Compact Koch Fractal Dipole RFID Antenna

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Abstract. In this paper, the design of Koch Fractal dipole antenna for first, second and third iteration have been presented. The third iteration of Koch Fractal Dipole Antenna shows a total size reduction of 21.25% compared to the basic dipole antenna optimized at the same frequency of 0.92 GHz. The new antenna is proposed based on the structure of the third iterated Koch fractal is designed using Rogers RO3010 substrate with thickness on 1.27 mm. The proposed antenna shows improvement of return loss to -34.57 dB, gain of 1.92 dB, 99% efficiency. The proposed antenna had reduced 17% of length compared to the basic dipole antenna.

Keywords. Koch Fractal, Dipole Antenna, UHF RFID Tag antenna.

1. Introduction

Recently, UHF RFID tag has been demanded in wearable applications for monitoring, access control and tracking. This technology requires low cost, low profile and long read range device. This allows for more applications such as inventory management and asset tracking to be done more efficiently as it is not required to find the barcode of each item; instead, the items can be passed through a RFID reader that is able to detect multiple items in its range. Although tags have been implemented in the tracking of animals, these tags suffer from short range due to their low frequency. Numerous antenna design has been reported in the literature to improve radiation performance of tagging. These antennas are usually mounted on flexible shapes as it fits more comfortably on the body of the animal [1]. The purpose of animal tagging is to control the safety of the animals and manage the food production [2]. The proposed antenna can be easily attached to the collar of the animal tagging.

Theoretically, higher frequency systems able to support longer reading range. The ultra-high frequency (UHF) passive RFID antenna has the best potential for future applications as it exhibits good performance in terms of range and number of detected tags [3]. By adjusting the iterations of fractal geometry, the parameter of antenna performance is increased such as ultra-wideband has been achieved by 2nd iteration of Koch geometry with 69% [4], wideband property [5] and high directivity [6]. The current along Koch fractal geometry has performed differently in electromagnetic radiation characteristic based on iteration curve and influenced the radiation patterns of the antenna as well [7].

The RFID antenna have been used in multiple application such as for automotive tire [8], temperature sensor [9] and military application [10]. For some application, requires smaller size of RFID tag due to the compact size of the tagged items. Miniaturization technique can be achieved by multiple application such as meandered shape, add slots to the structure or by applying high impedance surface layer at the
back of the antenna structure [11-12]. This paper discussed on the design synthesis of Koch Fractal dipole antenna to achieve the miniaturization for different Koch Fractal iterations. At the end on this paper, the new structure derived from the third iteration Koch Fractal design is presented to achieve the higher gain and return loss for the modified structure.

2. Iteration of Koch fractal dipole antenna

Fractal structure design has been approached to achieve antenna compact size, low profile and multiband response. The insertion of fractal space-filling to increase the antenna electrical length and radiation efficiency [13]. The fractal geometry concept was used in many antenna designs for obtaining multiband behavior and miniaturized size. Both characteristics were important requirements in antenna design trends to achieve compact design yet having a decent performance of a receiver [14]. Shapes of fractal are created based on repetition and self–similarity properties. The repetition of similar design or some called as meandered structure leads to bigger structure antenna. Koch fractal is based on the Euclidean geometry where which form an arithmetical conception of a triangle.

The Koch curve has an infinite length because of each iteration creates four times as many line segments as in the previous iteration, with the length of each one being one-third the length of the segments in the previous stage. Hence the total length of the curve increases by one third with each iteration. Figure 1 shows the division of Koch Fractal structure for different iteration. The 0th iteration is the original length of the line. Then the first iteration is divided into three section where the middle part forms a triangular shape with the same length of the one third of the original length. The length of the iteration section is defined by the equation (1) [16].

\[ L_i = R \left( \frac{\sec \theta + 2}{3} \right)^i \]  

(1)

where \( L_i \) is the length of the iteration number with \( i \) is the iteration number which starts from 1, \( R \) is the initial length and \( \theta \) is the angle between the base-angle.

