

A Miniaturized Multiband Minkowski-Like Pre-Fractal Patch Antenna for GPS and 3g IMT-2000 Handsets

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Abstract: A compact multiband Minkowski-Like Pre-Fractal (MLPF) microstrip patch antenna is proposed. This antenna is designed for GPS (L1), PCS, IMT-2000 and WLL frequency bands. Space-filling and self-similarity properties, the antenna possesses, result in a considerable size reduction and multiband operation as compared to the conventional microstrip antenna. The resulting antenna is characterized by a compact overall dimension applicable for use in cellular mobile handset. The antenna is a dual probe-fed Minkowski-like pre-fractal patch of iteration two. The high degree of freedom the proposed design offers, makes it possible to present and analyze many antenna structures. Simulations are carried out using EMSight™ from Applied Wave Research, which is based on the Method of Moments (MoM). Computed bandwidths are 1.48 to 1.61MHz and 1.64 to 2.56 GHz for S_{11} less than -10 dB. These bandwidths cover the GPS (L1), IMT-2000, WLL and 3G-PCS WLAN IEEE 802.11b at 2.4 GHz frequency bands with accepted radiation characteristics.

Key words: GPS, antenna miniaturization, fractal antenna, multiband antenna, PCS, IMT-2000, WLL

INTRODUCTION

The accelerating progress of the wireless communication and the ever increasing number of communication and navigation services such as cellular phones (GPRS), Global Positioning System (GPS) and Wireless Local Area Networks (WLAN) in the last few years, has created an ever-growing demand for multi systems application. To cover many or all of these services by one system, this requires a multi-band compact sized antenna with adequate performance.

Several methods have been considered to reduce the microstrip antenna size such as the use of shorting posts (Kumar, 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; Chen, 2006). Recently more research works have been devoted to make use of the space-filling property of some fractal objects to produce miniaturized antenna elements (El-Khamy, 2004). However, employing high dielectric constant substrates is the simplest solution, but it exhibits narrow bandwidth, high loss and poor efficiency due to surface wave excitation.

Works reported in the literature to achieve this purpose in the last few years had widely made use of either geometry optimization, slots with different shapes or both of these techniques.

Wu *et al.* (2001) a GPS ceramic patch antenna and a DCS annular patch antenna operated in a higher mode are integrated. The GPS antenna constructed with a ceramic substrate of a very high relative dielectric constant of 90.5. Nathan and Canttrel (2001) proposed a design of a compact and low-profile antenna that operates at both the conventional cellular phone band and the civilian GPS L1 frequency. An integrated unit that is a hybrid design of PIFA and dielectrically loaded patch antennas operates at the 2 different bands.

An H-shaped microstrip patch antenna with a shorting pin had been reported by Gao *et al.* (2001) in an attempt to achieve dual-frequency operation and a compact size compared with that of conventional rectangular patch antenna. A high-gain, compact and multiband antenna design that is capable of receiving and transmitting both GPS signals and covering three bands of WLAN had been reported (Jamal, 2004). A compact microstrip antenna practical for both the GPS/DCS dual-band mobile communications had been presented (Shun and Kuang, 2005). The proposed

antenna consists of 2 parts: A truncated square patch antenna, making the design suitable for the GPS and an annular ring patch antenna. Further, four slots were embedded into a ground plane. A compact square microstrip patch antenna is designed at three different frequencies, for mobile communication, GPS and Bluetooth applications (Vibha and Nisha, 2006). The antenna consists of a probe-fed truncated-corner square patch with four inserted slits along the four diagonals and four angular grooves along the four edges of the patch.

Jang and Go (2007) had proposed an L-shaped probe-fed U-slot patch antenna with coil as a low profile to cover the cellular, PCS, IMT-2000 and WLL.

In this study, a significantly different fractal antenna structure has been presented, the MLPF antenna, to cover the GPS (L1), IMT-2000, WLL and many other wireless communication services bandwidths with adequate performance. Many designs have been presented, for this purpose to realize an accepted coverage, the antenna can offer for such applications.

