Size Reduction of Printed Log-periodic Dipole Array Antenna Using Fractal Koch Geometry

Chairunnisa, Devy Freshia Sihaloho, and Achmad Munir

Radio Telecommunication and Microwave Laboratory
School of Electrical Engineering and Informatics
Institut Teknologi Bandung, Indonesia,
Jalan Ganesha 10, Bandung 40132, Indonesia
munir@ieee.org

Abstract: This paper deals with the development of printed log-periodic dipole array (LPDA) antenna in reduced size by applying fractal Koch geometry structure. The proposed printed LPDA fractal Koch antennas which are deployed on FR4 Epoxy dielectric substrates with the thickness of 1.6mm and relative permittivity of 4.3 are designed to have working bandwidth from 1.5GHz to 3GHz to cover some frequency bands of wireless communication. Some basic properties of antenna are analyzed numerically related to the physical parameters and its iterations in order to have optimum performance design. Three different iterations of printed LPDA fractal Koch antenna called as 0th, 1st, and 2nd iterations are introduced for the performance analysis. It shows that the printed LPDA fractal Koch antenna with the 2nd iteration has size reduction up to 21.18% and 25.28% than the 0th iteration and 1st iteration, respectively. Whilst from the performance result, although some properties of operating frequency and gain still need more improvement it shows that the 2nd iteration antenna has a better performance compared to others in term of working bandwidth.

Keywords: Fractal Koch geometry, iteration, log-periodic dipole array, size reduction.

1. Introduction

Recently, the growth in wireless communications technology has stimulated many opportunities for enhancing the performances of existing signal transmission and processing systems. It has also provided a strong motivation in the development of novel devices especially for supporting high rates and high speed wireless communications that almost need wide bandwidth requirement [1]-[3]. This means that wide bandwidth devices play an important role and should be forefront object in wireless communication research activities. In addition to the wide bandwidth, the devices should also have a compact dimension to suppress down the cost of fabrication particularly in mass production. Numerous attempts have been conducted intensively related to the size reduction; one of them is by introducing a fractal structure [4]-[6].

By definition, fractal is the repetition of some similar geometry shape which is implemented by scaling those geometry shapes. Actually, fractal was firstly defined by Benoit Mandelbrot in 1975 as the method to classify structure which is difficult to be defined with Euclidean geometry, such as cloud or tree branching [4]. Some application of fractal in electromagnetic and RF devices is implemented for antenna and filter [5]-[9]. This type of antenna uses fractal design or self-similar design to reduce the total length of antenna element or to increase the material amount which can be used to transmit and receive electromagnetic signal by keeping the same total length as the Euclidian geometry [10]. Due to its capability in reducing the length of antenna element, the fractal antenna has more dense structure than the conventional antenna so that it has smaller and compacter dimension. Besides having a compact dimension, the repetitive structure in fractal structure is also able to produce wideband or multiband characteristics. Moreover, self-similar structure is one of advantages to obtain the

Received: December 21st, 2014. Accepted: April 12nd, 2015
DOI: 10.15676/ijeei.2015.7.2.5

antenna performance is not affected by frequency response in a particular working bandwidth [10]-[12]. The antenna with such characteristic is usually referred as the frequency-independent antenna. This fact complements to the principle of Rumsey which states that the element of antenna has to be defined based merely on the angle of each element to make the antenna becomes a frequency independent [13].

The main goal of this paper is to apply one of fractal structures, i.e. fractal Koch geometry structure in printed log-periodic dipole array (LPDA) antenna elements to enhance its performances. As is already well-known, the log-periodic antenna that was invented by Dwight E. Isbell, Raymond DuHamel, and Paul Mayes is one type of antenna arrays which has characteristics of wideband and narrow beam width. Some developments of log-periodic antenna for wireless communication have been proposed recently with emphasizing in wideband characteristic [14]-[15]. While in [16], the design of log-periodic fractal Koch antennas in reduced size was proposed for ultra high frequency (UHF) band applications. Hence by applying the structure, the effect of fractal Koch geometry iterations to the performance of printed LPDA antenna will be analyzed. However in contrast to the result presented in [16], here the proposed printed LPDA antennas implement the different fractal Koch geometry iteration instead of series iteration with more improvement in size reduction.

