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Fractal-Shaped Reconfigurable Antennas

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1. Introduction

With the tremendous advancements in wireless communications, there is an increasing demand for miniature, low-cost, easy-to-fabricate, multiband and wideband antennas for use in commercial communications systems. As a part of an effort to further enhance modern communications systems technology, researchers have been studying different approaches for creating novel and innovative antennas. The fact that different wireless standards, such as UMTS, WLAN and WiMAX, use different operation bands, pushes the need for terminal antennas that are multiband and/or wideband. The antennas should also be well-suited in terms of cost, size, radiation patterns, gain and ease of integration in the circuit boards of communication devices.

Microstrip antennas have received increasing attention in satellite and communications applications because of their low profile, small size, light weight, low cost and ease of fabrication. Their simple feed methods, especially microstrip-line and coplanar waveguide (CPW) feeds, make them compatible with wireless communication integrated circuitry.

In this chapter, fractal-shaped and reconfigurable microstrip antennas are discussed. The space-filling and self-similarity properties of fractal geometries, from an antenna engineering perspective, are presented. Moreover, the recent techniques used in microstrip antennas with frequency-, polarization- and pattern-reconfigurability are surveyed. A separate section will focus on hybrid antenna design approaches, which combine fractal shapes and electronic reconfigurability.

2. Fractal antenna engineering

Fractal antenna engineering is a swiftly evolving field that aims at developing a new class of antennas that are multiband, wideband and/or compact in size (Werner & Ganguly, 2003). A fractal is a self-repetitive geometry which is generated using an iterative process and whose parts have the same shape as the whole geometry but at different scales, as shown in Fig. 1. Accordingly, fractal-based radiators are expected to operate similarly at multiple wavelengths and keep similar radiation parameters over several bands (El-Khamy, 2004).

Another property of fractal geometries, which makes them attractive candidates for use in the design of fractal antennas, is their space-filling property (Werner & Ganguly, 2003). Fig. 2 demonstrates the first four stages in the construction of a space-filling fractal curve known as Hilbert curve. This feature can be exploited to miniaturize classical antenna elements, such as dipoles and loops, and overcome some of the limitations of small antennas. The line that is used to represent the fractal geometry can meander in such a way that effectively fills the available space, leading to curves that are electrically long but compacted in a small physical

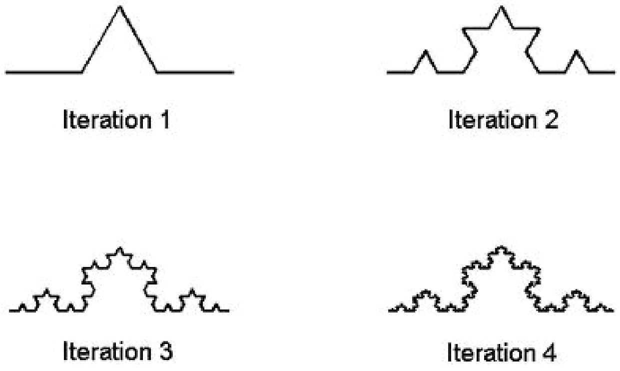


Fig. 1. The first four iterations in the construction of the standard Koch curve

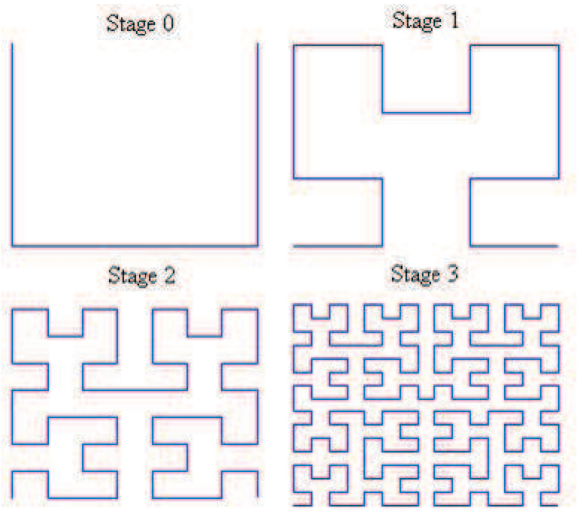
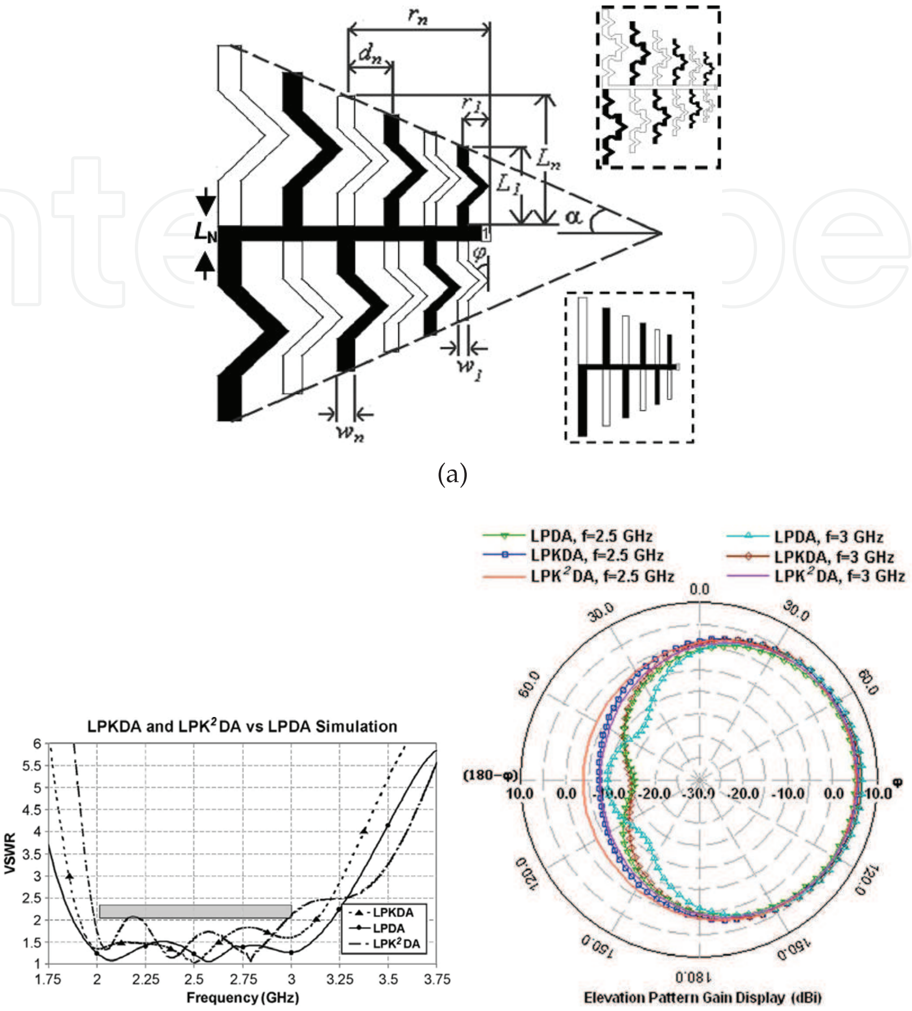


