RCS Reduction of Ultra-Wideband Koch Fractal Slot Antenna

Besharat Rezaei Shookooh, Alireza Monajati, and Hamid Khodabakhshi

Abstract — **An effective way to reduce the radar cross section (RCS) of a microstrip slot antenna is reduction of the metal areas. Koch fractal slot and rectangular loop feed-in patch are applied to reduce the RCS. In comparison with initial square slot antenna, the ultra-wideband (UWB) Koch fractal slot antenna has wider impedance bandwidth and lower RCS because of 6.78% metal areas reduction. Impedance bandwidth of the initial square slot antenna is 3.1~13.7 GHz, while the bandwidth of the Koch fractal slot antenna is from 2.8 GHz to more than 15 GHz. The RCS of the Koch fractal slot antenna can be reduced more by applying Koch fractal to outer perimeter of slot. As a result, the proposed slot antenna has lower RCS because of 38.56% metal areas reduction while bandwidth is the same.**

Keywords — **Fractal, Microstrip antenna, Radar cross section, Ultra-wideband.**

I. Introduction

Using of new absorbent materials and geometrical shaping are two typical techniques to reduce RCS of sensitive targets [1-3]. However, these techniques have found a limited application in antennas, because antennas that function as radiating and receiving electromagnetic waves, they also need a certain aperture size to produce a desired radiation pattern [4, 5]. So, reduction of the RCS of the antenna have gained more interest [6, 7]. On the other hand, UWB antennas have been key components in developing the wireless communication systems [8-11]. But because of its ultra-wide bandwidth, the RCS reduction in the inner band is difficult [12, 13].

Fractal geometry was introduced by B. B. Mandalbrot at 1975 and was later further investigated by many researchers within the field of antenna design. Koch, Sierpinski and Minkowski shapes are the most well-known fractal structures that are most often used as wideband and multiband antenna designs due to their self-similarity feature [14, 15].

Article history: Received November 07, 2020; Accepted December 20, 2020

Besharat Rezaei Shookooh is with Department of Electrical Engineering, Yadegar-e-Imam Khomeini (RAH) Shahre Rey Branch, Islamic Azad University, Tehran, Iran, E-mail: te.besharat@gmail.com

Alireza Monajati is with Department of Electrical Engineering, Yadegar-e-Imam Khomeini (RAH) Shahre Rey Branch, Islamic Azad University, Tehran, Iran. Corresponding author e-mail: alireza.monajati@yahoo.com

Hamid Khodabakhshi is with Department of Electrical Engineering, Yadegar-e-Imam Khomeini (RAH) Shahre Rey Branch, Islamic Azad University, Tehran, Iran, E-mail: Khodabakhshi.hamid@gmail.com

Koch fractal slot antenna due to self-similarity and convoluted properties of the fractals has the self-loaded characteristic, so it can expand the bandwidth without any matching additional element [16-20]. Simultaneously, the antenna has lower backscattering cross section almost in the whole operating bandwidth than the initial square slot antenna because of the metal area reduction [21, 22]. To further reduce RCS, an offset rectangular microstrip loop patch feeds the Koch fractal antenna instead of the rectangular offset microstrip patch which is used in the initial square slot antenna. Of course, from another point of view, metal area reduction decreases capacitance of the microstrip antenna that lead to quality factor reduction in its equal circuit and decreased quality factor also leads to impedance bandwidth improvement.

In this study, in order to more reduce the RCS, the Koch fractal is applied to the outer perimeter of the Koch fractal slot antenna. The simulation and measurement results show that this proposed antenna has lower backscattering cross section almost in the whole operating bandwidth than the Koch fractal slot antenna, while the bandwidth is the same.

II. Proposed Antenna Geometry

Fractals due to their geometrical self-similar properties and the ability of filling the space, are useful in designing UWB antennas with low RCS. At the first step the three sides of the initial square slot antenna (Antenna 1) are replaced by the Koch fractal form. As shown in Fig. 1, the Koch fractal slot antenna (Antenna 2) is achieved through 3 iterations. After 3 iterations, Antenna 2 has better self-loaded property, longer slot perimeter and 6.78% less metal areas in comparison with Antenna 1. In order to reduce the metal areas more, a rectangular loop patch feeds Antenna 2 instead of a rectangular one that feeds Antenna 1. At TE10 mode, current distribution in the center of the feed-in patch is almost zero, so this reform doesn't affect radiation and impedance characteristics of Antenna 2.

