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A New Compact Patch Antenna Design for Circular Polarization Applications Based on 3rd Iteration Minkowski-Like Pre-Fractal Geometry

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Abstract: A compact low profile microstrip antenna for circular polarization dual band applications has been presented in this study. The proposed antenna design is based on the 3rd iteration Minkowski-like pre-fractal geometry. The proposed antenna design offers a high degree of freedom making it attractive for the antenna designers as a result of the flexibility in the design gained. Antenna performance has been evaluated using the widely used software in industry; EMSight™ from the Applied Wave Research Inc. The proposed antenna has shown to possess dual resonance bands (for return loss = -10 dB). These 2 resonance bands can tuned remarkably using the antenna structure parameters. Good circular polarization characteristics with reasonable radiation characteristics have been achieved at these two bands. This makes the proposed antenna suitable to be in use in many mobile wireless systems incorporating dual band circularly polarized radiation such as GPS receivers operating at L1 and L2 bands, RFID systems operating at the ISM 2.4500 and 5.800 GHz bands, WCDMA RX operating at (2.110-2.170 GHz) frequency bands, etc.

Key words: Antenna miniaturization, fractal antenna, dual band antenna, circular polarization

INTRODUCTION

Micro strip antennas offer many advantages such as low profile, the ease of fabrication and the low cost. These make them very popular and attractive for the designers since the early days they appear. In many cases, where the antenna size is considered an important limitation, their large physical size, make them improper to be used in many applications. Several methods have been considered to reduce the microstrip antenna size (Kumar and Ray, 2003; Chen, 2006). These methods include the use of shorting posts (Kumar and Ray, 2003), material loading and geometry optimization (Shrivervik *et al*., 2001). Use of slots with different shapes in microstrip patch antennas had proved to be satisfactory in producing miniaturized elements (Kosiavas *et al*., 1989; Palaniswamy and Crag, 1985). By embedding suitable slots in the radiating patch, compact operation of microstrip antennas can be obtained. Figure 1 shows some slotted patches suitable for the design of compact microstrip antennas. In Fig. 1 (a), the embedded slot is a cross slot, whose two orthogonal arms can be of unequal or equal (Wong and Lin, 1998) lengths. This kind of slotted patch causes meandering of the patch surface current path in two orthogonal directions and is suitable for achieving compact circularly polarized radiation (Wong and Lin, 1998) or compact dual-frequency operation with orthogonal polarizations

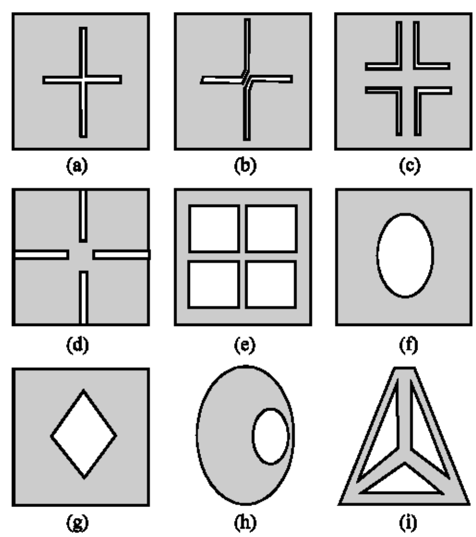

Fig. 1: Some of the published compact antenna for circular polarization applications (6-11)

(Yang and Wong, 1998). Similarly, designs with a pair of bent slots (Yang *et al*., 2000) (Fig. 1b), a group of 4 bent slots (Row *et al*., 2000) (Fig. 1c), 4 90°-spaced inserted slits (Wong and Wu, 1997) (Fig.1d), a perforated square patch or a square-ring patch with a cross strip (Chen, 1998) (Fig. 1e), a circular slot (Chen, 1998) (Fig. 1f), a square slot (Fig. 1g), an offset circular slot (Fig. 1h) and a perforated tip-truncated triangular patch (Fig. 1i) have been successfully applied to achieve compact circularly polarized or compact dual-frequency microstrip antennas.

