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Comparison Study of Hilbert Sierpinski and Koch Fractal Structure on Coplanar Vivaldi Antenna for L/S band Application

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***Abstract*—This article presents the comparison study of fractal structure on the Coplanar Vivaldi antenna that operated at L/S-band application. We compare three types of fractal structure i.e: Hilbert, Sierpinski, and Koch to the Coplanar Vivaldi element. By keeping the dimension for all types of elements, we compare the performance of return loss, directivity, and sidelobe level at 0.5 to 5.5 GHz of frequency. From the simulation, we found that by adding the fractal structure, the performance of return loss and radiation pattern can be improved. The best return lost in the lowest frequency is grasped for Koch fractal at 0.92 GHz while in conventional at 1.3 GHz. The directivity improvement is achieved for Hilbert, Koch, Sierpinski, and conventional as 10,02 dBi, 8.62 dBi, 7.79 dBi, and 7,02 dBi respectively at 5 GHz. While at 3.5 GHz by adding a Sierpinski structure, the directivity of the antenna improves as 4 dBi, if it is compared to conventional ones. At 3 GHz the increases of SLL also observed for Hilbert structure as -13.28 dB while conventional element as -5.6 dB. The fractal structure can enhance return loss and radiation pattern performance on Coplanar Vivaldi antenna**

Keywords—Vivaldi, Hilbert, Koch, Sierpinski, Fractal

I. INTRODUCTION (*HEADING 1*)

An antenna is the front end of the telecommunication system that holds an important role in our life. It can be applied to the Internet of Things (IoT)[1], military application[2], UWB communication [3], WIMAX/WLAN [4], satellite communication [5], etc. All of that application need to improve the performance of an element antenna. There is much technology that has been done to improve antenna gain and return loss performance by varying its radiator, feeding shape, and substrate type.

Vivaldi antenna as the planar antenna has high gain [6], directional radiation pattern [7], and work in wideband frequency has been discussed in [8] [9]. There are three types of Vivaldi element Coplanar Vivaldi antenna (CVA), Antipodal Vivaldi Antenna (AVA), and Balanced Antipodal Vivaldi Antenna (BAVA). The comparison of CVA and AVA has been explored in [10] with modified its radiator. In that literature exposed the Coplanar Vivaldi antenna has better radiation pattern performance than the Antipodal Vivaldi element.

Radiation pattern and return loss of antenna element can be improved by corrugated structure [11] [12], lens structure [13][14][7], or fractal structure [15]. The fractal structure has been discussed in microstrip by Koch Sierpinski [16], Minkowski [17], Koch monopole [18], and Koch AVA [15][19]. As far as now there is no discussion about fractal structure that has been applied in the Coplanar Vivaldi element. Accordingly, our addition makes a comparison study of some fractal structure to the Coplanar Vivaldi antenna by keeping the dimension of the element.

Seven types of elements i.e: two types of Hilbert, Sierpinski, and Koch structure on Coplanar Vivaldi element and conventional ones are compared to get the return loss and radiation performance. It shows that Hilbert structure performs improvement as 4dBi of directivity and 7.28dB of SLL at 3 GHz.

The next section of this article discussed as follows: Section II presents the antenna design. Section III about the return loss and surface current performance, Section IV result and discussion, and section V is the conclusion

II. ANTENNA DESIGN

Seven types of Coplanar Vivaldi elements as shown in Fg.1 used the FR4 substrate, with dielectric constant 4,3 and substrate thickness 1.6 mm,. However, the copper thickness is 0.035mm. We add a fractal structure to the conventional Coplanar Vivaldi element in Fig. 1(a) in the both edges of the copper radiator. The fractal structure is a complex structure by copying the self-similarity of its structure. There is six types of fractal structure i.e: Hilbert-A, Hilbert-B, Sierpinski-A,