Three different fractal Koch geometry iterations, i.e. 0th iteration, 1st iteration, and 2nd iteration, will be included in the investigation. The deployment of antennas is simulated on an FR4 Epoxy dielectric substrate with the relative permittivity of 4.3 and the thickness of 0.8mm. Prior to the implementation of fractal Koch geometry structure, the design of antennas is initiated using a basic LPDA antenna, called as 0th iteration. Hence, the antenna parameters such as return loss, working bandwidth, radiation pattern and overall gain as well as the physical dimension will be used as indicators in the evaluation of performance enhancement. The investigation results are then compared and analyzed for the overall performance of printed LPDA fractal Koch antenna. In addition, the discussion related to the experimental characterization of realized antenna prototypes is also presented and its results are reported to be compared with the design ones.

2. Overview of Printed LPDA Fractal Koch Antenna Design

The method implemented to apply fractal Koch structure in printed LPDA fractal Koch elements is by dividing an Euclidian dipole with length l becomes 4 parts, each of the part has length ¼ part. The second element is rotated 60 degrees to horizontal; while the third element is rotated -60 degrees to horizontal. The first and the fourth elements are kept parallel to horizontal. Thus, the total length will be the same as the total length of the Euclidian dipole, but the length from the starting point of the dipole to the end point of the dipole will become ¾ of the Euclidian dipole. The advantage of this method is to obtain the shorter length from the starting point to the end point by keeping the same total length of the Euclidian dipole.

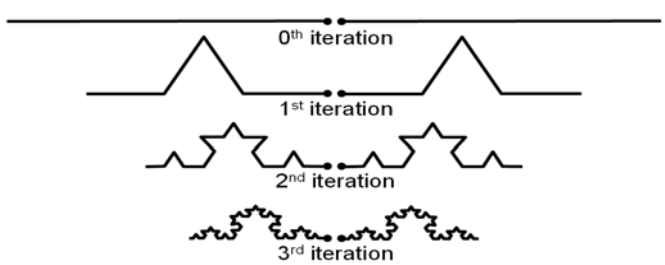


Figure 1. Geometry iteration of dipole fractal Koch antenna element

In the design of printed LPDA antenna, one of the most important parameters design is scaling factor (τ). For the 0th iteration of dipole fractal Koch antenna element, the relation

between scaling factor (τ), length of antenna element (l), width of antenna element (d), and separation between antenna elements (s) is expressed in (1) [17]. Whilst for the next consecutive iteration, it can follow the previous iteration.

$$\tau = \frac{l_n}{l_{n+1}} = \frac{d_n}{d_{n+1}} = \frac{s_n}{s_{n+1}} \tag{1}$$

where n is the index of antenna element order. Furthermore, the other important parameter for the design is relative spacing (σ) between antenna elements. The relation between σ, τ and antenna gain is depicted in Figure 2 [17]. It can be inferred that the antenna gain indicated by the curve lines is mostly determined by spacing factor (σ) and scaling factor (τ).

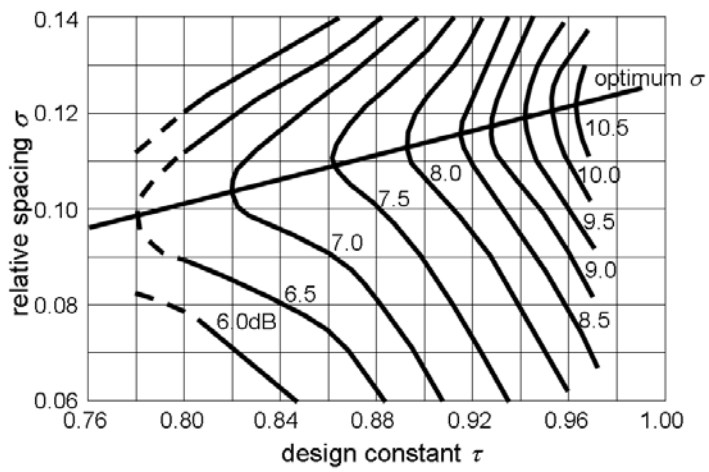
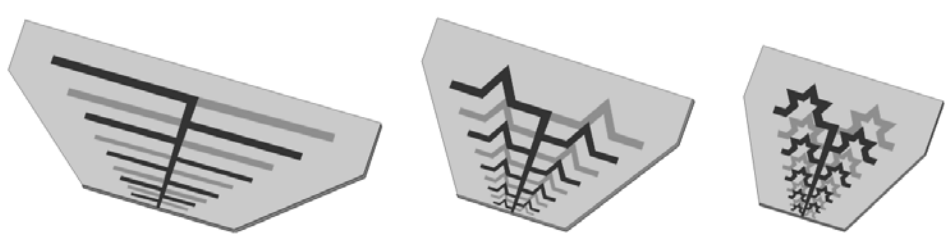