Dual-polarized operation has been an important subject in microstrip antenna design and finds application in wireless communication systems that require frequency reuse or polarization diversity such as GPS receivers operating at L1 and L2 bands, RFID systems operating at the 2.4 GHz ISM band and WCDMA RX operating at (2110-2170 MHz) frequency bands, which is of special interest for 3 G communications, etc. Microstrip antennas capable of performing dual-polarized operation can combat multipath effects in wireless communications and enhance system performance. Designs of compact microstrip antennas for dual-polarized operation have been reported. Figure 1 (a) shows a typical compact dual-polarized microstrip antenna, which can be fed by two probe feeds. Antenna size reduction is achieved by having four bent slots embedded in a square patch. Results (Wong and Wu, 1997) show that, with the use of an FR4 substrate, good antenna performance is obtained for the compact dual-polarized microstrip antenna shown in Fig. 1 (a), which is better than that of the corresponding conventional square microstrip antenna without embedded slots.

As a result, microstrip antennas are extensively used in the compact dual band circularly polarized applications. Antennas operating at dual bands have also, been realized using two stacked patches and a small air-gap between the substrates with aperture-coupled multiple patch antennas fed through feed divider network (Pozar and Duffy, 1997; Su and Wong, 2002).

Due to their promising application in microwave circuit and antenna design, much of research work had been devoted to the use of periodic structures (Row, 2004; Yang *et al*., 2000; Bao and Ammann, 2006). These periodic structures include the photonic crystals, Electromagnetic Bandgap (EBG) structures or metamaterials. The EBG structures have been applied to antennas with various polarizations to improve antenna gain and radiation patterns. Recently, more research works have been devoted to make use of the space-filling and self similarity properties of some fractal objects to produce miniaturized multiband antenna elements (El-Khamy, 2004; Cohen, 2005). Dual band GPS antennas had been also achieved using two elliptical annular patches that are concentrically printed on 2 stacked substrates separated by an airgap. A central conducting wall shorts the 2 patches to the ground plane. The sizes of the patches have been chosen to make the upper and bottom patches resonating on the 2 frequencies (Boccia *et al*., 2004; Amendola *et al*., 2005).

In this study, a compact multiband microstrip antenna based on 3rd iteration Minkowski-like pre-fractal structure has been designed to be used in dual band circular polarization applications. The antenna performance of many structures had been computed using a full-wave numerical Method of Moment (MoM). The proposed structures had been applied to a dual-frequency GPS antenna operating at the bands L2:1.2276 GHz and L1:1.57542 GHz with circular polarization radiation as a case study.

THE 3rd MINKOWSKI-LIKE PRE-FRACTAL ANTENNA

Fractal geometry defines a structure with long lengths that fit in a compact area. Due to the iterative

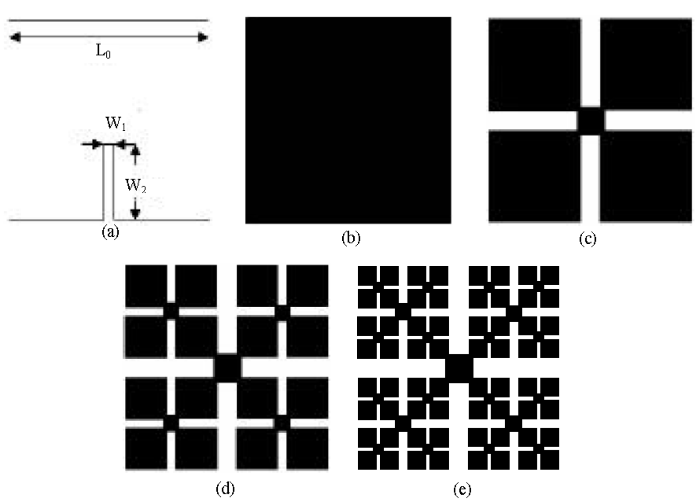

Fig. 2: The iterative generation of a Minkowski like Pre Fractal (MLPF), a) The generator, b) Square patch microstrip antenna, (initiator), c) The 1st iteration, d) The 2nd iteration and e) The proposed 3rd iteration MLPF structure

generating process, the multiple scales of the recurring geometry resonate at different frequency bands. The iterative generation procedure of a Minkowski-like pre-fractal up to the 3rd iteration is demonstrated in Fig. 2.

The dimension of a fractal provides a description of how much a space it fills. A dimension contains much information about the geometrical properties of a fractal. The generator used to develop the proposed MLPF structure (Fig. 2a) involves similarity transformations of >1 ratio; a_1 and a_2 and thus its dimension can be obtained from the solution of the following equation (Su and Wong, 2002):

$$2(\frac{1}{2}(1-a_1))^D + 2a_2^D + a_1^D = 1 \quad (1)$$

where:

- D = Represents the dimension
- a_1 = The ratio W_1/L_0
- a_2 = The ratio W_2/L_0

The perimeter, P_n of the nth iteration MLPF antenna is then calculated using (Ali and Jalal, 2007):

$$P_n = (1 + 2a_2)P_{n-1} \quad (2)$$

Many 3rd iteration MLPF antenna structures, corresponding to different values of a_1 and a_2 of its generating structures, had been designed and modeled at the design frequency.

