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LOG PERIODIC FRACTAL KOCH ANTENNA FOR UHF BAND APPLICATIONS

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Abstract—In this paper, the design of Log Periodic Fractal Koch Antennas (LPFKA) is proposed for Ultra High Frequency (UHF) band applications. The procedure to design the LPFKA with three different numbers of iterations in order to reduce the antenna size is discussed. The Computer Simulation Technology (CST) software has been used to analyze the performances of the designed antennas such as return loss, radiation patterns, current distribution and gain. The antennas have been fabricated using FR4 laminate board with wet etching technique. Using fractal Koch technique, the size of the antenna can be reduced up to 27% when the series iteration is applied to the antennas without degrading the overall performances. Both simulated and measured results are compared, analyzed and presented in this paper.

1. INTRODUCTION

In modern telecommunication systems, antennas with wider bandwidth and smaller dimensions than conventional ones are preferred. This has initiated antenna research in various directions; one of which uses fractal shaped antenna elements [1]. Several fractal geometries have been introduced for antenna applications with varying degrees of success in improving antenna characteristics. Some of these geometries have been particularly useful in reducing the size of the antenna, while other designs aim at incorporating multi-band characteristics [2–5].

Fractal shape antennas have already been proven to have unique characteristics linked to the geometry properties of fractal. Fractals

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were first defined by Benoit Mandelbrot in 1975 as a way of classifying structures whose dimensions were not whole numbers. Fractal geometry has unique geometrical features occurring in nature. It can be described as a branch of tree leaves and plant, jaggedness of coastline, and many more examples in nature [6]. Certain classes of fractal antennas can be configured to operate effectively at multi frequency bands. Other than that, fractal antennas can be utilized in a variety of applications, especially where space is limited [7–13].

There are several types that have been proven by other researchers, i.e., some of the fractal types can be used to reduce the antenna size [14]. Some papers discussed size reduction of space filling antenna using Hilbert curve compared to other method such as meander line and zigzag antenna. The configuration can reduce the antenna size further especially at lower frequency band. Other than that, Minkowski fractal patch antenna has also been proven to reduce the antenna size by 47% while maintaining the same resonant frequency [15]. The reduction in size indirectly reduces the mutual coupling between each element for array configuration antenna [16].

Koch curve is a good example of self-similar space-filling fractals which have been used to develop wideband/multiband and/or miniaturized antennas. The features of the Koch geometry can overcome some of the limitation of small antennas [17]. In this works, the fractal Koch geometry has been chosen due to its capabilities to reduce the size of the elements by applying different numbers of iteration such as the 0th, 1st and series iteration to investigate the performances of the antennas especially at the UHF band applications. The design methodology of the antennas using log periodic technique is discussed, and the detail results of the proposed antenna are presented in this paper.

2. DESIGN METHODOLOGY

The log periodic antenna was originally designed at the University of Illinois in the USA in 1955. The log periodic antenna exists in a number of forms. The most common one is the log periodic dipole array (LPDA). It consists of a number of dipole elements. One of the important parameters in this design is scaling factor which is closely related to log periodic. The dimensions such as the length l, width w, and distance d of the antenna can be related to the scaling factor τ as shown in Equation (1) [18].

$$\tau = \frac{l_n}{l_{n+1}} = \frac{w_n}{w_{n+1}} = \frac{d_n}{d_{n+1}} \tag{1}$$

From this technique, the resonant frequencies of the antenna can be combined to obtained wider bandwidth. The numbers of elements will influent the range of the bandwidth. The equations have been introduced to design a log periodic fractal Koch antenna. The scaling factor τ and spacing factor σ can be obtained by using Carrel's table. Then, the angle α is calculated using Equation (2). [18]

$$\alpha = \tan^{-1}\left[\frac{1-\tau}{4\sigma}\right] \tag{2}$$

Carrel has introduced a semi empirical equation to calculate the bandwidth of the active region B_{ar} related to τ and σ.

$$B_{ar} = 1.1 + 7.7(1-\tau)^2 \cot\alpha \tag{3}$$

In practice, a slightly larger bandwidth (B_s) is usually designed than desired bandwidth (B) which is required. The two are related by:

$$B_s = BB_{ar} = B[1.1 + 7.7(1-\tau)^2 \cot\alpha \tag{4}$$

where, B_s = designed bandwidth, B = desired bandwidth, B_{ar} = active region bandwidth.

The number of element is determined by:

$$N = 1 + \frac{\ln(B_S)}{\ln\left(\frac{1}{\tau}\right)} \tag{5}$$

Then, the length of the element is calculated using Equation (6).

$$\ell = 0.5 \times v/f \tag{6}$$

where, v is the actual propagation speed of the dipole. This speed depends on the dielectric constant of the environment surrounding the radials. The speed can be obtained by using Equation (7).

$$v = \frac{c}{\sqrt{\varepsilon r}} \tag{7}$$

Figure 1 shows the example of 1st iteration LPFKA. The higher degree of flare angle will influence the length of the element. The same method is applied to the series iteration LPFKA. The performance of the antennas are studied and presented in the next section.

