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Novel Miniaturized Sinuous Antenna for UWB Applications

Claudio Maria Lamacchia(1), Michele Gallo(1), Luciano Mescia(2), Pietro Bia(3), Domenico Gaetano(3), Christian Canestri(3), Cosmo Mitrano(3) and Antonio Manna(3)
(1) IAMAtek s.r.l. Bari, Italy, https://www.iamatek.com
(2) Politecnico di Bari, Bari, Italy
(3) Design Solution Department, Elettronica SpA, Rome, Italy, https://www.elt-roma.com

Abstract

This paper presents the design of an ultra-wideband (UWB) four arms non-conventional sinuous antenna exploiting the advantages of two optimized miniaturization techniques. The antenna works from 1.5 GHz to 18 GHz, radiating a slant 45 polarization. It is printed on a dielectric substrate having a diameter of 6 cm. Finally the antenna exhibits good matching properties, high realized gain and directive stable patterns over the entire frequency range.

1 Introduction

In the last few years, wireless applications require devices with a large number of functionalities while the size has dramatically decreased. Antennas, however, do not follow the same evolution since they are strictly connected to the electrical dimensions (i.e. dimensions compare to the wavelength). Consequently, antenna miniaturization is always a trade off between dimensions and radiation characteristics [1]. For ultra-wideband radiating elements, this challenge is even harder since gain, beam width and efficiency must be properly guaranteed. Antenna families that theoretically have these radiation characteristics are the frequency independent antennas [2]. These antennas have a structure defined only by angles and the current on their structure decreases with the distance while it is propagating. When the current intensity becomes negligible, the structure can be truncated and considered as infinite. This characteristic makes the antenna frequency independent while the truncation fixes its lowest operating frequency. The highest operating frequency is limited by manufacturing constraints or by the feeding network.
A well-known “quasi” frequency independent antenna is the sinuous one [3]. Its broad impedance bandwidth, its low profile and the stability of its radiation characteristics are very attractive features to be used in several wireless applications. Sinuous antennas are capable of radiating waves with two orthogonal senses of polarizations. Respect to the spiral antennas, four arms sinuous antennas could allow circular, linear and slant-45 polarizations [4]. The radiation pattern is bidirectional even if, sometimes, these antennas are loaded with a cavity to obtain unidirectional pattern. Unfortunately, the introduction of a cavity not only complicates the structure but also deteriorates the performances of the original sinuous due to the reflected backward radiation or to the power dissipation by absorbers.
In this paper, a four-arm miniaturized sinuous antenna has been designed. The antenna exhibits bidirectional radiation, slant-45 polarization and wideband performance within the frequency range 1.5 GHz to 18 GHz. However, reducing the antenna size will influence its bandwidth, gain, efficiency and polarization. This paper proposes two miniaturization techniques aimed at obtaining the best overall performances. A suitable meandering of the antenna geometry has been used to increase the current path an then the equivalent electrical dimension. Moreover, a special arrangement of high-contrast materials has been designed to suitably change the current phase velocity.

2 Antenna Design and Results

The design of the proposed antenna starts by modifying the conventional sinuous antenna introduced by Duhamel [3]. The dielectric substrate is RT/Duroid® 5880LZ with thickness of 0.127 mm and diameter equal to 6 cm. The proposed miniaturization techniques are able to improve the low frequency radiation characteristics maintaining the same outer dimensions. First of all, a reactive loading has been implemented. In [5], lumped elements have been distributed on the antenna, but this approach compromises the band at high frequency due to the losses of lumped elements and the soldering. In order to overcome this drawback, the antenna could be loaded with distributed inductance by meandering its arms [6]. In this way, the total shape of the antenna have been meandered but the resulting ripples in the internal cells disturb the high frequency affecting the input impedance and gain. Since the external cells of the antenna radiate in the lower part of the frequency band, the present design considers only the meandering of the external section of the sinuous profile (see Figure 1 (a)).
To obtain the meandering of the outer cell, the conventional sinuous equation has been modified as follow:

$$R = t\left[1 + r_p \cos\left(\zeta\phi\right)\right] \qquad \tau R_1 \le t \le R_1$$
$$\phi = \left(-1\right)^p \alpha \sin\left[\frac{\pi}{\ln\tau}\ln\left(\frac{t}{R_1}\right)\right] \pm \delta \tag{1}$$

where τ is the expansion factor, δ is the angular width, R_1 is the outer radius, ζ is the number of meanders, r_p is the relative amplitude, α is the angular expansion.

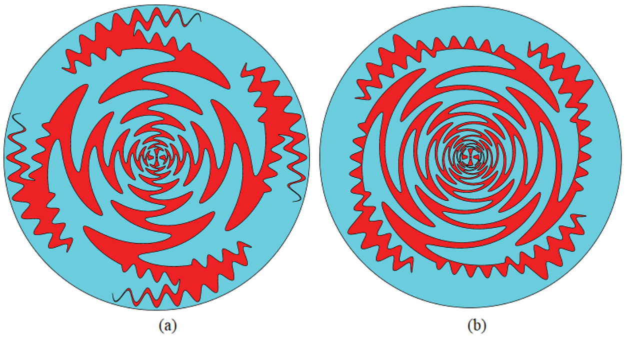

Figure 1. Modified meandered sinuous antenna with (a) and without (b) sharp ends.

The optimized design parameters are R_1=30 mm, p = 12, $\alpha = \pi/6$, $\delta = \pi/10$, τ = 0.79 and ζ=45.