THE MLPF ANTENNA

The fractal geometry defines a structure with long lengths that fit in a compact area. Due to the importance of lengths to a resonant antenna, this feature of fractals can be used to design miniaturized resonant antennas. And because of the self similarity of the geometry due to the iterative generating process, the multiple scales of the recurring geometry resonate at different frequency bands.

The antenna presented in this paper belongs to the fractal family antennas. It is fractally generated by the conventional method; employing a generator structure and a pre-fractal square shape (the initiator). Generation steps of this fractal structure are as illustrated in Fig. 1, (Jawad, 2007). Generally, 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. It is possible to define the dimension of a fractal in many ways, some satisfactory and other less so. It is important to realize that different definitions may give different values of dimension for the same fractal shape and also have very different properties.

According to Falconer (2003) since the generator used to develop the proposed MLPF structure involves similarity transformations of more than one ratio; a_1 and a_2 , its dimension can be obtained from the solution of the following equation:

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

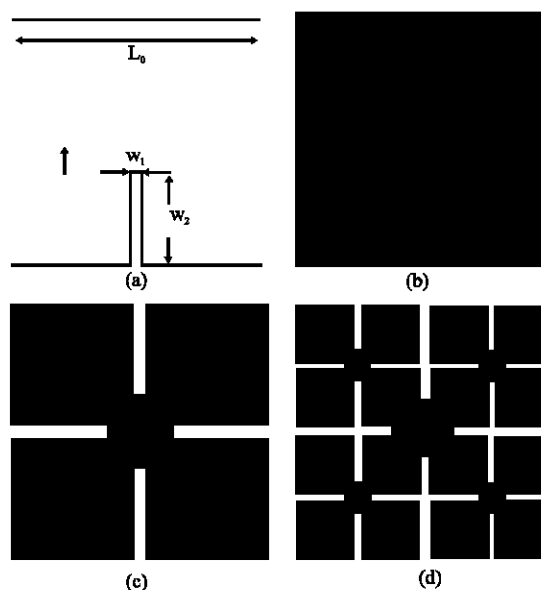


Fig. 1: The iterative generation procedure of a Minkowski-Like Pre-Fractal (MLPF); (a). The generator, (b). Square patch microstrip antenna, (the initiator), (c). and (d). The first two iterations

Table 1: The center frequencies and bandwidths

| Antenna type | A | B | C | D | E |
|------------------|---|---|---|---|-----------|
| a_1 | 0.056 | 0.110 | 0.165 | 0.22 | 0.33 |
| D | 1.582 | 1.545 | 1.521 | 1.504 | 1.492 |
| Bandwidths (GHz) | 1.42-1.71 | 1.51-1.70 | 1.43-1.61 | 1.48-1.61 | 1.54-1.84 |
| Application band | 1.74-1.96 | 1.79-2.14 | 1.64-2.04 | 1.64-2.56 | 1.90-2.61 |
| | GPS (L1), DECT, GPRS, IEEE 802.15.3a, PHS | GPS (L1), GSM, PSC, DECT, GPRS, IEEE 802.15.3a, PHS | GPS (L1), GSM, PSC, PACS, DECT, GPRS, IEEE 802.15.3a, PHS | GPS (L1), GSM, PSC, IMT-2000, Bluetooth, IEEE 802.16a/e, ISM-2400, IEEE 802.11b/g, IEEE 802.15.3a, PHS, PACS, DECT, GPRS, 3G-PCS, WLAN IEEE 802.11b, WCDMA RX | |

where D , represents the dimension, a_1 is the ratio W_1/L_0 and a_2 is the ratio W_2/L_0 . Then, according to Eq. 1, when a_1 , a_2 , or both are varied, then fractal structures with different dimensions may result in. The dimension of traditional Minkowski island fractal, according to Eq. 1 is equal to 1.465, where in such a case, a_1 and a_2 are both equal to one-third. The dimension of the pre-fractal can generally be assumed to be the same as the ideal fractal if enough iterations are used in the generation (Gianvittorio and Rahmat, 2001).