3. DESIGN DESCRIPTION AND SIMULATED RESULT

The design of the Fractal Koch Antennas for the 0th, 1st and series iterations is based on log periodic concepts. The Computer Simulation Technology (CST) software has been used to simulate the performance of the antennas. The antennas have been designed to operate from

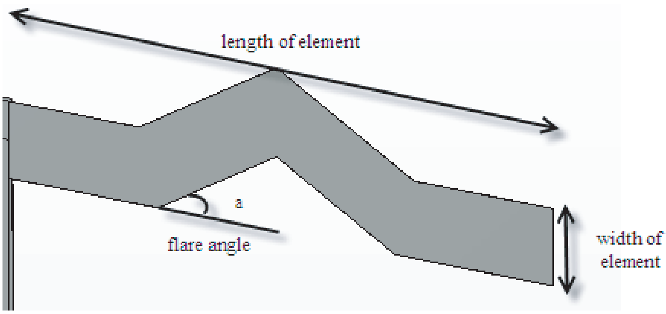


Figure 1. 1st iteration LPFKA.

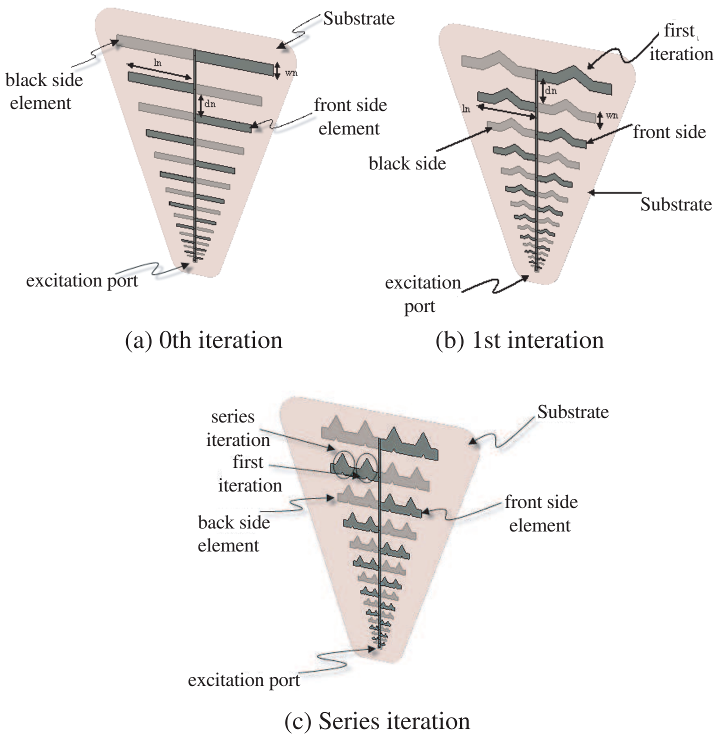


Figure 2. Log periodic Fractal Koch Antenna for UHF antenna.

0.5 GHz to 3 GHz. It consists of fifteen elements for the desired frequency range. The design specifications of the antennas such as operating frequency, bandwidth, gain, radiation pattern, polarization and scaling factor are tabulated in Table 1.

Table 1. Design specifications of the UHF Fractal Koch Antennas.

Types	**0th Iteration**	**1st Iteration**	**Series Iteration**
Operating Frequency (GHz)	0.5–3 GHz	0.5–3 GHz	0.5–3 GHz
Bandwidth (BW)	>200%	>200%	>200%
Gain	6–8 dBi	6–8 dBi	6–8 dBi
Radiation Pattern	Directional	Directional	Directional
Polarization	Linear	Linear	Linear
Scaling factor, τ	0.85	0.85	0.85

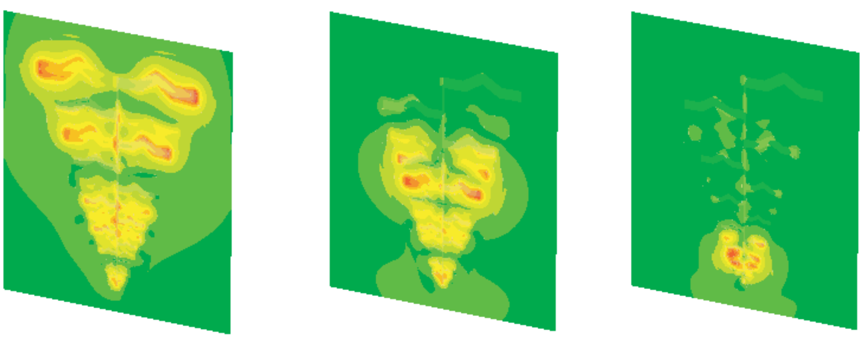
Table 2. Comparison of size reduction of UHF Fractal Koch Antenna.

Antenna type	Dimension ($L \times W \times t$) mm	Size reduction (%)
0th iteration	$244 \times 360 \times 1.6$	-
1st iteration	$227 \times 360 \times 1.6$	7%
Series iteration	$183 \times 360 \times 1.6$	26%

The 0th, 1st and series iterations of Fractal Koch antennas is shown in Figure 2. The parameters involved are length of the elements (l_n), width of the elements (w_n) and distance between the elements (d_n). The number of elements influences the bandwidth of the antennas. Thus, to obtain a wider bandwidth, the number of elements needs to be increased. The structure of the elements exists on both sides of the substrate. In other words, the elements are in crisscross arrangement. This arrangement needs to be satisfied to make sure the coupling between the elements is strong enough to radiate the electromagnetic waves. Other than that, Table 2 shows the comparison in terms of size reduction due to the number of iterations. As can be seen, the 1st iteration antenna reduces about 7% with 30 degree flare angle while the series iteration of the antenna is reduced to 26%.

