Compact Circularly Polarized Asymmetrical Fractal Boundary Microstrip Antenna for Wireless Applications

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***Abstract*—Compact fractal boundary microstrip antenna is proposed for circular polarization (CP). By replacing the sides of a square patch with asymmetrical prefractal curves, two orthogonal modes are excited for CP operation. The structure is asymmetric along the principal axes (x, y). The indentation parameter of the fractal boundary curve is optimized to design compact CP antennas. Experimental results show that 10-dB return loss and 3-dB axial-ratio bandwidths of the proposed fractal boundary Ant 2 are 162 and 50 MHz, respectively, at operating frequency of around 2540 MHz. Results show that an excellent CP is achieved with a single probe feed, besides reduction in the antenna size by applying fractal boundary concept.**

***Index Terms*—Axial-ratio bandwidth, circular polarization, fractal boundary, single probe feed.**

I. Introduction

RECENT developments in the field of wireless communication systems have accelerated the demand for compact circularly polarized microstrip antennas (CPMAs). In order to avoid the misalignment between transmitter and receiver, circularly polarized antennas have been used in a wide range of applications such as Wi-Fi, WiMAX, WLAN, and handheld devices. The conventional approach to achieve circular polarization (CP) involves feeding two orthogonal signals of equal amplitude and 90° out of phase to the radiating and nonradiating edges of a square patch antenna. Despite its high CP bandwidth and best axial ratio (AR) (0 dB), the dual-feed technique requires an external polarizer and occupies a lot of board space. Therefore, single-feed compact CPMAs have received much attention in recent years. The flexibility offered by printing technology also helps in designing various CP antennas with single probe feed.

In 1983, Sharma and Gupta came up with the concept of a single-feed CP antenna by truncating corners and implanting a diagonal slot at the center of the square patch [1]. Later, Iwasaki in 1996 using a proximity-coupled feed suggested a cross-shaped slot of unequal arms length embedded in the middle of the circular patch for CP operation [2]. Asymmetric cross slot provides the requisite perturbation to excite two orthogonal modes with 90° phase shift for CP radiation. By inserting four symmetrical slits along the diagonals of the corners truncated patch, CP is realized, and a considerable amount of size reduction is also reported [3]. Asymmetrical U-slot [4], Y-shaped monopole [5] antennas are available in the open literature for CP operation. Based on the slits [6], [7], stubs, and slot-loaded [8]–[10] techniques, several single-layer single-feed asymmetrical structures are suggested for CP operation. However, the reported 3-dB AR bandwidth of all these approaches is very narrow (less than 1%), while the best AR at desired frequency is more than 0.5 dB. However, designing compact single-feed CP antennas by applying fractal concept has not been adequately reported in literature, except in [11].

Fractal concept has significantly affected the microstrip antenna field. Fractals are categorized into mass and boundary fractals. Mass fractals have been used to design antennas for multiband or wideband applications [12], [13]. Space filling property of boundary fractals is used to design compact antennas [14], [15]. In this letter, a novel compact CPMA is proposed by using a prefractal curve as boundaries of a square patch. By effective adjustment of fractal curve, compact CPMAs can be realized.

II. Proposed Antenna Geometry Design

Construction laws of fractal curves are primarily characterized by two parameters: iteration order (IO) and indentation factor (IF). Here, IF of the proposed design is indentation radius (IR). Fig. 1 shows the generation process of the proposed compact CP antenna. The specifications of simulated antennas are the following: the length of the patch (L); thickness (h) of the substrate as 3.2 mm; relative permittivity (ε_{r}), which is 2.2; loss tangent is 0.0019; and $r_{\mathrm{x}}, r_{\mathrm{y}}$ are IRs along the x- and y-axes. The prefractal half-circled curve is deployed to accomplish the CP operation. The four sides of a square patch are replaced with a fractal curve of different IFs for CP realization. With the use of asymmetrical fractal curves as edges of a single-feed square patch, it is possible to excite two orthogonal modes with 90° phase shift for CP radiation. IFs of the prefractal curve are used to optimize the antenna for minimum AR, wide AR bandwidth, wide impedance bandwidth, and size reduction. The proposed square patch antenna with IO2 fractal boundary curves is pictured in Fig. 2.