A wide variety of MLPF antenna structures can be derived by varying the generator middle segment parameters W_1 , W_2 or both, Fig1a. In the present research, many values have been assigned to the width ratio, a_1 resulting in correspondingly different structures; all of the second iteration but with slightly different fractal dimensions. Table 1 summarizes the values of a_2 together with the resulting MLPA patch microstrip antenna structures and their corresponding fractal dimensions.

THE ANTENNA DESIGN

Figure 1d shows the geometry of the proposed MLPF antenna of the second iteration. In this study, the dielectric substrate used is having a relative dielectric constant of 4.5 with a thickness of 1.575 mm.

The first step is to calculate the dimensions of the traditional half-wavelength patch antenna, (Fig. 1b), at the GPS L1 design frequency of 1575.42 MHz using the prescribed substrate parameters. The perimeter, P_0 of this patch is found to be of about 107 mm. The corresponding perimeter, P_2 of the second iteration MLPF antenna is then calculated using (Jawad, 2007):

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

Where P_n in the perimeter of the n -th iteration pre-fractal. This results in an MLPF patch length of 26.67 mm. The middle segment width ratio of the generator structure, (Fig. 1a), has been adjusted to 5 different values. These values and the corresponding MLPF antenna structures are shown in Table 1. Theoretical performance of each of these antennas 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 predominately planar structures (Microwave office and EmSight). In presented designs, this software package was applied to simulate the typical characteristics of the proposed

antennas. For the excitation of these elements a two-port configuration was used having the same amplitude but in phase quadrature to enhance producing of circular polarization required for the GPS application, since the normal mobile handsets will be encountered with all kinds of possible polarization due to the multi-path propagation mechanism related to the mobile cellular systems (Wang and Lee, 2004).

RESULTS

Five MLPF antenna structures, corresponding to five values of a_1 of its generating structures, had been modeled at the design frequency of the GPS (L1). These elements have been designated as Antenna A to Antenna E. The antenna elements are supposed to be located parallel to x-y plane and centered at the origin (0, 0, 0).

The computed input return losses of these antenna patches are shown in Fig. 2. For each element, 2 resonant bands are noticed in the frequency range specified by this study. This does not prevent the possibility of other resonant bands out of this range. The detailed behavior of these elements at these 2 resonances, i.e., the center frequencies and bandwidths are depicted in Table 1.

As Fig.2 and Table1 imply that changes in a_1 result in different structures with slightly different fractal dimensions, which in turns affect the input return loss response. In the resonant band, the effect, on the average, is slight. The realized bandwidth extends from 130 to 300 MHz which is broad and provides a sufficient bandwidth satisfying the required GPS L1 bandwidth.

The higher band seems to be more sensitive to such changes in a_1 . As a_1 has been increased, the self similar shapes that constitute the fractal shape become having finer structures. As a matter of fact, these finer shapes