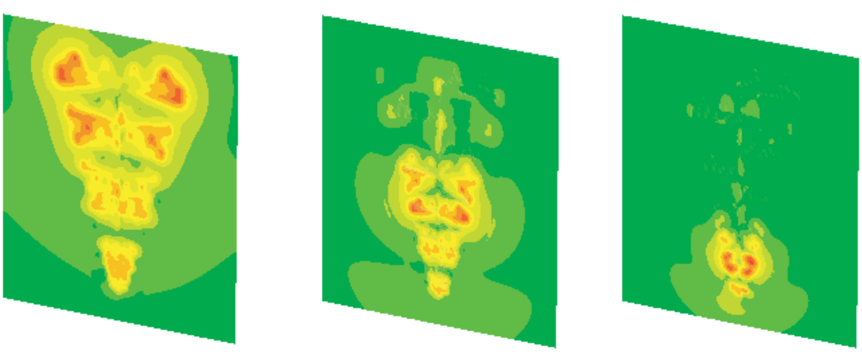
(a) 0.5 GHz (b) 0.8 GHz (c) 2 GHz

Figure 3. Current distribution of the 0th iteration antenna.



(a) 0.5 GHz (b) 0.8 GHz (c) 2 GHz

Figure 4. Current distribution of 1st iteration antenna.



(a) 0.5 GHz (b) 0.8 GHz (c) 2 GHz

Figure 5. Current distribution of series iteration antenna.

(a) 0th iteration (b) 1st iteration (c) Series iteration

Figure 6. Fabricated antennas.

3.1. Current Distribution

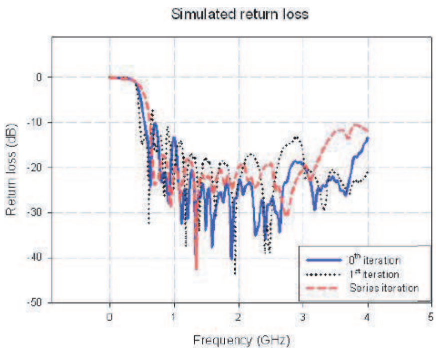
Figure 3 shows the simulated current distribution of the antenna for three different resonant frequencies. It can be observed that at the lower frequency, the current propagates at the bigger elements, which confirms that the antenna is resonating at the appropriate elements. Figure 3(b) shows the current distribution of the antenna at 0.8 GHz while Figure 3(c) shows the current propagating at the smaller elements. By monitoring the current distribution or surface current, the effect of mutual coupling can be observed, which is important in order to minimize the coupling effect among the adjacent elements for the antenna design. Figures 4 and 5 show the current distribution for 1st and series iterations at 0.5 GHz, 0.8 GHz and 2 GHz respectively.

4. MEASUREMENT RESULT

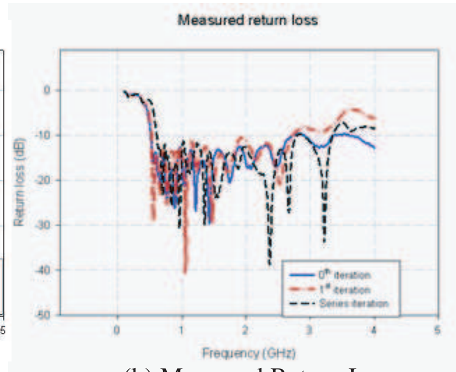
After the fabrication process, the prototypes of the antennas have been measured to validate the performances of the antenna in terms of input return loss, radiation pattern and gain. These measurements have been taken using the appropriate equipments such as network analyzer, spectrum analyzer, signal generator and antenna measurement system.

4.1. Input Return Loss Measurement

Figure 7 shows the simulated and measured return loss for the 0th, 1st and series iterations for UHF Fractal Koch antennas. The simulated return loss for these three antennas is shown in Figure 7(a). It shows that the antennas have a good return loss from 0.5 GHz up to 4 GHz with respect to −10 dB. It is clearly seen that at the lower frequency

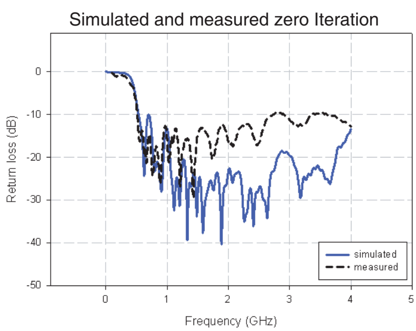


(a) Simulated Return Loss

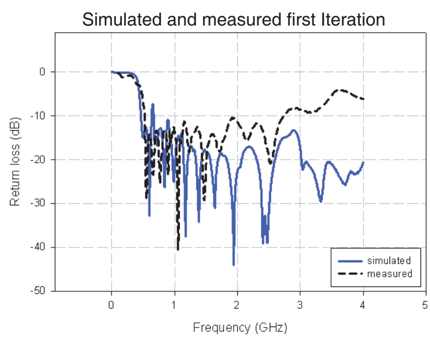


(b) Measured Return Loss

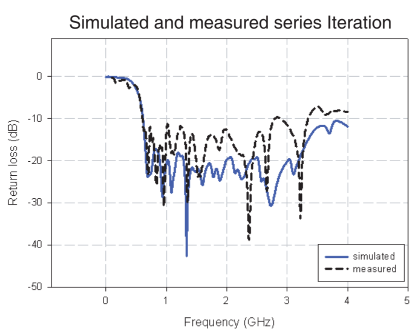
Figure 7. Simulated and measured input return loss for the 0th, 1st and series iteration Fractal Koch Antenna.