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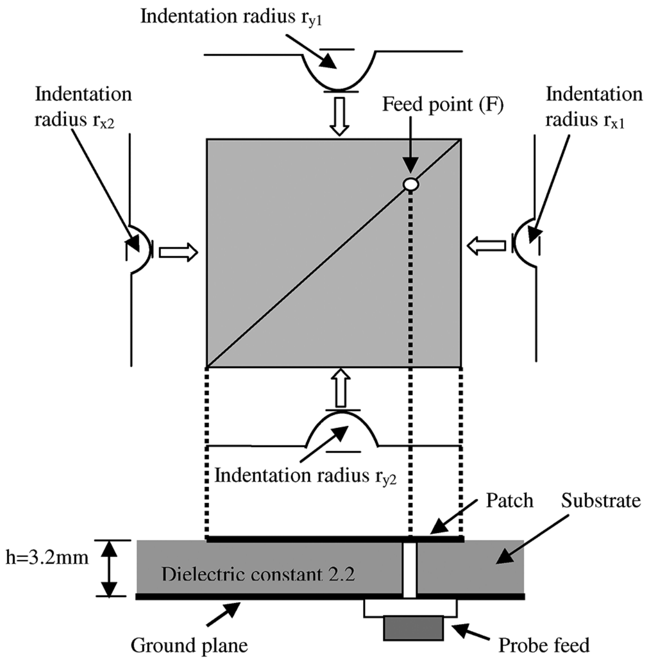

Fig. 1. Generation of proposed compact CP fractal boundary antenna.

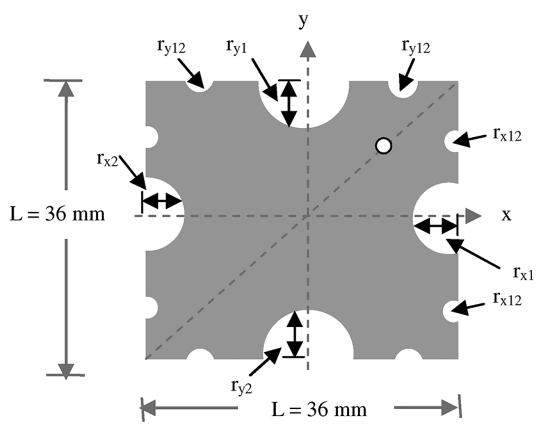

Fig. 2. IO2 asymmetrical fractal boundary patch.

III. Asymmetrical Fractal Boundary Structures and Simulation Results

The original antenna is chosen to be a square in order to excite two modes with close resonant frequencies required for circular polarization. Asymmetry to the structure is introduced through edges, so that the coaxial line feed (F) point is along the diagonal of the patch. Both left-hand CP (LHCP) and right-hand CP (RHCP) can be obtained by shifting the feed point to accurate positions on the diagonal axis. Fig. 3 shows the proposed fractal boundary antennas.

Side length of the original square (L) is chosen as 36 mm such that all proposed antennas resonating in the range of 2.3–2.7 GHz are useful for ISM band wireless applications. For IO1 linear polarization of Ant 1, the fractal antenna is of symmetric microstrip patch type, i.e., $r_{x1} = r_{x2} = r_{y1} = r_{y2}$. The CP radiation of a symmetric fractal patch can be achieved by using different IRs along x- and y-axes $[(r_{x1} = r_{x2}) \neq (r_{y1} = r_{y2})]$. If the IR is different

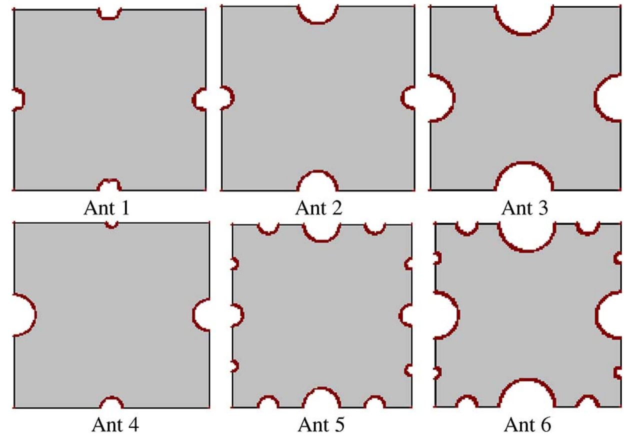

Fig. 3. Proposed fractal boundary patches.