Fig. 2. The first four stages in the construction of a Hilbert Curve

space (Balanis, 2005). Fractal geometries have also been used to design antenna arrays. Fractal arrays have shown to possess desirable attributes, including multiband performance, low side-lobe levels and the ability to develop rapid beamforming algorithms based on the recursive nature of fractals. Fractal elements and arrays have been also recognized as perfect candidates for use in reconfigurable systems (Werner & Ganguly, 2003).

3. Fractal-shaped antennas

Koch curves are a good example of self-similar space-filling fractals which have been used to develop wideband/multiband and/or miniaturized antennas. In the paper by (Krupenin, 2006), it was shown that self-similar fractals affect the electromagnetic properties of antennas created on the basis of these geometries, and that Koch fractal antennas are multiband structures. (Vinoy et al., 2003) related multiple resonant frequencies of Koch fractal antennas to their fractal dimension. (Krishna et al., 2008) proposed a dual wide-band CPW-fed modified Koch fractal printed slot antenna for WLAN and WiMAX operations. In the paper by (Anagnostou et al., 2008), Koch fractal dipoles were introduced as the basic structural elements of a planar Log-Periodic Koch-Dipole Antenna (LPKDA) array, thus replacing the full-sized Euclidean monopoles. Compared to the Euclidean LPDA, the proposed design revealed very similar characteristics, while achieving 12% less space. The geometrical structure of the proposed antenna along with its VSWR and radiation pattern plots, are shown in Fig. 3.



(a)

(b) (c)

Fig. 3. (a) Design parameters of the LPKDA, Euclidean LPDA (bottom right), and LPK^{2}DA antennas (b) VSWR and (c) radiation pattern plots (Anagnostou et al., 2008)

Another Koch-based antenna-size-compacting scenario was proposed by (Rao et al., 2008). Here, the authors introduced a second-iterated Koch fractal, with an indentation angle of 20° as depicted in Fig. 4, along the sides of a regular Euclidean shaped patch to increase the overall electrical length of the patch. With this proposed method, a 3 dB axial ratio bandwidth of 1.2% with a minimum value of 0.31 dB is obtained at 2.245 GHz. Moreover, antennas with smaller sizes can be designed if further iterations are considered.

Another fractal geometry, which has been used to design ultra-wideband antennas, is the Sierpinski carpet. In the paper by (Ramadan et al., 2009a), rotated square slots forming a 45°-rotated 2nd-iterated-Sierpinski-carpet are integrated in the patch. Herein, the computed VSWR showed a 3.5–11 GHz impedance bandwidth for a compact 2 cm × 2.5 cm PCB antenna. Fig. 5 illustrates the geometrical structure of a compact Sierpinski-carpet-based patch antenna for ultra-wideband applications, discussed by (Ramadan et al., 2009b). The return loss of the proposed antenna is given in Fig. 6. It is worth mentioning that satisfactory omnidirectional

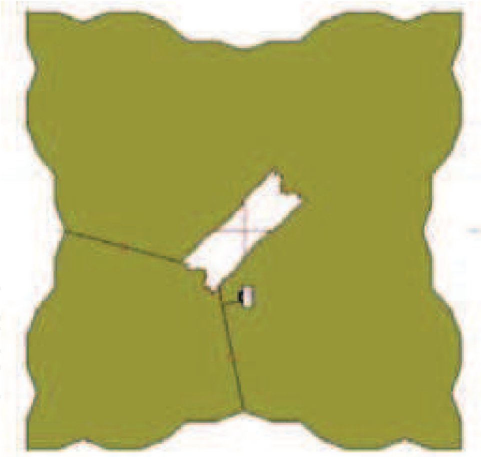


Fig. 4. Geometry of the circularly polarized antenna proposed by (Rao et al., 2008)

