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SUPERSHAPED SINUOUS ANTENNA FOR UWB RADAR APPLICATIONS

G. Mevoli(1), C.M. Lamacchia (2), P. Bia(3), A. Manna (3), D. Caratelli(4) and L. Mescia(1)
(1) Politecnico di Bari, Bari, Italy.
(2) IAMAtek srl, Bari, Italy.
(3) Elettronica SpA, Rome, Italy.
(4) The Antenna Company N.V., Eindhoven, The Netherlands.

Abstract

In this paper, we propose a novel class of sinuous antennas based on the integration of both 2D superformula and the sinuous one. The study was carried out with the aim to investigate the effects of some design parameters on the antenna performance in terms of radiation properties and impedance matching in a wide frequency range. In fact, thanks to the proposed formula, it is possible to generate a wide range of antenna shapes in a simple and analytical way by changing a reduced number of parameters. The analysis was carried out in the frequency range from 1 GHz to 10 GHz and the illustrated preliminary results highlight that the proposed approach could be an useful and flexible tool to create sinuous-like antennas having unique radiation properties.

1 Introduction

The research and study of the sinuous antenna have brought considerable advantages in the ultra-wide band (UWB) applications [1, 2, 3]. They can be seen as a combination of spiral and log–periodic antenna concepts, which result in a radiating element capable of producing UWB radiation in the broadside direction with polarization diversity.

The conventional planar sinuous antenna can be considered as a cascade of p cells generated from the sinuous curve. The number of cells controls the radiation pattern of the sinuous antenna, while their length control the input impedance [4]. Moreover, sinuous antennas are able to produce ultra-wideband radiation with polarization diversity in a low-profile form factor. These properties, have proven usefulness in a wide range of applications requiring spectrum-agility or multifunctionality such as direction finding systems, electromagnetic jamming, passive radar seeker, anti-radiation missile, and radar electronic support measures [5]. Some applications require specific radiation pattern characteristics over a wide impedance matching bandwidth. Other applications may require a dual linearly polarized radiation pattern and in same cases the pattern nulls should be avoided. In view of these requirements and with the aim to provide a more flexible tool for matching the different needs, in this paper we propose the supershaped sinuous antennas. This class of antennas is based on a intriguing analytical formula which makes possible the modeling of plenty innovative sinuous-like shapes. Moreover, due to the possibility of automatically reshaping the arm profile by acting on a reduced number of parameters, any automated optimization procedure can be conveniently adopted in order to identify the shape parameters yielding the optimal antenna characteristic.

2 Antenna Design

The curve profiles of the conductor forming the proposed supershaped sinuous antennas are obtained by combining the superformula [6, 7] with the sinuous formula [8]. In particular, upon assuming a Cartesian coordinate system, the sides of the antenna arms are defined by the following parametric equations

$$x = \frac{r\cos[\Phi(r)]}{\left\{\left|\frac{1}{a}\cos\left[\frac{m_1}{4}\Phi(r)\right]\right|^{n_1} + \left|\frac{1}{b}\sin\left[\frac{m_2}{4}\Phi(r)\right]\right|^{n_2}\right\}^{\frac{1}{b_1}}} \quad (1)$$

$$y = \frac{r\sin[\Phi(r)]}{\left\{\left|\frac{1}{a}\cos\left[\frac{m_1}{4}\Phi(r)\right]\right|^{n_1} + \left|\frac{1}{b}\sin\left[\frac{m_2}{4}\Phi(r)\right]\right|^{n_2}\right\}^{\frac{1}{b_1}}} \quad (2)$$

where

$$\Phi(r) = (-1)^p \alpha \sin\left[\frac{\pi}{\ln\tau}\ln\left(\frac{r}{R_0}\right)\right] \pm \delta \quad (3)$$

where $p = 1, 2, \ldots, N$, $N \in \mathbb{N}_0$ being the cell number, $R_{p+1} \le r \le R_p$, $\alpha > 0$ is the angular width of the cell, $0 < \tau < 1$ is the growth rate, i.e $R_{p+1} = \tau R_p$, and R_p defines the outer and inner radius of cells p and $p-1$, respectively. R_1 is the radius of the outermost cell, whose dimension controls performance at the lower frequencies, $R_N = \tau^N R_1$ is the radius of the innermost cell, whose dimension controls performance at the higher frequencies. Moreover, $a_p \in \mathbb{R}_0^+$, $n_p, m_p, b_1 \in \mathbb{R}^+$, $p = 1, 2$ are the superformula parameters.

