Fully Metallic Crooked Wire Antenna for UHF RFID Tags

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***Abstract*—In this paper, a 3 dimensions (3D) fully metallic antenna for an RFID tag is presented. It is a crooked wire monopole antenna. Close to the frequencies of the European UHF RFID band, it exhibits an input impedance that is the conjugate of the one of the Monza R6 chip. The latter with the proposed antenna presents a reading range of 11.87 meters and occupies a volume of 23 mm x 23.4 mm x 23.8 mm. This 3D tag structure could be useful for applications in metallic environments or applications in very severe environments where nonmetallic materials are useless such as in some aerospatiale applications. With a simple meander antenna, the proposed antenna, the reading range is approximately 6m.**

Keywords— Crooked wire antenna; Radio Frequency Identification (RFID); RFID chip.

I. INTRODUCTION

With the development of microelectronics technology, the usage of embedded systems that include wireless communication units is rapidly increasing rises in both civil and industrial domains. In these domains, Radio Frequency Identification (RFID) is one of the most popular wireless techniques. Its usage varies from simple identification to more advanced applications such as sensing and localization. New developments of RFID chip has to be accompanied with a parallel step towards novel antennas that are more efficient, more compact, and less expensive. Traditionally, RFID tags employ planar antennas realized on Printed Circuit Board (PCB). This includes a wide type of designs like dipoles, meander dipoles, bowtie antennas [1], [2]. These antennas present good performances and does not usually require a very complex fabrication process. On the other hand, obtaining good performances with smaller topologies becomes a challenge because the antenna efficiency decreases with its size reduction. Moreover, antenna substrates (dielectrics and ceramics in most cases) does not always behave well in some extremely severe environments. Also, a degradation of the antenna efficiency is caused by the lossy nature of these materials.

An alternative to such antennas on PCB could be a fully metallic antenna, like a wire one. It has a very high radiation efficiency because dielectric and ohmic losses are eliminated (almost totally in the second case). However, obtaining antennas that present a specific impedance value at a given frequency is a complicated subject for antennas whose size is much smaller than λ. In the present work, this difficulty is solved by using an optimization tool based on multi-objective genetic algorithms. The goal is to design a fully metallic wire antenna that fulfills the requirements of small size and high efficiency at the frequency of the European RFID band: 866 to 868 MHz.

First presented in 1997 by E. Altshuler [3], crooked wire topology has shown its great potential in solving very challenging tasks. Since then, it was used to design, wideband antennas [4], electrically small antenna [5], [6] and to optimize antennas radiation pattern and gain [7]–[9].

In this work, an antenna having the conjugate value of the Monza R6 chip input impedance optimized using CST Microwave Studio in conjunction with Matlab. A proof of concept prototype is realized and measured. In section II, the antenna design is presented and discussed. In Section III, simulation and experimental results obtained with a prototype are presented, compared, and discussed.

II. TAG DESIGN

The topology used in this work is based on a fixed number of straight segments oriented arbitrarily in space. Each straight segment is characterized by three variables: the length, l_i, the azimuth angle, φ_i, and the elevation angle, θ_i. The values of these variables describe the size and orientation of each segment in space. Elevation angles are restricted to $[0 - \pi/2]$ while azimuth angles are not restricted: $[0 - 2\pi]$. The minimum length of a segment is limited to 2.5 mm to avoid fabrication complexities. The maximum length is 0.1λ to avoid priorly bulky structures, λ is wavelength at the frequency 867 MHz, which is equivalent to 35 mm. The radius of all segments is fixed to 0.65 mm.

The implemented optimization algorithm starts by generating N arbitrary individuals. After evaluating the fitness functions of each individuals based on the results of electromagnetic simulations, a selection process using the non-dominated sorting method [10] and the crowding distance criterion [11] is realized to choose the best individuals. The later will survive to form the next generation after the mating and mutation processes.

A geometrical filter is also implemented with the optimization algorithm to avoid topologies considered unrealizable or incorrect. This includes topologies with intersecting segments, ground plane penetration, and topologies with very sharp angles (less than 25°). Fig. 1 shows an example of a 3D crooked wire antenna that has four segments. It is also important to mention that the optimization is elaborated over a ground plane considered infinite for simplification reasons. This makes this type of antennas suitable in metallic environments.

