Compact Shaped Antennas for Wide-Band Radiogoniometry

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Abstract **─** In this paper, a wide band monopole antenna with a shaped profile is presented. Shaped profile and end-caps allow for a compact antenna with respect to wavelength. Antenna is designed to be as isotropic as possible and with low phase deviation from spherical wave front to allow accurate detection of the direction of arrival of an unknown signal when used in radiogoniometry applications.

Index Terms **─** Antennas, shaped monopole, radiogoniometry, wide-band antennas.

I. INTRODUCTION

As part of the safety-related control of the territory, it is important to locate vehicles, aircraft or vessels not only actively, using surveillance radars, but also passively, on the basis of the electromagnetic emissions, intentional or not, of the target. This second system, or passive radar, detects the direction of the origin of the signal emitted by the target or emitted by an unrelated source and scattered by the target itself like a radio or television broadcasting station [1-3]. Of course, if more than one system is deployed, by integrating the data from each system, a 3D localization of the target is possible. Being the system fully passive, only a receiving chain is necessary and complexity, size and power consumption are much reduced with respect to an active radar.

On the other hand, while the antenna of an active radar must be highly directive and can be relatively narrow banded, the antenna of a passive detector must be necessarily as omnidirectional as possible and must cover the largest possible bandwidth, since it is not known a priori neither the position nor the emission spectrum of the target; direction of arrival of the signal being computed by comparing the delays with which signal is received from two or more antennas of the single system [1-3].

Broad band antennas are usually bulky and large, the dimension being comparable to the wavelength of the lowest working frequency. If a system is to be at the same time efficient but compact and possibly having a reduced impact on landscape, antenna must be conveniently miniaturized.

In this context, an electrically small antenna (ESA) is an antenna whose maximum dimension is less than $\lambda/2\pi$ (radianlength) [4,5]. Small antennas fitting this definition radiate the first order spherical modes of a Hertzian dipole and hence, are quite close to omnidirectional. Yet the main issue of an ESA is the presence of a strong reactive behavior in its input impedance which severely impairs radiation characteristics and band. Several techniques exist to solve this issue: it is possible to load the antenna with lumped elements or metamaterials inspired elements [6-9], alternatively, the electrical path of the currents can be made longer by folding conductors or applying appropriate sinuous shapes [10-14].

In this contribution the second technique is applied, and a printed monopole with a fractal-like profile designed. A shaped end cap is also added to further lengthen the current path without making the antenna too high. Particular attention has been given to the phase of antenna pattern in azimuth, since phase fluctuations directly reflect on direction finding errors. Being the antennas to be placed around a circle, with varying orientation, phase uniformity in azimuth is a key point in this application. The proposed design has then been realized and measured.

The paper is organized as follows. Section II presents the antenna design. Section III reports the comparison between simulations and measurements results. Finally, Section IV draws some conclusions.

II. ANTENNA DESIGN

The aim of this project has been the design,

Submitted On: July 31, 2015
Accepted On: February 14, 2016

optimization and realization of a high performance small antenna for direction finding applications.

The element presented in this paper is a monopole antenna placed over a circular ground plane, working in the frequency range 600 MHz – 3 GHz. The key feature of the monopole is keeping a small size even if it operates in a wide band, about 2.3 octaves (Fig. 1). Although the present paper concentrates on a single element, an array of such elements placed along a circumference on a conducting disk is the final goal.

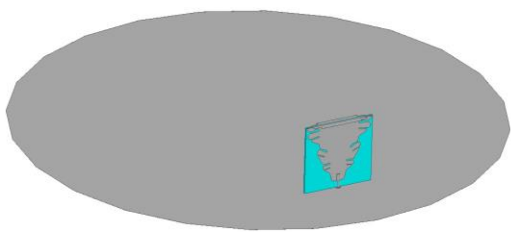

Fig. 1. Monopole antenna over a circular ground plane. Plane diameter is 300 mm, the antenna is placed at 125 mm from the disk center.

The element has been designed starting from a standard Bow-Tie Antenna (BTA), which has been modified improving its geometry with fractal based contour shaping. Furthermore, a fractal based contour shaping plate has been added at the end of the structure. These modifications allowed to extend the electric path of the currents achieving a better behavior in the lower-band of the antenna, without a significant increasing in its sizes.

The antenna shape derives from a spline base element whose shape is governed by 10 control points (Fig. 2), which is iterated and, at each iteration, rotated by α = -30° on odd iterations, by α = 30° on even ones, and scaled by a k = 0.2 scaling factor [15]. Dimensions, control points positions, and number of repetitions have been numerically optimized via genetic algorithms [16], so as to minimize the reflection loss, attaining the profile in Figs. 3, 4.

Miniaturization is also achieved via end-caps which, extending the antenna in the third dimension, allows for a better filling of Chu's sphere. End-caps are themselves realized with a sinuous contour devised, again, to allow extended paths for currents.