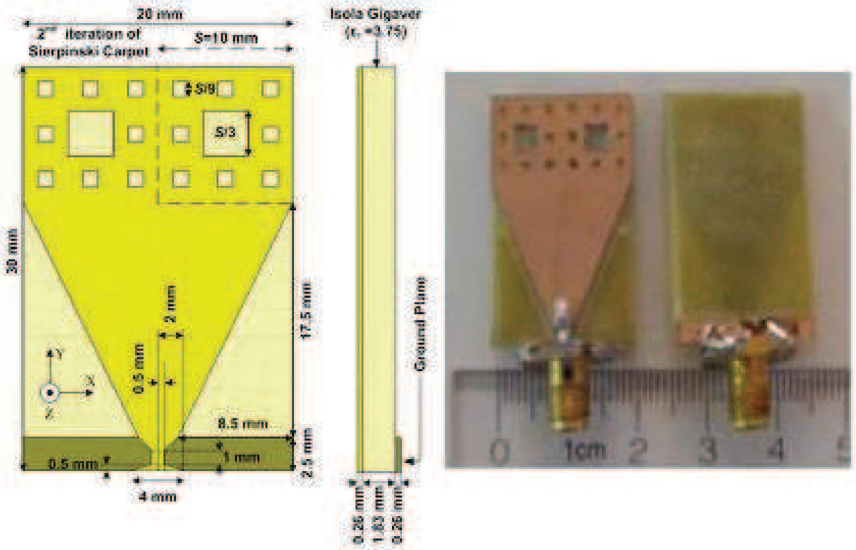


Fig. 5. Geometry and photo of the fabricated antenna presented by (Ramadan et al., 2009b)

radiation patterns, due to the self-similarity property, were attained over the 3.1–10.6 GHz frequency range.

4. Reconfigurability

Reconfigurability in antenna systems is a desired feature that has recently received significant attention in developing novel and pioneering multifunctional antenna designs. Compared to conventional antennas, reconfigurable antennas provide the ability to dynamically adjust various antenna parameters. The active tuning of such antenna parameters is typically achieved by manipulating a certain switching behavior. Reconfigurable antennas reduce any unfavorable effects resulting from co-site interference and jamming (Peroulis et al., 2005). In addition, they have a remarkable characteristic of achieving diversity in operation, meaning that one or multiple parameters, including operating frequency, radiation pattern, gain and/or polarization, can be reconfigured with a single antenna. The use of reconfigurability in coordination with a self-similar antenna leads to a considerable improvement in antenna performance. This is because not only a wider selection of frequencies is achieved, but also similar radiation properties for all designed frequency bands are obtained. Electronic,

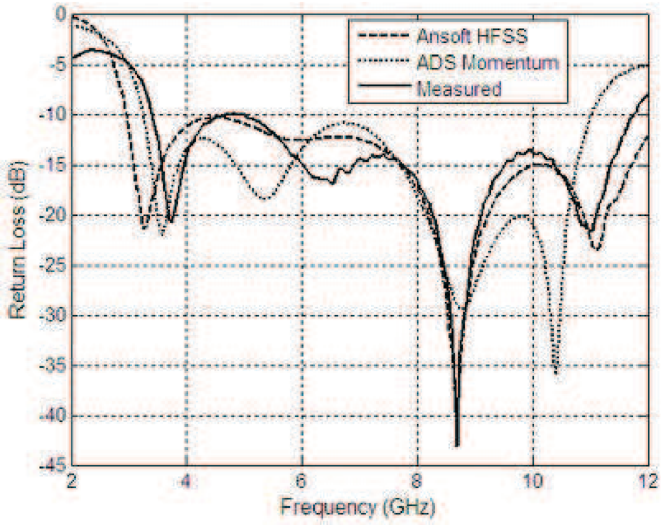


Fig. 6. Measured and simulated return loss of the antenna discussed by (Ramadan et al., 2009b)

mechanical or optical switching may be employed with reconfigurable antennas (Zhang et al., 2008). Nonetheless, electronic tunability is more frequently used because of its efficiency and reliability especially in dynamic bandwidth allocation. Electronic reconfigurability is often attained using lumped components such as PIN diodes, FET transistors or RF MEMS switches (Liu et al., 2007; Xiao et al., 2007). Compared to PIN diodes and FET transistors, RF MEMS switches have better performance in terms of isolation, insertion loss, power consumption and linearity (Xiao et al., 2007).

5. Reconfigurable antennas

Frequency-reconfigurable antennas allow either for smooth transitions within or between operating bands without jumps or for distinct switching mechanism to operate at separate frequency bands. In the paper by (Ramadan et al., 2009c), a small-sized reconfigurable antenna, which employs electronic reconfigurability, for ultra-wideband, C-band and X-band Operation was presented. The geometrical structure of the proposed antenna is given in Fig. 7. Four switching conditions were specifically selected to achieve multiband/wideband behavior, as shown in Fig. 8. For each switching condition, the antenna's computed peak gain and radiation efficiency show acceptable values, as illustrated in Fig. 9 and Fig. 10, over the frequency span of interest. The computed radiation patterns, for each case, of the proposed antenna reveal satisfactorily omnidirectional patterns over the desired frequency bands.

Pattern reconfigurability without significant changes in the operating frequency band is a desired feature in antenna systems. However, the relationship between the source currents and the resulting radiation makes this process difficult, but not impossible, to achieve. A novel frequency/pattern-reconfigurable microstrip antenna for WLAN applications was proposed by (Ramadan et al., 2010). Herein, the presented antenna features a circular patch fed using a microstrip line, a shape-optimized partial ground plane, and two PIN diodes mounted over two slots in the ground plane, as depicted in Fig. 11. Three switching cases were considered. The first resulted in a single-band operation at 5.2 GHz, whereas the other two cases offered a dual-band operation, at 2.4 GHz and 5.2 GHz. In all three cases, an omnidirectional radiation pattern was obtained in the 5.2 GHz band. However, in the two cases where operation at 2.4 GHz is possible, an equal-gain E-plane pattern and 180°-switchable H-plane patterns were