In the proposed slot antenna (Antenna 3), the Koch fractal is applied to the outer perimeter of Antenna 2 and after 3 iterations, the outer perimeter is longer in comparison with that of Antenna 2. The metal areas are reduced 38.56% in comparison with Antenna 1, so the RCS can be reduced effectively.

The configurations of Antenna 1 and Antenna 2 are shown in Fig. 2. The slot structure and the feed-in patch are located on each side of the substrate.

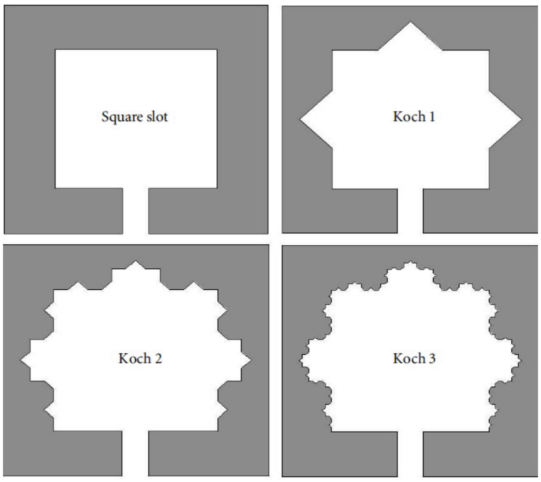

Fig. 1. Geometry of the square slot and three modified Koch slots with different iterations [2]

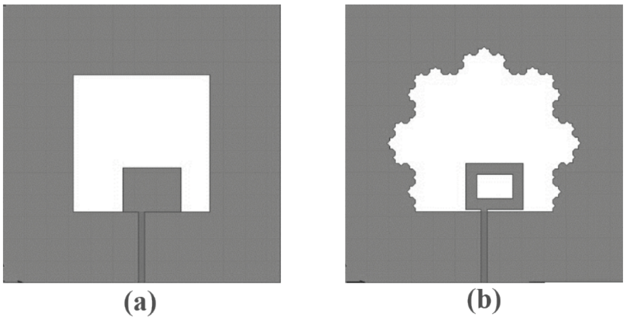

Fig. 2. Antenna configurations: (a) Initial square slot antenna (Antenna 1) [1], (b) Koch fractal slot antenna (Antenna 2) [1]

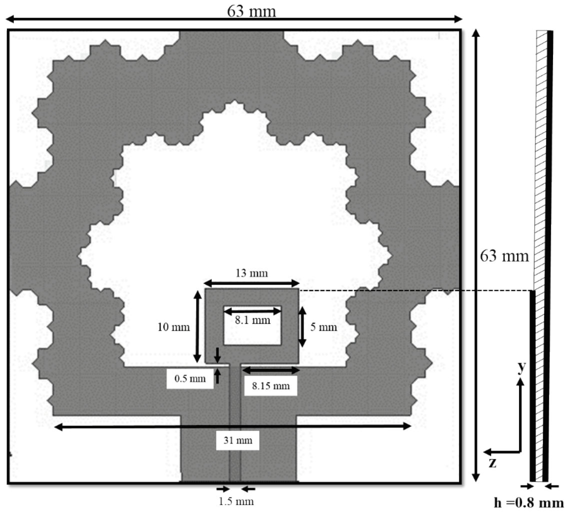

Fig. 3. Configuration of the proposed slot antenna (Antenna3)

