A Dual-band Printed Slot Antenna Based on Modified Sierpinski Triangle

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Abstract – **Thispaper presents the design of a compact microstrip fed printed slot antenna to be used for dual-band wireless applications. The slot structure of the proposed antenna is based on a modified Sierpinski triangle which is a variant of the conventional Sierpinski gasket of the first iteration. The slot structure has been etched on the ground plane of an FR-4 substrate with relative permittivity of 4.4 and 1.6 mm thickness. On the reverse side of the substrate, a 50 ohm microstrip line feed has been etched. Modeling and performance evaluation of the proposed antenna have been carried out using a method of moments based electromagnetic simulator, IE3D. Simulation results shows that the proposed antenna over perform that with the conventional Sierpinski gasket slot based slot of the same size and iteration level in that there is no need for a tuning stub to extract the dual-band response. Furthermore, results show that, varying the aspect ratio of the antenna structure results in return loss responses with dual-band behavior covering a wide variety of wireless communication applications below 6 GHz. Besides the compact size and the simple structure, the antenna offers reasonable radiation characteristics in the two bands.**

Keywords – **Dual-Band Antenna, Fractal Antenna, Printed Antenna, Sierpinski Triangle, Slot Antenna.**

I. INTRODUCTION

Many techniques have been adopted to design low profile slot antennas for dual-band wireless communication applications operating below 6 GHz. Among these techniques is the use of multiple slot structures etched in the ground plane of printed slot antenna [1]. In these antennas, one of the slot structures resonates at the lower band, while the upper resonant band is attributed by the second slot structure. Antennas designed according to this technique have been found to possess large sizes and being with complex structures. In this context, microstrip and printed antennas are promising candidates for this design due to their low profile, low-weight, and ease of fabrication [2]. Furthermore, various fractal geometries have found their way to be used in the antenna design to produce compact and multiband antennas benefiting from their unique properties; space filling and self similarity respectively.

In the other hand, to provide bandwidth enhancement of the resonant bands, fractal based slot structures are widely used in the design of multiband printed antennas. In this respect, Koch, Cantor, Hilbert, Sierpinski, Minkowski and other fractal geometries have been successfully used to produce dual-band and multiband printed slot antennas for various wireless applications [3-20]. In these reported works, it has been concluded that the application of fractal

geometries in the design of slot printed antennas can be classified into two categories. In the first category, direct application of fractal geometries has been adopted [3-12]. In such a case, the fractal geometries constitute the whole antenna slot structures. The multiband behavior of such antennas has been extracted almost directly without the need of any tuning elements or slot shape modification. However, in the second category, the slot structure is a combination of Euclidian structures, such as triangle, square, rectangle and other polygons, and fractal geometries superimposed on these structures, where each line segment is replaced by fractal curve with certain iteration level [13-20]. In this case, the multiband behavior has been reached in different techniques. These include the addition of tuning stubs to the feed line and modification of the slot structures by rotating it around the antenna axis.

In this respect, Koch, Cantor, Hilbert, Sierpinski, Minkowski and other fractal geometries have been successfully used to produce dual-band and multiband printed slot antennas for various wireless applications [3–23]. In these reported works, it has been concluded that the application of fractal geometries in the design of slot printed antennas can be classified into two categories [3]. In the first category, direct application of fractal geometries has been adopted [4–14]. In such a case, the fractal geometries constitute the whole antenna slot structures. The multiband behavior of such antennas has been extracted almost directly without the need of any tuning elements or slot shape modification. However, in the second category, the slot structure is a combination of Euclidian structures, such as triangle, square, rectangle and other polygons, and fractal geometries superimposed on these structures, where each line segment is replaced by fractal curve with certain iteration level [15–23]. In this case, the multiband behavior has been reached in different techniques. These include the addition of tuning stubs to the feed line and modification of the slot structures by rotating it around the antenna axis.