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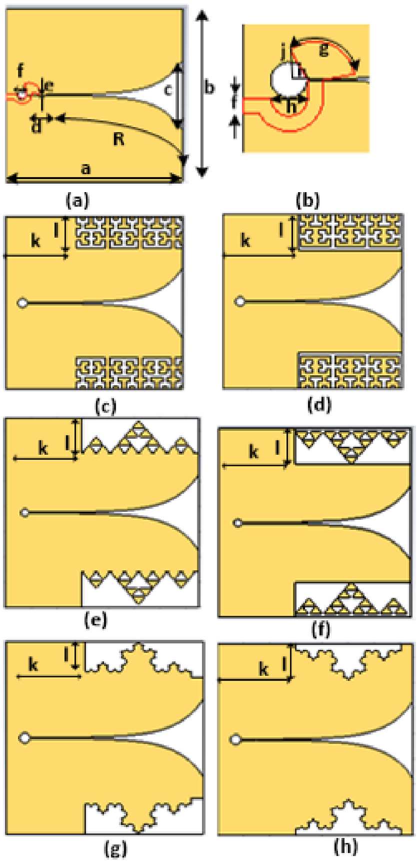

Fig. 1. Coplanar Vivaldi Antenna elements: (a) Convensional, (b) feeding shape, (c) Hilbert-A structure, (d) Hilbert-B structure, (e) Sierpinski-A, (f) Sierpinski-B, (g) Koch-A and (h) Koch-B

Table. 1. Dimension of Coplanar Vivaldi elements and the fractal structure in Fig. 1 and Fig. 2

Parameter and dimension of element in mm											
a	150	e	0,5	i	4	m	6,3	q	2,5	t	2,6
b	150	f	4	j	8	n	3,5	r	6,8	u	3
c	60	g	120	k	60	o	3,5	R	0,1	v	60
d	13	h	4	l	30	p	11	s	9		

Sierpinski-B, Koch-A, and Koch-B as shown in Fig. 1(c)-(h) sequentially. We used Hilbert as a fractal structure from first to third order. The total length (S) of the Hilbert transform with d is the side length of each segment and n iteration follows[20]:

$$S = \left(2^n - 1\right) d \quad (1)$$

Structure 1(c) and (d) are the opposite copper shape of the Hilbert fractal structure. Sierpinski triangle or Sierpinski gasket fractal structure is designed with an isosceles triangular patch. We make that structure from zero, first and second iteration for Sierpinski. The area for the big triangle will reduce by factor ¾ [21].

$$A_n = A_0 \left(3/4\right)^n \quad (2)$$

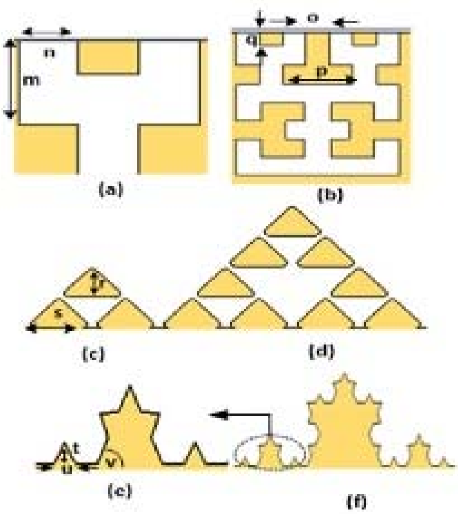

Fig. 2. The fractal structure of (a) the 1st order of Hilbert-A, (b) the 2nd order of Hilbert-A, (c) The 1st order of Sirpinski triangle, (c) The 2nd order of Sirpinski triangle, (e) the 2nd and (f) the 3rd order of Koch fractal structure.

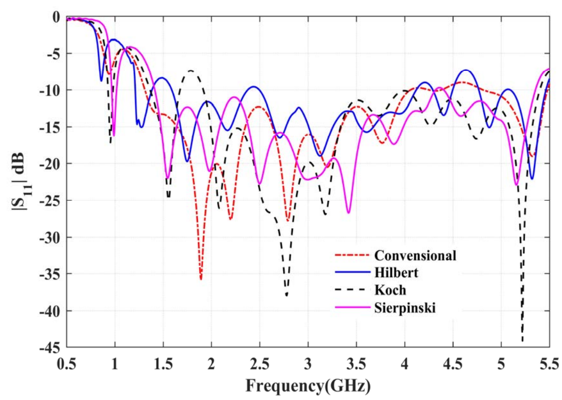

Fig. 3. The Return Loss of Conventional Coplanar Vivaldi element, Hilbert-A, Koch-A and Sierpinski-A.

