

Miniaturization of Dual-Band Planar Inverted-F Antennas using Peano-Curve Elements

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Abstract

Radiating elements patterned after Peano space-filling curves are used to miniaturize dual-band planar inverted-F antennas (PIFA) for wireless mobile application in the 900MHz and 1900MHz bands. A mixed-parameter Evolutionary Programming algorithm in combination with a Method of Moments numerical engine is employed to optimize several Peano-curve PIFA structures. Hybrid geometry of Peano-curve and polygonal patch is found to reduce by more than 50% the volume of a conventional rectangular PIFA, while still providing acceptable bandwidth.

1. INTRODUCTION

Over the years, there has been a considerable amount of interest in development of small multi-band antennas for wireless mobile communications. Among various techniques for antenna miniaturization, the concept of space-filling curves (SFC) [1] has been explored in recent years to design diverse electrically small antennas [2]-[6]. The resonant structures based on these curves can have very small footprints as one increase the step order in iterative filling of a two-dimensional (2-D) region. Peano curve and Hilbert curve are two of the most well known of these curves. The primary radiation characteristics of the Hilbert and Peano antennas and use of off-centred feed points in their matched designs have been studied in [5] and [6]. These curves have also been used as compact inclusions in design of high-impedance surfaces as well in development of double-negative (DNG) metamaterial media [7].

Recently, a miniaturized dual-band planar inverted-F antenna (PIFA) based on the 3rd order Hilbert curve was proposed in [8]. This Hilbert PIFA, which operates in the 900/1900 MHz mobile telephone operating frequency bands, occupies only half volume of its conventional counterpart. In this paper, based on the concept given in [8], we introduce another low profile space-filling curve PIFA antenna that consists of the 2nd order Peano geometry that also can support dual-band operations in the 900MHz band for GSM and 1900MHz for PCS applications. In general as has been shown in [6], the Peano-curve has a higher compression rate for antenna miniaturization and also results in a significantly lower cross-polarization level than a Hilbert antenna of the same order. A mixed-parameter Evolutionary Programming method combined with the Method of Moments [MoM]

numerical engine of Ansoft Designer is applied to optimize the geometry of the antenna structure. Our proposed design has a volume close to that of the Hilbert counterpart in [8] but with much wider bandwidth.

2. EVOLUTIONARY DESIGN OF PEANO-CURVE PIFA

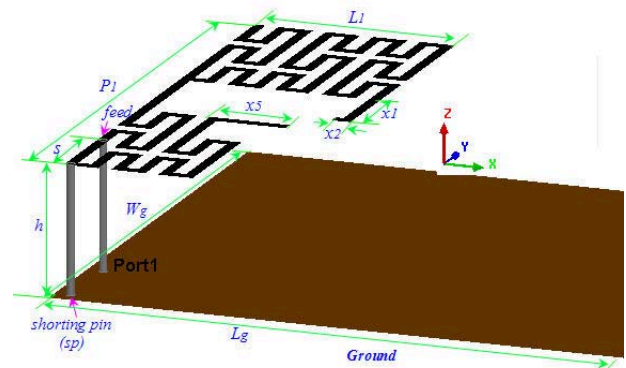


Fig. 1: Dual-band 2nd Order Peano PIFA

Evolutionary Programming (EP) [9], as an alternative global optimization method to Genetic Algorithms (GAs), has been previously used in a number of applications in electromagnetics and antenna optimizations (e.g., see the bibliography in [10]). In the present work, a mixed continuous-discrete EP (MEP) method [11] was employed to synthesize the optimal dimensions of the proposed PIFA antenna. A primary control code was developed in Matlab to direct and automate the optimization flow and determine the final results. Ansoft Designer, the commercial MoM-based electromagnetic simulator, was called in by the control code as the core engine to create PIFA structure and calculate its performance numerically. This evolutionary design process directly yielded the optimal results within the constraints, avoiding the painstaking adjustments required in standard manual design methods. In the MEP algorithm, the population size was set to 10, and about 200 generations of calculations (depending on the range of initial parameter constraints) were used for convergent results.

Two branches of a radiating element are required for dual-band performance. The basic antenna geometry consists of two strip elements, which were created following the 2nd order Peano curve antenna in [6], and connected to each other near the coaxial cable feed with a comparatively large ground,

as shown in Figure 1. The full-size Peano curve part is responsible for the resonance in the low frequency band while the nearly half-size Peano curve resonates in high frequency band. The strip trace width was fixed as 0.7 mm for fabrication and comparison purposes.

