SLOTTED LOG PERIODIC FRACTAL KOCH ANTENNA FOR ULTRA HIGH FREQUENCY DIGITAL TELEVISION APPLICATION

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Specially dedicated to my beloved parent, Radziah Long and Mohd Yaziz Ahmad
my supportive husband, Muhammad Ridduan Ramli
my siblings, Syazwan, Syuhada and Syazana
with love for their prays and encouragement.

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ABSTRACT

The Ultra High Frequency (UHF) band has long been used for voice, data and video communications. For the terrestrial television broadcasting, the lower frequency band of the UHF is used which ranges between 470 to 890 MHz. The conventional UHF antennas for receiving TV signals are quite large. One method that can be utilized is by using a compact and directional antenna that can be easily fabricated. The geometry used in this antenna design is Koch curve fractal structure. The advantage of using fractals in designing the antenna is to minimize the antenna size. The Log Periodic Antenna (LPA) is chosen because it had a wide bandwidth. This thesis describes the design of the planar fractal Koch antenna with slots for the UHF band. Four different iterations which is 0th iteration, 1st iteration, 2nd iteration and series iteration have been designed and simulated. The simulation process was done using Computer Simulation Technology (CST). The antenna has been fabricated on the Flame Retardant 4 (FR4) laminate microstrip board with dielectric constant of 5.4 and thickness of 1.6 mm. The simulation results show that the Koch curve technique can be used to minimize the length of the arm LPA, but the lower frequency tends to shift to the higher frequency as the number of iterations increases. Thus, a slot is introduced at each of the element of the Log Periodic Antenna in order to avoid the lower designed frequencies from shifting to higher band. A 28.7% reduction of the antenna size has been achieved by using slotted fractal Koch technique at the 2nd iteration. All antennas have been tested and measured in terms of reflection coefficient, radiation pattern and its realized gain. The simulation and measurement results have been compared and analyzed. A good agreement was achieved with reflection coefficient, S_{11}< -10 dB for the entire UHF digital television band frequency design, directional radiation patterns with beamwidth of 75°, wide bandwidth up to 95% and an average gain of 6 dBi along the frequency range. This proposed antenna suitable for the intended application.

ABSTRAK

Jalur Frekuensi Ultra Tinggi (UHF) telah lama digunakan untuk komunikasi suara, data dan video. Untuk penyiaran televisyen terestrial, jalur frekuensi rendah UHF yang digunakan adalah antara 470 hingga 890 MHz. Kebanyakan antena konvensional UHF yang telah digunakan untuk menerima isyarat televisyen agak besar saiznya. Salah satu dari kaedah untuk memenuhi permintaan ini adalah dengan menggunakan antena kompak dan berarah. Geometri yang digunakan dalam reka bentuk antena ini adalah struktur fraktal lengkuk Koch. Salah satu kelebihan menggunakan fraktal dalam mereka bentuk antena adalah untuk mengecilkan saiz antena. Antena log berkala (LPA) dipilih kerana ia boleh menghasilkan jalur lebar yang lebih luas. Tesis ini menerangkan reka bentuk fraktal Koch dengan gabungan slot untuk antena frekuensi UHF. Empat rekabentuk yang berbeza seperti iterasi 0, 1, 2 dan sesiri telah direka dan disimulasi. Proses simulasi telah dilakukan dengan menggunakan perisian Teknologi Simulasi Komputer (CST). Rekabentuk yang diperoleh dari simulasi telah difabrikasikan dengan substrat bahan rencat nyala 4 (FR4) dengan pemalar dielektrik 5.4 dan ketebalan 1.6 mm. Hasil simulasi menunjukkan bahawa teknik geometri Koch boleh digunakan untuk mengurangkan panjang elemen LPA, tetapi frekuensi yang lebih rendah cenderung untuk beralih ke frekuensi yang lebih tinggi apabila bilangan iterasi bertambah. Frekuensi yang teranjak telah dipulih dengan memperkenalkan slot di setiap elemen LPA. Dengan menggunakan teknik slot fraktal Koch pada leleran ke-2, didapati saiz antenna berkurang sebanyak 28.7 %. Kesemua antena telah diuji dan diukur dari segi pekali pantulan, corak radiasi dan gandaan. Keputusan simulasi dan pengukuran telah dibandingkan dan dianalisa. Kesemua antena menunjukkan keputusan yang baik dengan nilai pemalar pantulan S_{11}<-10 dB pada frekuensi jalur UHF televisyen digital, corak sinaran terarah dengan lebaralur 75°, lebar jalur yang besar iaitu melebihi 95% serta gandaan purata 6 dBi sepanjang julat frekuensi. Antena yang dicadangkan adalah sesuai digunakan untuk aplikasi ini.