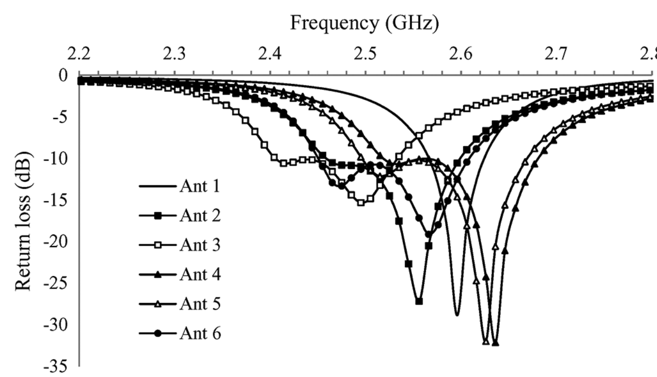

Fig. 4. Simulated return loss for half-circled fractal boundary antennas.

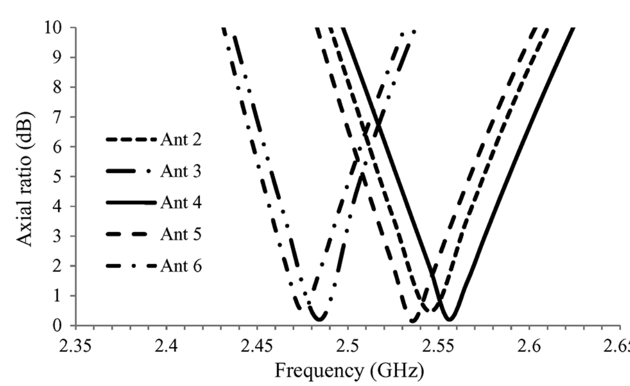

Fig. 5. Simulated axial ratio of half-circled fractal CP antennas.

in one of the axes (x or y) or both the axes (x and y), the structure is called asymmetrical fractal boundary microstrip patch antenna. For CP radiation, the relation between the IRs along x- and y-axes should be $r_{x1} \neq r_{x2} = r_{y1} = r_{y2}$, or $r_{x1} = r_{x2} \neq r_{y1} = r_{y2}$, or $r_{x1} = r_{x2} = r_{y1} \neq r_{y2}$, or $r_{x1} \neq r_{x2} \neq r_{y1} \neq r_{y2}$, and so on. These asymmetrical conditions are applicable for IO2, IO3, and so on.

By adjusting the IRs of the half-circled fractal curves to an optimum value along the x- and y-directions, satisfactory CP can be achieved. For the Ant 2 and Ant 3, with the CP condition $(r_{x1} = r_{x2} = r_x) \neq (r_{y1} = r_{y2} = r_y)$ and at a fixed probe feed point, the antenna is right-hand circularly polarized if $r_x < r_y$. The left-hand circularly polarized antenna is obtained if $r_x >$

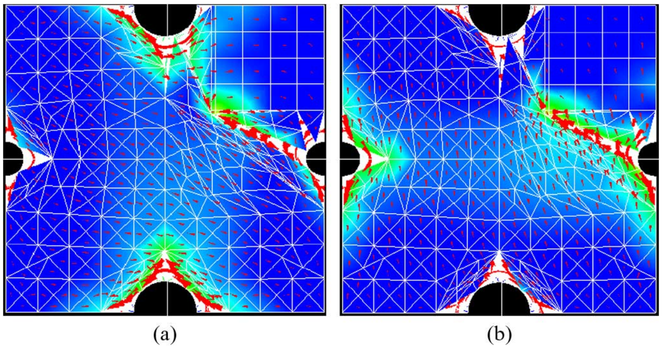

Fig. 6. Current distribution along the fractal curves of Ant 2 antenna at 2540 MHz: (a) TM_{10} mode, and (b) TM_{01} mode.

TABLE I
SUMMARIZED SIMULATION RESULTS OF THE HALF-CIRCLED ANTENNAS

Antenna / IO	IRs (r_{x1}, r_{x2}) / (r_{y1}, r_{y2}) or (r_{x1}/r_{x12}) , (r_{y1}/r_{y12})	Minimum AR frequency (MHz)	10-dB return loss bandwidth (%)	3-dB axial ratio bandwidth (%)
Ant 1/ 1	0.11	-	2.2	-
Ant 2 / 1	0.11/ 0.2	2540	6.8	2
Ant 3 / 1	0.25/ 0.3	2485	4.8	1.2
Ant 4 / 1	(0.15,0.2)/(0.05,0.1)	2555	5.9	1.16
Ant 5 / 2	(0.1/0.05),(0.2/0.1)	2535	6.1	1.17
Ant 6 / 2	(0.2/0.05),(0.3/0.1)	2495	5.7	1.2

r_y. Design condition for Antenna 4 is $r_{x1} \neq r_{x2} \neq r_{y1} \neq r_{y2}$. Antennas 5 and 6 are IO2 fractal boundary patches. The simulated return-loss characteristics of proposed antennas are plotted in Fig. 4. As shown in Fig. 5, all the designed half-circled asymmetrical CP antennas attest to good circular polarized radiation (AR < 0.5 dB).