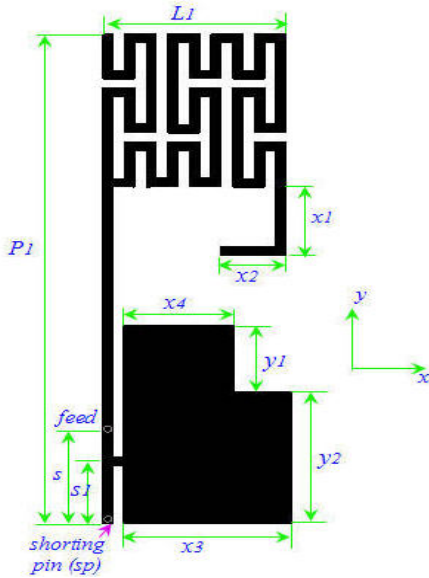


Fig.2: Hybrid Peano PIFA-Antenna C.

The dimensions of the antenna structure were then optimized through mixed-parameter EP optimization process. The design parameters included both continuous as well as discrete (binary) parameters, for a total of 15 optimization parameters. A Cauchy mutation operator in EP [12] was utilized to facilitate the converge of the continuous parameters, including the total PIFA length (P_1), the footprint side length of the Peano curve (L_1), the distance between the feed point and the shorting pin (s), the antenna height (h) and the length of finite ground (L_g). Some extra traces extended from the original Peano curve, such as x_1 , x_2 , and x_3 in Figure 1, might be necessary to adjust impedance match in the desired frequency band. A sequence of discrete numbers 0 and 1 was generated as a switch to determine the presence of an extra trace. A Poisson distribution operator was used in the discrete (binary) mutation step in EP to update such sequence. The lengths of such extra traces were calculated as continuous parameters. The fitness (cost) function used in MEP optimization was constructed as:

$$Fitness = \sum_{j=1}^2 \sum_{i=1}^N W_{ij} (VSWR_{ij}) + \sum_{j=1}^2 \sum_{i=1}^N \alpha_{ij} |V_{max} - VSWR_{ij}|^2$$

where VSWR is the voltage standing ratio, N is the total number of frequency points sampled in each band, and W_{ij} is weighting constant that can be adjusted to shape the frequency response of each band. The second double-sum term is used to penalize solutions that violate the maximum tolerable standing wave ratio, V_{max} , within each band, with α_{ij} being equal to 0 or 1 for $VSWR \leq V_{max}$ and $VSWR > V_{max}$, respectively. In this work V_{max} was set to 2.5.

Some parameters must be initially constrained for practical fabrication. Thus the total PIFA length was limited between 33 mm to 40 mm and its height, from 8 mm to 10 mm. The Peano footprint side length was restricted into a range from 8 mm to 15 mm. The width of the ground was set equal to the PIFA length, while ground length was a parameter to be optimized within 90 mm to 120 mm. In fact, the ground edges were extended one trace width beyond the projection of the PIFA elements for easier meshing and faster computer simulation. The comparison showed that the result difference due to such extension could be ignored.

At first two antenna models composed of only Peano curve elements were created, one entirely suspended on air substrate, called antenna A, and the other built on the top of a 0.25 mm Duroid-5880 dielectric substrate ($\epsilon_r=2.2$), then suspended on air-substrate, called antenna B. Copper conductors were assumed in all cases.

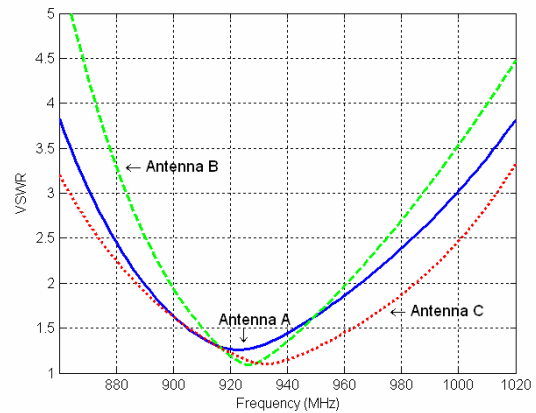


Fig. 3: Computed VSWR data for antenna A, B and C near 900MHz band.