The monopole is fed by a 50 Ω coaxial cable passing through the aluminum ground whose probe is directly connected on the antenna surface. The element is printed over a DE104 (ε_r = 4.46 @ 100 MHz, tanδ = 0.023 @ 2 GHz) substrate 1.6 mm thick and covered with a 0.0018 mm thick copper metallization. The whole antenna spans a box 56x10x50 mm^3, considering the 10 mm wide end-cap (Figs. 3, 4).

The behavior of antenna has been simulated numerically in the shape optimization phase of the design. To have a most realistic simulation both the finite aluminum ground and the coaxial cable connector were considered in the numerical model.

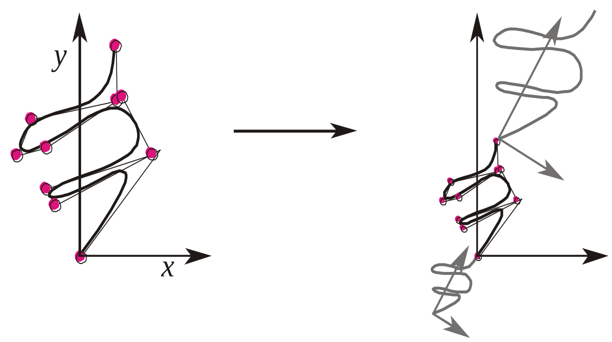

Fig. 2. Profile primitive (spline control points in purple) and profile generation by scaled replication.

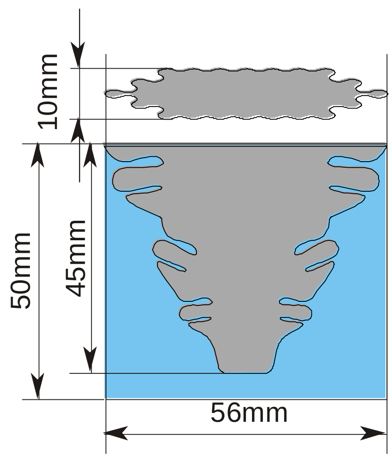

Fig. 3. Antenna basic layout and dimensions.

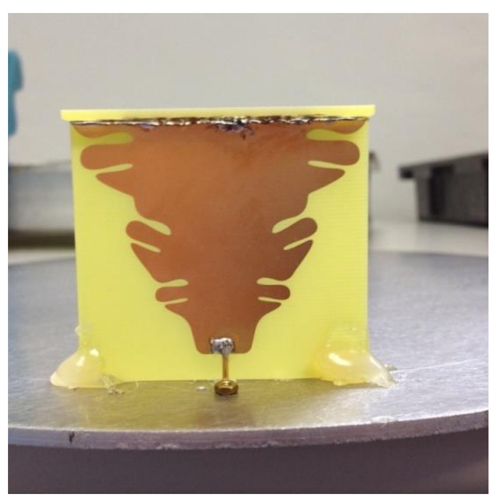

Fig. 4. Prototype of the monopole antenna

III. MEASUREMENT RESULTS

The realized prototype is shown in Fig. 4 and the results of its measurements have been compared to simulations.

Figure 5 presents the comparison between simulations and measures for S_{11}, an excellent agreement is shown. Hatched rectangle shows requirements. An $|S_{11}|<-5$ dB is considered acceptable. Requirements are relaxed in comparison to standard ones, but key point in the application is band, not matching.

Measures were carried out in the University of Florence semi-anechoic chamber, which is 3500 mm x 4900 mm x 3000 mm, with anechoic multilayer wideband absorbers Eccosorb An-79, made of polyurethane foam loaded with graphite featuring an optimized conductance profile, for a reflection coefficient amplitude of at least -17 dB.

Signal generator is an Agilent Technologies E4438C, capable of sweeping from 250 kHz to 6 GHz, with -136 dBm to 25 dBm output. For the receiving side, the Agilent (Hp) 8596E spectrum analyzer was used, capable of spanning 100 kHz - 12.8 GHz in AC with a resolution bandwidth from 1 kHz to 3 MHz.

Measurements were made exploiting two identical realization of the proposed antenna, one transmitting and one receiving.

Figure 6 shows experimental results for the phase of the received signal as a function of frequency and for two values of the elevation angle. Phase is given as an average over the azimuth angle. Error bars at $\pm 2\sigma$ with respect to average, σ being the standard deviation, shows the limits within which 95% of the phase values fall. As it can be seen phase variation along azimuth is very limited. This being the most relevant aspect in accurate radiogoniometry. Gain patterns are nearly omnidirectional, with a variance of less than 1.8 dB over the whole azimuth angle, and are not reported for brevity. This is due to the ground plane, being the antenna placed next to the border, which deteriorates the pattern symmetry. System specifications allowed for a maximum variance of 2 dB, hence results satisfy them. Finally, Fig. 7 shows simulated and measured gain for the proposed monopole, while Fig. 8 shows the realized gain at centerband; good isotropy can be observed on azimuth. It must be noted that simulations concerned the dipole plus the finite ground disk in free space, while measurements were carried out in the semi-anechoic chamber at the University of Florence, hence fluctuations in the measured gain are due to multipath. It is anyway important to note that such fluctuations are very close to simulations results, as the best fit dotted line in Fig. 7 shows.