Furthermore, a lot of research work has been reported in the literature applying the Sierpinski gasket based structures and their related variants in the antenna design [6, 21-32]. Except for the work reported in [6], in the majority of the reported antennas, the Sierpinski gasket structures are used as microstrip patch antennas.

In this paper, a compact printed antenna with slot structure based modified Sierpinski triangle fractal geometry of the first iteration is presented as a candidate for use in dual-band wireless applications. The antenna has been fed with a 50 Ω microstrip line etched on the reverse side of the ground plane. Comparative study reveals that

the proposed antenna over performs the printed slot antenna with slot structure based on the conventional Sierpinski gasket in many respects. Results show that, varying the aspect ratio of this antenna results in return loss responses with dual-band behavior covering a wide variety of wireless communication applications below 6 GHz.

II. THE PROPOSED ANTENNA STRUCTURE

Printed slot antenna design based on the conventional Sierpinski gasket fractal geometry has been reported in the literature [6]. Figure 1 shows the generation process of the conventional Sierpinski gasket up to the second iteration. An interesting variation of the Sierpinski gasket may be obtained if one dissects the initial triangle into nine congruent triangles and removes three as indicated in Fig. 2(b). The next step is illustrated in Fig. 2(c). The resulting fractal structure is referred to as the modified Sierpinski triangle [33]. However, a multiband patch monopole antenna based on this structure has been reported in [34] and referred to as a mod-p Sierpinski fractal antenna.

As it is implied in Fig. 2, the first iteration of the modified Sierpinski triangle is composed of nine equal sized triangular substructures, whereas the conventional Sierpinski gasket of the same iteration is composed of four triangular substructures. This means that the modified Sierpinski triangle fills the space in a rate faster than that of the Sierpinski gasket.
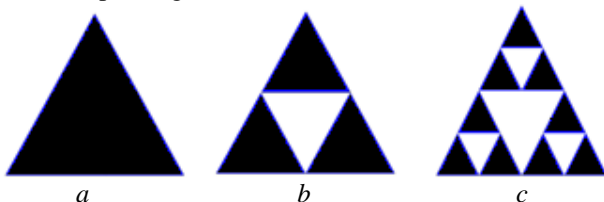

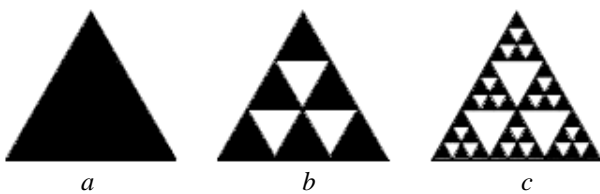Fig. 1.The steps of growth of the conventional Sierpinski gasket up to the second iteration.

Fig.2. The steps of growth of the modified Sierpinski triangle upto the second iteration [33].

III. THE ANTENNA DESIGN

The A printed antenna with a slot structure based on the 1st iteration of the modified Sierpinski triangle depicted in Fig. 2(b) has been initially designed. The slot structure is supposed to be etched on the ground plane of an FR4 substrate with relative dielectric constant of $\varepsilon_r = 4.4$ and thickness of 1.6 mm. On the reverse side of the substrate, a 50 Ω microstrip feed line has been etched. It has a length of 22.5 mm and a width of 3.0 mm. Initial return loss response shows that the antenna has dual-band characteristics within a swept frequency range 1–7 GHz.

Appropriate dimension scaling of the antenna structure has been carried out in order to allocate the lower resonant band around 2.4 GHz. The resulting antenna has been found to have a triangular slot with side length of 40 mm and a square ground plane with a side length of about 50mm. Numerical analysis of the antenna performance is carried out using the commercially available EM simulator, the IE3D [35]. For comparative purposes, another printed antenna of the same size but with slot structure based on the conventional Sierpinski gasket has been modeled using the same substrate and feed line structure. It is worth to note here that a printed antenna based on this slot structure has been reported in [6] but with a stub loaded feed line to enhance the coupling of the two resonating bands.