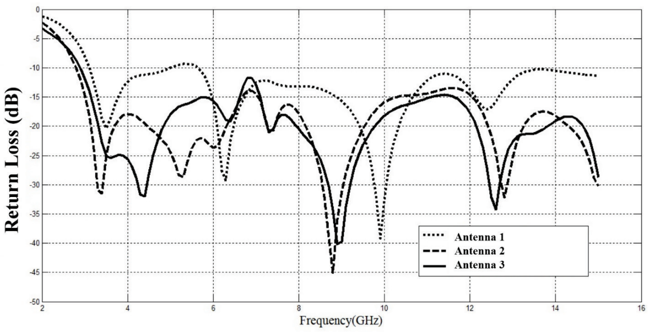

Fig. 4. The impedance bandwidth comparison of the three antennas

III. SIMULATION RESULTS

The configuration of the proposed Antenna 3 is shown in Fig. 3. The antenna is printed on the RO4003 substrate with thickness of 0.8 mm and relative permittivity of εr=3.55. In order to verify configuration improvement of the proposed slot antenna, all of the antenna parameters such as substrate thickness, materials and dimensions are same as that of Antenna 1 and Antenna 2.

The simulated results are obtained by HFSS software. As shown in Fig. 4, -10dB impedance bandwidth of Antenna 1 is from 3.1 GHz to 13.7 GHz, however return loss around 5.4 GHz is a little above -10dB. The bandwidth of Antenna 2 is from 2.8 GHz to more than 15 GHz, so the bandwidth is more expanded in comparison with Antenna 1. The fractal self-loaded property can expand the impedance bandwidth, less metal areas can reduce the RCS and the longer slot perimeter can make the Antenna 2 operate at a lower frequency, so, as a result lower frequency of the impedance bandwidth becomes from 3.1 GHz to 2.8 GHz. Also, from another point of view, metal area reduction decreases capacitance of the microstrip antenna that lead to quality factor reduction in its equal circuit and decreased quality factor also leads to impedance bandwidth improvement.

The bandwidth of Antenna 3 is the same as that of Antenna 2. In this antenna, despite the application of fractal shape to the outer perimeter of Antenna 2, the input current distribution didn't change in comparison with Antenna 2, so the impedance bandwidth of Antenna 3 is the same as for Antenna 2 but because of metal areas reduction, has lower RCS effectively. So, the impedance bandwidth of Antenna 3 is expanded in comparison with Antenna 1 and operates at a lower frequency.

Antenna 2 has 6.78% less metal areas than Antenna 1 to reduce its backscattering cross section. Also Antenna 3 has 38.56% less metal areas than Antenna 1. Therefore, the proposed slot antenna has lower RCS in the whole operating frequency band. It is impossible to reduce metal areas more than in the case of Antenna 3 because of increasing the surface resistance of the antenna and reducing antenna efficiency. The optimum design has achieved as shown in Fig. 3.

RCS simulation results are given for vertical polarization. It means that both the incident and reflected electric field are parallel to the y-axis. The incident waves are parallel to the z-axis. The RCS results versus frequency of the three antennas are shown in Fig. 5. As shown in Fig. 5, the RCS of Antenna 3 is greatly reduced in comparison with Antennas 1 and 2, especially in the frequency bands 6~9 GHz and 11~15 GHz.

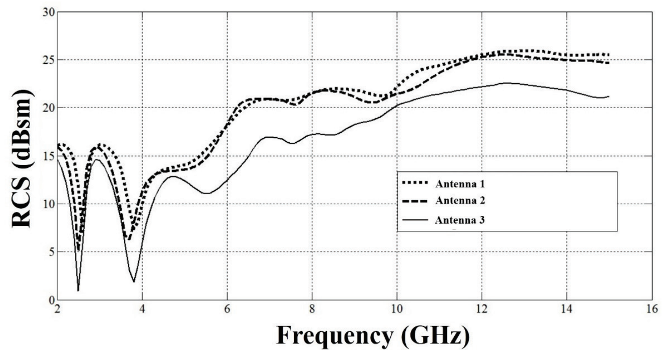

Fig. 5. The RCS comparison of the three antennas

Table 1 shows characteristics, such as impedance bandwidth and metal area reduction of the three antennas. Simulated radiation patterns of Antennas 1-3 at 3 and 9 GHz are given in Fig. 6. It is shown that the gain of Antenna 3 is improved 1.2 dB in comparison with that of Antenna 1.