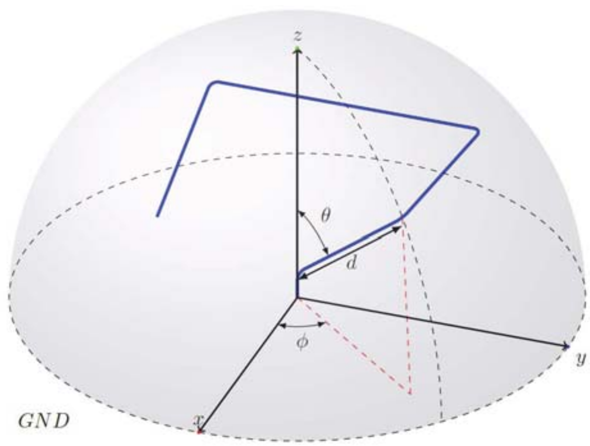


Fig. 1. 3D structure of a crooked wire antenna with four segments.

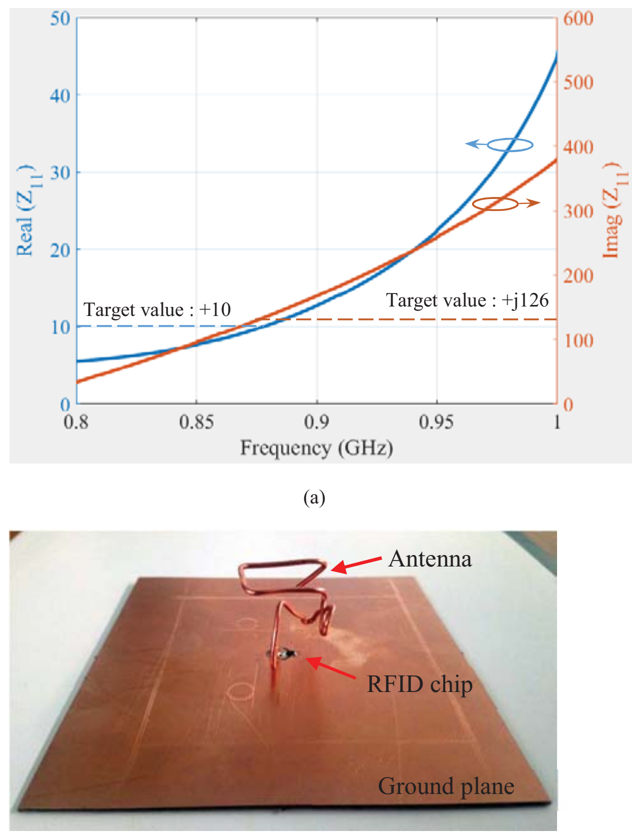
Every iteration, individuals' electromagnetic properties are simulated, and with it, the fitness functions of each individual is calculated. In this work, three fitness functions are used: the maximal size of the antenna, the real part of the input impedance of the antenna and its imaginary part. It concerns the antenna size and its input impedance. Table 1 resumes the implemented fitness functions.

TABLE I
FITNESS FUNCTIONS

	Expression
f_1	Antenna maximal size
f_2	Real ($Z_{antenna}$) - Real (Z_{chip})
f_3	Imag ($Z_{antenna}$) + Imag (Z_{chip})

The fitness functions mentioned in Table 1 are calculated in the frequency range 840-880 MHz with a sampling of 1 MHz. The average of the 31 samples is calculated to produce the values of f_2 and f_3. The first fitness function produces the minimization of the antenna size while the second and third fitness functions forces the antenna impedance to the conjugate value of the input impedance of the RFID chip. The non-dominated sorting method minimizes all three functions simultaneously.

After almost 150 generations with a population of 512 individuals, the optimization tool halted since it reached a point where no significant amelioration between two generations is observed. A topology with the best fitness values among the last generation is chosen. The topology is first re-simulated in a more accurate environment that includes the RFID chip MONZA R6 [12] package and a finite ground plane of a size of 100 mm x 100 mm. The simulated input impedance of the designed tag antenna shows a real part very close to 10 and an imaginary part of +j133 close to 867 MHz. The impedance of the MONZA R6 chip is 10 -j126@867 MHz.



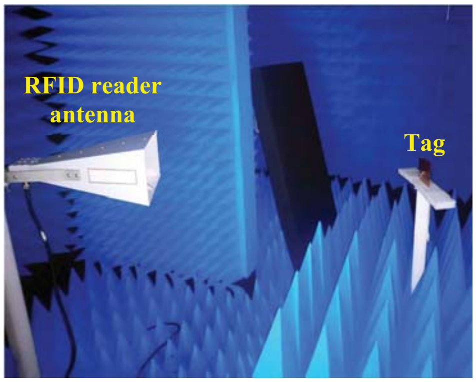
(a)

(b)

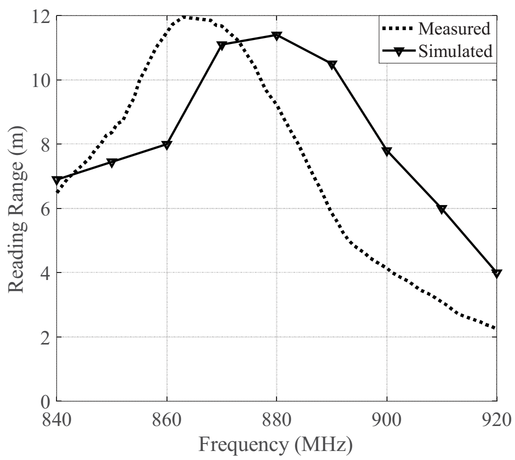
Fig. 2. Selected design. (a) Simulated real and imaginary input impedance. (b) The fabricated 3D crooked wire RFID tag.

