Some Pre-Fractal Self-Complementary Antennas

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Abstract. The design of self-complementary antennas with pre-fractal profiles is investigated in this paper for its potentiality in designing wideband antennas. This new family of antennas is expected to combine the performances of self-complementary antennas and pre-fractals. Two new antenna designs, the self-complementary Koch-tie dipole and the Gosper Island dipole, are fully described.

1. Introduction: Self-Complementarity and Fractals

A planar metallic antenna is said to be self-complementary when the metal area and the open area have the same shape -but a rotation-, i.e. when they are congruent [1]. In a strict sense, self-complementarity is only defined on infinite size antennas. According to Babinet’s principle, the input impedance of a self-complementary antenna has no frequency dependence and is equal to 188\(\Omega\).

A practical limitation in the frequency response of the input impedance of a self-complementary antenna comes from its whole size and the size of its terminals. The design of a self-complementary antenna with a pre-fractal profile (typically generated by an Iterative Function System [2]) is expected to provide a new family of antennas with combined performances: the frequency independent input impedance, typical of self-complementary antennas, and the miniaturization capability of pre-fractals. This combination of characteristics should be evidenced by the shift to lower frequency values of the frequency band where the input impedance is closer to 188\(\Omega\) when compared with a standard design of the same size.

The performance of fractal devices in miniaturization have been investigated in the frame on the FractalComs Project [3]. The FractalComs Project lasted two years (2002-2003) and was carried out by a consortium of five European partners funded by the European Commission.

In this communication we present some of the analyzed designs, such as the self-complementary Koch-tie dipole and the Gosper Island dipole. Other designs, such as logarithmic spirals mapped with Koch curves, will be discussed in the oral presentation.

2. The Self-Complementary Koch-Tie Dipole

A typical self-complementary design is the bow-tie dipole of Figure 1. The concentration of currents in the borders of the bow-tie surface suggested that by replacing the straight borders of the antenna by a Koch curve: (a) the effective size of the truncated structure would be large due to the longer path followed by the signal along the antenna borders; and (b), the field radiated at the curve corners would greatly reduce the amount of energy that reflects at the truncation of the structure. Additionally, if the self-complementarity of the structure is maintained, the result
would be a frequency independent behavior of the input impedance starting at a lower frequency.

Self-complementary Koch-tie dipoles until the fourth iteration have been designed and are also shown in Figure 1. The input impedance of these dipoles was computed using the method of moments code FIESTA 3D (Fast Integral Equation Solver for Scattierers and Antennas in 3D, proprietary of UPC) [4] after meshing the structure with the meshing software GiD [5]. Results are displayed in Figure 2. The frequency shift to the lower frequency range where the input impedance is expected to be constant is observed, but the improvement is too small to correspond with the increasing intricacy and contour length of the structure.

Figure 1. (From up to down and from left to right) Bow-tie dipole and the first four iterations of the self-complementary Koch-tie dipole.

Figure 2. Computed input impedance of the bow-tie dipole and the first four iterations of self-complementary Koch-tie dipoles.
3. The Gosper Island Dipole

A quasi-self complementary pre-fractal antenna based in the Gosper Island (GI) has also been investigated. The GI pre-fractal curve is generated through an IFS of 7 affine linear transformations. A planar strip antenna is designed giving width to the pre-fractal curve. Figure 3 shows the forth iteration of a Gosper island (GI-4) (left) and its complementary antenna (right). At first look they do not make any difference. A closer inspection reveals that they look self-complementary only in the central region of the pre-fractal (inside the circle).

![Figure 3. Complementary designs of a fourth iteration of a Gosper Island (GI-4) pre-fractal surface made with strips. The central surface of both designs (enclosed in the circle) seems self-complementary.](image)

Although the Gosper Island pre-fractal is not strictly self-complementary, the quasi-self complementarity property of its surface and the existence of a large number of segments with different lengths make the GI pre-fractal a potential candidate for a dipole antenna with a frequency independent input impedance or, at least, a multi-resonant antenna. Consequently, the input impedance response as a function of the feeding point position has been computed using FIESTA 3D.

The unsymmetrical geometry of the GI pre-fractal dipole forces the search for the location of the antenna terminals. They should be located along the longest path on the antenna and in a position where the input impedance is constant and close to 188 Ω. Some of the terminal positions tested are shown in Figure 4.

According to the initial hypothesis of self-complementarity, the input impedance should be close to 188 Ω. The terminal position at which the dipole is well-matched at a wide frequency band has been determined by numerical simulations. The results really show that there are bands where the dipole is matched to 188 Ω, but they are not as wideband as expected for a self-complementary dipole. For instance, for the GI-3 dipole values of the matching coefficient (to 188 Ω) are lower than –10 dB for a frequency band of 5.5 to 7.9 GHz (35.8% fractional bandwidth) for the feeding point B, and from 6.4 to 8.6 GHz (29.3% fractional bandwidth) for the feeding point H.

Figure 5 shows the current distribution on the surface of the GI-3 dipole fed when the terminals are at H, for the operating frequencies 6.5, 7.5 and 8.5 GHz. These frequencies are in the band where the input impedance is well-matched to the expected
188 Ω for a self-complementary antenna. The same effect of current attenuation around the terminals happening to an spiral antenna are observed in the GI-3 dipole. This effect is supposed to be the main responsible for the input impedance near the 188 Ω, typical for a self-complementary antenna.

4. Conclusions

The self-complementary Koch-tie dipole was built by mapping the Koch curve on the four sides of a bow-tie antenna. The results of simulations show that the input impedance is approximately constant starting at a lower frequency than the conventional bow-tie antenna. The lower limit of the usable frequency band decreases with increasing number of iterations of the pre-fractal curve. However, the practical improvement of the usable frequency band is not significant.

After looking for the matching to 188 Ω, the quasi-self-complementary Gosper Island dipole has revealed a wide band input impedance behavior, but not as large as expected for a self-complementary dipole.

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