All the designed half-circled fractal boundary antennas provide more than 6-dBi gain at minimum AR frequencies. The current distribution on half-circled fractal boundary Ant 2 at 2540 MHz is shown in Fig. 6. The strongest current distribution is along the high IR fractal curve side (y-axis) for fundamental excited mode TM_{10}. For TM_{01}, it is along the low IR side (x-axis). The movement of current distribution elements at the minimum AR frequency in a circular fashion shows that the proposed antennas are circularly polarized. The valid observation from Table I is that the asymmetry in two perpendicular axes (Ant 2 and Ant 3, $[(r_{x1} = r_{x2}) \neq (r_{y1} = r_{y2})]$) generates more bandwidth than the asymmetric condition $(r_{x1} \neq r_{x2} \neq r_{y1} \neq r_{y2})$ used by Ant 4. Thus, 3-dB AR bandwidth obtained by Ant 2 is as large as 2% because of the high optimized asymmetry along the two perpendicular directions for good CP radiation. By properly choosing the end-to-end length (L) and optimizing the indentation parameters, one can design a compact CPMA at the desired resonance frequency by applying fractal boundary concept.

IV. MEASURED RESULTS AND DISCUSSIONS

To validate the hypothesis made pertaining to the proposed antennas experimentally, the best performer antenna Ant 2 is fabricated and tested. The microstrip antenna of side length L

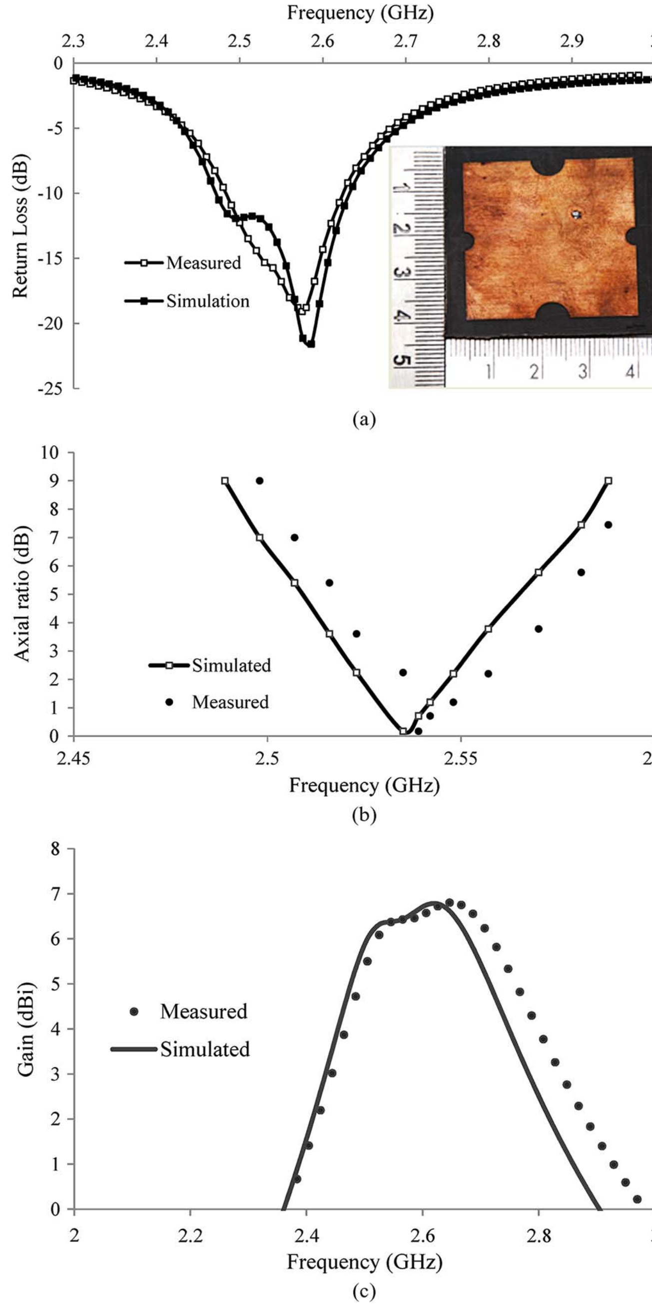

Fig. 7. Comparison of simulated and measured results: (a) return-loss characteristics, (b) axial ratio, and (c) gain in boresight direction.