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LIST OF ABBREVIATIONS

BW	-	Bandwidth
CPW	-	Co-Planar Waveguide
CST	-	Computer Simulation Technology
dB	-	Decibel
dBi	-	Decibel Isotropic
DCS	-	Digital Code Squelch
DTV	-	Digital Terrestrial Video
FR-4	-	Flame Retardant-4
FKLPA	-	Fractal Koch Log Periodic Antenna
GSM	-	Global System Mobile
LPA	-	Log Periodic Antenna
LPDA	-	Log Periodic Dipole Antenna
ISM	-	Industrial Sciences Medical
PCS	-	Personal Communications Service
RF	-	Radio Frequency
RFID	-	Radio Frequency Identification
SMA	-	Sub Miniature Version A
TV	-	Television
TVWS	-	Television White Spectrum
UHF	-	Ultra High Frequency
UWB	-	Ultra Wide Band
VSWR	-	Voltage Standing Wave Ratio
WiMAX	-	Worldwide Interoperability for Microwave Access
WLAN	-	Wireless Local Area Network

LIST OF SYMBOLS

λ	-	Wavelength
c	-	Speed of light
ε_r	-	permittivity
λ_0	-	Free Space wavelength
λ_c	-	wavelength at center frequency
λ_g	-	guided wavelength
f_c	-	Center frequency
f_H	-	High frequency
f_L	-	Low frequency
h	-	Height of substrate
L	-	Length of patch
W	-	Width of patch
L_{eff}	-	Effective length

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Antenna design has grown to be one of the most active fields in the wireless communication [22]. In the early years, whilst radio frequency became determined, simple antenna design was the main tool used to transmit electrical energy or radio wave via the air in all paths [23]. The wireless technology has improved swiftly not only simply for commercial use, but also for navigation [24], [25].

In modern-day telecommunication systems, the requirement for antennas with wider bandwidth [26] and smaller dimensions [27] than conventional ones are desired. This has initiated studies of the antenna in numerous directions, one among those via the usage of fractal shaped antenna elements. In current years [28], numerous fractal geometries [29] have been brought for antenna applications with varying degrees of achievement in enhancing antenna characteristics [30]. Some of these geometries were especially beneficial in decreasing the dimensions of the antenna [31], [32] whilst other designs intended to be incorporating multi-band [33], [34], [35] behaviors. Several researches were made in designing the fractal shape properties for the antennas.

The deployment of digital terrestrial broadcasting (DTV) has stretched all over the world and Malaysia has announced their involvement since 2005 [36]. The Malaysian conventional analog TV will be replaced with DTV by 2018 [36]. DTV standard allows contents provider to transmit programs in high definition video and six channel-surround audios. The bandwidth allocation of DTV is rather extensive and imposes the need for a broadband [9] reception antenna. In order to support the DTV front end device, a compact yet broadband [37] reception antenna which covers from 460 MHz to 870 MHz [36] [38] will be designed for the DTV receiver.

Many studies have been carried on frequency independent antennas since the late 1950s and experiments with several geometries such as spiral, biconical and fractal have been developed. Log periodic dipole array (LPDA) was firstly introduced by DuHamel and Isbell in 1957 [39] as one of the frequency independent antenna. Printed log-periodic dipole antenna has been given a great deal of interest and is becoming an attractive candidate in this area due to its merits such as a light weight, low cost, and easy to integrate [40]. Directional antenna has an advantage of higher gain [41] than omni-directional antenna because it can radiate in a specific direction. Besides, log-periodic dipole array (LPDA) antennas are extensively used in different applications due to their broadband characteristics [42], high gain [43], and low cross-polarization ratio [44]. This type of antenna was recommended at the beginning of the 1960s. In [45], Carrel demonstrated on how to design an LPDA per specifications in terms of bandwidth and directivity [46], [47].