III. PROTOTYPE AND EXPERIMENTAL CHARACTERIZATION

A prototype of the chosen solution was realized as illustrated in Fig. 2(b). The fabrication of the antenna was hand-made assisted with a 3D printed polymer model to reduce fabrication errors. A copper wire of a radius 0.65 mm is employed, bending was done manually. The antenna occupies a total volume of $\lambda/15 \times \lambda/14.8 \times \lambda/14.56$ where λ is the wavelength at the frequency 866MHz. The RFID chip is connected to the antenna on one end and to the ground plane on the other end.



(a)



(b)

Fig. 3. Tag characterization. (a) Measurements environment. (b) Measured and simulated reading range.

The tag is measured in an anechoic chamber, as illustrated in Fig. 3(a)with the Voyantic UHF RFID system. The simulated and measured reading range of the fabricated prototype is shown in Fig. 3(b). As it can be seen, the measured values have the same behavior as the one simulated but with a shift towards lower frequencies. This can be explained by the fact that the fabricated prototype is slightly longer than it should be because of the hand-made fabrication process. The additional length is the accumulation of the wire length in the bents areas which makes the current path longer than expected. The fabricated tag presents a maximal reading range of 11.87 m at the central frequency of the European UHF RFID band: 867 MHz while it is 11.3 m at 880 MHz for simulation. It's important to mention that the MONZA R6 RFID chip can perform the auto-tuning. This feature gives to the chip the ability to adjust its capacitive impedance part to assure the best adaptation impedance with load (antenna). It worth nothing that the tag also response in the American RFID UHF band, 902 to 928 MHz. The measured reading range at 915 MHz is 2.6 m.

IV. Conclusion

In this paper, a 3D RFID tag based on a crooked wire antenna is optimized, realized, and measured. The tag shows good performances in terms of adaptation and efficiency at the desired frequencies. Further results will be presented at the conference.

References

[1] K. H. Lin, S. L. Chen, and R. Mittra, "A looped-bowtie RFID tag antenna design for metallic objects," *IEEE Trans. Antennas Propag.*, 2013.

[2] B. D. Braaten, M. Reich, and J. Glower, "A compact meander-line UHF RFID tag antenna loaded with elements found in right/left-handed coplanar waveguide structures," *IEEE Antennas Wirel. Propag. Lett.*, 2009.

[3] E. E. Altshuler and D. S. Linden, "Wire-antenna designs using genetic algorithms," *IEEE Antennas Propag. Mag.*, 1997.

[4] E. E. Altshuler and D. S. Linden, "An Ultrawide-Band Impedance-Loaded Genetic Antenna," vol. 52, no. 11, pp. 133–136, 2004.

[5] H. Choo, R. L. Rogers, and H. Ling, "Design of electrically small wire antennas using a Pareto genetic algorithm," *IEEE Trans. Antennas Propag.*, 2005.

[6] F. Benmahmoud, P. Lemaitre-Auger, and S. Tedjini, "Design of electrically small 3D wire antennas for UHF RFID applications using genetic algorithm." 32nd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS). IEEE, 2017.

[7] J. D. Lohn, D. S. Linden, B. Blevins, T. Greenling, and M. R. Allard, "Automated synthesis of a lunar satellite antenna system," *IEEE Trans. Antennas Propag.*, vol. 63, no. 4, pp. 1436–1444, 2015.

[8] G. S. Hornby, J. D. Lohn, and D. S. Linden, "Computer-Automated evolution of an X-band antenna for NASA's space technology 5mission," *Evol. Comput.*, vol. 19, no. 1, pp. 1–23, 2011.

[9] A. Ghosh and M. K. Das, "Non-dominated rank based sorting genetic algorithms," *Fundam. Informaticae*, 2008.

[10] N. Hallam, G. Kendall, and P. Blanchfield, "Handling Diversity in Evolutionary Multiobjective Optimistion," 2005.

[11] Datasheet of Impinj Monza R6 UHF RFID Microchip accessed on July. 21, 2019. [Online]. Available: https://support.impinj.com/hc/en-us/articles/202765328-Monza-R6-Product-Datasheet.