Figure 2. Relation of σ, τ and antenna gain for the LPDA antenna design

The designed 9 elements printed LPDA fractal Koch antennas for 3 different iterations, i.e. 0th iteration, 1st iteration, and 2nd iteration are shown in Figure 3. The angle of fractal used in the 1st and 2nd iterations is 60 degrees. The proposed antennas are designed to have working bandwidth from 1.5GHz to 3GHz with the gain of more than 6dB. By using equations in [16] for determining the design parameters with the scaling factor (τ) of 0.098 and the spacing factor (σ) of 0.78 obtained from Figure 2, the number of antenna elements is calculated to be 9 for each side. The dielectric substrate used for all designs is FR4 Epoxy with the relative permittivity 4.3 and the thickness of 0.8mm. To obtain an accurate investigation, the thickness of metal copper radiator elements is set to be 0.035mm, whilst the conductive losses of antenna elements and the dielectric loss of substrate are accounted for. Since the fractal structure is applied in 1st iteration and 2nd iteration, therefore the dimension of dielectric substrate required for the deployment will be affected remarkably.



a) 0th iteration b) 1st iteration c) 2nd iteration

Figure 3. Designed 9 elements printed LPDA fractal Koch antennas

Figure 4 shows the detail geometry of 0th iteration printed LPDA fractal Koch antenna. It is excited using a transmission line extended from the center pin of SMA connector. The length of longest antenna element (l_{max}) and its width (d_{max}) can be determined from the desired lowest frequency. Hence, the maximum spacing between the longest antenna element and the next one (s_{max}) can be derived from the correlation between the length of longest antenna element (l_{max}) and its impedance characteristic. As the ratio of length or width or spacing between two consecutive antenna elements is constant and equals to the scaling factor (σ); therefore the length of each element (l_n), the width (d_n), and the spacing (s_n) can be calculated accordingly. The calculation summary of element length (l_n), the width (d_n), and the spacing (s_n) for the 0th iteration printed LPDA fractal Koch antenna is shown in Table 1.

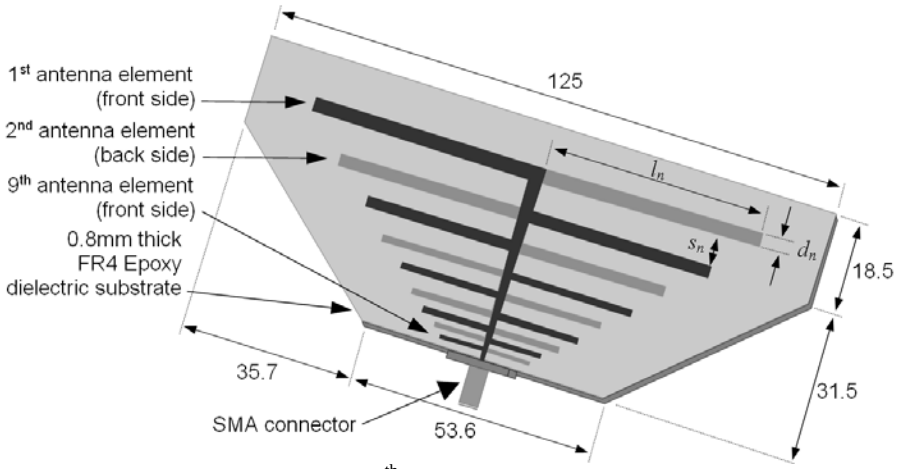


Figure 4. Geometry of designed 0th iteration printed LPDA fractal Koch antenna

Table 2 summarizes the total area and volume comparison of each LPDA fractal Koch antenna which indicates the ratio of size reduction. It can be noted that the fractal structure applied in dipole elements affects the reduction of substrate area. The reduced area between 1st iteration and 0th iteration printed LPDA fractal Koch antenna is 3.38%. Hence, the reduced area between 2nd iteration and 1st iteration printed LPDA fractal Koch antenna is 21.18%, and between 2nd iteration and 0th iteration printed LPDA fractal Koch antenna is 25.28%. Therefore, the increasing number of fractal Koch iteration results in more reduction of antenna dimension.