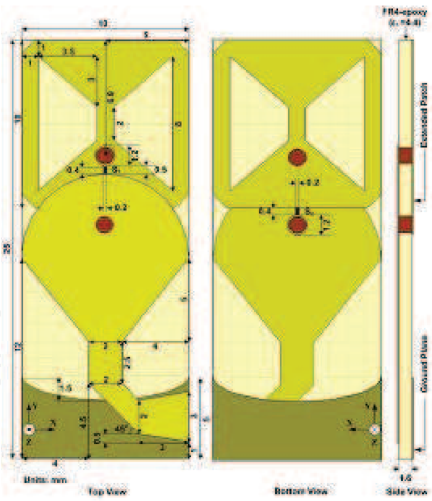


Fig. 7. Geometry of the antenna presented by (Ramadan et al., 2009c)

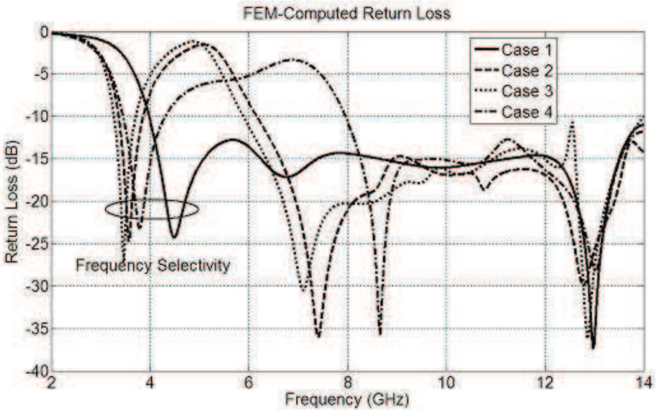


Fig. 8. Superimposed FEM-Computed S11 plots of the antenna for four switching conditions (Ramadan et al., 2009c)

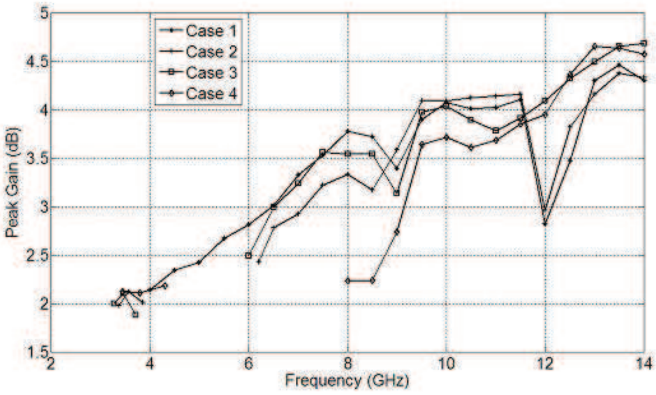


Fig. 9. Peak gain of the antenna (Ramadan et al., 2009c)

offered depending on the switching condition. The configuration, measured return loss and normalized gain patterns of the antenna are demonstrated in Fig. 11, Fig. 12 and Fig. 13, respectively.

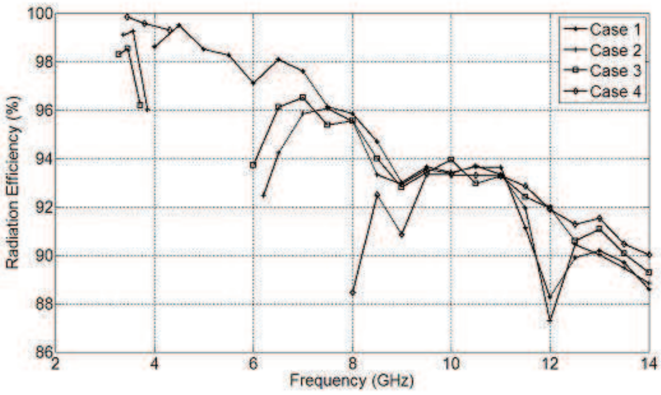


Fig. 10. Radiation efficiency of the antenna (Ramadan et al., 2009c)

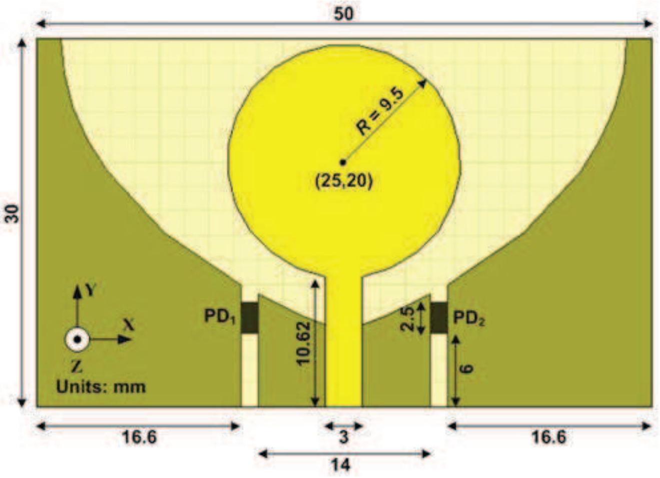


Fig. 11. Antenna configuration (Ramadan et al., 2010)

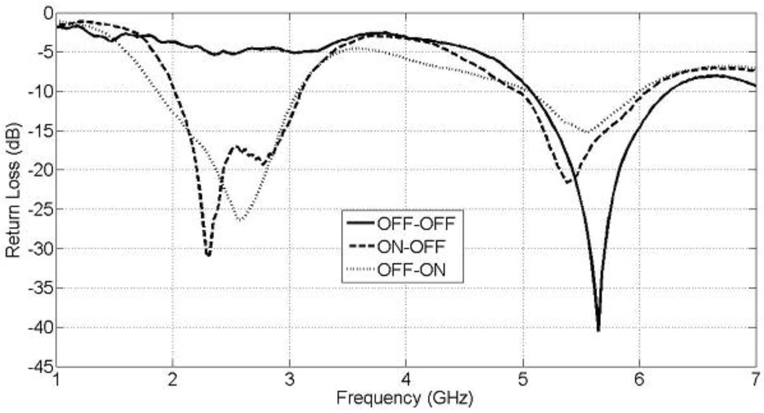


Fig. 12. Measured return loss of the antenna for the three cases (Ramadan et al., 2010)

Another type of printed antennas, which deals with both frequency and polarization reconfigurability, was reported by (Monti et al., 2009). The proposed design approach, illustrated in Fig. 14, is based on the use of two pairs of switches in order to obtain both types of reconfigurability. Specifically, three different polarization states were achieved. These are right-hand and left-hand circular polarization in one frequency band, and linear polarization in other bands, as given in Fig. 15 and Fig. 16, respectively.