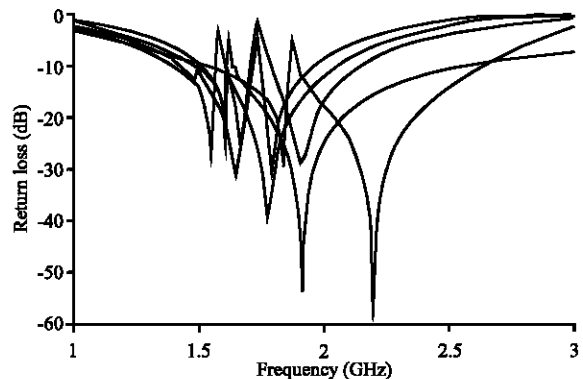


Fig. 2: The calculated input return loss for the 5 modeled MLPF patch elements

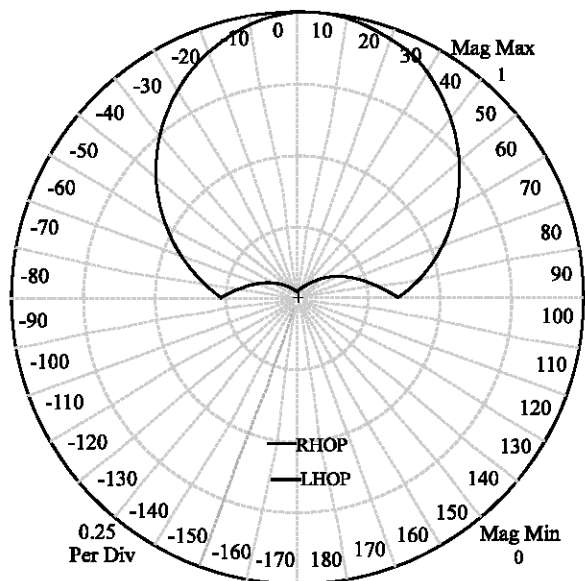


Fig. 3: Normalized E-plane RHCP and LHCP radiation patterns for Antenna D at 1575.42 MHz

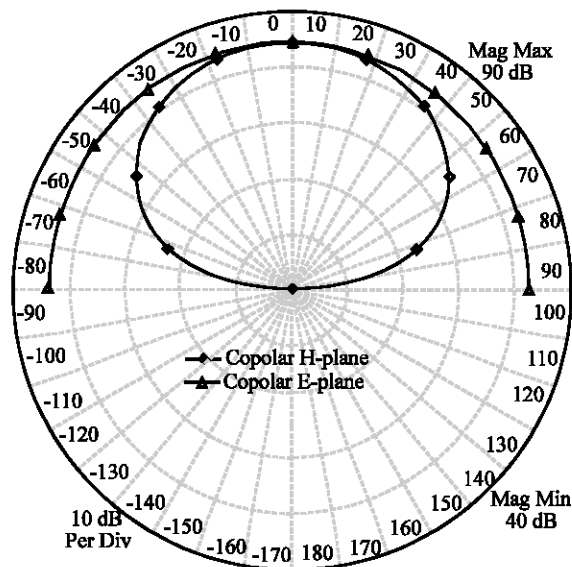


Fig. 5: E-plane and H-plane copolar radiation patterns for Antenna D at 2.45 GHz

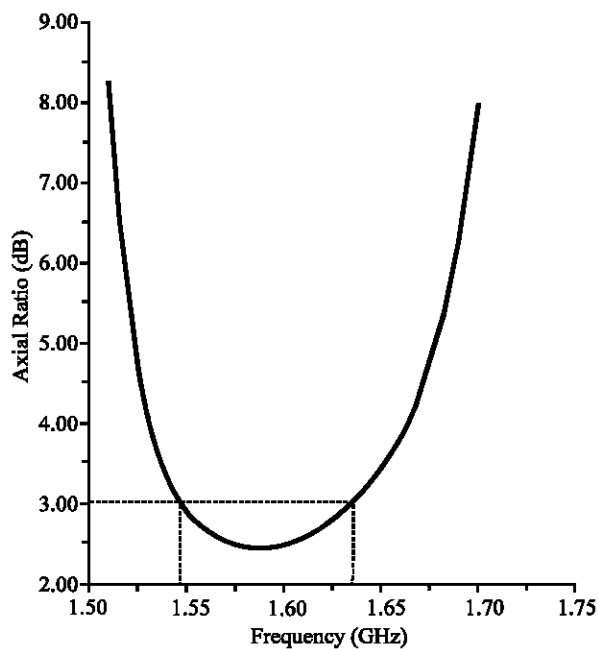


Fig. 4: The computed axial ratios around the GPS L1 frequency, for Antenna D

will contribute mainly in the higher resonance frequencies (Krupenin, 2006). As result, the center frequencies increase from 1.78 to 2.19 GHz, while the realized bandwidths range from 220 to 920 MHz. Antenna D has realized an upper resonant bandwidth of 920 MHz corresponding to a_1 equals to 0.22. With such a broadest bandwidth which is centered at a frequency of