Table 1. Dimension of designed 0th iteration printed LPDA fractal Koch antenna

Element - *n*th	***l* (mm)**	***d* (mm)**	***s* (mm)**
1	48.0	3.0	5.9
2	39.4	2.4	4.8
3	32.3	2.0	4.0
4	26.5	1.6	3.3
5	21.7	1.3	2.7
6	17.8	1.1	2.2
7	14.6	0.9	1.8
8	12.0	0.7	1.5
9	9.8	0.6	1.2

Table 2. Total area and volume comparison of printed LPDA fractal Koch antenna

Item	0th iteration	1st iteration	2nd iteration
Area (mm^2)	5135.80	4967.60	4099.32
Volume (mm^3)	8217.28	7948.16	6558.91
Reduced area (%)	-	3.38%	21.18% 25.28%

3. Numerical Characterization and Discussion

Figure 5 plots the simulated reflection coefficient for 3 different iterations of printed LPDA fractal Koch antenna. The graph shows that the increasing number of fractal Koch iteration produces wider working bandwidth response. It shows that the -10dB working bandwidth of 0th iteration, 1st iteration, and 2nd iteration printed LPDA fractal Koch antenna are 1.79GHz, 2.65GHz and 2.89GHz, respectively.

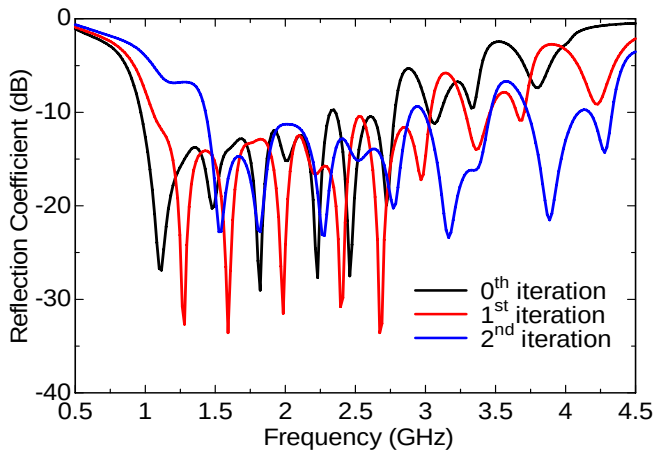


Figure 5. Simulated reflection coefficient of printed LPDA fractal Koch antennas

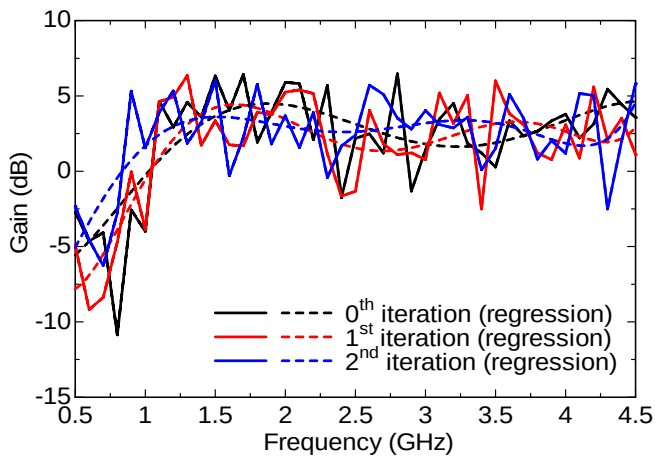
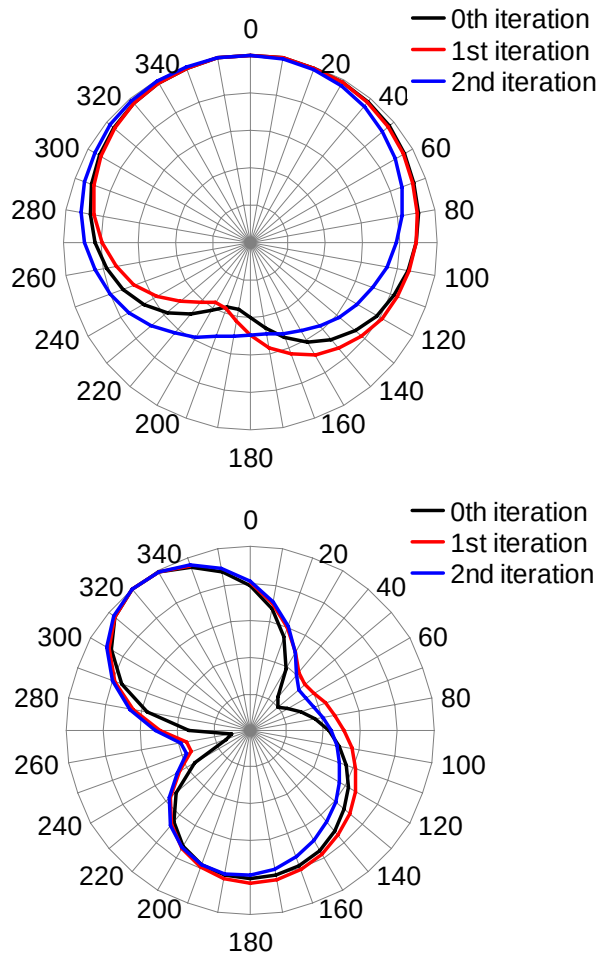


Figure 6. Simulated gain of printed LPDA fractal Koch antennas

From the result, it is also shown that increasing fractal Koch iteration number shifts the lower operating frequency to be higher. This can be figured out that in spite of total length of fractal Koch dipole is the same as the Euclidian dipole, however the transversal dimension of dipole still has strong contribution to shift higher the resonant frequency of each element especially for the shortest element. Hence, the lower frequency affected by the longest element

is not significantly shifted. The lower operating frequency of 0th iteration, 1st iteration, and 2nd iteration printed LPDA fractal Koch antenna are 0.98GHz, 1.06GHz, and 1.42GHz, respectively.