TABLE 1
CHARACTERISTICS, IMPEDANCE BANDWIDTH AND METAL AREA REDUCTION OF THE THREE ANTENNAS

	Antenna type	Impedance bandwidth	Feed type	Metal area reduction
Antenna 1	Initial square slot antenna	3.1~13.7 GHz	Rectangular patch	-
Antenna 2	Koch fractal slot antenna	F_L=2.8 GHz F_H > 15 GHz	Rectangular loop patch	6.78%
Antenna 3	Proposed slot antenna	F_L=2.8 GHz F_H > 15 GHz	Rectangular loop patch	38.56%

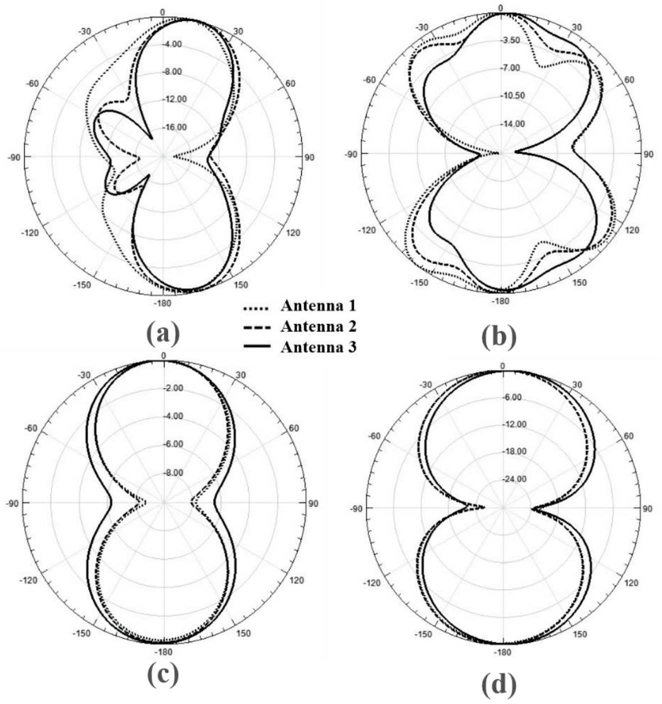

Fig. 6. Simulated radiation patterns of the three antennas: (a) 9 GHz H-plane, (b) 9 GHz E-plane, (c) 3 GHz H-plane, (d) 3 GHz E-plane

IV. MEASUREMENT RESULTS AND DISCUSSION

As mentioned before, Antennas 1-3 were fabricated using the RO4003 substrate with a thickness of 0.8 mm and a relative permittivity of εr=3.55. Fabricated antennas are shown in Fig. 7. The return losses of all three antennas were measured by network analyzer Anritsu 37269A. Fig. 8 shows the measured return loss results of the three antennas at 0.4~12 GHz frequency band. As shown in Fig. 8, Antennas 2 and 3 have broader bandwidth.