As demonstrated in [6] the gain flatness improves by removing the sharp ends of the antenna. In fact, these sharp ends resonate when their length is half wavelength and create undesirable spikes in the input impedance and in the antenna gain. To this aim, a parametric study has been carried out to find the suitable shape of the sharp ends. The resulting antenna geometry is reported in Figure 1(b). A new parameter t_R has been introduced to control the reduction of the sharp ends. The optimized t_R value makes possible the improvement of gain flatness and half power beam width (HPBW). Figure 3 shows the realized gain versus frequency and t_R parameter. It is possible to note that, for t_R higher than 10 mm the spikes at low frequency disappear, as well as the realized gain is flat from 2 GHz to 8 GHz.

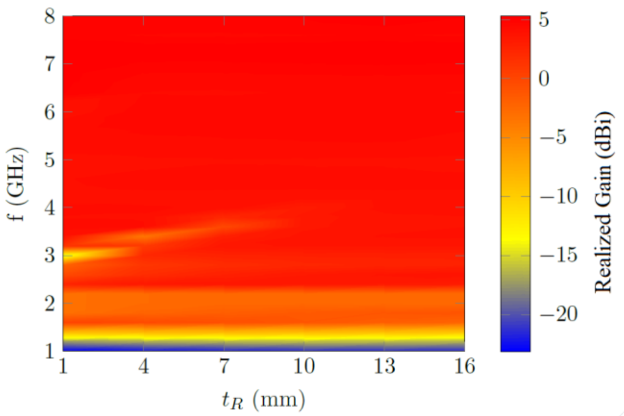

Figure 3. Realized gain of the antenna versus frequency and the t_R parameter.

The optimized antenna structure is then loaded through a special arrangement of high-contrast dielectric cylinders placed on the back of the dielectric antenna substrate. As shown in Figure 4, ten concentric cylinders have been considered. Each one has a thickness of 1 cm, a proper dielectric permittivity, and a radial-dependence of the width. The permittivity and width of each cylinder have been chosen to reduce the velocity of the current wave on the antenna in order to achieve the desired miniaturization. A parametric study has been carried out obtaining the following values for each section: ε_{r1}=1; ε_{r2}=1; ε_{r3}=1.5; ε_{r4}=2; ε_{r5}=2.5; ε_{r6}=3; ε_{r7}=3.5; ε_{r8}=4; ε_{r9}=5; ε_{r10}=6. The simulated boresight realized gain versus frequency is shown in Figure 5 for the standard and optimized sinuous structure. Thanks to the meandering shape with sharp end cuts and the dielectric concentric cylinders, the minimum working frequency is shifted from 2.9 GHz to 1.5 GHz. Moreover the optimized boresight gain has a stable behavior inside the interested frequency band. The simulated radiation pattern, at the frequency f=8 GHz, is shown in Figure 6. As expected, the radiation is bidirectional, and the main lobe amplitude is 5.2 dBi with a HPBW of about 65 degrees. The simulation results indicate that the designed sinuous antenna presents high realized gain and similar patterns on the principal planes (azimuth=0 degrees and elevation=0 degrees).

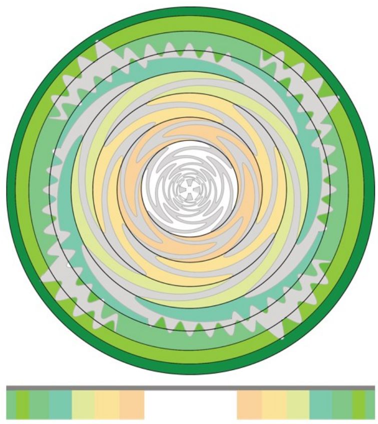

Figure 4. Sketch and projection of the high-contrast dielectric cylinders. Each colour identifies a dielectric with different $\boldsymbol{\varepsilon_r}$.

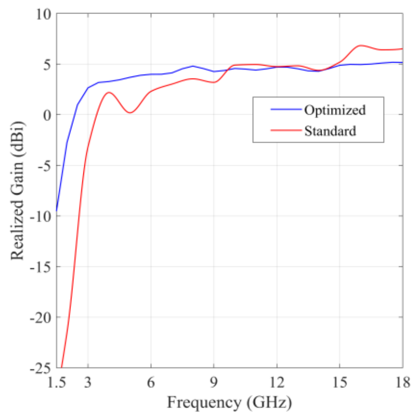

Figure 5. Boresight realized gain versus frequency for slant-45 polarization in case of standard and optimized sinuous structure.

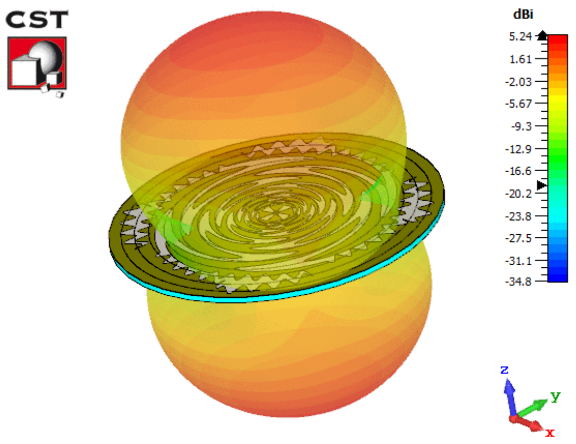

Figure 6. 3D radiation pattern of the sinuous antenna at frequency f=8 GHz.

3 Conclusions

In this paper, the design of an ultra-wideband (UWB) four arms non-conventional sinuous antenna has been described. The antenna has been properly miniaturized to work from 1.5 GHz to 18 GHz with a diameter of 6 cm. Two miniaturization techniques have been used. The first one considers the implementation of equivalent inductive loads by meandering the outer cells of the sinuous profile. The second one exploits special concentric cylinders with optimized width and permittivity that are placed on the back of the antenna dielectric substrate. Simulations provide good matching, directive stable patterns and high realized gain.

7 References

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