Several antenna configurations which are totally based on fractal geometries [48], [49] had been pronounced in recent years. These were low profile antennas with slight benefits [50] and can be made operative at many frequency bands [51] and as a result, they become multifunctional [52]. In this study, the antennas with a reduced size had been obtained by using Koch curve fractal geometry with a combination of slot curve [53]. Furthermore, design equations for the antennas are acquired in phrases of its geometrical parameters such as fractal size. Antenna properties have also been linked to the fractal dimension of the geometry. In an effort to lay the principles for the understanding of the behavior of such antennas, the nature of fractal geometries is explained first, before providing the reputation of literature on antennas using such geometries.

1.2 Problem Statement

As the demands for UHF communication system have increased, a low-profile system has been drawn and brought much interest to researchers. The size of the antenna is important for making it to be a low-profile communication system. Hence, numerous methods such as using dielectric substrate, multiple layers and by optimizing the shape of the antennas have been proposed and applied to the microstrip and planar antennas.

Most televisions, whether analog or digital, need antennas to receive signals. Generally, former antenna used for television broadcasting is bulky in size and is usually placed outdoor. Therefore, this research aims to design and develop a compact log periodic dipole antenna for UHF digital TV application. The proposed antenna design will be compact in size and can be incorporated with the digital box. A new approach inspired by the fractal geometry with slot will be employed in order to design the compact antenna. Furthermore, it will provide a stable radiation pattern and gain throughout the DTV band.

1.3 Objectives

The primary objectives of this project are as follows:

i. To design and develop a new technique of size reduction in a log periodic dipole antenna for UHF/DVB TV application.

ii. To reduce the size and improve the shifting frequency of the antenna using fractal Koch technique and slotted insertion for first, second and series iterations LPA.

iii. To compare and analyze the antenna performance between simulation and measurement results in terms of reflection coefficient, radiation pattern, gain and current distributions of the antenna.

1.4 Scope of Works

The scope of this research begins with the understanding the concept and characteristics of the log periodic dipole antenna (LPDA), fractal geometries and slot techniques. The literature and the advantages of fractal antenna and slot techniques have been studied.

Four different iteration have been designed which were on 0^{th} iteration, 1^{st} iteration, 2^{nd} iteration and series iteration fractal Koch log periodic antenna. Then follow by slotted 0^{th} iteration, slotted 1^{st} iteration, slotted 2^{nd} iteration and slotted series iteration which improves more on the bandwidth performance.

The simulation process has been carried out using Computer Simulation Technology (CST) software to analyse the performance of the antennas. After the optimal design is confirmed, the designed structures are fabricated on Flame Retardant 4 (FR4) board using wet etching technique.

The antenna performances were then investigated and compared in terms of reflection coefficient, gain and radiation pattern. Lastly, all data were compiled for thesis documentation.

1.5 Thesis Outline

This thesis is organized into six chapters whereas in each chapter will describe the several aspects and design of the work. The outline of the study in six chapters is organized as follows:

A brief introduction to the UHF antenna, the principle motivation, scope of research and objectives are presented in Chapter 1.

In chapter two, the background of the log periodic antenna, UHF fractal antenna and microstrip slot antenna are discussed. Previous works on UHF antenna design which include log periodic antenna, fractal Koch antenna and slot technique are reported and summarized.

As for chapter three, it discusses the methodology of the research. The flow of work is presented, where two main work stages are described. The first stage of work which is the design and simulation are explained in detail. For the second stage of work, the fabrication and measurement of the antennas are thoroughly discussed.

Chapter four provides detailed discussions of the basic log periodic fractal Koch antenna. It starts with an explanation of the design for 0^{th}, 1^{st}, 2^{nd} and series iteration. Analysis of the suitable flare angle on the radiating element for compactness is also discussed in this chapter as a contribution to the compact design using fractal Koch geometry. The critical part of this design is to know how the parameter of the antenna affects the bandwidth of the antenna. A detailed examination of the different iteration of fractal Koch that influences the performance has been studied.

Chapter five explains the bandwidth enhancement performance of the previous antenna design with the slotted design on each of the elements. Slotted ring at the element is implemented for compactness. The size of the radiating element becomes smaller compared to its fundamental lambda.

Chapter six concludes the overall research work and discusses some potential future work. It highlights the significance of this study in this field and how it can be developed further in the future.

REFERENCES

[1] C. Yang, H. Kim, and C. Jung, “Compact broad dual-band antenna using inverted-L and loop for DVB-H applications,” *Electron. Lett.*, vol. 46, no. 21, p. 1418, 2010.