is printed on Rogers RT/duroid 5880 substrate of thickness 3.2 mm, and the ground plane size is 42×42 mm^2. The comparison of the simulated and the measured results of the fabricated antenna are portrayed in Fig. 7. The deviations appearing between simulated and experimental results are due to tolerance levels during the fabrication process of the antenna.

The measured 3-dB axial-ratio plot points out that minimum AR value is achieved at the center frequency. The measured 10-dB return loss and 3-dB AR bandwidths are 6.4% (2455–2625 MHz) and 50 MHz, respectively. The measured radiation patterns of the proposed antenna in the horizontal plane (HP) and vertical plane (VP) at 2540 MHz are depicted in Fig. 8. The difference between the two curves in the radiation

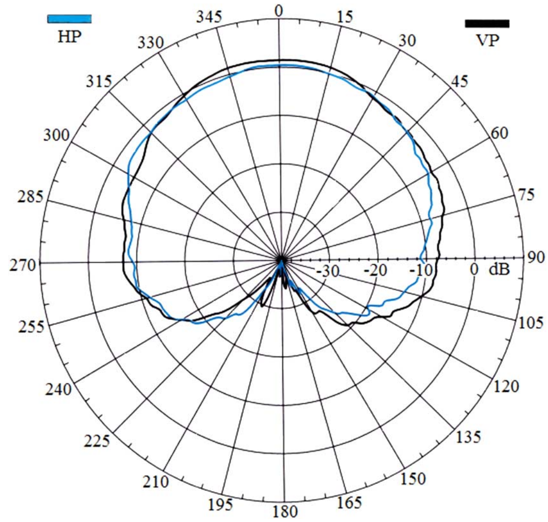

Fig. 8. Measured radiation patterns of the Ant 2 at 2540 MHz.

TABLE II
COMPARISON OF CONVENTIONAL SINGLE-LAYER SINGLE-FEED CP ANTENNAS

Antenna	Description	3-dB AR bandwidth (%)	Minimum AR value (dB)	Volume
Proposed	Fractal patch Ant 2	2	0.42	$0.35\lambda_o \times 0.35\lambda_o \times 0.027\,\lambda_o$
[1]	Truncated corners	< 0.6	0.2	-
[2]	Cross slot	< 1	0.5	-
[3]	Symmetrical slits to corners truncated patch	0.84	0.6	-
[4]	U-slot	4	0.5	$0.78\lambda_o \times 0.78\lambda_o \times 0.085\,\lambda_o$
[5]	Y-shape	4	2	$0.38\lambda_o \times 0.42\lambda_o \times 0.006\,\lambda_o$
[6]	Asymmetrical slits	0.5	1	$0.25\lambda_o \times 0.25\lambda_o \times 0.012\,\lambda_o$
[8]	Single cross shaped slot	0.7	0.5	$0.27\lambda_o \times 0.27\lambda_o \times 0.013\,\lambda_o$
[10]	Asymmetric circular slots	0.65	0.5	$0.27\lambda_o \times 0.27\lambda_o \times 0.013\,\lambda_o$
[11]	Peano fractal	< 1	1.2	$0.37\lambda_o \times 0.37\lambda_o \times 0.009\,\lambda_o$

pattern is equal to the axial ratio in that direction. It shows that Ant 2 generates 3-dB AR beamwidth in the range of $\pm 45°$. From the simulation and measured results, it is observed that by compromising the best minimum AR value of 1 dB and 3-dB AR bandwidth to 1%, more compact CPMAs can be designed with increasing the IO and IF of the fractal curves.

Table II compares the results of proposed antenna with the already existing conventional single-layer single-feed CP antennas in the available literature. It is apparent that even though U-slot, Y-shaped antennas generate a larger AR bandwidth than the proposed antenna, the thickness of the substrate used for [4] and the minimum AR value of the [5] antennas are very high when compared to the nominated fractal boundary antenna. The presented antenna generates wide 3-dB AR bandwidth and provides minimum AR value at center frequency.