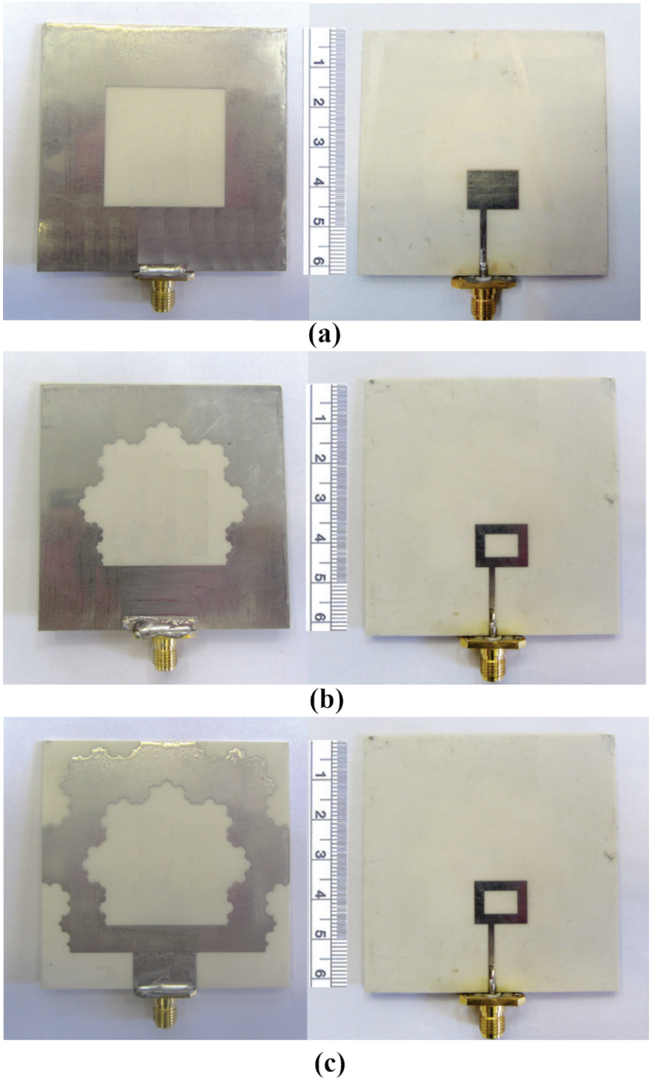

Fig. 7. Fabricated antennas on RO4003: (a) Antenna 1, (b) Antenna 2, and (c) Antenna 3

The co-pol and cross-pol radiation patterns of the fabricated antennas were measured at E and H planes at 9 GHz frequency. Fig. 9 shows the setup for measurement of co-pol and X-pol radiation patterns in tapered anechoic chamber of ITRC[1]. Figs. 10-12 show the measured radiation pattern results of the fabricated antennas.

[1] Iran Telecommunication Research Center (ITRC)

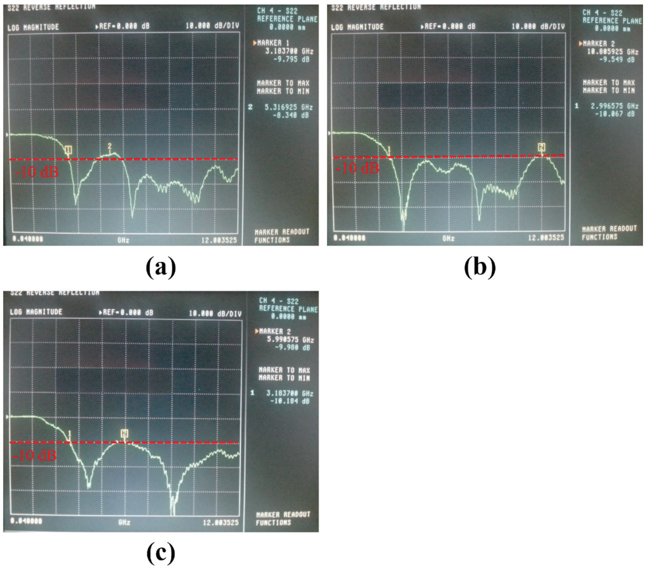

Fig. 8. Measured return loss of the three antennas: (a) Antenna 1, (b) Antenna 2, and (c) Antenna 3

Fig. 9. Radiation pattern measurement of the three antennas: (a) co-pol measurement and (b) cross-pol measurement

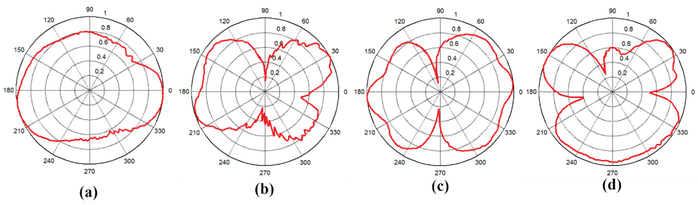

Fig. 10. Measured radiation pattern of Antenna 1 at frequency 9 GHz: (a) E-plane co-pol, (b) E-plane cross-pol, (c) H-plane co-pol, and (d) H-plane cross-pol

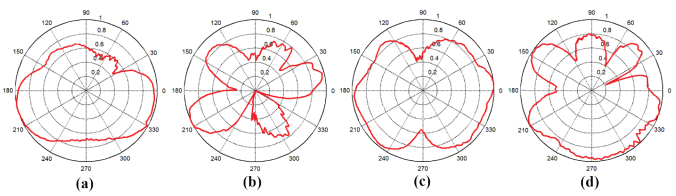

Fig. 11. Measured radiation pattern of Antenna 2 at frequency 9 GHz: (a) E-plane co-pol, (b) E-plane cross-pol, (c) H-plane co-pol, and (d) H-plane cross-pol