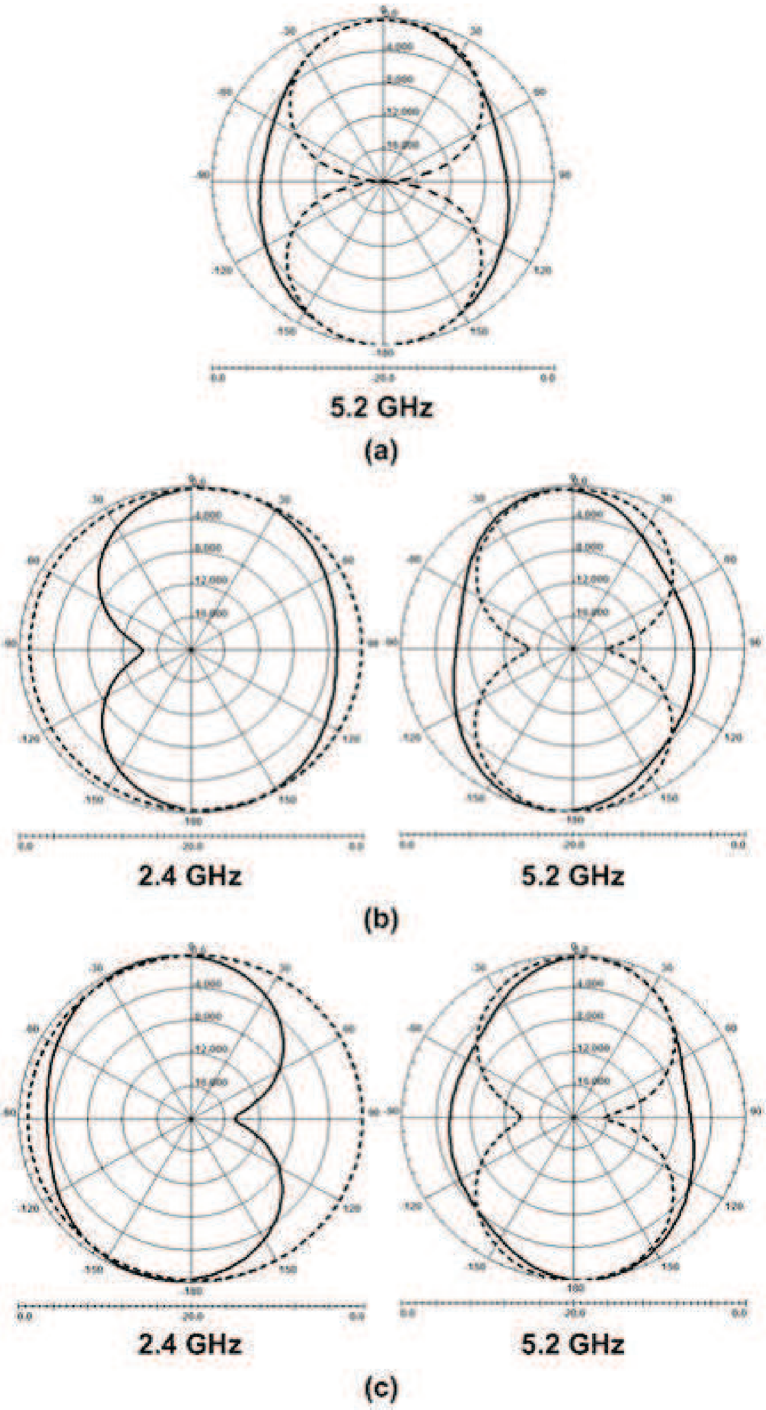


Fig. 13. Normalized gain pattern of the antenna in the X–Z (solid line) and Y–Z (dotted line) planes for (a) Case 1, (b) Case 2 and (c) Case 3 (Ramadan et al., 2010)

6. Fractal-shaped reconfigurable antennas

Hybrid antenna design approaches, which combine fractal shapes and electronic reconfigurability, are presented in this section. A low-cost multiband printed-circuit-board (PCB) antenna that employs Koch fractal geometry and tunability was demonstrated by (Ramadan et al., 2009). In their work, the authors combined the space-filling property of Koch fractal with reconfigurability in order to a multiband/wideband operation with the antenna

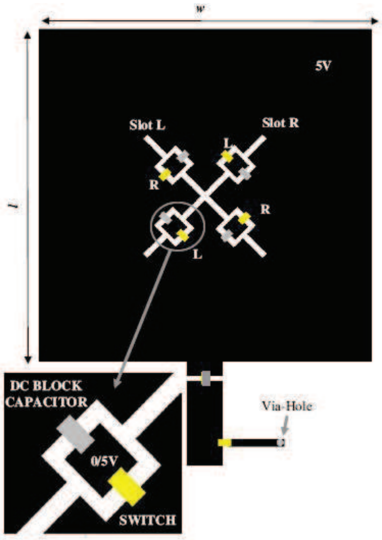


Fig. 14. A patch antenna with diagonal rectangular slots along both diagonals. Two couples (*R* and *L*) of switches are used to select the active slot (*L* or *R*) (Monti et al., 2009)