IV. PERFORMANCE EVALUATION

Figure 4, demonstrates the simulated return loss responses of the proposed antenna structure depicted in Fig. 3 with the feed line length as a parameter. The feed line length has been varied with respect to the antenna center, in steps of 2 mm.
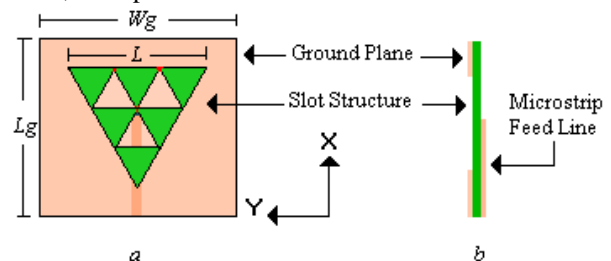

Fig.3. The layout of the modeled antenna with respect to the coordinate system, (a) The top view and (b) The side view.

It is clear that the proposed antenna structure exhibits a dual-band resonant response within the swept frequency range of 1–7 GHz. This does not prevent the possibility of the existence of higher resonant bands outside this range. The variation of the feed line length has a little effect on the positions of the two resonant bands. However, as the feed line length is increased away from the antenna center, the lower resonant band becomes with increased coupling at the expense of reduced coupling of the upper resonant band. Consequently, between two extreme values of the feed line length, one of the resonant bands has diminished.
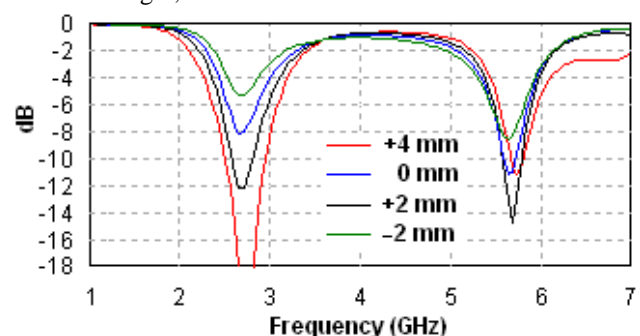

Fig.4. Simulated return loss responses of the antenna depicted in Fig. 3 with the feed line length as a parameter.

Observing the influence of the various parameters on the antenna performance, it has been found that the dominant factor in the antenna is the triangle slot side length L in terms of the guided wavelength λ_g:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}} \qquad (1)$$

Where ε_{eff} is the effective dielectric constant. In terms of the triangular slot side length L and the guided wavelength λ_g, the lower resonant frequency, f_1, is given by:

$$f_1 = \frac{2\,c}{3L\sqrt{\varepsilon_{re}}} \qquad (2)$$

where c is the speed of light in free space.

For the sake of comparison, another printed antenna with a slot structure in the form of 1st iteration conventional Sierpinski fractal geometry shown in Fig. 1(b) has been modeled with the same size and using the same substrate and feed structure. The return loss response of this antenna together with that of the proposed antenna have been shown in Fig. 5 for a feed line length of +3 mm away from the antenna center.
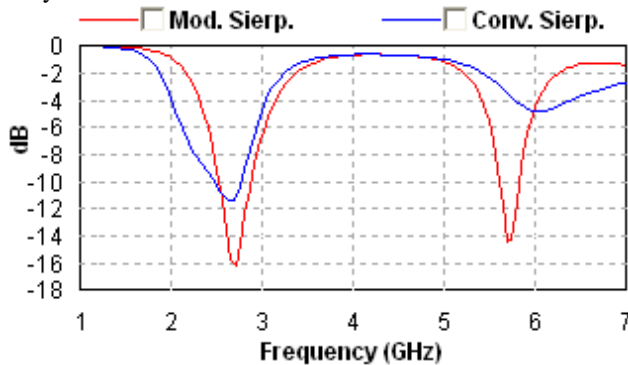

Fig.5. Simulated return loss responses of a printed slot antenna with the slot based on the conventional Sierpinski gasket of the 1st iteration and the modified Sierpinski triangle of the same iteration level.