[2] J. Lee, J. Yeo, and Y.-K. Cho, “Broadband Compact Quasi-Yagi Antenna for Indoor Digital TV,” *Microw. Opt. Technol. Lett.*, vol. 55, pp. 2781–2784, 2013.

[3] M. H. Jamaluddin, T. A. Rahman, H. Mohamad, N. Ramli, and M. T. Islam, “Wideband Planar U-shaped Monopole Antenna with Meandering Technique for TV White Space Application,” *Radioengineering*, vol. 22, pp. 708–713, 2013.

[4] A. R. Raslan and A. M. E. Safwat, “N-internal port design for wide band electrically small antennas with application for UHF band,” *IEEE Trans. Antennas Propag.*, vol. 61, pp. 4431–4437, 2013.

[5] H. Jardon-Aguilar, J. A. Tirado-Mandez, R. Flores-Leal, and R. Linares-Miranda, “Reduced Log-Periodic Dipole Antenna Using a Cylindrical-Hat Cover,” *IET Microwaves, Antennas Propag.*, vol. 5, pp. 1697–1702, 2011.

[6] J. Yeo and J. Lee, “Planar Log-Periodic Bow-Tie Dipole Array Antenna with Reduced Size and Enhanced Front-Back Ratio,” *Microw. Opt. Technol. Lett.*, vol. 57, pp. 1435–1441, 2012.

[7] S. H. Kim, J. H. Choi, J. W. Baik, and Y. S. Kim, “CPW-Fed Log Periodic Dumb-Bell Slot Antenna Array,” *Electron. Lett.*, vol. 42, pp. 8–9, 2006.

[8] A. Chauloux, F. Colombel, M. Himdi, J. Lasserre, and P. Pouliguen, “Low-Return-Loss Printed Log-Periodic Dipole Antenna,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 503–506, 2014.

[9] G. A. Casula, P. Maxia, G. Montisci, G. Mazzarella, and F. Gaudiomonte, “A Printed LPDA Fed By A Coplanar Waveguide for Broadband Applications,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 12, pp. 1232–1235, 2013.

[10] Q. Wu, R. Jin, and J. Geng, “A Single-Layer Ultrawideband Microstrip Antenna,” *IEEE Trans. Antennas Propag.*, vol. 58, pp. 211–214, 2010.

[11] G. Bozdag and A. Kustepeli, “Subsectional Tapered Fed Printed LPDA Antenna With a Feeding Point Patch,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 15, pp. 437–440, 2016.

[12] D. Li and J. F. Mao, “A Koch-Like Sided Fractal Bow-Tie Dipole Antenna,” *IEEE Trans. Antennas Propag.*, vol. 60, pp. 2242–2251, 2012.

[13] G. Liu, L. Xu, and Z. Wu, “Miniaturised Wideband Circularly-polarised Log-periodic Koch Fractal Antenna,” *Electron. Lett.*, vol. 49, pp. 1315–1316, 2013.

[14] D. Elsheakh and E. Abdallah, “Compact Printed Log-periodic Dipole Antenna for Terrestrial Digital Video Broadcast Application,” *Microw. Opt. Technol. Lett.*, vol. 56, pp. 1002–1007, 2014.

[15] M. K. A. Rahim, M. N. A. Karim, F. Zubir, O. Ayop, and N. A. Samsuri, “Second Iteration Fractal Koch Planar Log Periodic Antenna Design,” *Microw. Opt. Technol. Lett.*, vol. 53, pp. 1869–1875, 2011.

[16] S. R. Patre and S. P. Singh, "Study of Microstrip Line-fed Flower-shaped Patch Antenna Providing Enhanced Bandwidth and Radiation Efficiency," *Microw. Opt. Technol. Lett.*, vol. 58, pp. 2041–2046, 2016.

[17] S. Chen, P. Wang, P. Hsu, S. Member, and A. Abstract, "Uniplanar Log-Periodic Slot Antenna Fed by a CPW for UWB Applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 5, pp. 256–259, 2006.

[18] S. E. Muthumani, R. Vallikannu, and H. R. Patnam, "Compact slot loaded Koch fractal microstrip patch antenna," in *2013 IEEE Applied Electromagnetics Conference, AEMC 2013*, 2014, pp. 2–3.

