of microstrip patch antenna to deploy unmanned aerial vehicle as UE in 5G wireless network," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 5, pp. 4202–4213, Oct. 2021, doi: 10.11591/ijece.v11i5.pp4202-4213.

[11] S. R. Saunders and A. Aragón-Zavala, "Antennas for mobile systems," *Modern Antenna Handbook*. Wiley, pp. 1229–1254, Nov. 2007, doi: 10.1002/9780470294154.ch24.
[12] Y. Huang and K. Boyle, *Antennas: From Theory to Practice*. John Wiley & Sons, Ltd, 2008.
[13] G. S. Smith, "A direct derivation of a single-antenna reciprocity relation for the time domain," *IEEE Transactions on Antennas and Propagation*, vol. 52, no. 6, pp. 1568–1577, Jun. 2004, doi: 10.1109/TAP.2004.830257.
[14] L. H. Trinh *et al.*, "Miniature antenna for IoT devices using LoRa technology," in *International Conference on Advanced Technologies for Communications*, Oct. 2017, vol. 2017-Octob, pp. 170–173, doi: 10.1109/ATC.2017.8167611.
[15] S. S. Lodhi, P. K. Singhal, and V. V. Thakare, "Design and analysis of tripple band koch fractal yagi uda antenna," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 3, no. 4, May 2013, doi: 10.11591/ijece.v3i4.2572.
[16] M. Ihamji, E. Abdelmounim, H. Bennis, M. Hefnawi, and M. Latrach, "Design of compact tri-band fractal antenna for RFID readers," *International Journal of Electrical and Computer Engineering*, vol. 7, no. 4, pp. 2036–2044, Aug. 2017, doi: 10.11591/ijece.v7i4.pp2036-2044.
[17] D. H. Werner and S. Ganguly, "An overview of fractal antenna engineering research," *IEEE Antennas and Propagation Magazine*, vol. 45, no. 1, pp. 38–57, Feb. 2003, doi: 10.1109/MAP.2003.1189650.
[18] H. Ahmad, W. Zaman, M. U. Rahman, and F. C. Seman, "The smallest form factor monopole antenna with meandered radiator for WLAN and WiMAX applications," *IETE Journal of Research*, pp. 1–9, Mar. 2020, doi: 10.1080/03772063.2020.1742805.
[19] D. Tumakov, D. Chikrin, and P. Kokunin, "Miniaturization of a koch-type fractal antenna for wi-fi applications," *Fractal and Fractional*, vol. 4, no. 2, pp. 1–12, Jun. 2020, doi: 10.3390/fractalfract4020025.
[20] J. Anguera *et al.*, "Fractal antennas: An historical perspective," *Fractal and Fractional*, vol. 4, no. 1, pp. 1–26, Jan. 2020, doi: 10.3390/fractalfract4010003.
[21] E. P. Bellido, G. D. Bernasconi, D. Rossouw, J. Butet, O. J. F. Martin, and G. A. Botton, "Self-similarity of plasmon edge modes on koch fractal antennas," *ACS Nano*, vol. 11, no. 11, pp. 11240–11249, Nov. 2017, doi: 10.1021/acsnano.7b05554.
[22] D. G. Patanvariya, A. Chatterjee, K. Kola, and S. Naik, "Design of a linear array of fractal antennas with high directivity and low cross-polarization for dedicated short range communication application," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 30, no. 3, Dec. 2020, doi: 10.1002/mmce.22083.
[23] A. Gupta, H. D. Joshi, and R. Khanna, "An X-shaped fractal antenna with DGS for multiband applications," *International Journal of Microwave and Wireless Technologies*, vol. 9, no. 5, pp. 1075–1083, Sep. 2017, doi: 10.1017/S1759078716000994.
[24] Q. Liu, J. Shen, J. Yin, H. Liu, and Y. Liu, "Compact 0.92/2.45-GH dual-band directional circularly polarized microstrip antenna for handheld RFID reader applications," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 9, pp. 3849–3856, Sep. 2015, doi: 10.1109/TAP.2015.2452954.
[25] S. Ullah, F. Faisal, A. Ahmad, U. Ali, F. A. Tahir, and J. A. Flint, "Design and analysis of a novel tri-band flower-shaped planar antenna for GPS and WiMAX applications," *Journal of Electromagnetic Waves and Applications*, vol. 31, no. 9, pp. 927–940, May 2017, doi: 10.1080/09205071.2017.1330160.
[26] K. Wei, B. Zhu, and M. Tao, "The circular polarization diversity antennas achieved by a fractal defected ground structure," *IEEE Access*, vol. 7, pp. 92030–92036, 2019, doi: 10.1109/ACCESS.2019.2927280.
[27] J. Dong, X. Yu, and L. Deng, "A decoupled multiband dual-antenna system for WWAN/LTE smartphone applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 1528–1532, 2017, doi: 10.1109/LAWP.2017.2647807.
[28] S. Velan *et al.*, "Dual-band EBG integrated monopole antenna deploying fractal geometry for wearable applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 249–252, 2015, doi: 10.1109/LAWP.2014.2360710.
[29] K. J. Vinoy, K. A. Jose, V. K. Varadan, and V. V. Varadan, "Resonant frequency of Hilbert curve fractal antennas," in *IEEE Antennas and Propagation Society, AP-S International Symposium (Digest)*, 2001, vol. 3, pp. 648–651, doi: 10.1109/aps.2001.960180.
[30] C. P. Baliarda, C. B. Borau, M. N. Rodero, and J. R. Robert, "An iterative model for fractal antennas: Application to the Sierpinski gasket antenna," *IEEE Transactions on Antennas and Propagation*, vol. 48, no. 5, pp. 713–719, May 2000, doi: 10.1109/8.855489.
[31] S. Suganthi, K. S. Tharini, P. S. Sarankumar, S. Raghavan, and D. Kumar, "Design and simulation of planar Minkowski fractal antennas," *Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology (Wireless VITAE)*, Feb. 2011, doi: 10.1109/WIRELESSVITAE.2011.5940935.

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