![Figure 1. Koch Fractal structure from 0th to 3rd iterations.](image)

2.1. Straight Dipole Antenna

The core of this design is a dipole antenna. The wavelength of the antenna at 0.92 GHz is calculated and applied as basic dipole antenna. Then the \( \lambda/2 \) is calculated as applied to as the patch with width, \( w_{dipole} \) of 1 mm. The Rogers substrate RO3003 was then applied as substrate to the dipole antenna. The antenna was then optimized so that it can operated at 0.92 GHz frequency. Figure 2 shows the structure of optimized dipole antenna with each dipole length is 66.0 mm applied of the 144.0 mm substrate. The simulated result of the patch dipole antenna is shown in Table 1 with gain and directivity of 1.96 dB and 2.02 dB respectively.
2.2. First, Second and Third Iteration of Koch Fractal Dipole Antenna for 0.92 GHz

For the first iteration dipole patch antenna design, the total length of each dipole side was divided to three section making each section become 22 mm. Subsequently, the middle segment is replaced by two equal segments which form the two sides of the isosceles triangle. Considering the miniaturization structure, the base-angle for the middle structure is fixed to 60°. The structure and dimensions of the left side of first iteration of Koch Fractal dipole antenna is shown in Figure 3. The resonant frequency of the antenna decreases at every iteration due to the increase in antenna length because the antenna can radiate more due to the increase in electrical length. The antenna was optimized to operates at 0.92 GHz and the total reduction of 18.4% from the basic straight dipole antenna is achieved under the first iteration level.

![Figure 3. Structure and dimensions of the left side of first iteration of Koch Fractal dipole antenna.](image)

The full dimension of the first iteration Koch Fractal dipole antenna on the RO3003 substrate is shown in Figure 3(a) with gain and directivity of 1.8 dB and 1.92 dB respectively. The process for the second and third iteration continues and the structure and length of the second and third iteration Koch Fractal dipole antenna. Figure 4 (b) and (c) shows the structure and dimension of the second and third iteration of Koch Fractal dipole antenna with total reduction of 32 % and 21% respectively. Due to the complexity and limitation of $L_i$, the iteration for the Koch Fractal antenna ends at the third iteration with the length of 2.44 mm of each Koch section. Table 1 shows the comparison of bandwidth, gain and directivity for all antenna design presented in this paper. The radiation pattern of the basic, first iteration, second iteration and third iteration of the optimized Koch Fractal antenna is shown in Figure 5.

**Table 1. Results for basic to third iteration of koch fractal dipole antenna optimized at 0.92 GHz**

| Design        | Length (mm) | Bandwidth (%) | Gain (dB)  | Directivity (dB) |
|---------------|-------------|---------------|------------|------------------|
| Basic optimized | 144         | 9.39          | 1.964      | 2.028            |
| First Iteration | 117.5        | 7.29          | 1.796      | 1.918            |
| Second Iterations | 98.3         | 5.52          | 1.609      | 1.893            |
| Third Iterations | 113.4        | 7.47          | 1.749      | 1.912            |

The gain of the Koch Fractal dipole antenna for all three iterations presented in this paper shows small decrement with differences below 17.8% compared to the based dipole antenna. The directivity of the antennas presented in this paper show a very small differences of $-0.1 \ dB$ compared to the basic straight dipole antenna. As the size of the optimized Koch Fractal dipole antenna decreased towards higher iteration, the bandwidth shows small decrement from 9.39% for basic straight basic straight dipole antenna to 7.47% for the third iteration of Koch Fractal dipole antenna. The efficiency for the basic, first iteration, second iteration and third iteration of the
optimized Koch Fractal antenna are simulated to be above 98% of efficiency. Table 2 shows the summary of total width, return loss and efficiency of all 4 antennas discussed in this section.

In Table 2, the third iteration of Koch Fractal Dipole Antenna shows a total size reduction of 21.25% compared to the basic dipole antenna optimized at the same frequency of 0.92 GHz. This shows that the implementation of Koch Fractal design can be used to achieve the miniaturization of dipole antenna designed at low frequency. The third iteration Koch Fractal dipole antenna shows better simulated results in term of return loss, gain, directivity and efficiency. However, all results are acceptable and achieve the minimum requirement for dipole antenna for RFID application. Figure 6 shows the return loss graph for the basic, first iteration, second iteration and third iteration of the optimized Koch Fractal antenna.