A_0 is the initial triangle area and n is sequences of iterations. In the simulation, we can modify the height and the side of the triangle. For the Koch fractal structure, we designed the dimension according to [22]. For n-th iteration the length of the Koch fractal structure will reduce:

$$L_t = L_0 \left(4/3\right)^n \quad (3)$$

$$D = \frac{\log (4)}{\log (s)} \quad (4)$$

$$s = 2\left(1 + \cos\ \theta\right) \quad (5)$$

L_t the total length of Koch fractal structure, n is the iteration number, s is the scaling factor 3, and the angle of triangle 60^0. The dimension of the antenna and the fractal structure is shown in Table 1. The fractal structure in the first, second, and third-order with detail is explored in Fig. 2.

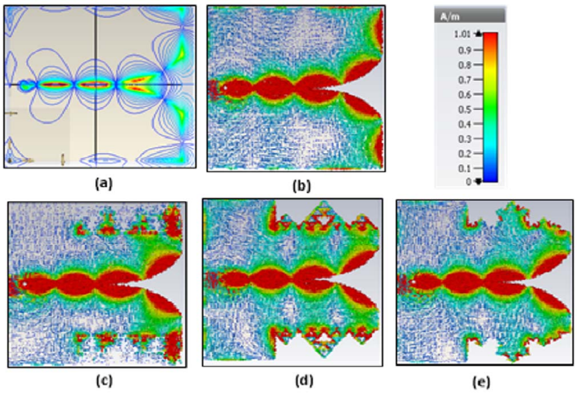

Fig. 4. The 2D plot: (a) electric Field of Conventional Coplanar Vivaldi, (b) surface current of Coplanar Vivaldi element, (c) surface current with Hilbert-A fractal structure, (d) surface current with Sierpinsky-A fractal structure and (e) surface current of Koch-A fractal structure.

III. Return Loss and Surface Current Performance

A. Return Loss performance

Return loss is the antenna parameter that shown the frequency work of the antenna if it has S_{11} below -10dB. Fig. 2 shows that the performance of return loss at the low-end of frequency is grasped for Koch-A, Sierpinsky-A, Hilbert-A, and conventional. The values of the low-end frequency of those structures that simulated from 0.5 to 5.5 GHz are 0,93 GHz, 0,96 GHz, 1,2 GHz, and 1,31 GHz sequentially. The best impedance bandwidth is achieved for Koch-A structure at 5,22 GHz of -44,17 dB. In this session, we just compared the conventional and the type-A. It shows that Koch-A has the best performance of return loss. The electric field that formed between two tapered slots will move out and some of them will move toward the patch and trapped in the fractal structure.

B. Surface current performance

The surface current performance of the Coplanar Vivaldi element without and with fractal structure at 3 GHz is performed in Fig. 4. The antenna element has designed with dimension $0,25\lambda_l \times 0,25\lambda_l$ at the low-end of frequency (0,5 GHz), but $1,5\lambda \times 1,5\lambda$ at 3 GHz. Fig. 4(a) displays the electric field and (b)-(e) is the surface current. Surface current performance at each frequency has a different performance. From the end of the feed point, the electric source resulted from feeding resonates with the cavity and the tapered slot on the patch so it produces an electric field between two tapered slots that are related to its frequency. The higher the surface current in the element patch, the higher the electric field that resulted surrounding the element and it signified by the red color (see Fig. 4). Fractal structure yields the increasing of the electric field that goes and traps around the structure.