THE ANTENNA DESIGN

The geometry of the 3rd iteration MLPF microstrip antenna is shown in Fig. 2e. As a case study, the proposed antenna had been applied to the GPS receiving antenna operating at L1:1.57542 and L2:1.2276 GHz with right-handed circular polarization a radiation pattern. Many antenna designs had been computed using an FR 4 substrate, which has a relative dielectric constant of 4.4 and a substrate height of 1.6 mm. The design frequency is the lower frequency band, which is GPS L2:1227.6 MHz, since the multiresonance behavior of the MLPF antenna implies that the lowest resonance frequency takes place at the design frequency (Ali, 2007; Ali and Jalal, 2007). The dimensions of the traditional half-wavelength patch antenna, (Fig. 1b), have been calculated at the design frequency using the prescribed substrate parameters. The perimeter, P_o of this patch is found to be of about 228 mm. The corresponding perimeter, P_3 of the 3rd iteration MLPF antenna is then calculated using Eq. 2. This results in an Mlpf patch length of 26.3 mm

The resulting dimension of the 3rd iteration MLPF microstrip antenna corresponds to a reduction in size of about 78% compared with the conventional microstrip antenna operating at the same frequency and using the same substrate.

Many different values has been specified to the middle segment width and segment heights ratios of the generator structure, (Fig. 2a). These values and the corresponding MLPF antenna structures had been modeled to study the different aspects of this antenna. All of elements had been excited with a 2 port configuration having the same amplitude but in phase quadrature to enhance producing the required circular polarization.

RESULTS AND DISCUSSION

Theoretical performance of each of the modeled antenna structures has been predicted using a full-wave numerical Method of Moment (MoM). EMSight, of the Applied Wave Research, includes a full-wave electromagnetic solver that uses a modified spectral-domain method of moments to accurately determine the multi-port scattering parameters for planar structures (Microwave Office).

The proposed antenna structure had been modeled at the design frequency of the GPS (L1). It has been supposed that the antenna element to be etched on the upper side of an FR4 substrate located parallel to x-y plane and centered at the origin (0, 0, 0), as shown in Fig. 3.

Eight antenna structures had been modeled in this study. In the first four structures, shown in Fig. 4, a_2 has been kept constant with a value of 0.32, while a_1 has been assigned four values; 0.10, 0.15, 0.20 and 0.25. These

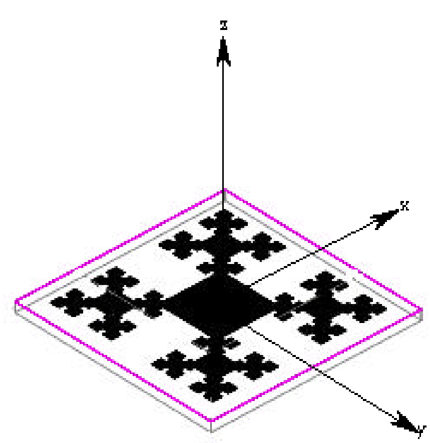

Fig. 3: The modeled antenna layout with respect to the coordinate system

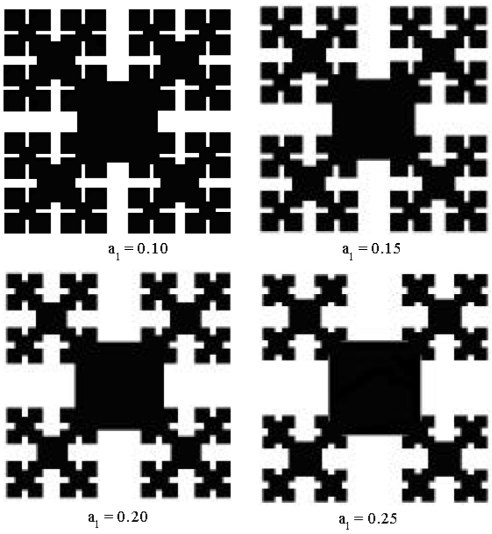

Fig. 4: The first four 3rd iteration MLPA with constant a_2 = 0.32 and a_1 = 0.1, 0.15, 0.20 and 0.25, respectively