Simulation results imply that the proposed antenna over performs that with slot based on conventional Sierpinski fractal in that it offers a return loss response with better coupling of both resonant band. This problem has been solved in the other antenna by adding a tuning stub to its feed line structure as reported in [6].

V. PARAMETRIC STUDY

An A parametric study has been carried out to explore the effects of the aspect ratio of the proposed antenna on its return loss performance. The aspect ratio of the fractal slot structure is defined as the ratio of the antenna ground plane width, W_g, to its length, L_g, as pointed out in Fig. 3. In this context, the variable values of the slot aspect ratio, which will appear in Figs. 6–7, are obtained by only varying the ground plane width, W_g, and keeping its length, L_g, with a constant value of 45 mm. The performance of all of the modeled antennas has been evaluated within the swept frequency range of 1–7 GHz using the prescribed substrate and a fixed value of the feed line length. The frequency ratio of the two resonant bands, f_2/f_1, offered by any dual-band antenna is of considerable importance in order to cover the different communication services below 6 GHz. Simulation results have shown that the proposed antenna exhibits a dual-band response within the prescribed sweep frequency for a certain range of the aspect ratio. An interesting feature, the antenna design offers, is that it possesses dual-band return loss responses with a considerable range of the resonant frequency ratio f_2/f_1 within the specified sweep frequency range when varying the antenna aspect ratio.
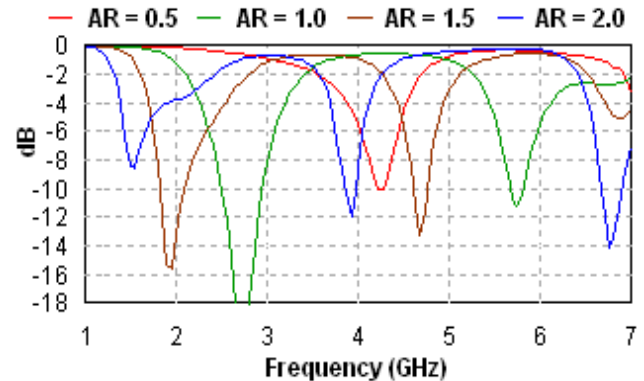

Fig.6. Simulated return loss responses of the antenna depicted in Fig. 3 with the aspect ratio, AR, as a parameter

Figure 6 demonstrates the simulated return loss responses of the proposed antenna for selected values of the aspect ratio in the range of $0.5 - 2.0$, in steps of 0.5. As it is implied from Fig. 6, as the aspect ratio is varied, both the lower and the upper resonant band positions are changed. However, it is clear that for larger values of the aspect ratio, the antenna starts to possess a triple band resonant behavior within the specified swept frequency range.

Figure 7 provides more details concerning the effects of change of the antenna aspect ratio both the lower and the upper resonant frequencies within the prescribed frequency range. The aspect ratio is varied in the range 0.5–2.25 in steps of 0.25. It is clear that both frequencies decrease as the aspect ratio becomes higher but with different rates of change. This results in variable resonant frequency ratios corresponding to the different values of the aspect ratios. Figure 8 illustrates the variation of the resonant frequency ratios f_2/f_1 versus the prescribed range of the aspect ratio.
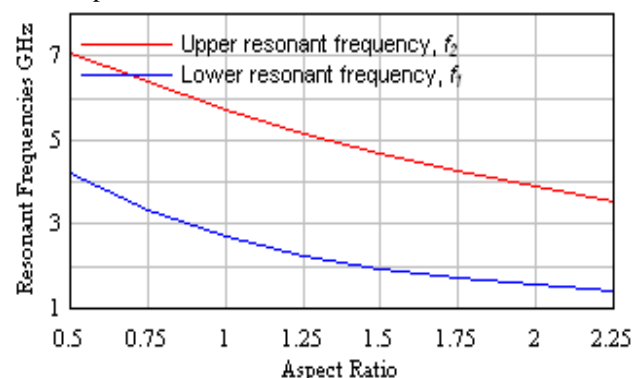

Fig.7. Variation of the lower resonant frequency, f_1, and the upper resonant frequency f_2, versus the change of the antenna aspect ratio.