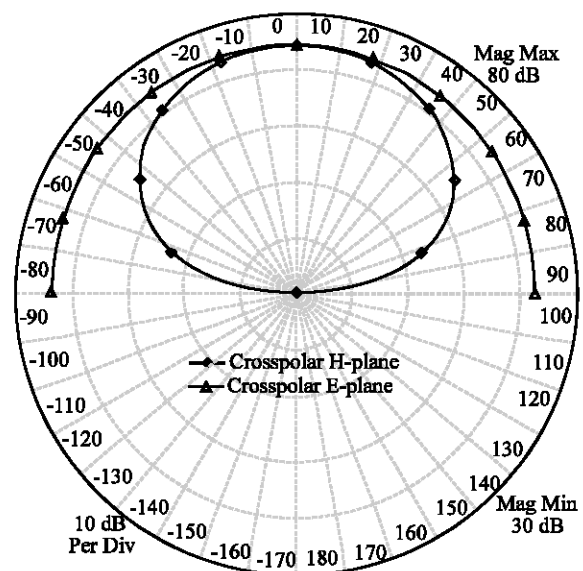


Fig. 6: E-plane and H-plane crosspolar radiation patterns for Antenna D at 2.45 GHz

2.19 GHz, this antenna could cover many services such as GPS (L1) at 1.57-1.58 GHz, GPRS at 1.8/1.9 GHz, 3G-PCS at 2-2.1 GHz, WLAN IEEE 802.11b at 2.4 GHz and the IMT-2000 frequency spectra of 1.885-2.200 GHz for both the up-link and down-link.

E-plane RHCP and LHCP radiation patterns at the GPS L1 frequency of 1575.42 MHz are shown in Fig. 3 for Antenna D. It is clear that this antenna supports the required RHCP electric field radiation

pattern. The required axial ratio AR has been calculated using (Thomas, 2005; Vaughan and Bach, 2003):

$$AR(\text{dB}) = 20 \log \frac{E_R + E_L}{E_R - E_L} \quad (3)$$

The resulting axial ratio as a function of frequency is depicted in Fig. 4. It can be seen that the axial ratio in the broadside direction is below 3 dB throughout a bandwidth of 88 MHz, which is greater than the CP bandwidth required for the GPS L1 application.

The upper resonant band covers the rest of the prescribed applications. Accepted radiation patterns have been realized throughout this bandwidth. Copolar and crosspolar radiation patterns for both E-plane and H-planes at a sample frequency of 2.170 GHz have been depicted in Fig. 5 and 6.

The copolar components in the E and H-planes are E_θ in $\phi = 0^\circ$ and E_ϕ in $\phi = 90^\circ$ planes, respectively. The cross-polar components in the E and H-planes are E_ϕ in $\phi = 90^\circ$ and E_θ in $\phi = 0^\circ$ planes, respectively.

CONCLUSION

A compact multiband dual probe-fed Minkowski-like pre-fractal microstrip patch antenna of iteration two has been investigated. The reduction of about 64%, as compared with the conventional microstrip patch antenna. It is inferred that the new design proposed in this study be applicable for use in mobile handset, in spite of relatively low dielectric constant of the substrate incorporated. Two main impedance bandwidths (return loss = -10 dB) have been realized within the frequency spectra from 1.48-1.61 GHz and 1.64-2.56 GHz with accepted radiation characteristics. These bandwidths satisfy the requirements the many services including GPS (L1), GPRS, 3G-PCS, WLAN IEEE 802.11b and the IMT-2000 frequency spectra for both the up-link and down-link

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