[19] N. A. A. Rahman, M. F. Jamlos, H. Lago, M. A. Jamlos, P. J. Soh, and A. A. Al-Hadi, "Reduced Size of Slotted-Fractal Koch Log-Periodic Antenna for 802.11af TVWS Application," *Microw. Opt. Technol. Lett.*, vol. 57, pp. 2781–2784, 2015.

[20] D. D. Krishna, M. Gopikrishna, C. K. Aanandan, P. Mohanan, and K. Vasudevan, "Compact Wideband Koch Fractal Printed Slot Antenna," *IET Microwaves, Antennas Propag.*, vol. 3, no. October 2008, p. 782, 2009.

[21] C. A. Balanis, *Antenna Theory Analysis and Design Third Edition*. 2005.

[22] L. X. Truong and N. C. Tien, "Design a Log Periodic Fractal Koch Microstrip Antenna for S Band and C Band Applications," in *International Conference on Advanced Tegnologies for Coomunications (ATC)*, 2015, vol. 7, pp. 556–560.

[23] G. Falciasecca, "Marconi's early experiments in wireless telegraphy, 1895," *IEEE Antennas Propag. Mag.*, vol. 52, pp. 220–221, 2010.

[24] J. B. L. Rao, R. Mital, D. P. Patel, M. G. Parent, and G. Tavik, "Low-Cost Multibeam Phased Array Antenna for Communications with GEO Satellites," *IEEE Aerosp. Electron. Syst. Mag.*, vol. 28, pp. 32–37, 2013.

[25] M. Jusoh, M. Jamlos, M. R. Kamarudin, and F. Malek, "Progress In Electromagnetics Research B, Vol. 36, 357–371, 2012," *Prog. Electromagn. Res. B*, vol. 36, pp. 357–371, 2012.

[26] L. Zhou, Y. Jiao, C. Zhang, Y. Qi, and T. Ni, "Wide Bandwidth Horizontally-Polarized Omnidirectional Antennas for Indoor Distributed Antenna System Applications," *Prog. Electromagn. Res. C*, vol. 61, pp. 47–54, 2016.

[27] C. P. Baliarda, J. Romeu, and A. Cardama, "The Koch Monopole: A Small Fractal Antenna," *IEEE Trans. Antennas Propag.*, vol. 48, pp. 1773–1781, 2000.

[28] W. C. Weng and C. L. Hung, "An H-fractal antenna for multiband applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 1705–1708, 2014.

[29] S. Singhal and A. K. Singh, "CPW-fed hexagonal Sierpinski super wideband fractal antenna," *IET Microwaves, Antennas Propag.*, vol. 10, pp. 1701–1707, 2016.

[30] Y. B. Thakare and Rajkumar, "Design of Fractal Patch Antenna for Size and Radar Cross-Section Reduction," *IET Microwaves, Antennas Propag.*, vol. 4, pp. 175–181, 2010.

[31] R. Sammeta and D. S. Filipovic, "Reduced Size Planar Dual-Polarized Log-Periodic Antenna for Bidirectional High Power Transmit and Receive Applications," *IEEE Trans. Antennas Propag.*, vol. 62, pp. 5453–5461, 2014.

[32] H. Oraizi and S. Hedayati, "Miniaturized UWB Monopole Microstrip Antenna Design by the Combination of Giusepe Peano and Sierpinski Carpet Fractals," *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 67–70, 2011.

[33] O. M. Khan, Z. U. Islam, I. Rashid, F. I. Bhatti, and Q. U. Islam, "Novel Miniaturized Koch Pentagonal Fractal Antenna for Multiband Wireless