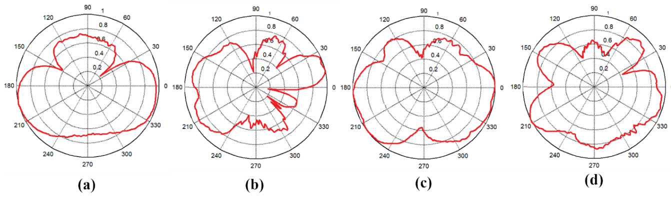

Fig. 12. Measured radiation pattern of Antenna 3 at frequency 9 GHz: (a) E-plane co-pol, (b) E-plane cross-pol, (c) H-plane co-pol, and (d) H-plane cross-pol

Also, gains of the fabricated antennas were measured in the main lobe direction at 9 GHz frequency. Table 2 shows the measured gains of the fabricated antennas. It can be seen from Table 2 that the gain of Antenna 3 is improved 1.17 dBi in comparison with that one of Antenna 1.

TABLE 2
THE MEASURED GAIN OF THE FABRICATED ANTENNAS AT MAIN LOBE DIRECTION AND 9 GHZ FREQUENCY AT TAPERED ANECHOIC CHAMBER OF ITRC

Gain comparison	**Fabricated antennas**		
	Antenna 1	**Antenna 2**	**Antenna 3**
Measured gain (dBi)	2.4	3.4	3.57

In practice, due to the small size of the antennas, there is no possibility of measuring RCS in the anechoic chamber. So, there is no data for RCS measurements. Although, as shown in Fig. 5, Antennas 2 and 3 have lower RCS because of 6.78% and 38.56% metal areas reduction, respectively.

V. CONCLUSION

In order to achieve RCS reduction, the Koch fractal is applied to square slot antenna and antenna is fed by a rectangular loop patch. As a result, the bandwidth of the Koch fractal slot antenna is wider than bandwith of the initial square slot antenna. Impedance bandwidth of the initial square slot antenna is 3.1~13.7 GHz, while the bandwidth of the Koch fractal slot antenna is from 2.8 GHz to more than 15 GHz. In this study, the Koch fractal is applied to square slot antenna and also is applied to the outer perimeter of the slot, in order to increasing the RCS reduction. The bandwidth of the proposed antenna is the same as the bandwidth of the Koch fractal slot antenna, so it is wider than the bandwidth of the initial square slot antenna. The proposed slot antenna has lower backscattering cross section almost in the whole operating bandwidth than the fractal Koch slot antenna.

REFERENCES

[1] H.-Y. Xu, H. Zhang, X. Yin, and K. Lu, “Ultra-Wideband Koch Fractal Antenna with low Backscattering Cross Section”, *Journal of Electromagnetic Waves and Applications*, 2010.
[2] H. Zhang, H.-Y. Xu, B. Tian, and X.-F. Zeng, “CPW-Fed Fractal Slot Antenna for UWB Application”, *International Journal of Antennas and Propagation*, vol. 2012, Article ID 129852.