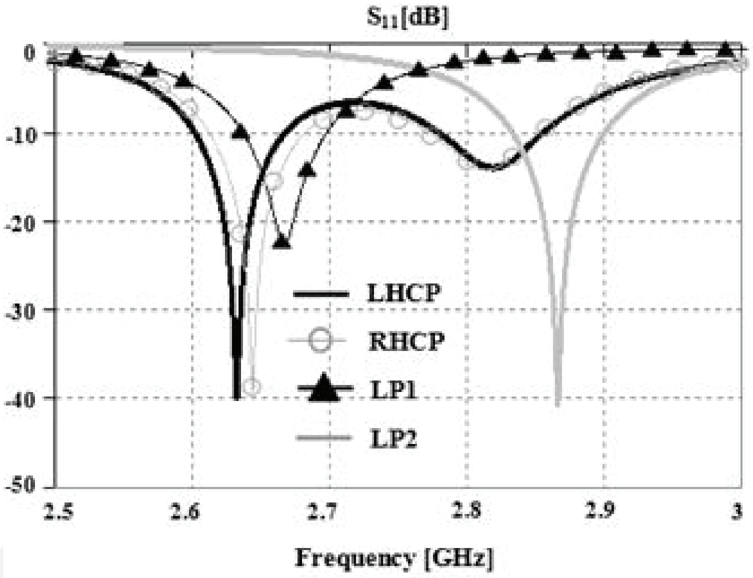


Fig. 15. Measured return loss of the antenna for several switching conditions (Monti et al., 2009)

still compact in size. A prototype of the fabricated design along with its return loss plot, for three switching conditions, is shown in Fig. 18. Fig. 19 illustrates the design of a Sierpinski Gasket-shaped reconfigurable antenna (Anagnostou et al., 2006). Herein, the authors got the switching components, mainly RF-MEMS, integrated with the proposed self-similar structure. The return loss plots of the Sierpinski Gasket-shaped reconfigurable antenna when all switches are off or on are shown in Fig. 20. Accordingly and due to Sierpinski fractal's self-similarity feature, the antenna was found to operate over three frequency bands with similar radiation patterns, as depicted in Fig. 21.

A pattern-reconfigurable fractal-shaped microstrip antenna, operable at 10 GHz, was presented by (Zhang et al., 2005). The geometry of this antenna, which is based on a Hilbert curve, is shown in Fig. 22. Eight slots were etched in the patch, and two RF MEMS switches

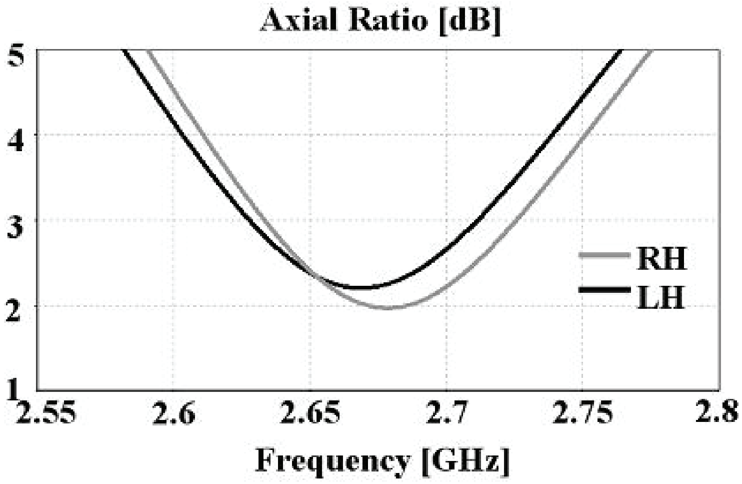


Fig. 16. Computed axial ratio of the antenna for the circular polarization cases (Monti et al., 2009)

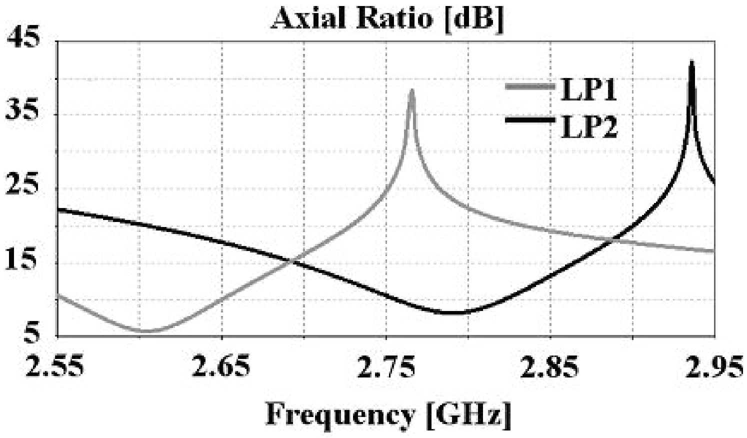


Fig. 17. Computed axial ratio of the antenna for the linear polarization cases (Monti et al., 2009)