Appliations," *Prog. Electromagn. Res.*, vol. 141, pp. 693–710, 2013.
[34] M. Ihamji, E. Abdelmounim, H. Bennis, M. Hefnawi, and M. Latrach, "Design of Compact Tri-Band Fractal Antenna for RFID Readers," *Int. J. Electr. Comput. Eng.*, vol. 7, p. 2036, 2017.
[35] S. Singh, P. K. Singhal, and V. V Thakare, "Design and Analysis of Tripple Band Koch Fractal Yagi Uda Antenna," *Int. J. Electr. Comput. Eng.*, vol. 3, pp. 456–460, 2013.
[36] Malaysian Communications and Multimedia Commission (MCMC), "Requirements for Digital Terrestrial Television (including digital terrestrial sound) (DTT) Service Operating In The Frequency Bands 174 MHz to 230 MHz and 470 MHz to 742 MHz," 2007.
[37] R. Wang and J. Yang, "A New Compact Antenna for Digital Television Reception Based on the Eleven Antenna," *Microw. Opt. Technol. Lett.*, vol. 53, pp. 824–827, 2011.
[38] W. Webb, "On Using White Space Spectrum," *IEEE Communications Magazine*, pp. 145–151, 2012.
[39] R. H. DuHamel and D. E. Isbell, "Broadband Logarithmically Periodic Antenna Structure," *1958 IRE Int. Conv. Rec.*, pp. 119–128, 1957.
[40] A. Hakimi and M. Movahhedi, "UWB Active Integrated Antenna Design and Simulation," in *2014 First International Conference on Systems Informatics, Modelling and Simulation*, 2014, pp. 168–172.
[41] M. Van Rooyen, J. W. Odendaal, S. Member, J. Joubert, and S. Member, "High-Gain Directional Antenna for WLAN and WiMAX Applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 16, pp. 286–289, 2017.
[42] J. O. Yang, S. Bo, J. Zhang, and F. Yang, "A Low-Profile Unidirectional Cavity-Backed Log-Periodic Slot Antenna," *Prog. Electromagn. Res.*, vol. 119, pp. 423–433, 2011.
[43] S. R. Agrawal, K. A. Lele, and A. A. Deshmukh, "Review on Printed Log Periodic and Yagi MSA," *Int. J. Comput. Appl.*, vol. 126, pp. 38–44, 2015.
[44] S. M. Hashemi, V. Nayyeri, M. Soleimani, and A. Mallahzadeh, "Designing a Compact-Optimized Planar Dipole Array Antenna," *IEEE Antennas Propag. Lett.*, vol. 10, pp. 243–246, 2011.
[45] R. Carrel, "The Design of Log Periodic Dipole Antennas," *1958 IRE Int. Conv. Rec.*, pp. 61–75, 1961.
[46] S. S. Pawar, M. Shandilya, and V. Chaurasia, "Parametric evaluation of microstrip log periodic dipole array antenna using transmission line equivalent circuit," *Eng. Sci. Technol. an Int. J.*, vol. 20, no. 4, pp. 1260–1274, 2017.
[47] R. S. Pavlov, A. G. Curto, and N. F. Van Hulst, "Log-periodic optical antennas with broadband directivity," *Opt. Commun.*, vol. 285, no. 16, pp. 3334–3340, 2012.
[48] Y. Wang, Z. Wang, and J. Li, "UHF Moore Fractal Antennas for Online GIS PD Detection," *IEEE Antennas Wirel. Propag. Lett.*, vol. 16, pp. 852–855, 2017.
[49] F. Wang, F. Bin, Q. Sun, J. Fan, and H. Ye, "A Compact UHF Antenna Based on Complementary Fractal Technique," *IEEE Access*, vol. 5, pp. 21118–21125, 2017.
[50] S. R. Emadian, C. Ghobadi, J. Nourinia, M. H. Mirmozafari, and J. Pourahmadazar, "Bandwidth Enhancement of CPW-Fed Circle-Like Slot Antenna With Dual Band-Notched Characteristic," *IEEE Antennas Wirel. Propag. Lett.*, vol. 11, pp. 543–546, 2012.

[51] A. Azari, "A New Super Wideband Fractal Microstrip Antenna," *IEEE Trans. Antennas Propag.*, vol. 59, pp. 1724–1727, 2011.

[52] Y. K. Choukiker and S. K. Behera, "Wideband Frequency Reconfigurable Koch Snowflake Fractal Antenna," *IET Microwaves, Antennas Propag.*, vol. 11, pp. 203–208, 2017.

[53] Y. Sung, "Bandwidth Enhancement of a Microstrip Line-Fed Printed Wide-Slot Antenna With a Parasitic Center Patch," *IEEE Trans. Antennas Propag.*, vol. 60, pp. 1712–1716, 2012.

[54] T. O. L. Y. Alxtelvxas, "Log Periodic Dipole Arrays *," *IRE Trans. ANTENNAS Propag.*, pp. 260–267, 1960.