[3] E. Heidrich, and W. Wiesbeck, “Reduction and Minimization of Antenna Scattering”, *IEEE Antennas and Propagation Society International Symposium*, vol. 2, pp. 904-907, 1992.
[4] Y. Li, Y. Liu, and S.-X. Gong, “Microstrip Antenna using Groundcut Slots for low RCS with Size Miniaturization Techniques”, *PIER*, vol. 1, pp. 211-220, 2008.
[5] H.-D. Chen, “Broadband CPW-fed Square Slot Antennas with a Widened Tunning Stub”, *IEEE Transactions on Antennas and Propagation*, vol. 51, pp. 1982-1986, 2003.
[6] W.-Q. Li, X.-Y. Cao, J. Gao, Z. Zhang, and L.-l. Cong, “Broadband RCS Reduction and Gain Enhancement Microstrip Antenna Using Shared Aperture Artificial Composite Material Based on Quasi-Fractal Tree”, *IET Microwaves, Antennas and Propagation*, vol. 10, pp. 370-377, 2016.
[7] A. Gorai, M. Pal, and R. Ghatak, “A Compact Fractal-Shaped Antenna for UWB and Bluetooth Wireless Systems with WLAN Rejection Functionality”, *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2163-2166, 2017.
[8] S. Tripathi, A. Mohan, and S. Yadav, “A Compact Koch Fractal UWB MIMO Antenna with WLAN Band-Rejection”, *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1565-1568, 2015.
[9] O. M. Khan, Z. U. Islam, I. Rashid, F. A. Bhatti, and Q. U. Islam, “Novel Miniaturized Koch Pentagonal Fractal Antenna for Multiband Wireless Applications”, *PIER*, vol. 141, pp. 693-710, 2013.
[10] J. Padhi, A. Behera, and M. Dash, “Design of an UWB Slotted Koch Fractal Antenna for C-band Application”, *IEEE Conference on Communication and Signal Processing (ICCSP)*, pp. 548-552, 2017.
[11] T. Saeidi, I. bin Ismail, V. Saleh, and A. R. H. Alhawari, “Triple Band Modified 90 Degree Koch Fractal H-slot Microstrip Antenna”, *6th International Conference on Intelligent and Advanced Systems (ICIAS)*, pp. 1-5, 2016.
[12] H. Oraizi, and A. Abdolali, “Ultra-wide Band RCS Optimization of Multilayered Cylindrical Structures for Arbitrarily Polarized Incident Plane Waves”, *PIER*, vol. 78, pp. 129-157, 2008.
[13] J.-H. Zheng, Y. Liu, and S.-X. Gong, “Aperture Coupled Microstrip Antenna with low RCS”, *PIER Letters*, vol. 3, pp. 61-68, 2008.
[14] B. R. Shookooh, A. Monajati, and H. Khodabakhshi, “The Novel Design and Modeling of Ultra-Wideband Metamaterial-Loaded Microstrip Array Antenna Using the Fractal & Fibonacci Geometric Patterns”, *Journal of Electromagnetic Engineering and Science*, vol. 20, no. 1, pp. 53-63, 2020.
[15] B. R. Shookooh, A. Monajati, and H. Khodabakhshi, “Ultra-Wideband Metamaterial-Loaded Microstrip Array Antennas Using Fibonacci & Fractal Geometric Patterns, Design and Modelling”, *EJECE, European Journal of Electrical Engineering and Computer Science*, vol. 4, no. 5, October 2020.
[16] X.-F. Li, Y.-J. Xie, and R. Yang, “Bistatic RCS Prediction Complex Targets Using Modified Current Marching Technique”, *PIER*, vol. 93, pp. 13-28, 2009.
[17] E. E. E. De Oliveira, P. H da F. Silva, and A. L. P. S. Compos, et al., “Overall Size Antenna Reduction Using Fractal Elements”, *Microwave and Optical Technology Letters*, vol. 51, pp. 671-675, 2009.
[18] B. Mirzapour, and H. R. Hassani, “Size Reduction and Bandwidth Enhancement of Snowflake Fractal Antenna”, *IET Microwaves, Antennas and Propagation*, vol. 2, pp. 180-187, 2008.
[19] Y. B. Thakare, and Rajkumar, “Design of Fractal Patch Antenna for Size and Radar Cross-Section Reduction”, *IET Microwaves, Antennas and Propagation*, vol. 4, no. 2, pp. 175-181, 2010.
[20] S. Hu, H. Chen, and C. L. Law, “Backscattering Cross Section of Ultra-Wideband Antennas”, *IEEE Antennas and Wireless Propagation Letter*, vol. 6, pp. 70-73, 2007.
[21] Q.-R. Zheng, Y.-M. Yan, X.-Y. Cao, and N.-C. Yuan, “High Impedance Ground Plane (HIGP) Incorporated with Resistance for Radar-Cross Section (RCS) Reduction of Antenna”, *PIER*, vol. 84, pp. 307-319, 2008.
[22] W. Jiang, S.-X. Gong, Y.-P. Li, T. Hong, X. Wang, and L.-T. Jiang, “A Novel low RCS Mobius-Band Monopole Antenna”, *Journal of Electromagnetic Waves and Applications*, vol. 23, no. 14-15, pp. 1887-1895, 2009.