The simulation results presented in Figs. 4–8 and with appropriate dimension scaling, the proposed antenna offers dual-band responses covering a wide variety of communication applications below 6 GHz, such as 2.4 GHz WLAN band (2.4–2.483 GHz), the 2.50 GHz mobile WiMAX operating band (2.5–2.7 GHz), U-NII mid-band (5.47–5.725 GHz), U-NII high-band (5.725 –5.875 GHz) and many others.

In this context, the following is an example of the design of a dual-band antenna design for 2.4/5.2 GHz WLAN applications. From Figures 7 and 8, the aspect ratio required to satisfy these bands is of about 1.6. Figure 9 presents the return loss response of the proposed antenna at this aspect ratio. It is clear that the antenna is suitable to provide the required −10 dB return loss bandwidths for the 2.4/5.2 GHz dual-band WLAN applications.
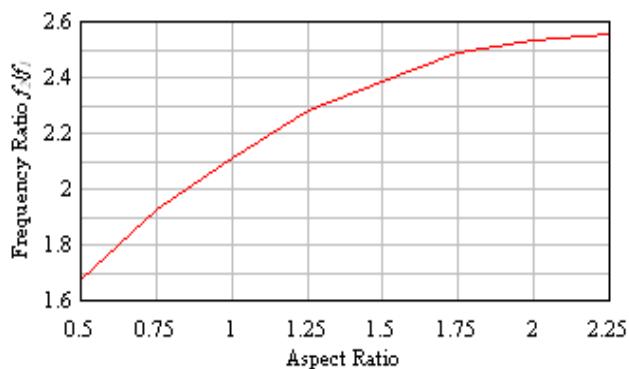

Fig.8. Thevariation of the resonant frequency ratio, $f2/f_1$, versus the change of the antenna aspect ratio.

The 3D far field radiation patterns of proposed antenna, with feed line length of 3 mm away from the antenna center and aspect ratio of 1.6, are demonstrated in Fig. 10 at 2.4 and 5.2 GHz. The results show almost monopole like radiation patterns. The related antenna gains at these frequencies are found to be of about 2.1 dBi at both bands which is sufficient for such an application.
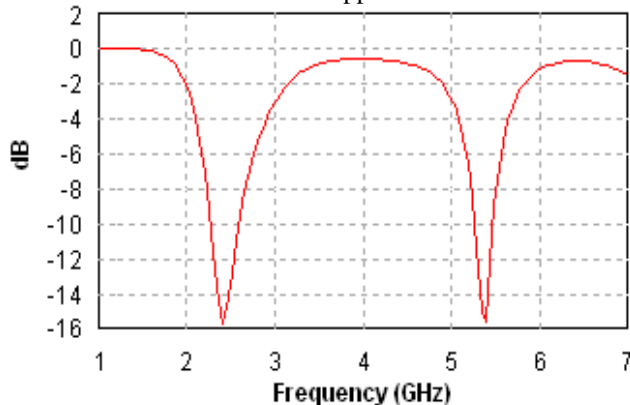

Fig.9. Thesimulated return loss response of the antenna depicted in Fig. 3 with the aspect ratio = 1.6, for 2.4/5.2 GHz applications.