[55] R. DuHamel and F. Ore, "Logarithmically Periodic Antenna Designs," *IRE Int. Conv. Rec.*, vol. 6, 1958.

[56] M. N. A. Karim, M. K. A. Rahim, H. A. Majid, O. Ayop, M. Abu, and F. Zubir, "Log Periodic Fractal Koch Antenna for UHF Band Applications," *Prog. Electromagn. Res.*, vol. 100, pp. 201–218, 2010.

[57] A. Gheethan and D. Anagnostou, "The Design and Optimization of Planar LPDAs," *PIERS Online*, vol. 4, pp. 811–814, 2008.

[58] T. Tauqeer, M. U. Afzal, H. T. Butt, M. Islam, M. A. Tarar, and B. A. Khawaja, "Analytical Comparison Of Wideband Microstrip Log-Periodic and Coplanar Waveguide Antennas," *Microw. Opt. Technol. Lett.*, vol. 56, no. 8, pp. 79–81, 2014.

[59] L. Gurel and O. Ergul, "Design and Simulation of Circular Arrays of Trapezoidal-Tooth Log-Periodic Antennas Via Genetic Optimization," *Prog. Electromagn. Res.*, vol. 85, pp. 243–260, 2008.

[60] J. I. Kim and A. Safaai-Jazi, "Log-Periodic Loop Antennas with High Gain and Linear Polarization," *Microw. Opt. Technol. Lett.*, vol. 27, pp. 66–68, 2000.

[61] R. L. Carrel, "Analysis and Design of the Log-Periodic Dipole Antenna," *Antenna Lab. Univ. Illinois, Urbana, Illinois USA*, vol. Technical, 1961.

[62] H. Oraizi, A. Amini, and M. K. Mehr, "Design of Miniaturised UWB Log-Periodic End-Fire Antenna Using Several Fractals With WLAN Band-Rejection," *IET Microwaves, Antennas Propag.*, vol. 11, pp. 193–202, 2017.

[63] J. Hettenhausen, A. Lewis, D. Thiel, and M. Shahpari, "An investigation of the performance limits of small, planar antennas using optimisation," *Procedia Comput. Sci.*, vol. 51, pp. 2307–2316, 2015.

[64] Y. Lee and J. Sun, "Compact Printed Slot Antennas for Wireless Dual and Multi-Band Operations," *Prog. Electromagn. Res.*, vol. 88, pp. 289–305, 2008.

[65] A. M. Abbosh and S. Member, "Miniaturized Microstrip-Fed Tapered-Slot Antenna With Ultrawideband Performance," *IEEE Antennas Wirel. Propag. Lett.*, vol. 8, pp. 690–692, 2009.

[66] J. Mazloum, "Reconfigurable Active Integrated Antenna with Log-periodic Matching Network Structures and Reduced Pin Diodes for WLAN/WIMAX Applications," *Microw. Opt. Technol. Lett.*, vol. 58, pp. 787–791, 2016.

[67] M. N. A. Karim, M. K. A. Rahim, and T. Masri, "Fractal Koch Dipole Antenna for UHF Band Application," *Microw. Opt. Technol. Lett.*, vol. 51, pp. 2612–2614, 2009.

[68] B. B. Mandelbrot, *The Fractal Geometry of Nature*, vol. 51. 1983.

[69] S. Tripathi, A. Mohan, and S. Yadav, "Ultra-Wideband Antenna using Minkoski-Like Fractal Geometry," *Microw. Opt. Technol. Lett.*, vol. 59, no. 1, pp. 2273–2279, 2014.

[70] A. Barcellos, "The Fractal Geometry of Mandelbrot," *Coll. Math. J.*, vol. 15,

pp. 98–114, 1984.

[71] Anuradha, “Design and Simulation of Koch Fractal Antenna Array for Mobile Communications,” Mater Thesis, Deemed University, 2006.

[72] D. H. Werner, R. L. Haupt, and P. L. Werner, “Fractal Antenna Engineering: The Theory and Design of Fractal Antenna Arrays,” *IEEE Antennas Propag. Mag.*, vol. 41, pp. 37–59, 1999.

[73] A. Chatterjee, T. Mondal, D. G. Patanvariya, and R. P. K. Jagannath, “Fractal-based design and fabrication of low-sidelobe antenna array,” *AEU - Int. J. Electron. Commun.*, vol. 83, no. November 2017, pp. 549–557, 2018.