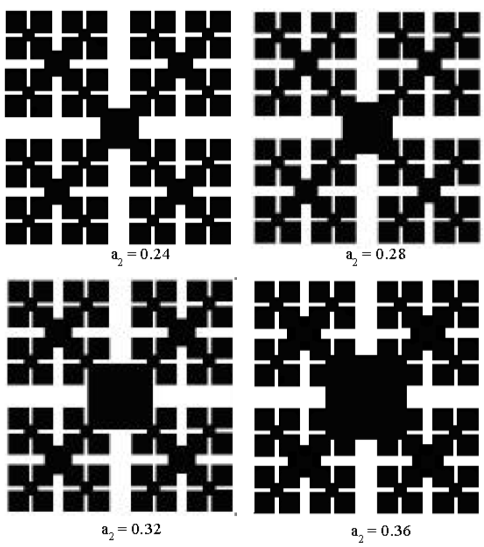

Fig. 5: The first four 3rd iteration MLPA with constant a_1 = 0.1 and a_2 = 0.24, 0.28, 0.32 and 0.36, respectively

correspond to antenna structures 1-4, respectively. The second four structures are shown in Fig. 5, where as it is clear, a_1 is kept constant with a value of 0.1, while a_2 has been assigned four values; 0.24, 0.28, 0.32 and 0.36 corresponding to antenna structure 5-8, respectively.

Figure 6 and 7 show the computed return loss for each of the modeled antennas. It is clear that each antenna has two resonance bands. This does not prevent the possibility of other resonant bands out of this range (Ali, 2007; Ali and Jalal, 2007). Table 1 and 2 show the impedance bandwidths for VSWR = 2, for each of the antenna structures described in Fig. 5 and 6, respectively.

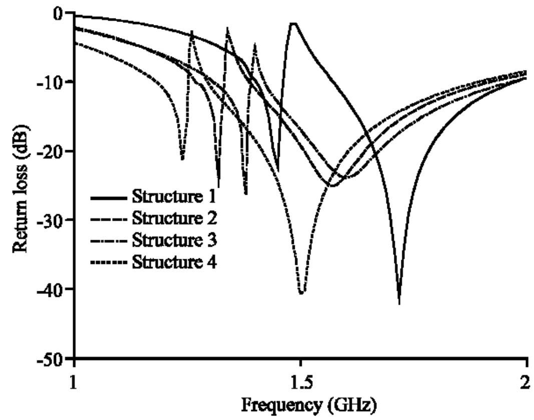

Fig. 6: Simulated return losses for the antenna structures in Fig. 4

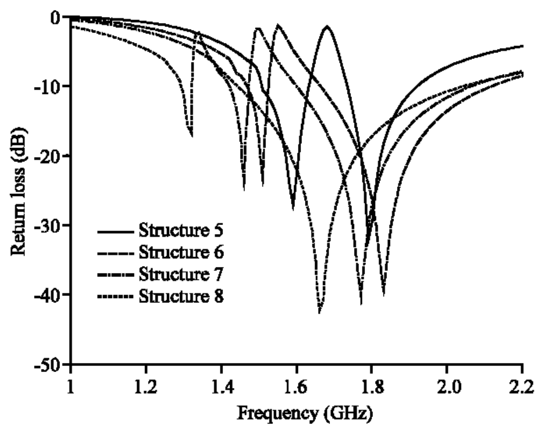

Fig. 7: Simulated return losses for the antenna structures in Fig. 5

Results in Table 1 and 2 indicate that the increase in a_1, a_2, or both will generally decrease the values of both resonance frequencies of the 2 bands. This can be simply explained as follows; the increase of these parameters will result in a decrease in the overall radiating edges length, which consequently leads to corresponding decrease in the resonance frequencies. Here, it is worth to note that, the decrease or increase of these parameters is not unlimited, since the fractal shape may loss its meaning. For instance, if a_1, a_2, or both has been made equal to zero, the fractal shape will entirely disappear and the structure will be now just a square patch that will resonate at a higher frequency according to its new length. In this extreme case, there will not be multiresonance anymore, since the self-similar structures, which constitute the fractal shape, are practically not exist.