To gain more insight about the EM characteristics of the proposed antenna, the current distributions generated on its surface have been simulated at 2.40 and 5.20 GHz, as shown in Fig. 11.
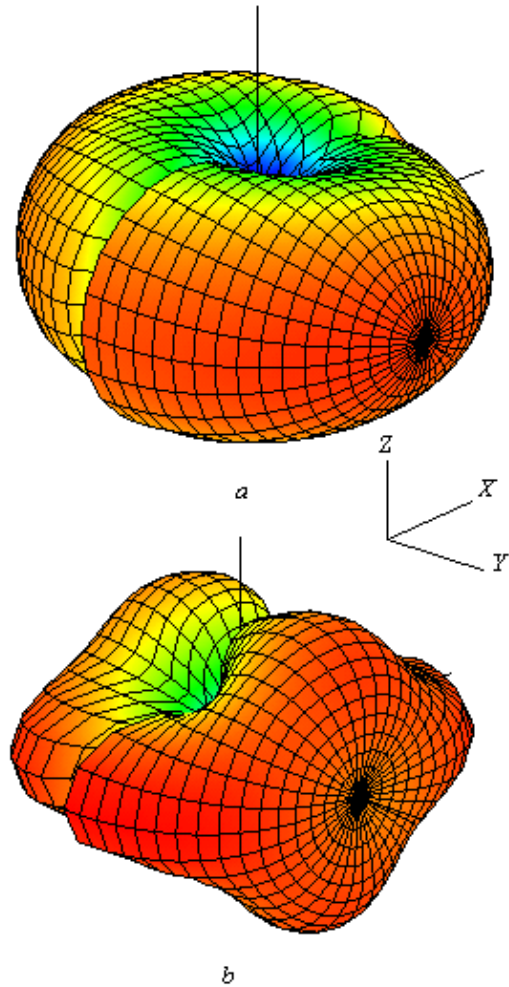

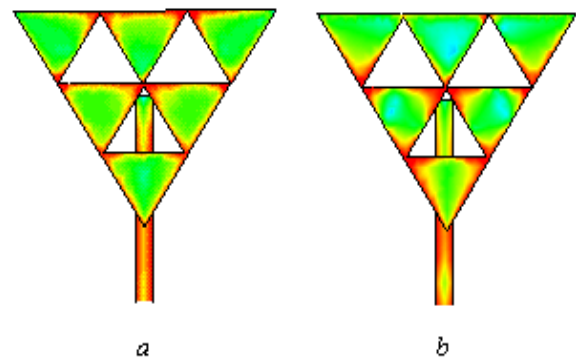Fig.10. Simulated 3D radiation patterns of the modeled antenna at (a). 2.40 GHz, and (b). 5.20 GHz.

Fig.11. Simulatedcurrent distributions on the surface of the modeled antenna at (a). 2.40 GHz and (b). 5.20 GHz.

It is worth to note that the same color scale has been adopted for the simulated current distributions at the two frequencies. As the results of Fig. 11(a) implies, the resonance at 2.40 GHz is attributed to the larger current path in the slot structure. At the 5.20 GHz resonance, it is clear from Fig. 11(b) that only a portion from the slot structure has the current responsible of the higher frequency radiation field of this band.

VI. CONCLUSION

The modified Sierpinski triangle fractal has been suggested in this paper to constitute the slot structure of a new printed antenna. The proposed slot antenna is presented as a candidate for use in dual-band wireless applications. Simulation results show that the proposed antenna over performs the conventional Sierpinski gasket based slot antenna of the same size in that it has simpler structure with no need to a tuning stub to achieve the required dual-band resonance. In addition, it offers better return loss response with enhanced coupling of the two resonant bands.

A parametric study carried out on this antenna reveals that the antenna aspect ratio has a considerable effect on it return loss response. Simulation results show that for a certain range of the aspect ratios, the antenna is capable to offer return loss responses covering almost most of the recently available communication services below 6 GHz. A deign example presented for 2.4/5.2 GHz dual-band WLAN applications, shows that the antenna exhibits a dual-band behavior with the two resonant bands centered at 2.40 and 5.30 GHz and the corresponding fractional bandwidths are sufficient for such an application. Furthermore, the proposed antenna offers reasonable gain and radiation characteristics. The compact size of the proposed antenna makes it suitable for a wide variety of dual-band wireless applications within the specified frequency range.

REFERENCES

[1] K. -L. Wong, *Planar Antennas for Wireless Communications*, New Jersey: Wiley, 2003.

[2] C. A. Balanis, *Antenna Theory; Analysis and Design*, Third Ed., New York: Wiley, 2005.