[74] S. Singhal, T. Goel, and A. K. Singh, “Inner Tapered Tree-Shaped Fractal Antenna for UWB Application,” *Microw. Opt. Technol. Lett.*, vol. 57, pp. 559–567, 2015.

[75] N. Wideband, P. Fractal, and M. Antenna, “Novel Wideband Planar Fractal Monopole Antenna,” *IEEE Trans. Antennas Propag.*, vol. 56, pp. 3844–3849, 2008.

[76] P. N. Rao and N. V. S. N. Sarma, “The Effect of Indentation Angle of Koch Fractal Boundary on the Performance of Microstrip Antenna,” *Int. J. Antennas Propag.*, vol. 2008, pp. 1–5, 2008.

[77] H. Rajabloo, V. Amiri Kooshki, and H. Oraizi, “Compact microstrip fractal Koch slot antenna with ELC coupling load for triple band application,” *AEU - Int. J. Electron. Commun.*, vol. 73, pp. 144–149, 2017.

[78] R. S. Brar, S. Singhal, and A. K. Singh, “Fractal Dipole Antenna for UWB Application,” *Microw. Opt. Technol. Lett.*, vol. 58, pp. 39–47, 2016.

[79] D. B. Oliveira and E. J. Silva, “Design of the compact UHF RFID meander-line antenna loaded with CPW elements,” *AEU - Int. J. Electron. Commun.*, vol. 77, pp. 57–60, 2017.

[80] J. Yang, F. Kong, K. Li, and S. Sheng, “Analysis of a log periodic nano-antenna for multi-resonant broadband field enhancement and the Purcell factor,” *Opt. Commun.*, vol. 342, pp. 230–237, 2015.

[81] M. Gupta and V. Mathur, “Sierpinski fractal antenna for internet of things applications,” *Mater. Today Proc.*, vol. 4, pp. 10298–10303, 2017.

[82] M. Gupta and V. Mathur, “Wheel shaped modified fractal antenna realization for wireless communications,” *AEU - Int. J. Electron. Commun.*, vol. 79, pp. 257–266, 2017.

[83] T. Ali, A. W. Mohammad Saadh, R. C. Biradar, J. Anguera, and A. Andújar, “A miniaturized metamaterial slot antenna for wireless applications,” *AEU - Int. J. Electron. Commun.*, vol. 82, pp. 368–382, 2017.

[84] T. Ali, M. M. Khaleeq, and R. C. Biradar, “A multiband reconfigurable slot antenna for wireless applications,” *Int. J. Electron. Commun.*, vol. 84, pp. 273–280, 2018.

[85] G. Varamini, A. Keshtkar, N. Daryasafar, and M. Naser -Moghadasi, “Microstrip Sierpinski fractal carpet for slot antenna with metamaterial loads for dual-band wireless application,” *AEU - Int. J. Electron. Commun.*, vol. 84, pp. 93–99, 2018.

[86] A. Farswan, A. K. Gautam, B. K. Kanaujia, and K. Rambabu, “Design of Koch Fractal Circularly Polarized Antenna for Handheld UHF RFID Reader Applications,” *IEEE Trans. Antennas Propag.*, vol. 64, pp. 771–775, 2016.

[87] K. Kamardin, “Artificial Magnetic Conductor Waveguide Sheet for Transmission Enhancement Between Antennas for Body Centric Communication,” Phd Thesis, Universiti Teknologi Malaysia, 2014.

[88] R. Janaswamy and D. H. Schaubert, “Characteristic Impedance of a Wide Slotline on Low-Permittivity Substrates,” *IEEE Trans. Microw. Theory Tech.*, vol. 34, pp. 900–902, 1986.

[89] Y. M. Madany, A. I. Almahallawy, and H. M. Elkamchouchi, “Methodology of band rejection / addition for microstrip antennas design using slot line theory and current distribution analysis,” *2014 Loughbrgh. Antennas Propag. Conf. LAPC 2014*, pp. 602–606, 2014.

[90] R. Dewan, S. K. A. Rahim, S. F. Ausordin, and T. Purnamirza, “The Improvement of Array Antenna Performance with the Implementation of an Artificial Magnetic Conductor (Amc) Ground Plane and in-Phase Superstrate,” *Prog. Electromagn. Res.*, vol. 140, pp. 147–167, 2013.