IV. Radiation Pattern Performance

The radiation pattern is the parameter that displays the strength of the electric field in the angular direction. It can be seen in the rectangular or polar plot in two dimensions and also in the three-dimension. The radiation pattern of the antenna consists of the main lobe, side lobe, and back lobe level. The max value of the main lobe can be seen in the directivity, gain, or electric field. The directivity of the element shows how directive the radiated power

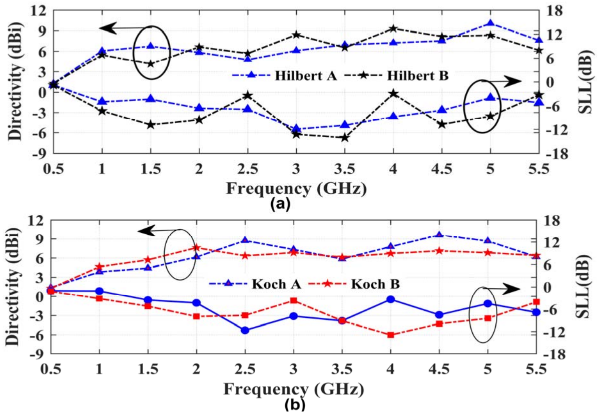

Fig. 5. The performance of directivity and side lobe level (a) Hilbert-A and Hilbert-B and (b). Koch-A and Koch B for the fractal struccture on Coplanar Vivaldi element. structure

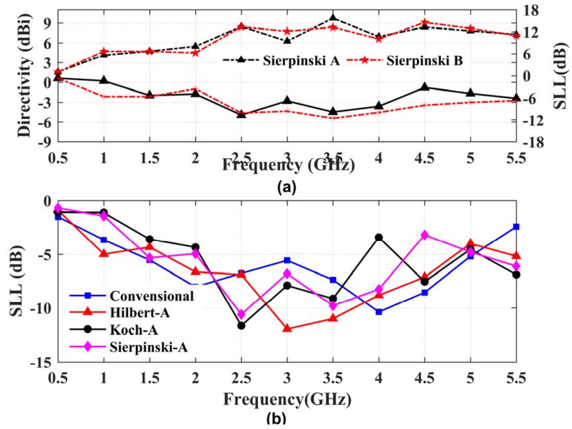

Fig. 6. (a) Directivity and SLL performance of Sierpinski-A and Sierpinski-B and (b). SLL of Convensional, Hilbert-A, Koch-A and Sierpinski-A

electromagnetic wave is concentrated. Fig. 5 shows the value of directivity on the upper side and SLL(side lobe level) on the lower side. Fig. 5(a) shows that Hilbert-B has better directivity in the middle frequency i.e 2 GHz, 2,5 GHz, 3 GHz, 4 GHz, 4.5GHz than Hilbert-A. However, in the low and high-end frequency, Hilbert-A has better directivity than Hilbert-B. For most of the part of the frequency range, Hilbert-A has the better performance of SLL than Hilbert B. The Structure of Hilbert-A and B can be seen in Fig.2 (c) and (d). The Koch and Sierpinski structure A and B that has an opposite side of the fractal structure has the different performance of directivity and SLL in each frequency as shown in Fig. 5 and 6.

Fig. 6(a), in the upper side, shows that the highest directivity is grasped for Sierpinski A at 3.5 GHz. On the lower side of Fig. 6(a), Sierpinski-B has the lower SLL than Siierpinski-A in the mainly of frequency range. Fig. 6(b) shows the comparison SLL for Conventional, Hilbert-A, Koch-A, and Sierpinski-A. The lowest SLL is gotten for Hilbert-A at 3.5 GHz of -9,78 dB. However, Fig. 7 shows the performance of directivity for Conventional, Hilbert-A, Koch-A, and Sierpinski-A. The improvement of directivity is achieved for conventional, Sierpinski, Koch, and Hilbert