Figure 8 and 9 show the E field radiation patterns for RHCP and LHCP at the GPS frequencies L2:1.2276 Ghz

Table 1: Effects of varying a_1 on the resulting bandwidths and resonance frequencies

a_1	BW_1 (GHz)	f_{r1} (GHz)	BW_2 (GHz)	f_{r2} (Ghz)
0.10	1.40-1.46	1.45	1.57-1.98	1.72
0.15	1.31-1.39	1.38	1.42-1.97	1.60
0.20	1.27-1.33	1.32	1.39-1.93	1.57
0.25	1.18-1.25	1.24	1.29-1.90	1.50

Table 2: Effects of varying a_2 on the resulting bandwidths and resonance frequencies

a_2	BW_1 (GHz)	f_{r1} (GHz)	BW_2 (GHz)	f_{r2} (Ghz)
0.24	1.51-1.63	1.59	1.73-1.92	1.79
0.28	1.47-1.53	1.51	1.66-2.05	1.83
0.32	1.42-1.47	1.46	1.60-2.07	1.77
0.36	1.29-1.32	1.31	1.44-2.12	1.66

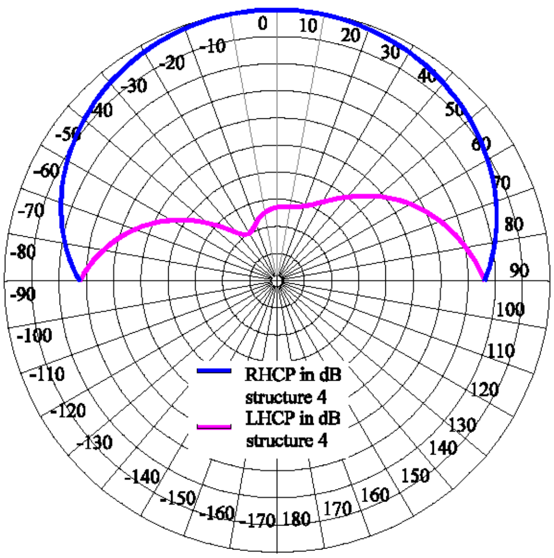

Fig. 8: Normalized RHCP and LHCP radiation patterns of the antenna structure 4 at the GPS L2 = 1.2276 Ghz

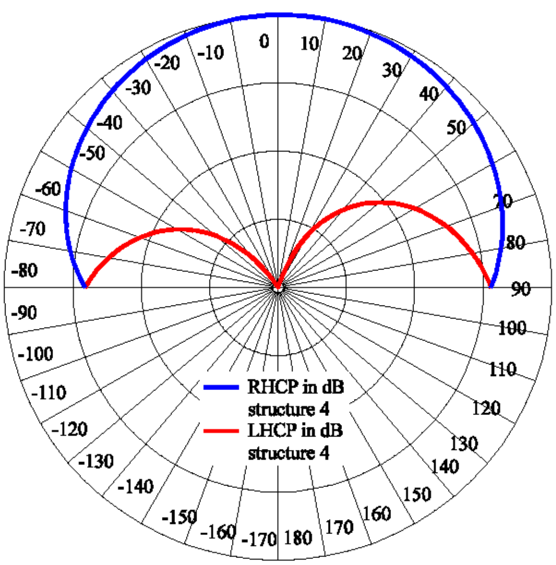

Fig. 9: Normalized RHCP and LHCP radiation patterns of the antenna structure 4 at the GPS L1 = 1.57542 Ghz

and L1:1.57542 GHz, respectively. Antenna structure 4 has been chosen, since it meets the bandwidth requirements of the case under study. It is clear that this antenna supports the required RHCP electric field radiation pattern. For applications incorporate LHCP, the required LHCP can be produced by interchanging the feeds locations.

CONCLUSION

A new compact low profile microstrip patch antenna had been presented to be in use for dual band circular polarization applications. The proposed antenna is based on the 3rd iteration Minkowski-like pre-fractal geometry. The antenna performance had been analyzed in accordance to the antenna structure parameters. Results had shown the high design flexibility offered by this antenna due to the variation of antenna structure parameters. Furthermore, it has been found that the proposed antenna possesses adequate circular polarization radiation characteristics besides the compact size and low profile. These make the proposed antenna a candidate for use in many wireless mobile receiving systems incorporating dual band circular polarization such as GPS receivers operating at L1 and L2 bands, antenna tags in RFID systems operating at operation at the ISM 2.45 GHz and 5.8 GHz bands, WCDMA RX operating at (2110-2170 MHz) frequency bands, which is of special interest for 3 G communications and many more, after appropriate designs.

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