Furthermore, as shown in Figure 6, the overall gain of antenna decreases as the increase of fractal Koch iteration number. It indicates that the fractal structure in the dipole elements of printed LPDA fractal Koch antenna affects to the reduction for the overall gain. From the graph, it shows that increasing number of fractal Koch iteration increases the total capacitance of printed LDPA fractal Koch antenna. As a result, the antenna efficiency decreases due to the dissipated power in the antenna. Therefore, the gain of printed LPDA with fractal Koch structure is lower compared to Euclidian LPDA structure requires more improvement.



a) Azimuth plane b) Elevation plane

Figure 7. Simulated radiation patterns of printed LPDA fractal Koch antennas

The simulated radiation pattern for 3 different iterations of printed LPDA fractal Koch antenna at frequency of 1.7GHz is depicted in Figure 7. From the figure, it seems that the radiation patterns for 0th iteration, 1st iteration, and 2nd iteration are directional. It should be noted that the used fractal Koch structure has no significant effect to the radiation pattern for the elevation plane. Whilst for the azimuth plane, a slight different in the direction angle occurs for the 2nd iteration printed LPDA fractal Koch antenna.

4. Hardware realization and Experimental Characterization

Prior to the experimental characterization, the prototypes of proposed antenna are realized based on the design results. Figure 8 shows the pictures of fabricated printed LPDA fractal Koch antennas to be experimentally characterized. The realized antennas are deployed on 0.8mm thick of FR4 Epoxy dielectric substrate through wet etching technique. The measured results are plotted in Figures 9–11 for reflection coefficient, gain, and radiation pattern, respectively.

a) 0th iteration b) 1st iteration c) 2nd iteration

Figure 8. Picture of fabricated 9 elements printed LPDA fractal Koch antenna prototypes