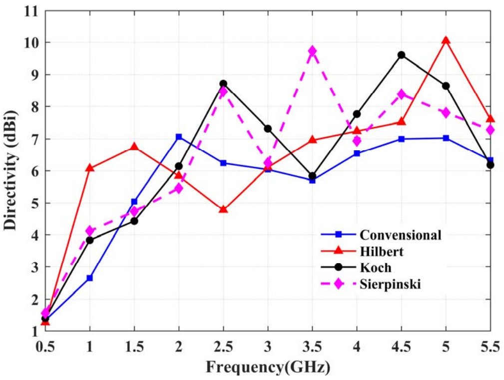

Fig. 7. The directivity performance of Convensional, Hilbert-A, Koch-A and Sierpinski-A

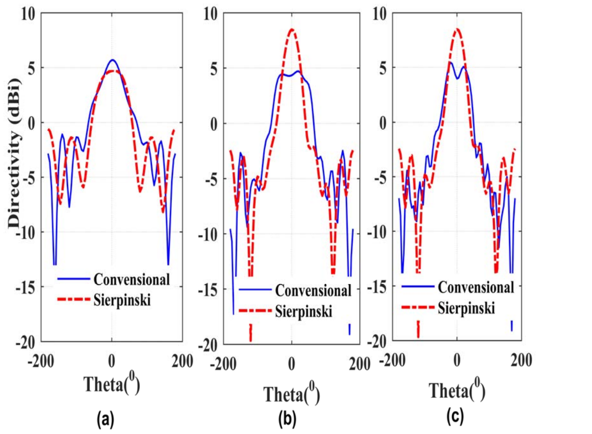

Fig. 8. Radiation pattern performance in the E-plane at (a) 1.5 GHz, (b) 2,5 GHz and (c) 3.5 GHz

structure i.e. 7,01dBi, 7,79 dBi, 8,62 dBi, and 10,02 dB at 5 GHz. But the highest improvement is achieved for Sierpinski of 4 dBi at 3.5 GHz. All of the structure indicates the various performance of directivity and SLL in each frequency.

Fig. 8 shows the performance of the radiation pattern of Conventional and Sierpinsky-A structure at 1.5 GHz, 2.5 GHz, and 3.5 GHz. For 1.5 GHz, Conventional Coplanar Vivaldi has a better radiation pattern than Sierpinski-A. However, at 2.5 GHz and 3.5 GHz, Sierpinski has better directivity than conventional ones. The directivity of the Conventional Coplanar Vivaldi antenna at 1,5 GHz, 2,5Ghz, and 3,5 GHz are 5,05 dBi, 6,24 dBi and 5,7dBi with the main lobe direction of its frequency are 5^0, $5^{0,}$ and 20^0. On the other hand for Sierpinski-A, the directivity at those frequencies are 4,71 dBi, 8,47 dBi and 9,73 dBi with the main lobe directions are 5^0, $0^{0,}$ and 0^0. SLL at 1,5 GHz, 2,5 GHz and 3,5 GHz for conventional Coplanar Vivaldi are -5.5 dB,-6,8 dB and -7,4 dB. While Sierpinski structure has SLL of -5,3 dB, -10,6 dB and -9,8 dB. Sierpinski-A can reduce the SLL -3,8 dB at 2.5 GHz. Sierpinski structure can improve directivity, main lobe direction, and SLL performance. Fig. 9 Shows Radiation pattern performance for Conventional Coplanar Vivaldi element, Hilbert-A, Koch-A, and Sierpinski-A at frequency 1 GHz. It displays that Sierpinsky has a directivity of 6,07 dBi,

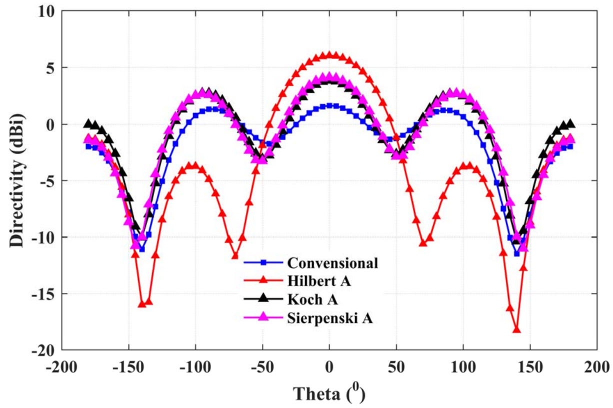

Fig. 9. Comparison of radiation pattern performance in the E-plane of the Conventional, Hilbert-A, Koch-A and Sirpinski-A on Coplanar Vivaldi element.