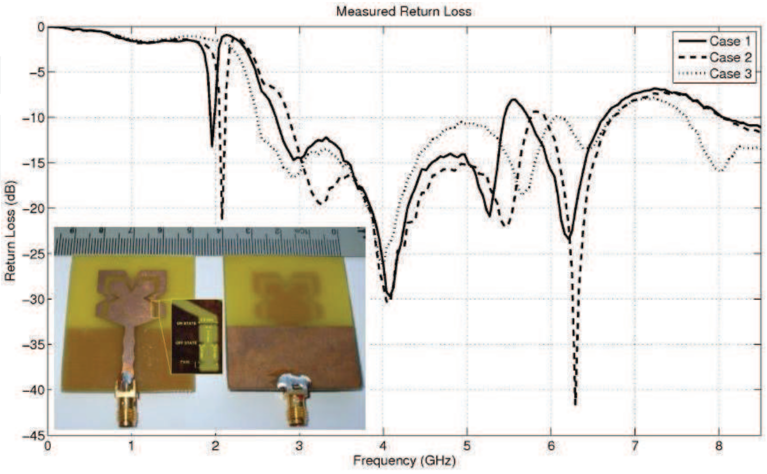


Fig. 18. Measured S11 of the proposed antenna in the 0.3–8.5 GHz frequency range (Ramadan et al., 2009)

were mounted across each slot. These switches control the direction of the current flow, thus leading to radiation pattern reconfigurability. Two switching scenarios were adopted. The resulting radiation patterns, at 10 GHz, are depicted in Fig. 23. The E-plane beam is directed along $\theta = -32°$ for the first switching case, and along $\theta = +32°$ for the other switching case. The H-plane pattern is almost identical for both switching scenarios.

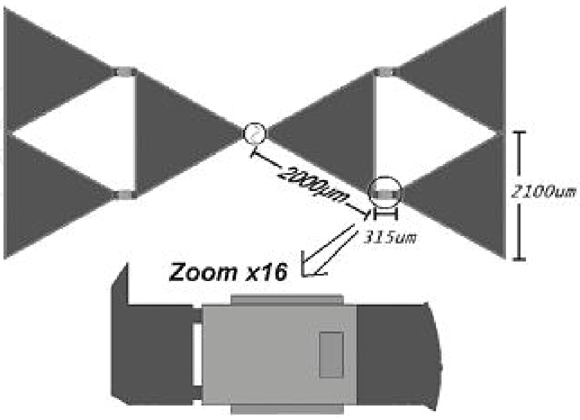


Fig. 19. Initial antenna design and RF-MEMS switch connections (Anagnostou et al., 2006)

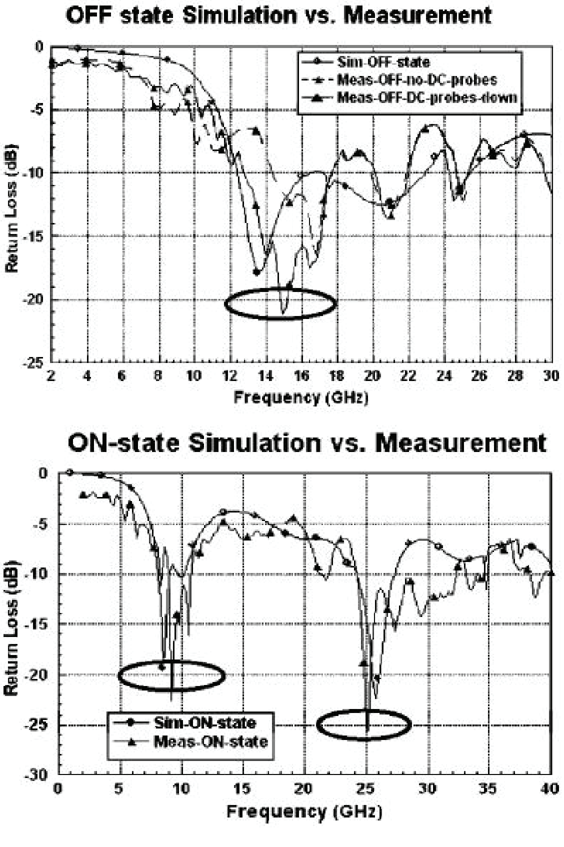


Fig. 20. Return loss of the antenna when switches are all OFF or ON (Anagnostou et al., 2006)

7. Conclusion

Fractal-shaped reconfigurable microstrip antennas are discussed in this chapter. The space filling and self-similarity properties of fractal geometries are presented from an antenna

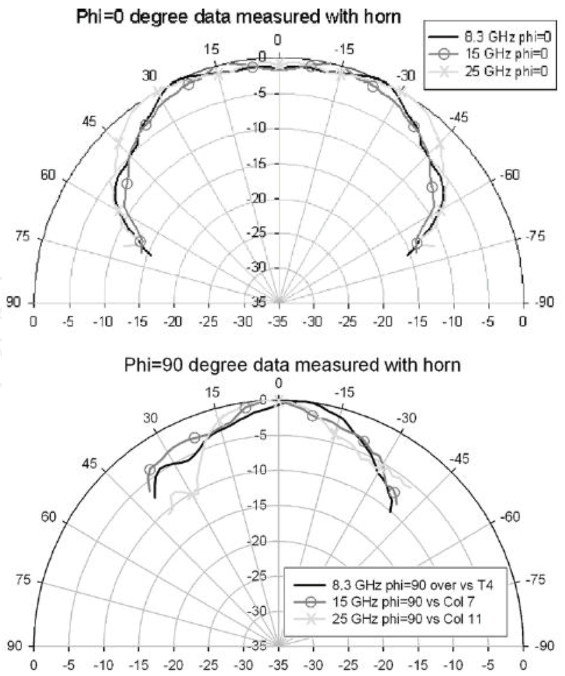
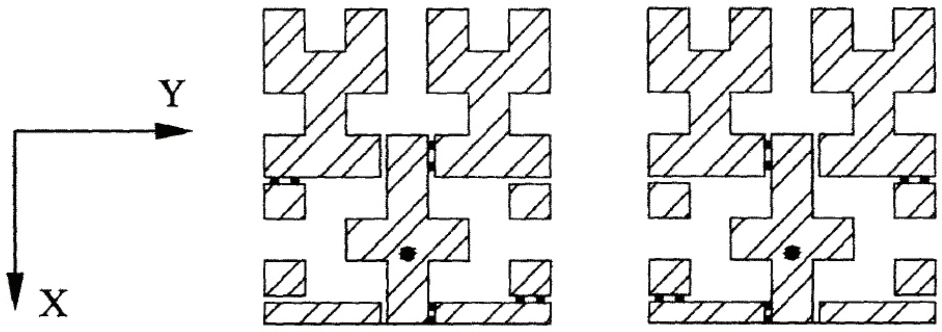