(a) 0th iteration



(b) 1st iteration



(c) Series iteration

Figure 8. Comparison between simulated and measured return loss UHF Fractal Koch Antennas.

the return loss for series iteration shifted to the right a little bit, but for the 1st iteration UHF antenna shifted to the left side. This phenomenon happened in many cases in antenna design that might occurr due to the misalignment between the upper and lower printed antennas. In addition, it can be observed that the simulated bandwidth of the antennas is around 267%. Besides, the measured return loss for 1st, 2nd and series iterations is depicted in Figure 7(b). It can be seen that the graph gives similar pattern to each other. At the lower part, the graph has many ripples compared with that at the upper part. It might be due to the properties of the material used, which has higher dielectric constant. However, the return loss for fabricated antennas is slightly shifted up especially at the higher frequency range.

The comparisons for each simulated and fabricated antenna are shown in Figure 8. As can be seen, the return loss for the 0th iteration antenna shows slight difference at the higher frequency, but it remains below −10 dB. Nevertheless, the 1st and series iteration results are shown in Figures 8(b) and 8(c) respectively.

4.2. Radiation Pattern Measurement Setup

As can be seen in Figure 9, the AUT is placed at the antenna holder and connected to the spectrum analyzer. The signals at the spectrum analyzer represent the power received from the transmitted antenna at a certain angle. The signal generator is connected to the transmitter. In this case, a horn antenna has been used as reference antenna. The transmitting frequencies can be set at the signal generator.

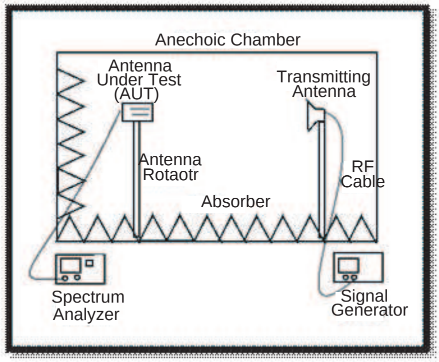
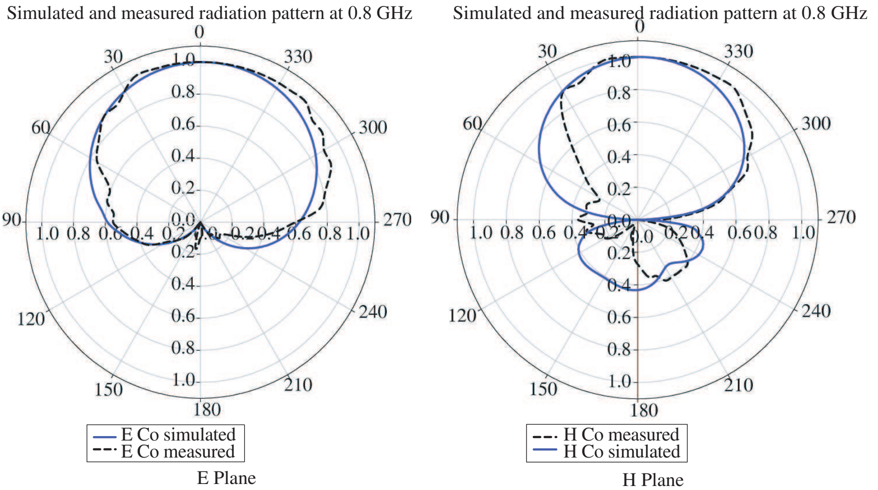
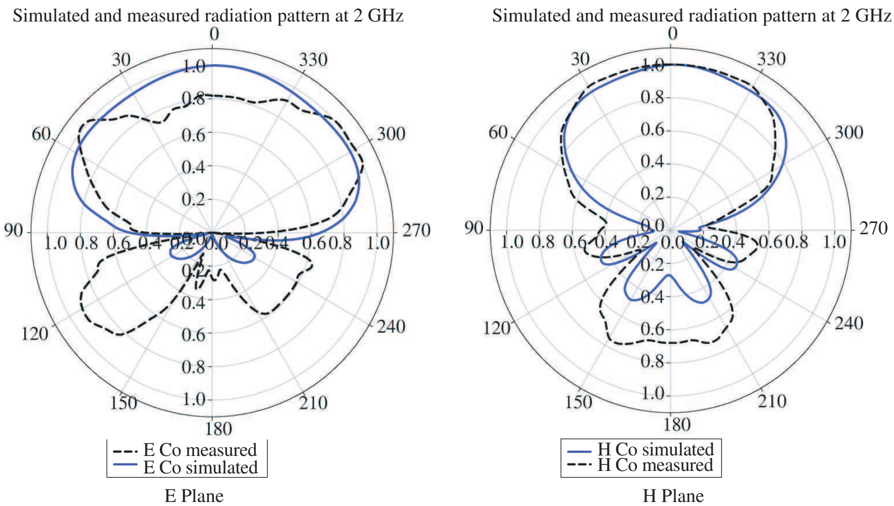


Figure 9. Radiation pattern measurement setup in anechoic chamber.