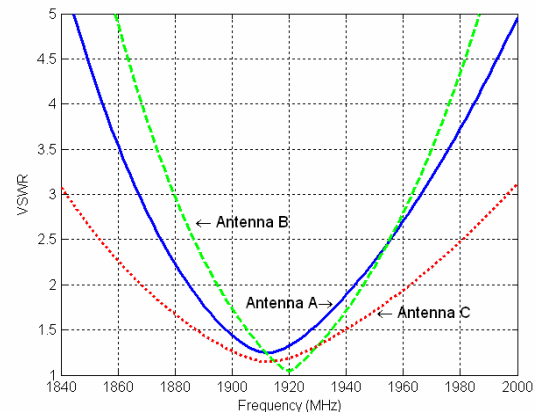


Fig. 4: Computed VSWR data for antenna A, B and C near 1900MHz band.

The two antennas have the same shape as in Figure 1 but different optimized dimensions to satisfy the design requirement (see Table 1). Both antennas resonate at about 920MHz and 1920MHz with a good operating bandwidth in the low frequency band but relatively narrow bandwidth in the high band. Following a similar scheme as the one suggested for Hilbert PIFA in [7], we replaced the half-size

Peano element, namely, the high frequency element, with a modified rectangular patch, as illustrated in Figure 2. This antenna, called antenna C, was also assumed to be on a 0.25 mm Duroid 5880 dielectric substrate. The side lengths of the polygonal element were optimized as part of continuous parameters when applying the MEP technique.

The geometry sizes for these three antennas are listed in Table I. The antenna heights of antenna A and B were 8.25mm while antenna C, 8mm. The lengths of their ground varied from 110mm to 120 mm.

TABLE I: OPTIMIZED ANTENNA PARAMETERS

	P_1	L_1	S	x_1	x_2	x_3	x_4	x_5	y_1	y_2
A	34.4	14.3	6	4.6	--	--	--	5.4	--	--
B	32.9	13	6	5.1	1.2	--	--	5.1	--	--
C	40	12.5	7.7	5.6	4.5	11.4	7.5	--	5.4	10.8

3. RESULTS

Comparison of the computed VSWR data for these three antennas is shown in Figures 3 and 4. The impedance bandwidths of antenna A are 11.4% and 4.2% within 2.5:1 VSWR in the 900MHz and 1900MHz bands, respectively. The bandwidth in the low frequency band is quite good for GSM application but the high frequency bandwidth is not satisfying if used for PCS communication. These bandwidths are further narrowed by the introduction of the thin Duroid 5880 substrate in antenna B, which only has bandwidths of 9.2% and 3.6% at the two bands, respectively. Peano PIFA A occupies a volume of only 4.1 cm³ (14.3mm by 34.4 mm by 8.25mm), close to the Hilbert PIFA volume (4.3cm³) [8]. Both save more than 50% volume compared with the conventional rectangular patch dual-band PIFA, which occupies a volume of 8.8 cm³ [8]. The volume of antenna B is only 3.54 cm³ (13mm by 33mm by 8.25mm), 17.6% smaller than that of the Hilbert PIFA, 60% smaller than that of the conventional PIFA.

Compared with the antenna B, the hybrid Peano-patch PIFA of Figure 2 widens the bandwidths up to 13.6% and 6.6% in two frequency bands respectively, resulting in increases of about 48% and 83% in bandwidth of Peano-only PIFA. The computed bandwidths of the modified hybrid Hilbert-patch PIFA were reported as 9.6% in the 900MHz band and 6.5% in the 1900MHz [8]. The Hybrid Peano PIFA outperforms its Hilbert counterpart 42% in the low frequency bandwidth while keeping approximately the same bandwidth in the high frequency band. At the same time, the volume of antenna C is only 4.1 cm³ (12.8mm by 40mm by 8mm), slightly smaller than the hybrid Hilbert PIFA. Some of these improvements can be attributed to the optimal evolutionary design of the proposed Peano-curve based PIFA.

Computed radiation patterns for antenna B and C are given in Figures 6 and 7. Patterns are computed at the desired central frequencies of 920MHz and 1920MHz. At the lower frequency, both antennas provide a pattern at $\phi=90^\circ$ with uniform coverage in the y-z plane with the E_ϕ component

being dominant. In the plane $\phi=0^\circ$, the pattern is similar to that of a dipole antenna put along x axis with a cross-pol level below 20 dB. At 1920 MHz, the pattern in the $\phi=90^\circ$ plane is approximately uniform with two components E_ϕ and E_θ having similar shapes and magnitude, whereas in the $\phi=0^\circ$ plane, the E_θ pattern is non-uniform. These Peano-curve based PIFAs have all nonzero fields along $\theta=0^\circ$ direction to provide better coverage in the upper hemisphere. These features of the Peano PIFA are very similar to those of the Hilbert PIFA given in [7]. For antenna B, the maximal accepted gain at 920 MHz is 2.04 dBi and at 1920 MHz it is 4.58 dBi. For antenna C, the peak accepted gain at 920 MHz is 2.18 dBi while at 1920 MHz, it is 4.68 dBi. The antenna and ground are relatively longer at high frequency band resulting in a higher gain, as expected.