[3] A. Sayem, and M. Ali, "Characteristics of a microstrip-fed miniature printed Hilbert slot antenna," Progress In Electromagnetics Research, vol. 56, pp. 1-18, 2006.

[4] D.D. Krishna, A.R. Chandran, and C.K. Aanandan, "A compact dual frequency antenna with Sierpinski gasket based slots," in Proceedings of the European Conference on Wireless Technologies, pp.320-322, Oct. 2007.

[5] J. K. Ali, "A new microstrip-fed printed slot antenna based on Moore space-filling geometry," in Proceedings of IEEE 2009 Loughborough Antennas and Propagation Conference, LAPC, UK., 2009.

[6] J. K. Ali, and E. S. Ahmed, "A new fractal based printed slot antenna for dual band wireless communication applications," in Proceedings of Progress In Electromagnetics Research Symposium, Kuala Lumpur, Malaysia, 2012.

[7] J. K. Ali and S. F. Abdulkareem, "A Circle-based Fractal Slot Antenna for Dual-band Wireless Applications," Accepted at the 13th IEEE Mediterranean Microwave Symposium, MMS'13, Saida, Lebanon, 2013.

[8] H. B. Kim, and K. C. Hwang, "Dual-port spidron fractal slot antenna for multiband gap-filler applications," IEEE Transactions on Antennas and Propagation, vol. 60, no. 10, pp. 4940-4943, 2012.

[9] D. C. Chang, B. H. Zeng, and J. C. Liu, "CPW-fed circular fractal slot antenna design for dual-band applications," IEEE Transactions on Antennas and Propagation, vol. 56, no. 12, pp. 3630-3636, 2008.

[10] C. Mahatthanajatuphat, P. Akkaraekthalin, S. Saleekaw, and M. Krairiksh, "A bidirectional multiband antenna with modified fractal slot FED by CPW," Progress In Electromagnetics Research, vol. 95, pp. 59-72, 2009.

[11] Y. K. Choukiker, S. Rai, and S. K. Behera, "Modified half-circle fractal antenna using DC theorem for 2.4/5.2 GHz WLAN application," in Proceedings of IEEENational Conference on Communications (NCC), 2011.

[12] N. Bisht, and P. Kumar, "A dual band fractal circular microstrip patch antenna for C-band applications," in Proceedings of Progress In Electromagnetics Research Symposium, Suzhou, China, 2011.

[13] D. D. Krishna, M. Gopikrishna, C. K. Anandan, P. Mohanan, and K. Vasudevan,"CPW-fed Koch fractal slot antenna for WLAN/WiMAX applications," IEEE Antennas and Wireless Propagation Letters, vol.7, pp. 389-392, 2008.

[14] J. K. Ali, M. T. Yassen, M. R. Hussan, and A. J. Salim, "A printed fractal based slot antenna for multi-band wireless communication applications," in Proceedings of Progress In Electromagnetics Research Symposium, Moscow, Russia, 2012.

[15] J. K. Ali, and A. S. A. Jalal, "A Miniaturized multiband Minkowski-like pre-fractal patch antenna for GPS and 3g IMT-2000 Handsets," Asian J. Inform. Tech, vol. 6, no. 5, pp. 584-588, 2007.

[16] H. Zhang, H. Y. Xu, B. Tian, and X. F. Zeng, "CPW-fed fractal slot antenna for UWB application," International Journal of Antennas and Propagation, vol. 2012, Article ID 129852, pp. 1-4, 2012.

[17] Y. K. Choukiker, and S. K. Behera, "ACS fed Koch fractal antenna for wide–band applications," International Journal of Signal and Imaging Systems Engineering, vol. 6, no. 1, pp. 9-15, 2013.

[18] S. F. Abdulkarim, A. J. Salim, J. K. Ali, A. I. Hammoodi, M. T. Yassen, and M. R. Hassan, "A compact Peano-type fractal based printed slot antenna for dual-band wireless applications," in Proceedings of the 2013 IEEE International RF and Microwave Conference (RFM2013), Penang, Malaysia, 2013.