Fig. 21. Measured radiation patterns at different frequencies in the $\phi = 0^\circ$ and $\phi = 90^\circ$ cut-planes (Anagnostou et al., 2006)



(a) State One (b) State Two

Fig. 22. Configuration of the pattern-reconfigurable Hilbert-shaped antenna in its two switching states (Zhang et al., 2005)

engineering perspective. Moreover, a survey on recent fractal-shaped microstrip antennas that are compact in size or multi-band/wideband in operation has been included. Some recent frequency-, pattern- and polarization-electronically reconfigurable microstrip antennas were also reviewed in this chapter. It was shown that reconfigurability is a demanding antenna design traits in building multiple-in-1 antennas. Three hybrid antenna design approaches, which combine fractal shapes and electronic reconfigurability, were also presented. The first employs Koch fractal geometry and tunability to cover several frequency bands while keeping the antenna compact in size. The second is based on the design of a Sierpinski Gasket-shaped reconfigurable antenna and achieves similar radiation patterns at several frequency bands. The latter employs Hilbert curves in the design of a compact pattern-reconfigurable antenna.

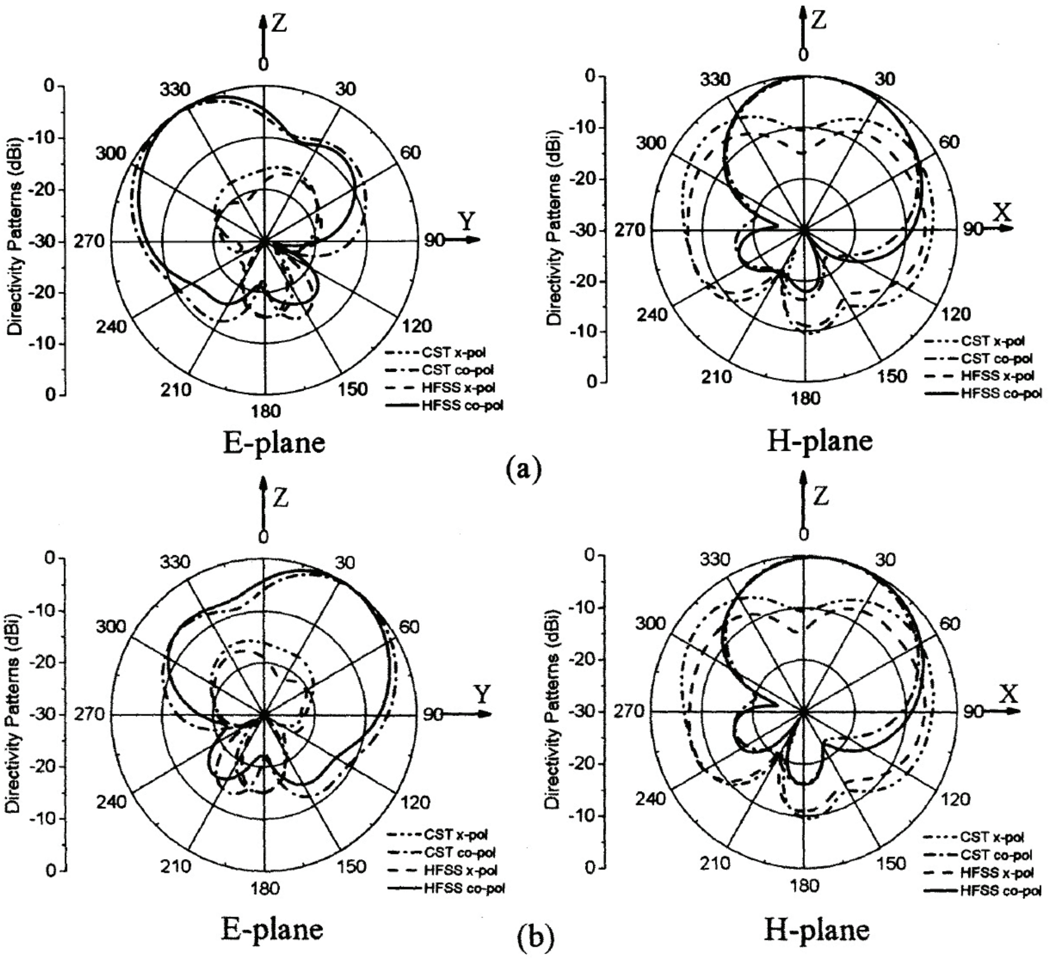


Fig. 23. Radiation patterns at 10 GHz of the antenna in (Zhang et al., 2005) for the two switching states

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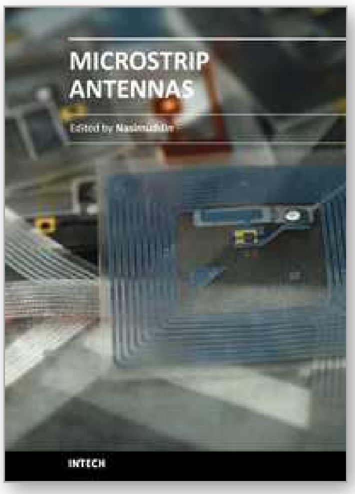

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In the last 40 years, the microstrip antenna has been developed for many communication systems such as radars, sensors, wireless, satellite, broadcasting, ultra-wideband, radio frequency identifications (RFIDs), reader devices etc. The progress in modern wireless communication systems has dramatically increased the demand for microstrip antennas. In this book some recent advances in microstrip antennas are presented.

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