**Table 2.** The summary of total width return loss and efficiency of basic, first iteration, second iteration and third iteration of the optimized Koch Fractal antenna.

| Design         | Total substrate length | Return Loss | Efficiency |
|----------------|------------------------|-------------|------------|
|                | Length mm | Percentage reduce | dB | %         |
| Basic optimized| 144       | -             | -20.744   | 99.42%    |
| First Iteration| 117.5     | 18.40         | -17.134   | 99.15%    |
| Second Iterations| 98.3      | 31.74         | -13.049   | 98.57%    |
| Third Iterations| 113.4     | 21.25         | -16.316   | 98.69%    |
Figure 5. The radiation pattern of the (a) basic, (b) first iteration, (c) second iteration and (d) third iteration of the optimized Koch Fractal antenna

Figure 6: Return loss graph of the optimized structure for basic dipole, first iteration, second iteration and third iteration of Koch Fractal Dipole Antenna.

3. Modified structure of third iteration koch fractal dipole antenna
The new dipole antenna design proposed in this paper is shown in Figure 7. The structure is designed based on the middle structure of third iteration Koch Fractal dipole antenna arranged in multiple straight array arrangement. The parametric study was conducted, and the best results was achieved for 8 array
arrangement for the middle structure of third iteration of Koch Fractal dipole antenna. The new proposed antenna shows good achievement in the return loss and bandwidth of -34.57dB and 9.33% respectively.

![Figure 7](image1.png)

**Figure 7.** Modified structure based on the middle structure of third iteration Koch Fractal dipole antenna.

Table 3 shows the simulated results of return loss, gain, directivity and efficiency of the proposed Modified Koch Fractal based on the third iteration. The results show that the proposed antenna with 120 mm length give almost the same results compared to the optimized basic dipole antenna designed at the same frequency. The proposed antenna was optimized to 0.92 GHz frequency with total length of 120 mm which reduced 17% of length compared to the basic dipole antenna. Figure 8 shows the radiation pattern of the new proposed antenna with angular width of 3dB at 82.4°.

![Figure 8](image2.png)

**Figure 8.** Radiation pattern of the new proposed antenna

### Table 3: Performance of the proposed antenna

|                          | Return Loss, dB | Gain, dB | Directivity, dB | Efficiency % |
|--------------------------|-----------------|---------|-----------------|--------------|
| Modified Koch Fractal    | -34.57          | 1.92    | 1.86            | 99           |
| based on the Third Iteration |                |         |                 |              |

4. **Conclusion**

In this paper, the structure of Koch Fractal Dipole antenna for first, second and third iteration have been designed and simulated at 0.92 GHz using Rogers RO3003 substrate. The simulated results show that the Koch Fractal design had reduce up to 21.25% of size compared to the based straight dipole antenna. These findings emphasize on the idea of the implementation of Koch Fractal design can be used as a design parameter for dipole antenna. Despite its complexity structure, the Koch Fractal antenna help to achieve the miniaturization structure of antenna with acceptable range of performance for simple dipole
antenna. The new structure based on the third iteration of Koch Fractal dipole antenna have been proposed in this paper which shows better performance in term of efficiency, bandwidth and return loss. The new proposed antenna is design and simulated at 0.92 GHz frequency can be used for UHF RFID application for long distance application. It is expected that design of the proposed antenna can be further enhance in term of size reduction and beet performance with the implementation of systematics optimization approaches.