(a) Frequency 0.8 GHz



(b) Frequency 2 GHz

Figure 10. Simulated and measured radiation pattern for the 0th iteration LPFKA.

4.3. Analysis Radiation Pattern for Fractal Koch Antennas

The analysis for simulated and measured radiation patterns for Fractal Koch antennas for the 0th, 1st and series iterations is discussed in this part. The co-polar and cross-polar radiation patterns have been measured at two different frequencies at 0.8 GHz and 2 GHz for both E- and H-planes. The simulated and measured radiation pattern data are normalized in order to plot the radiation pattern in one graph.

Figure 10 shows the comparison between simulated and measured

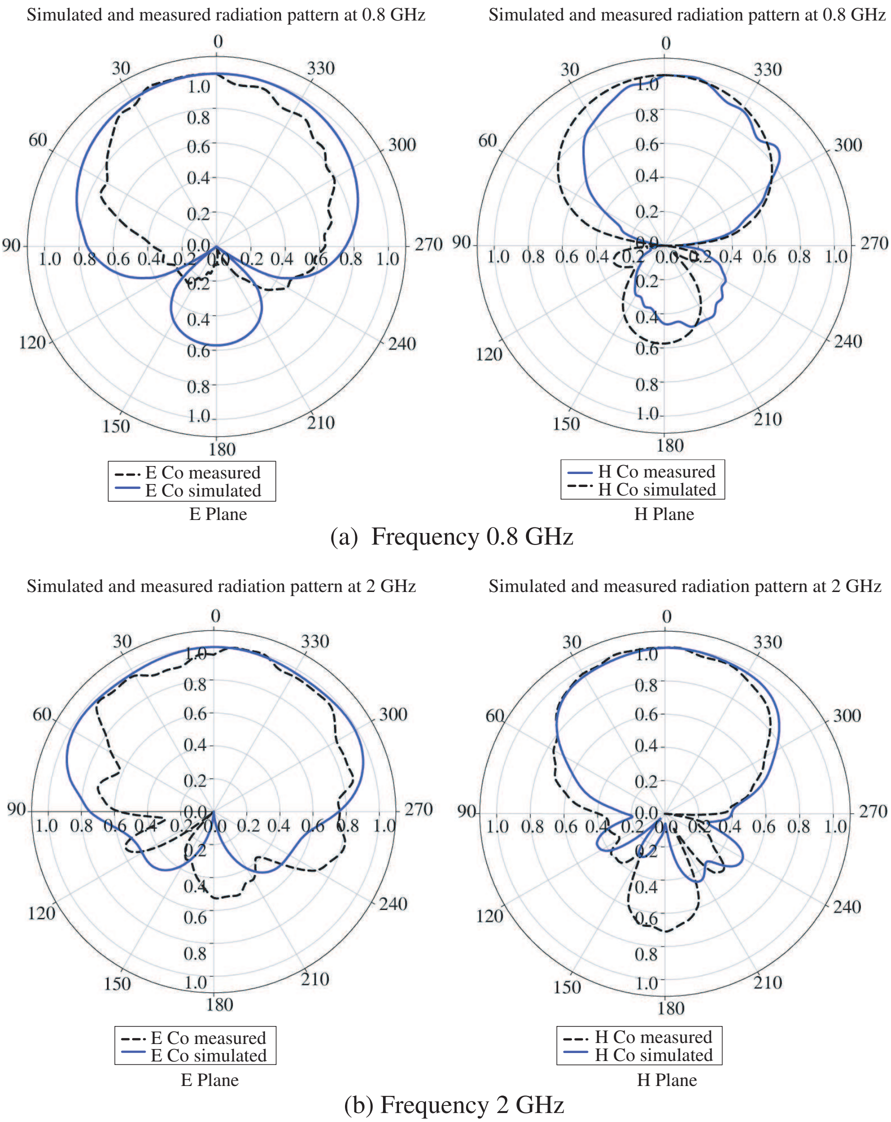


Figure 11. Simulated and measured radiation pattern for 1st iteration LPFKA.