The geometrical description provided by transformation (1)–(3) allows the tailoring of the planar sinuous-like antennas shape in a simple and analytical way by changing

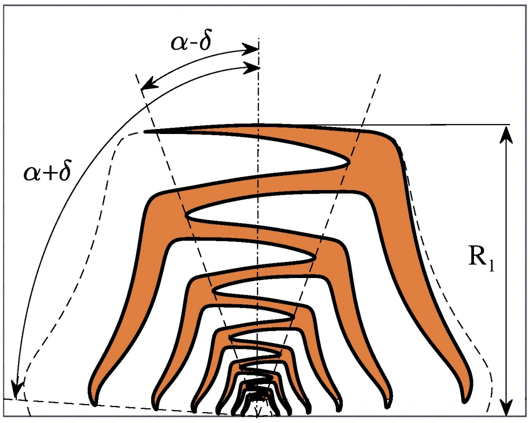

Figure 1. Supershaped sinuous with $a = b = 1$, $m = 6$, $n_1 = 20$, $n_2 = 7$, $n_3 = 18$. The used sinuous parameters are $p = 12$, $\tau = 0.79$, $\alpha = 1$, $\delta = 30°$ and $R_0 = 85$ mm.

a reduced number of parameters. The parameters m_1, m_2 identify the shape symmetry as well as the number of sectors in which the plane is folded. The parameters a_1, a_2 control the relative scale of the supershape over each sector. The values of n_1, n_2 determine whether the shape is inscribed in or circumscribing the unit circle. The parameter b_1 further determine the shape and it acts as a pull or push force on the sides of the shape. Corners can be sharpened or flattened and the sides can be straight, convex or concave.

Figure 1 shows a schematic picture of one supershaped sinuous antenna arm for a specific set of the free parameters. It is formed by rotating the curve of equations (1)–(3) by positive and negative angle δ around the origin. Moreover, two curves defined by the same equations and having angular width 2δ are used to outline the innermost and outermost sections. In this way, the whole antenna arm oscillates between the two angular limits $\pm(\alpha+\delta)$. However, respect to the conventional sinuous antenna, the arm shape can be tailored in unimaginable ways by changing just a few free parameters.

3 Numerical Results

In this study, a two-arm supershaped sinuous antenna with α, τ and δ constant for all cells is considered. The opposing antenna arms were driven by a lumped port. Moreover, to less perturb the higher operating frequency, the shape of the arms near the driving points was chosen to be bow-tie pattern. The whole design was numerically carried out using the 3D electromagnetic simulation software CST Studio Suite®. In particular, the solver based on the method of moments was used. The simulations were performed from 1 to 10 GHz and in the free space contest. Moreover, the perfectly matched layers boundary conditions, designed at the lower frequency of 1 GHz, were used to bound the computational domain. In this way the far field condition for the whole frequency band was fulfilled.

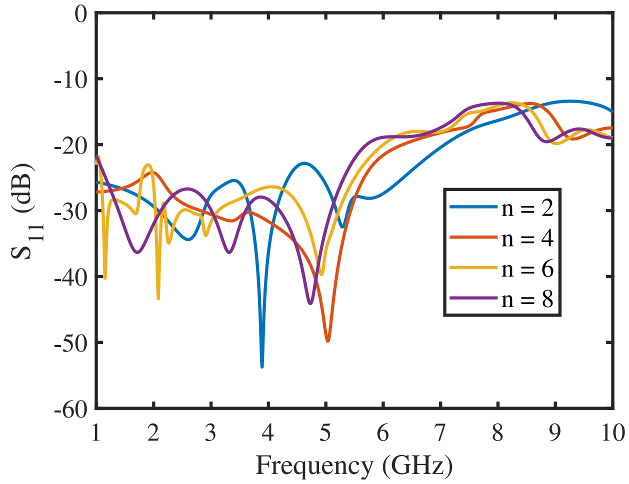

Figure 2. Reflection coefficient of the simulated antennas when referenced to 250 Ω.

A preliminary study of a self complementary structure was performed. In particular, by analyzing equations (1)–(3) we observed that the conditions for a 2-arm antenna structure to be self complementary are $\delta = \pi/4$, $m_1 = m_2 = m$, with $m = 4, 8, 12, \ldots$. All the other superformula parameters can be changed as one likes. In view of these constrain, the other design parameters used in the simulations are $\tau = 0.8$, $p = 12$, $\alpha = \pi/2$ and $R_1 = 85$ mm. Moreover, to understand the effect of shape profiles on basic antenna characteristics, a preliminary parametric study was carried out by changing the parameters n_1, n_2, b_1 so that $n_1 = n_2 = b_1 = n$.