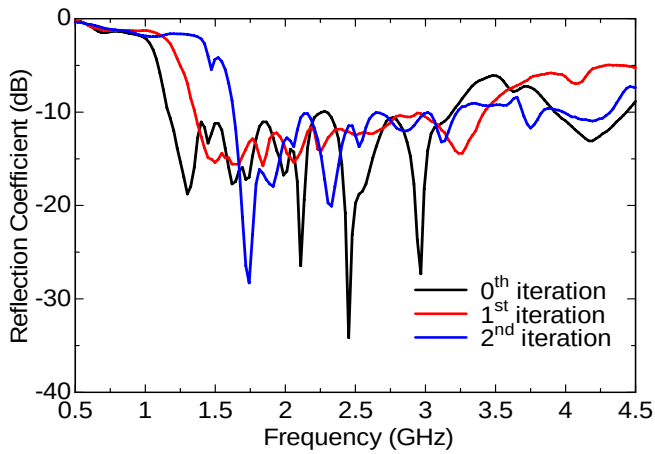


Figure 9. Measured reflection coefficient of printed LPDA fractal Koch antennas

From Figure 9, it is shown that the lower operating frequency becomes higher as the increase of number of fractal Koch iteration. These results have similar tendency with the simulated ones as shown in Figure 5. In addition to the previous explanation, the shift of lower operating frequency is evoked by the decrease of distance between starting point and end point of Euclidian dipole element so that in the higher operating frequency it produces more impedance antenna matching. Moreover, although the measured working bandwidths have satisfied the requirement, the measured results have shown some discrepancies compared to the simulated ones. This is probably evoked by the value of dielectric substrate used in the realization which is slightly lower than in the design. As the relative permittivity is lower, thus the antenna impedance reacts to move to be bigger and it is happened at the lower operating frequency yielding the difference of measured working bandwidth.

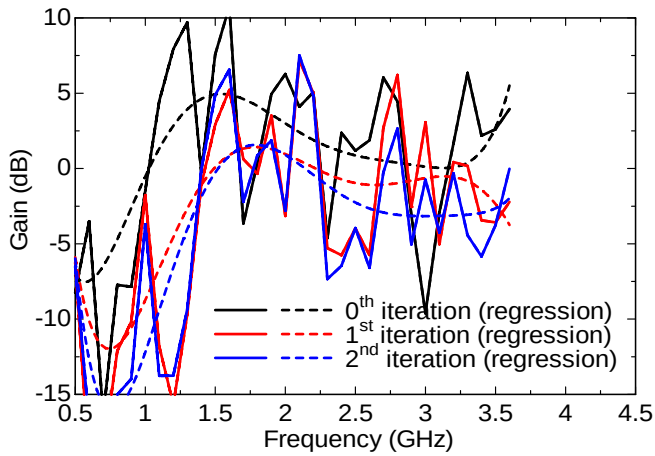
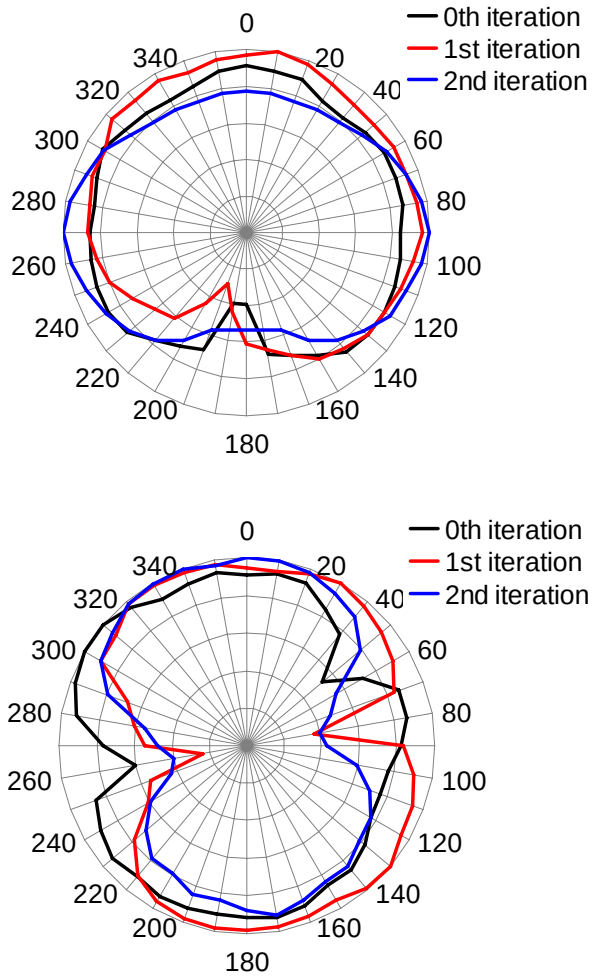