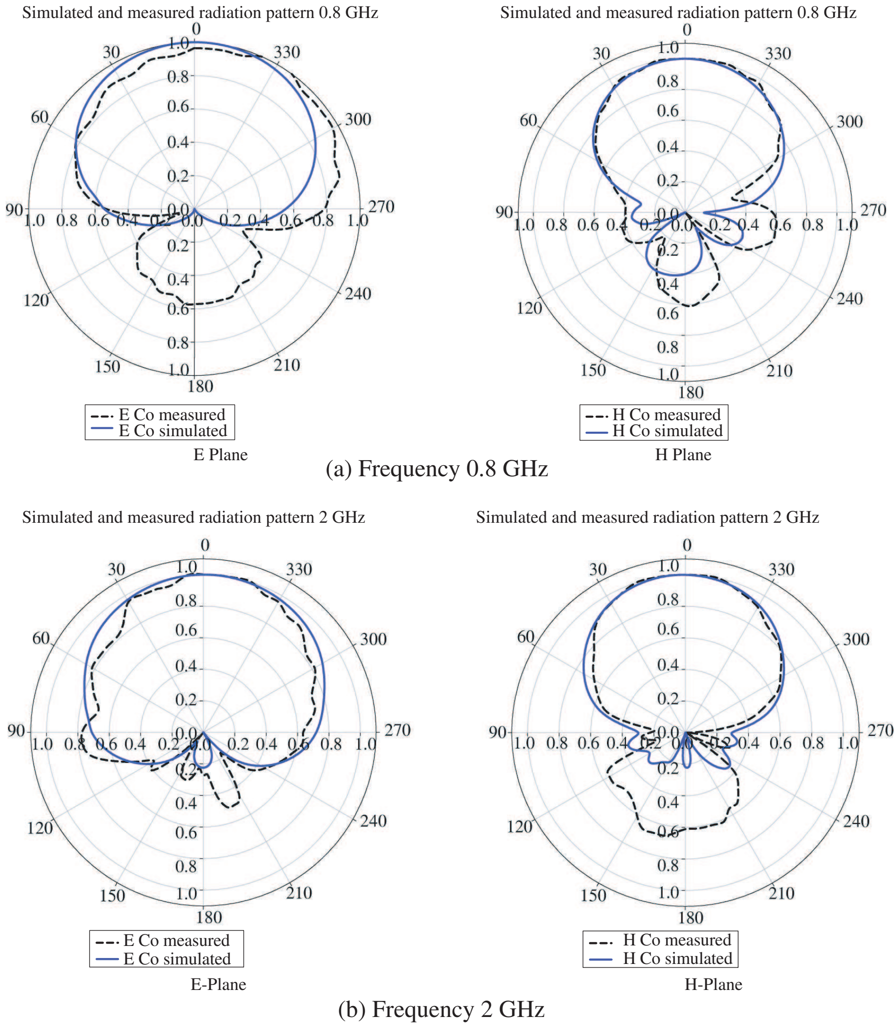
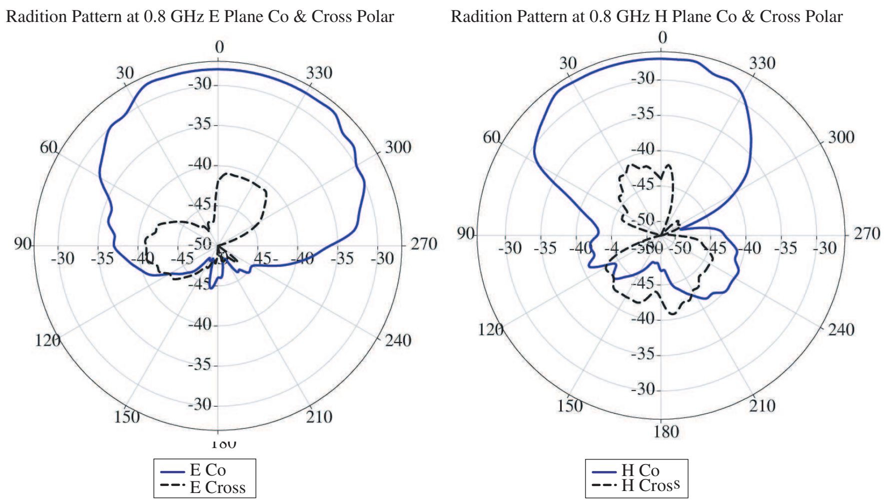


Figure 12. Simulated and measured radiation pattern for series iteration LPFKA.

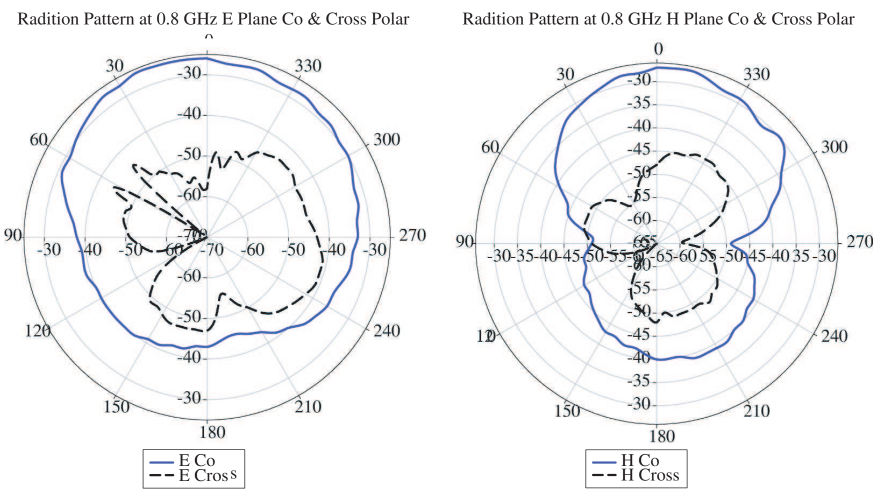
radiation patterns at 0.8 GHz and 2 GHz for *E*- and *H*-co polar for 0th iteration Fractal Koch antenna for UHF band application. The measured radiation patterns are similar to the simulated one at 0.8 GHz for *E*-co, but there is a little bit difference for *H*-co polar at the left side of the measured radiation pattern. The measured radiation pattern at 2 GHz for *E*-co polar is lower than the simulated one. As can be seen in Figure 10(b), the measured radiation pattern produces bigger back lobes. Consequently, the main lobes of the measured pattern are lower than the simulated pattern.