[19] S. F. Abdulkareem, A. J. Salim, A. I. Hammoodi, and J. K. Ali, "A fractal-based printed slot antenna for multi-band wireless applications," in Proceedings of Progress In Electromagnetics Research Symposium, Stockholm,, Sweden, 2012.

[20] H. Oraizi, and S. Hedayati, "A novel wide slot antenna design using the Giusepe Peano fractal geometry," in Proceedings of the 20th Iranian Conference on Electrical Engineering, (ICEE2012), Tehran, Iran, 2012.

[21] C. Puente-Baliarda, J. Romeu, R. Pous, and A. Cardama, "On the behavior of the Sierpinski multiband fractal antenna," IEEE Transactions on Antennas and Propagation, vol. 46, no. 4, pp. 517-524, 1998.

[22] 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, 2000.

[23] J. Parrón, J. Romeu, J.M. Rius, and J.R. Mosig, "Method of moments enhancement technique for the analysis of Sierpinski pre-fractal," IEEE Transactions on Antennas and Propagation, vol. 51, no. 8, pp. 1872-1876, 2003.

[24] D. Anagnostou, M. T. Chryssomallis, J. C. Lyke, and C. G. Christodoulou,. "Improved multiband performance with self-similar fractal antennas," in IEEE Topical Conference on Wireless Communications Technology, Honolulu, HI.,Oct. 2003.

[25] G.F. Tsachtsiris, C.F. Soras, M. P. Karaboikis, and V.T. Makios, "Analysis of a modified Sierpinski gasket monopole antenna printed on dual band wireless devices," IEEE Transactions on Antennas and Propagation, ,vol. 52, no. 10, pp. 2571-2579, 2004.

[26] N. Kingsley, D. E. Anagnostou, M.Tentzeris, and J. Papapolymerou, RF "MEMS sequentially reconfigurable Sierpinski antenna on a flexible organic substrate with novel DC-biasing technique," Journal of Microelectromechanical Systems, vol. 16, no. 5, pp. 1185-1192, 2007.

[27] R. Azaro, L. Debiasi, E. Zeni, M. Benedetti, P. Rocca, and A. Massa, "A hybrid prefractal three-band antenna for multistandard mobile wireless applications," IEEE Antennas and Wireless Propagation Letters, vol. 8, pp. 905-908, 2009.

[28] W. J. Krzysztofik, "Modified Sierpinski fractal monopole for ISM-bands handset applications," IEEE Transactions on Antennas and Propagation, vol. 57, no. 3, pp. 606-615, 2009.

[29] Y. K. Choukiker, and S.K. Behera, "CPW-fed compact multiband Sierpinski triangle antenna," in IEEE Annual India Conference (INDICON), 2010, pp. 1-3, Dec. 2010.

[30] L. Lizzi, and G. Oliveri, "Hybrid design of a fractal-shaped GSM/UMTS antenna," Journal of Electromagnetic Waves and Applications," vol. 24, no. 5-6, pp. 707-719, 2010.

[31] P. J. Soh, G. A. E. Vandenbosch, S. L. Ooi, and M. R. N. Husna, "Wearable dual-band Sierpinski fractal PIFA using conductive fabric," Electronics letters, vol. 47, no. 6, pp. 365-367, 2011.

[32] F. Viani, "Dual-band Sierpinski pre-fractal antenna for 2.4 GHz-WLAN and 800 MHz-LTE wireless devices," Progress In Electromagnetics Research C, vol. 35, pp. 63-71, 2013.

[33] H. Sagan, *Space-Filling Curves*, Springer-Verlag New York Inc., 1994.

[34] J.Soler, J.Romeu, and C. Puente, "Mod-P Sierpinski fractal multiband antenna," in Proceedings of the International Symposium on Antennas and Propagation, ISAP'2000, Japan, April 2000.

[35] *IE3D User's Manual*, Release 12.3, Zeland Software, Inc., Fremont, CA, 2007.

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