however, the Conventional Coplanar Vivaldi element results in the directivity of 2,65 dBi. The sidelobe level for Sierpinski-A -7,3 dB, while the SLL of conventional ones is -3,7 dB. By adding Hilbert-A structure, the performance of the radiation pattern at 1 GHz can increase as 3,42 dBi for directivity and 3,6 dB for SLL. It is shown that the fractal structure can improve directivity and SLL performance.

V. CONCLUSION

A comparison study of seven antenna elements i.e: Conventional, Hilbert-A and B, Sierpinski A and B, and Koch A and B structure on Coplanar Vivaldi element have been explored to show the return loss, surface current, and radiation pattern performance. All of the antenna element has the dimension of $0{,}25\lambda_l \times 0{,}25\lambda_l$ at the low-end of frequency (0,5 GHz) and simulated from 0.5 GHz to 5.5 GHz.The best return loss and impedance bandwidth are achieved for the Koch-A structure of 0,93GHz in the lowest frequency and -44,17 dB at 5,22 GHz. Antenna with the fractal structure has different radiation pattern performance in each frequency. At 3.5 GHz the improvement of directivity is achieved for the Sierpinski structure of 4 dBi if it is compared to the conventional ones. However the increase of SLL performance is grasped for Hilbert-A of -14,07 dB, but the SLL of Conventional Coplanar Vivaldi element is -7,39 dB. By adding the fractal structure, the performance of return loss, directivity, sidelobe level, and main lobe direction can be improved. This indicated that structure can be considered to be applied in L/S band application.

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REFERENCES

[1] M. Gupta and V. Mathur, "ScienceDirect Sierpinski fractal antenna for the internet of things applications," *Mater. Today Proc.*, vol. 4, no. 9, pp. 10298–10303, 2017, DOI: 10.1016/j.matpr.2017.06.368.

[2] M. Gupta, V. Mathur, A. Kumar, V. Saxena, and D. Bhatnagar, "Microstrip Hexagonal Fractal Antenna for Military Applications," vol. 73, pp. 321–330, 2019.

[3] A. O. Kaka and M. Toycan, "Modified hexagonal Sierpinski gasket-based antenna design with multiband and miniaturized characteristics for UWB wireless communication," pp. 464–473, 2016, DOI: 10.3906/elk-1306-197.

[4] W. Technologies, C. Engineering, G. Era, and B. Road, "Complementary Sierpinski gasket fractal antenna for dual-band WiMAX / WLAN," vol. 5, no. 4, pp. 499–505, 2013, DOI: 10.1017/S1759078713000123.

[5] A. Kumar, "Design of micro-machined modified Sierpinski gasket fractal antenna for satellite communications," no. February, pp. 1–10, 2019, DOI: 10.1002/mmce.21786.

[6] W. T. D. Lens, M. Moosazadeh, S. Member, and S. Kharkovsky, "A Compact High-Gain and Front-to-Back Ratio Elliptically Tapered Antipodal Vivaldi Antenna," vol. 15, pp. 552–555, 2016.

[7] M. Moosazadeh, S. Kharkovsky, J. T. Case, and B. Samali, "Improved Radiation Characteristics of Small Antipodal Vivaldi Antenna for Microwave and Millimeter-Wave Imaging Applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 16, 2017, DOI: 10.1109/LAWP.2017.2690441.

[8] M. Kanagasabai *et al.*, "Modified antipodal Vivaldi antenna for ultra-wideband communications," *IET Microwaves, Antennas Propag.*, vol. 10, no. 4, pp. 401–405, 2016, DOI: 10.1049/iet-map.2015.0089.