4. CONCLUSION

Peano curve elements were investigated in miniaturization of planar inverted-F antennas. It was found that a hybrid of Peano curve and conducting patch elements can be optimized to design a dual-band PIFA for application at 900 MHz and 1900 MHz mobile bands. The proposed Peano-curve based PIFA has improved bandwidth as compared with a previously reported PIFA based on Hilbert curves. The PIFA is 50% smaller in volume than the conventional plate-type PIFA. Even smaller PIFA, but with narrower bandwidth, may be achieved using higher order Peano or Hilbert curve elements in conjunction with the evolutionary design procedure described in this paper.

ACKNOWLEDGEMENT

This work was supported in parts by National Science Foundation under Grants No. 0203459 and No. 0332490.

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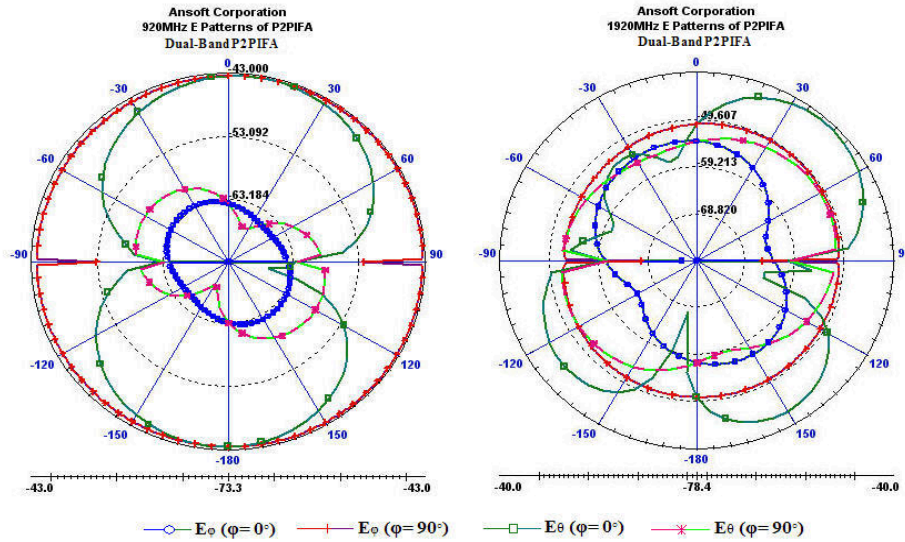


Fig. 6 Computed radiation patterns for antenna B at 920 MHz (left) and 1920 MHz (right)

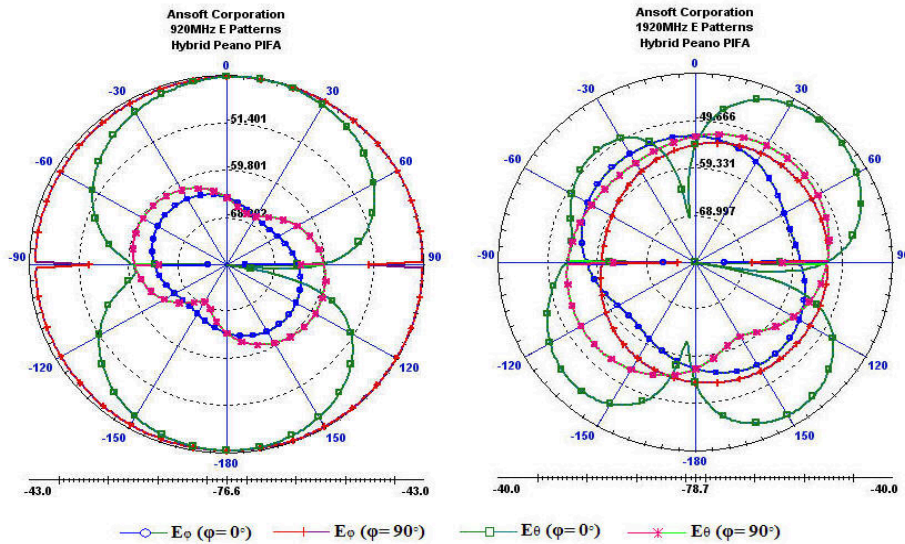


Fig. 7 Computed radiation patterns for antenna C at 920 MHz (left) and 1920 MHz (right)

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