V. CONCLUSION

A novel approach to generate circular polarization using boundary fractal has been presented. By introducing perturbation in a square patch using asymmetrical prefractal curves as edges, a single-feed compact antenna for CP operation is successfully obtained. Indentation parameter of the proposed prefractal curve is optimized for good CP at the center frequency. Simulation results show that by adjusting indentation parameters, larger AR bandwidth can be obtained if the optimized asymmetry between the two fractal curves in two perpendicular directions (x, y) is high. Measured results of Ant 2 show that 10-dB return loss and 3-dB axial-ratio bandwidths are 6.4% and 2%, respectively. Experimental outcomes prove that an excellent compact CP operation is achieved using fractal boundary antennas.

REFERENCES

[1] P. C. Sharma and K. C. Gupta, "Analysis and optimized design of single feed circularly polarized microstrip antennas," *IEEE Trans. Antennas Propag.*, vol. AP-31, no. 6, pp. 949–955, Nov. 1983.
[2] H. Iwasaki, "A circularly polarized small size microstrip antenna with cross slot," *IEEE Trans. Antennas Propag.*, vol. 44, no. 10, pp. 1399–1402, Oct. 1996.
[3] C. Wen-Shyang, K.-L. Chum-Kum, and Wong, "Novel compact circularly polarized square microstrip antenna," *IEEE Trans. Antennas Propag.*, vol. 49, no. 3, pp. 340–342, Mar. 2001.
[4] K.-F. Tong and T.-P. Wong, "Circularly polarized U-slot antenna," *IEEE Trans. Antennas Propag.*, vol. 55, no. 8, pp. 2382–2385, Aug. 2007.
[5] A. Ghobadi and M. Dehmollaian, "A printed circularly polarized Y-shaped monopole antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 22–25, 2012.
[6] Nasimuddin, X. Qing, and Z. N. Chen, "Compact asymmetric-slit microstrip antennas for circular polarization," *IEEE Trans. Antennas Propag.*, vol. 59, no. 1, pp. 285–288, Jan. 2011.
[7] Nasimuddin, *Microstrip Antennas*. Rijeka, Croatia: InTech, 2011.
[8] Nasimuddin, X. Qing, and Z. N. Chen, "A compact circular polarized cross-shaped slotted microstrip antenna," *IEEE Trans. Antennas Propag.*, vol. 60, no. 3, pp. 1584–1588, Mar. 2012.
[9] T.-C. Yo, C.-M. Lee, C.-M. Hsu, and C.-H. Luo, "Compact circularly polarized rectenna with unbalanced circular slots," *IEEE Trans. Antennas Propag.*, vol. 56, no. 3, pp. 882–886, Mar. 2008.
[10] Nasimuddin, X. Qing, and Z. N. Chen, "Asymmetric-circular shaped slotted microstrip antennas for circular polarization and RFID applications," *IEEE Trans. Antennas Propag.*, vol. 58, no. 12, pp. 3821–3828, Dec. 2010.
[11] H. Oraizi and S. Hedayati, "Miniaturization of microstrip antennas by the novel application of the Giuseppe Peano fractal geometries," *IEEE Trans. Antennas Propag.*, vol. 60, no. 8, pp. 3559–3567, Aug. 2012.
[12] C. Borja and J. Romeu, "On the behavior of the Koch island fractal boundary microstrip patch antenna," *IEEE Trans. Antennas Propag.*, vol. 51, no. 6, pp. 1281–1291, Jun. 2003.
[13] J. Anguera, C. Puente, C. Borja, and J. Soler, "Fractal-shaped antennas: A review," *Encycl. RF Microw. Eng.*, vol. 2, pp. 1620–1635, 2005.
[14] L. Daotie and J. Mao, "A Koch-like sided fractal bow-tie dipole antenna," *IEEE Trans. Antennas Propag.*, vol. 60, no. 5, pp. 2242–2251, May 2012.
[15] K. J. Vinoy, J. K. Abraham, and V. K. Varadan, "On the relationship between fractal dimension and the performance of multi-resonant dipole antennas using Koch curves," *IEEE Trans. Antennas Propag.*, vol. 51, no. 9, pp. 2296–2303, Sep. 2003.