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References
[1] J. Li, Y. Huang, G. Wen, R. Xu, and L. Ma, “Compact UHF RFID Tag Antenna for Application of Domestic Animals Management,” 2018 Cross Strait Quad-Regional Radio Sci. Wirel. Technol. Conf. CSQRWC 2018, vol. 2, pp. 1–2, 2018, doi: 10.1109/CSQRWC.2018.8455440.
[2] J. Bodkhe, H. DIghe, A. Gupta, and L. Bopche, “Animal Identification,” 2018 Int. Conf. Adv. Comput. Telecommun. ICAACAT 2018, pp. 1–4, 2018, doi: 10.1109/ICACAT.2018.8933624
[3] A. E. Abdulhadi and R. Abhari, “Multiport UHF RFID-Tag Antenna for Enhanced Energy Harvesting of Self-Powered Wireless Sensors,” IEEE Trans. Ind. Informatics, vol. 12, no. 2, pp. 801–808, 2016, doi: 10.1109/TII.2015.2470538.
[4] N.M. Sahar, & Islam, Mohammad & Misran, Norbahiah. (2014). Analysis of Fractal Antenna for Ultra Wideband Application. Research Journal of Applied Sciences, Engineering and Technology. 7. 2022-2026. 10.19026/rjaset.7.494.
[5] G. Liu, L., Xu and Z. Wu, "Miniaturised wideband circularly-polarised log-periodic koch fractal antenna," in Electronics Letters, vol. 49, no. 21, pp. 1315-1316, 10 October 2013, doi: 10.1049/el.2013.2418
[6] S. A. Hamzah, M. Esa and N. N. N. A. Malik, "Reduced size harmonic suppressed fractal dipole antenna with reconfigurable feature." 2010 Asia-Pacific Microwave Conference, Yokohama, 2010, pp. 2040-2043, doi: 10.1109/TII.2015.2470538.
[7] Yu, Zhen, et al. "A novel Koch and Sierpinski combined fractal antenna for 2G/3G/4G/5G/WLAN/navigation applications. " Microwave and Optical Technology Letters 59.9 (2017): 2147-2155.
[8] Sonkki, M., Sanchez-Escuderos, D., Hovinen, V., Salonen, E. T., & Ferrando-Bataller, M. (2015). Wideband dual-polarized cross-shaped vivaldi antenna. IEEE Transactions on Antennas and Propagation, 63(6), 2813–2819. https://doi.org/10.1109/TAP.2015.241552
[9] Lin, Y., Xu, Y., Chen, S., & Ma, L. (2019). Design of a Meander Line Dipole RFID Tag Antenna for Temperature Sensor. 181(1ec2me), 23–26. https://doi.org/10.2991/icme2me19.2019.6
[10] M. Abu, E. Hussin, A. R. Othman, F. mohd johar, N. M. Yatim, and R. F. Munawar, “Design of 0.92 GHz Artificial Magnetic Conductor for metal object detection in RFID tag application with little sensitivity to incidence of angle,” J. Theor. Appl. Inf. Technol., vol. 60, pp. 307–313, 2014.
[11] Bong, F. L., Lim, E. H., & Lo, F. L. (2017). Miniaturized dipolar patch antenna with narrow meandered slotline for UHF tag. IEEE Transactions on Antennas and Propagation, 65(9), 4435–4442. https://doi.org/10.1109/TAP.2017.2724074
[12] Aznabet, I., Ennasar, M., El Mrabet, O., Tedjini, S., & Khalladi, M. (2017). Meander-line UHF RFID tag antenna loaded with split ring rersonator. International Conference on Multimedia
Computing and Systems -Proceedings, 0, 757–759. https://doi.org/10.1109/ICMCS.2016.7905576

[13] Sivasundarapandian, S., and C. D. Suriyakala. "A planar multiband Koch snowflake fractal antenna for cognitive radio." International Journal of Microwave and Wireless Technologies 9.2 (2017): 335.

[14] Kaboli, Omid, Ali Gashtasbi, and Alireza Monajati. "Design, Simulation, Fabrication and Measurement of 900MHZ Newhybrid Fractal Dipole Antenna." International Journal of Electronics Communication and Computer Engineering 6.1 (2015): 20.

[15] Tripathi, Shrivishal, Akhilesh Mohan, and Sandeep Yadav. "A compact UWB Koch fractal antenna for UWB antenna Array applications." Wireless Personal Communications 92.4 (2017): 1423-1442.