The radiation pattern for the 1st iteration at 0.8 GHz and 2 GHz is depicted in Figure 11. It can be observe that the simulated and measured radiation patterns for E- and H-planes are close to each other.

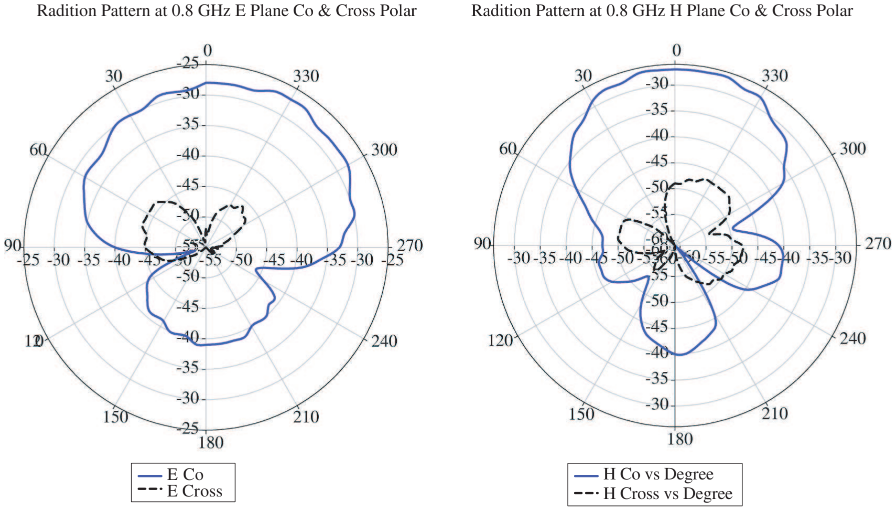
The radiation patterns for series iteration antenna are shown in



(a) 0th Iteration



(b) 1st Iteration



(c) Series Iteration

Figure 13. Co and cross polar for E and H plane LPFKA at 0.8 GHz.

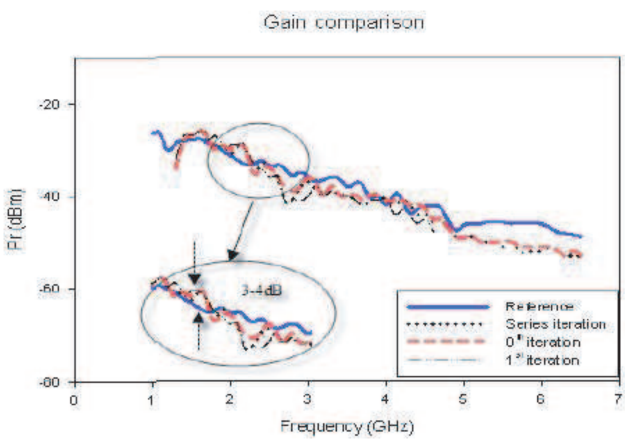


Figure 14. Gain comparison between horn antenna and LPFKA.

Figure 12. The simulated and measured radiation patterns for E-co and H-co correlate well. However, the existing of the back lobes for measured radiation pattern does not much affect the main beam of the antenna especially at 0.8 GHz for E-co polar and at 2 GHz for H-co polar. The measured radiation patterns show that the antennas are linearly polarized. The differences between co and cross polar determined the polarization of the antennas. In this case, co and

cross polar for both E and H planes are more than 3 dB as shown in Figure 13.

4.4. Analysis of Gain for Fractal Koch Antenna

The measured gain for UHF Fractal Koch antennas has been compared with the reference antenna. All three prototypes of this antenna exhibit a similar pattern compared to each other. As can be seen, the 0th, 1st and series iteration LPFKA give similar patterns. The antennas have been measured and compared in terms of power received by varying the frequency range and the value of power received in dBm. The antenna has a higher gain when it gives higher values at that particular frequency. However, it might have a lower gain when it is working outside its operating region.

5. CONCLUSION

The Log Periodic Fractal Koch antennas with three different structures such as the 0th, 1st and series iterations have been designed, simulated and fabricated. The simulated and measured results in terms of return loss, radiation pattern and gain have been compared and analyzed. The simulated current distribution of the antennas shows a good correlation between radiating elements and resonant frequencies. Moreover, the size of the antennas has been reduced up to 7% for the 1st iteration and up to 26% for series iteration antenna compared to the 0th iteration. The radiation patterns of all fabricated antennas are similar to the simulated ones. In addition, the gains of the antennas also are similar to that of the fabricated antennas. It shows that by applying the number of iterations to the antenna, the size of the antennas can be reduced. The performances of the antennas are maintained throughout the frequency range of the designed. The comparison between simulated and measured results has been shown and discussed in this paper, and it shows a good agreement for both results.