Fig. 2 shows the simulated input reflection coefficient spectrum for different configurations of the supershaped sinuous characterized by $n = 2, 4, 6, 8$, respectively. It is worth noticing that all the antennas operate with a reflection lower than -10 dB in the whole frequency range. Moreover, the modification of the antenna arms does not deteriorate the impedance matching bandwidth. The simulated boresight realized gain versus frequency is shown Fig. 3 for the different values of the parameter n. Thanks to the arms reshaping it is possible to modify the antenna gain in term of amplitude and flatness. In particular, quite high values close to 7 dB can be obtained.

The simulated radiation pattern, at the frequency $f = 10$ GHz is illustrate in figure 4. As expected, the radiation is bidirectional, and the main lobe amplitude is about 5.5 dB with half power beam width of about 76° and 72° on the $\phi = 0°$ and $\phi = 90°$, respectively. The simulation results indicate that the considered supershaped sinuous antenna exhibits similar patterns on the principal planes (azimuth=0 degrees and elevation=0 degrees).

4 Conclusions

In this paper, a novel class of antenna, called supershaped sinuous antenna, was presented. We have developed an

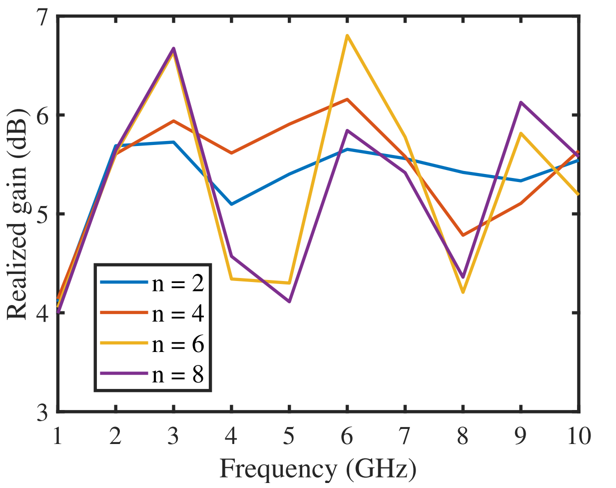

Figure 3. Realized gain versus the frequency for different antenna arms shape.

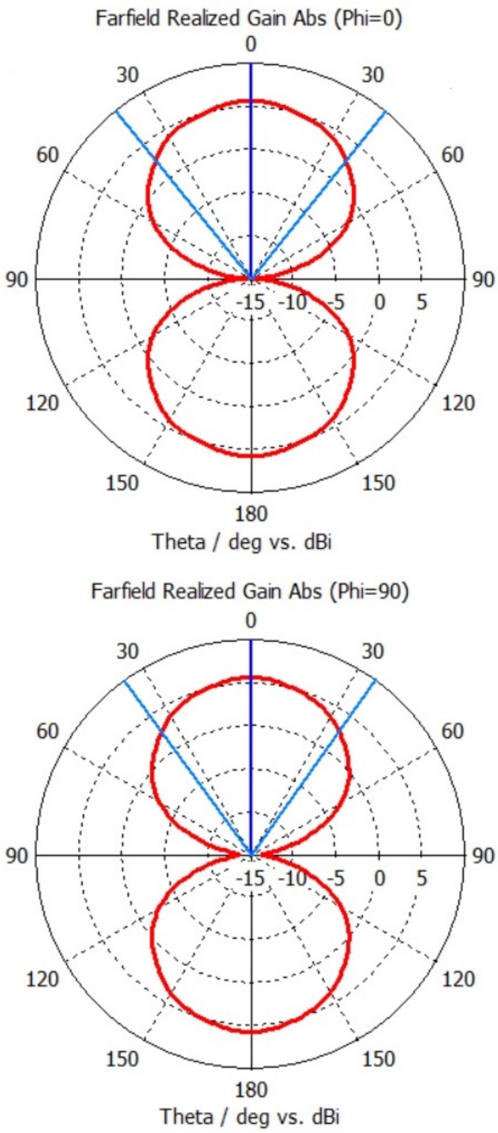

Figure 4. Far field pattern at the frequency $f = 10\,\mathrm{GHz}$ for the supershaped sinuous antenna characterized by $m_1 = m_2 = m = 4$ and $n_1 = n_2 = b_1 = 4$.

analytical approach based on the reshaping of the conventional sinuous antenna arm by using a novel mathematical formula. The illustrated preliminary results, highlighted the huge potentials of the proposed model for the tailoring of the antenna performance as well as to retrieve the optimal arms shape useful to achieve the desired antenna performance. Moreover, the proposed model could be usefully adopted to design complex antennas allowing performance improvement in terms of gain, bandwidth, impedance matching, radiation efficiency and radiation pattern characteristics as well as to reduce the antenna size.

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