Figure 10. Measured gain of printed LPDA fractal Koch antennas



a) Azimuth plane b) Elevation plane

Figure 11. Measured radiation patterns of printed LPDA fractal Koch antennas

The measured gain of printed LPDA fractal Koch antennas which is plotted in Figure 10 indicates that the realized antennas have the average gain less than 6dB. It shows that the measured results are lower than the simulated ones almost for each number of iteration. It should be noted that both results are fluctuated almost in all frequency ranges. This happens as each antenna element with its resonant frequency and bandwidth characteristic has its own gain contribution independently without any significant influences to other antenna elements.

Moreover, the measured radiation patterns of printed LPDA fractal Koch antennas performed at frequency of 1.7GHz are plotted in Figure 11. It shows that the direction angle of 2nd iteration printed LPDA fractal Koch antenna is shifted to the left side up to 15° from the 0th iteration both for azimuth and elevation planes. Meanwhile for the 1st iteration, it is also shifted in the same direction but lesser than the 2nd iteration. This discrepancy probably occurs as the misalignment of axis in the measurement which evokes inaccuracy in obtaining the measured data. Nevertheless, in general it shows that the measured radiation patterns are coincided and agreed well with the simulated results.

5. Conclusions

The development of printed log-periodic dipole array (LPDA) antenna in reduced size based on fractal Koch geometry structure has been demonstrated numerically and experimentally. The proposed antennas deployed on an FR4 Epoxy dielectric substrate have been designed in 3 different fractal Koch geometry iterations to analyze the performances including the physical dimension. From the results, it has been shown that the fractal Koch geometry structure applied on dipole elements of antenna reduces the total area of antenna and total volume of substrate. It should be noted that the increasing number of fractal Koch iteration has reduced remarkably the antenna dimension. The biggest size reduction was achieved by the 2nd iteration that had size reduction up to 21.18% and 25.28% than the 0th iteration and 1st iteration, respectively. Furthermore, the used of fractal Koch structure has shifted the lower operating frequency of antenna to be higher. Increasing number of fractal Koch iteration has also decreased the return loss, especially in higher frequencies, as well as increased the working bandwidth. In other hand, the applied fractal Koch structure in printed LPDA antenna element affected to the overall gain of antenna.

6. Acknowledgement

This work is partially supported by the Directorate General of Higher Education (DGHE), the Ministry of Education and Culture, the Republic of Indonesia, under the Grant of Decentralization Research Program 2012 contract number 003.57/TL-J/DIPA/SPK/2012 and by the Asahi Glass Foundation, Japan. The authors wish to thank Mr. Zenal Aripin, a technician at Laboratory of Radio Telecommunication and Microwave, School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Indonesia for supporting the experimentation and measurement.

7. References

[1] J. H. Reed, An Introduction to Ultra Wideband Communication Systems, New Jersey: Prentice Hall, 2005.

[2] R. Gharpurey and Peter Kinget, Ultra Wideband: Circuits, Transceivers and Systems (Integrated Circuits and Systems), New York, Springer, 2008.

[3] L. Zhu, S, Sun and R. Li, Microwave Bandpass Filters for Wideband Communications, New Jersey: John Wiley & Sons, 2012.

[4] K. Falconer, Fractal Geometry: Mathematical Foundations and Applications, 2nd Edition, New Jersey: John Wiley & Sons, 2003.

[5] J. Volakis, Antenna Engineering Handbook, 4th Edition. New York: McGraw-Hill, 2008.

[6] P. Jarry and J. Beneat, Design and Realizations of Miniaturized Fractal Microwave and RF Filters, New Jersey: John Wiley & Sons, 2009.