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REFERENCES

1. Vinoy, K. J., "Fractal shape antenna elements for wide band and multi band wireless applications," Ph.D. Thesis, The Pennsylvania State University, August 2002.
2. Cohen, N., "Fractal antenna applications in wireless telecommunications," *Professional Program Proc. of Electronics Industries Forum of New England, 1997, IEEE*, 43–49, 1997.
3. Puente-Baliarda, C., J. Romeu, R. Pous, J. Ramis, and A. Hijazo, "Small but long Koch fractal monopole," *Electron. Lett.*, Vol. 34, 9–10, 1998.
4. Kim, L. K., J. G. Yook, and H. K. Park, "Fractal shape small size microstrip patch antenna," *Microwave and Optical Technology Letters*, Vol. 34, No. 1, Jul. 5, 2002.
5. Gianvittorio, J. P. and Y. Rahmat-Samii, "Fractal antenna: A novel antenna miniaturization technique, and applications," *IEEE Antenna's and Propagation Magazine*, Department of Electrical Engineering, University of California, Los Angeles Engr. IV, Los Angeles, California, Vol. 44, No. 1, Feb. 2002.
6. Gianvittorio, J., "Fractal antenna: Design, characterization, and application," Master Thesis, University of California, 2000.
7. Vinoy, K. J., K. A. Jose, V. K. Varadan, and V. V. Varadan, "Hilbert curve fractal antenna: A small resonant antenna for VHF/UHF applications," *Microwave and Optical Technology Letters*, Vol. 29, No. 4, May 20, 2001.
8. Puente, C., J. Romeu, R. Bartoleme, and R. Pous, "Fractal multiband antenna based on Sierpinski gasket," *Electron. Letter.*, Vol. 32, 1–2, 1996.
9. Puente-Baliarda, C., J. Romeu, R. Pous, and A. Cardama, "On the behavior of the Sierpinski multiband fractal antenna," *IEEE Trans. Ant. Propagat.*, Vol. 46, 517–524, 1998.
10. Cohen, N., "Fractal antenna applications in wireless telecommunications," *Professional Program Proc. of Electronics Industries Forum of New England, 1997, IEEE*, 43–49, 1997.
11. Puente-Baliarda, C., J. Romeu, R. Pous, J. Ramis, and A. Hijazo, "Small but long Koch Fractal monopole," *Electron. Lett.*, Vol. 34, 9–10, 1998.
12. Kim, L. K., J. G. Yook, and H. K. Park, "Fractal shape small size microstrip patch antenna," *Microwave and Optical Technology Letters,* Vol. 34, No. 1, Jul. 5, 2002.
13. Gianvittorio, J., "Fractal antenna: Design, characterization, and

application," Master Thesis, University of California, 2000.

14. Johnson, P., "Fractal antenna design for RFID application," Mid-Sweden University, Department of Information Technology and Media, Electronic Design Division, 2006.
15. Vinoy, K. J., K. A. Jose, V. K. Varadan, and V. V. Varadan, "Hilbert curve fractal antenna: A small resonant antenna for VHF/UHF applications," *Microwave and Optical Technology Letters*, Vol. 29, No. 4, May 20, 2001.
16. Zheng, L. X., X. X. Ming, L. S. Li, and Z. Xiang, "Analysis of patch antenna based on the minkowski fractal," *International Conference on Microwave and Milimeterwave Technology Proceeding, IEEE 2004*, 2004.
17. Ramadan, A., K. Y. Kabalan, A. El-Hajj, S. Khoury, and M. Al-Husseini, "A reconfigurable U-koch microstrip antenna for wireless applications," *Progress In Electromagnetics Research*, PIER 93, 355–367, 2009.
18. Balanis, C. A., *Antenna Theory: Analysis and Design*, 2nd edition, John Wiley and Sons, New York, 1997.
19. Eldek, A. A., "Design of double dipole antenna with enhanced usable bandwidth for wideband phased array applications," *Progress In Electromagnetics Research*, PIER 59, 1–15, 2006.
20. Zainud-Deen, S. H., H. A. Malhat, and K. H. Awadalla, "Fractal antenna for passive UHF RFID," *Progress In Electromagnetics Research B*, Vol. 16, 209–228, 2009.
21. Saidatul, N. A., A. A. H. Azremi, R. B. Ahmad, P. J. Soh, and F. Malek, "Multiband Fractal Planar Inverted F Antenna (F-PIFA) for mobile phone application," *Progress In Electromagnetics Research B*, Vol. 14, 127–148, 2009.
22. Kordzadeh, A. and F. Hojatkashani, "A new reduced size microstrip patch antenna with fractal shaped defects," *Progress In Electromagnetics Research B*, Vol. 11, 29–37, 2009.
23. Zheng, L. X., X. X. Ming, L. S. Li, and Z. Xiang, "Analysis of patch antenna based on the minkowski fractal," *International Conference on Microwave and Milimeterwave Technology Proceeding, IEEE 2004*, 2004.
24. Werner, D. H. and S. Gangul, "An overview of fractal antenna engineering research," *IEEE Antennas and Propagation Magazine*, Vol. 45, No. 1, Feb. 2003.
25. Mirzapour, B. and H. R. Hassani, "Size reduction and bandwidth enhancement of snowflake fractal antenna," *Microwaves, Antennas & Propagation, IET*, 180–187, Mar. 2008.

26. Gianvittorio, J. P. and Y. Rahmat-Samii, "Fractal antenna: A novel antenna miniaturization technique, and applications," *IEEE Antenna's and Propagation Magazine*, Department of Electrical Engineering, University of California, Los Angeles Engr. IV, Los Angeles, California, Vol. 44, No. 1, February 2002.
27. Garg, R., P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House, Boston London, 2001.
28. Wadell, B. C., *Transmission Line Design Handbook*, Artech House, Boston London, 1991.
29. Computer Simulation Technology-workflow and Solver Overview, 1998–2007 CST GmbH-computer Simulation Technology.