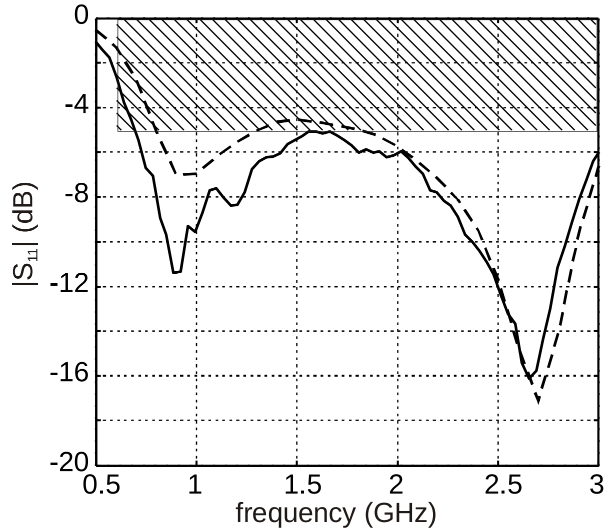

Fig. 5. |S11| for the monopole antenna. The figure shows the comparison between simulation result (dashed line) and measured result (solid line).

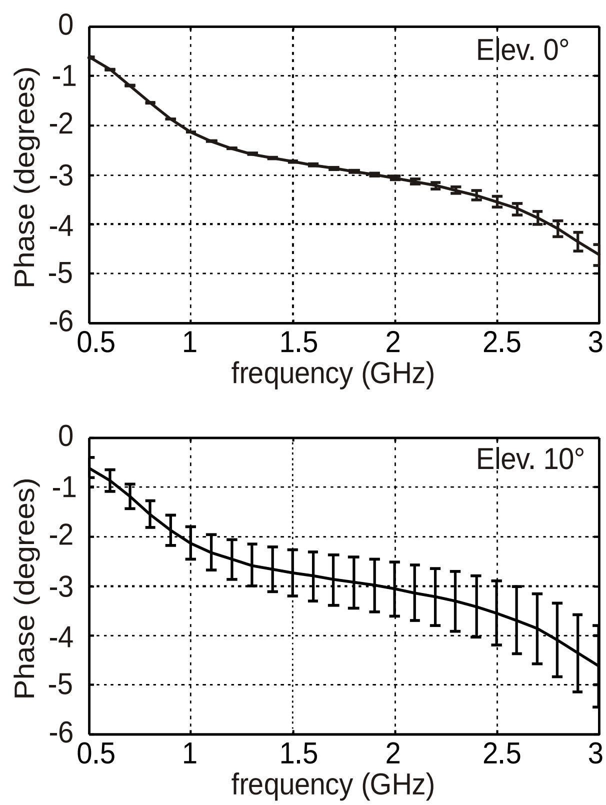

Fig. 6. Average and standard deviation of the received signal phase over azimuth, for elevation equal to 0 (top) and 10° (bottom).

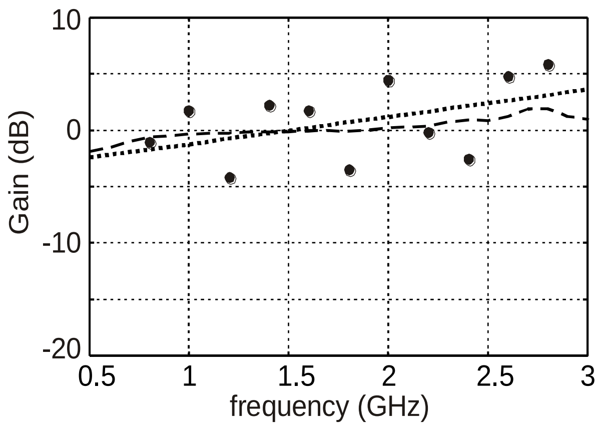

Fig. 7. Simulated (dashed line) and measured (bullets) gain for the proposed antenna. Dotted line represents a first order polynomial best fit on the measured gain.

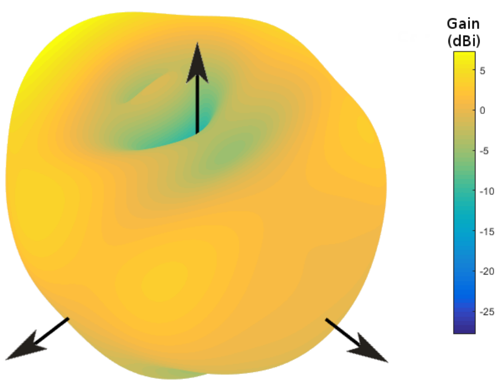

Fig. 8. Simulated realized gain for the proposed antenna.

VI. CONCLUSION

Preliminary results for a compact UWB monopole antenna for radiogoniometry have been presented, measured data fit well with simulations and prove the effectiveness of the proposed fractal-based design.

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