[7] A. Munir, T. Praludi and M.R. Effendi, "Characterization of narrowband hairpin bandpass filter composed of fractal Koch geometry," 35th *Progress In Electromagnetics Research Symposium (PIERS)* Proc., pp. 1843-1846, Guangzhou, China, Aug. 2014.

[8] C. P. Baliarda, J. Romeu, and A. Cardama, "The Koch monopole: A small fractal antenna," *IEEE Trans. on Antennas and Propag*., Vol. 48, Issue 11, pp. 1773-1781, Nov. 2000.

[9] A. Munir, D.T. Putranto, and H. Wijanto, "Characterization of series iteration log-periodic fractal Koch printed antenna equipped with balun unit," *Journal of ICT Research and Applications*, Vol. 7C, No. 3, pp. 191-204, Dec. 2013.

[10] R. G. Hohlfeld and N. Cohen, "Self-similarity and the geometric requirements for frequency independence in antennae," Fractals, Vol. 7, No. 1, pp.79 -84, Mar. 1999

[11] S. D. Ahirwar, Y. Purushottam, T. Khumanthem, "Wideband traveling wave Koch dipole antenna," Progress In *Electromagnetics Research (PIER)* C, Vol. 18, pp. 103–110, 2011.

[12] A. Munir, D. T. Putranto, D. Freshia and Chairunnisa "Characteristic of printed log-periodic fractal Koch antenna as influence of its elements," 5th *Indonesia Japan Joint Scientific Symposium (IJJSS)* 2012 Proc., pp. 524-527, Chiba, Japan, Oct. 2012.

[13] V. H. Rumsey, Frequency independent antennas. New York: Academic Press, 1966.

[14] H-T. Hsu, J. C. Rautio, S-W. Chang, "Novel planar wideband omni-directional quasi log-periodic antenna," *Asia Pacific Microwave Conference (APMC)* Proc., pp. 1-4, Suzhou. China, Dec. 2005.

[15] M. M. Tajdini and M. Shahabadi, "Wideband planar log-periodic antenna," *International Workshop on Antenna Technology (IWAT)* Proc., pp. 331-334, Cambridge, USA, Mar. 2007.

[16] 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," *Progress In Electromagnetics Research*, PIER 100, pp. 201-218, 2010.

[17] C. A. Balanis, Antenna Theory: Analysis and Design, 2nd Edition, New York: John Wiley & Sons, 1997.

Chairunnisa received the B.Eng. degree in Electrical Engineering from Institut Teknologi Bandung, Indonesia, in 1998. She continued her study at the same university and received M.Eng. degree in 2002. From 2003 until 2007, she received scholarship from DAAD Germany. At that time, she was doing research at Hoch Frequenz Technik, Fakultät für Elektrotechnik und Informationstechnik, Ruhr-Universitaet Bochum, Germany and received Dr.-Ing. degree. Since January 2008, she joined the School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Indonesia, as Lecturer. Her research interests include fractal antenna design, electromagnetics field and wave propagation.

Devy Freshia Sihaloho received the B.E. degree in Telecommunication Engineering from the School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Indonesia in 2011. From 2010-2011, during her study in undergraduate program, she joined the Osaka University Short-term Student Exchange Program (OUSSEP), Japan. Her research interests cover antenna and wave propagation.

Achmad Munir received the B.E. degree in Electrical Engineering from Institut Teknologi Bandung, Indonesia, in 1995, the M.E. and D.E. degrees in science and engineering from Yamaguchi University, Japan, in 2002 and 2005, respectively. From 2005 to 2007, he was a Research Fellow under JSPS fellowship program with department of Electrical and Electronics Engineering, Faculty of Engineering, Yamaguchi University, Japan, working on the artificial materials research, particularly, artificial dielectric and artificial magnetic materials. From 2007 to 2009, he was a Research Fellow with the Institute of Electronics, Communications, and Information Technology, Queens University Belfast, Northern Ireland, United Kingdom, involved in the experimental study of novel nonlinear artificial material including high impedance surface and artificial magnetic conductor for advanced EM applications. In January 2009, he joined the School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Indonesia, as Lecturer. His research interests include linear and nonlinear artificial materials, electromagnetics wave propagation, and microwave devices.