[9] D. H. Schaubert, "Wide-Band Phased Arrays of Vivaldi Notch Antennas."

[10]N. Nurhayati, A. M. De Oliveira, J. F. Justo, E. Setijadi, B. E. Sukoco, and E. Endryansyah, "Palm tree coplanar Vivaldi antenna for near field radar application," *Microw. Opt. Technol. Lett.*, vol. 62, no. 2, 2020, DOI: 10.1002/mop.32127.

[11] M. Abbak, M. N. Akıncı, M. Ç. Ayören, and ˙ I Akduman, "Experimental Microwave Imaging with a Novel Corrugated Vivaldi Antenna," *IEEE Trans. Antennas Propag.*, vol. 65, pp. 3302–3307, 2017, DOI: 10.1109/TAP.2017.2670228.

[12] Nurhayati, G. Hendrantoro, T. Fukusako, and E. Setijadi, "Mutual Coupling Reduction for a UWB Coplanar Vivaldi Array by a Truncated and Corrugated Slot," *IEEE Antennas Wirel. Propag. Lett.*, vol. 17, no. 12, 2018, DOI: 10.1109/LAWP.2018.2873115.

[13] M. Moosazadeh, S. Kharkovsky, and J. T. Case, "Microwave and millimeter-wave antipodal Vivaldi antenna with a trapezoid-shaped dielectric lens for imaging of construction materials," *IET Microwaves, Antennas Propag.*, vol. 10, pp. 301–309, 2016, DOI: 10.1049/iet-map.2015.0374.

[14] M. Moosazadeh and S. Kharkovsky, "A Compact High-Gain and Front-to-Back Ratio Elliptically Tapered Antipodal Vivaldi Antenna With Trapezoid-Shaped Dielectric Lens," *IEEE Antennas Wirel. Propag. Lett.*, vol. 15, 2016, DOI: 10.1109/LAWP.2015.2457919.

[15] B. Biswas, R. Ghatak, and D. R. Poddar, "A Fern Fractal Leaf Inspired Wideband Antipodal Vivaldi Antenna for Microwave Imaging System," no. c, pp. 1–4, 2017, DOI: 10.1109/TAP.2017.2748361.

[16] M. G. Siddiqui, A. K. Saroj, and D. Tiwari, "Koch – Sierpinski Fractal Microstrip antenna for C / X / Ku-band applications," *Aust. J. Electr. Electron. Eng.*, vol. 0, no. 0, pp. 1–9, 2019, DOI: 10.1080/1448837X.2019.1677121.

[17] R. Kubacki and M. Czy, "applied sciences Minkowski Island and Crossbar Fractal Microstrip Antennas for Broadband Applications," 2018, DOI: 10.3390/app8030334.

[18] C. P. Baliarda, J. Romeu, and A. Cardama, "The Koch Monopole : A Small Fractal Antenna," vol. 48, no. 11, pp. 1773–1781, 2000.

[19] A. de Oliveira *et al.*, "A HIGH DIRECTIVE KOCH FRACTAL VIVALDI ANTENNA DESIGN FOR MEDICAL NEAR-FIELD MICROWAVE," vol. 59, no. 2, pp. 337–346, 2017, DOI: 10.1002/mop.

[20] S. A. Saputro and J. Y. Chung, "Hilbert curve fractal antenna for dual on- and off-body communication," *Prog. Electromagn. Res. Lett.*, vol. 58, no. November 2015, pp. 81–88, 2016, DOI: 10.2528/PIERL15111107.

[21] I. R. Gonzalez-rangel, G. Hernandez-valdez, E. A. Andrade-gonzalez, and M. Reyes-ayala, "Relationship among resonant multiband fractal antennas frequencies of," vol. 3012, pp. 4–8, 2017.

[22] R. Poonkuzhali, Z. C. Alex, and T. Balakrishnan, "Miniaturized wearable fractal antenna for military applications at VHF band," *Prog. Electromagn. Res. C*, vol. 62, no. February, pp. 179–190, 2016, DOI: 10.2528/PIERC15070105.