3D HF RFID Reader Antenna for Tag Detection in different angular orientations

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***Abstract*—Herein, a 3D 13, 56 MHz (HF) RFID reader antenna is proposed in order to optimize detection performance whatever the tag angular positioning. The design is made of a multi-loop structure, based on serial complementary antennas, as said “twisted” antennas. The RFID tag detection is optimized by two factors which rely on the modifications of the magnetic field (i) vectorial distribution and (ii) magnitude density. The reader antenna design is analyzed with electromagnetic simulation under HFSS (High Frequency Electromagnetic Field Simulation), and validated by detection measurements, in coplanar mode. A multi-loop structure, composed by 4 sub-loops, is then conformed onto a tube surface to provide the 3D structure. The goal of this improvement is to provide tag detection for any angular positions. At the center of the tube (3D reader structure), the detection of the tag is performed whatever its angular orientation, that is to say for any radial orientation.**

Keywords—HF RFHD; magnetic coupling; reader antenna; detection, 3D antenna

I. INTRODUCTION

HF RFID (High Frequency Radio Frequency IDentification) systems are used in several applications for tracking and logistics. An inductively coupled RFID HF system is based on the magnetic coupling between the reader and the tag loops [1]. The main drawback of such RFID technology is the difficulty in providing a sufficient magnetic coupling for different scenarii of tag orientation and positions. This is all the more difficult than the tag size is small compared to the reader loop antenna. Herein, we focus on the case of small tags falling into a tube of detection, as can be used for any small tagged object in logistic applications. The challenge of the proposed system is to improve range and tag detection in function of its position and especially orientation. To optimize the generated magnetic field distribution, and consequently the ability of magnetic coupling with small tags for any orientation, the reader antenna must have large size and a complex structure made of complementary sub-loops [2]. A current challenge in HF RFID is to increase the surface and the volume of detection by changing the shape of the reader antenna [3][4][5][6]. In the state-of-the-art bibliography, several reader antennas are proposed in coplanar or 3D model and the range and the surface of detection are often maximized in parallel configuration [5][7][8]. However, all other angular orientations of the tags, especially for a perpendicular configuration, reach their limit of detection close to the antenna loop.

In this study, an improvement of tag detection ability is obtained by using complementary loops conformed onto the tube external surface. The sub-loops of the proposed design allow to reduce the difference in size between the tag and the reader loops, and consequently to increase the magnitude of the mutual coupling values. Additionally, these complementary sub-loops modify the distribution of the magnetic field above their common edges. The design is validated by HFSS electromagnetic simulations and measurements of detection in parallel and perpendicular configuration. The same design is used to realize the 3D structure. The use of complementary loops consequently creates a peak of equivalent mutual inductance, which is fruitful in the 3D structure for a randomly orientated tag.

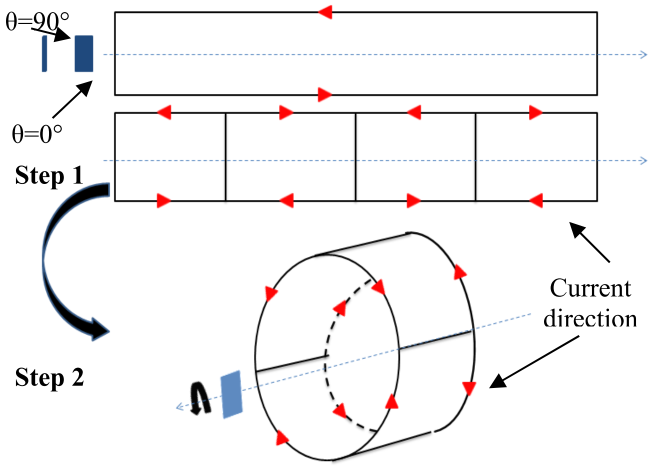


Fig.1 Proposed design antenna in coplanar (step 1) and 3D model (step 2)

II. STEP 1:COPLANAR DESIGN

The proposed structure in Fig.1 has four sub-loops of (10x17cm^2). The tag coil corresponds to 7% of the surface of the conventional antenna (10*68cm^2), while in the proposed design the tag coil corresponds to 26.6% of each sub-loop size.

The use of sub-loops fed with opposite phase current creates the reorientation of the magnetic field lines at the common zones between each two juxtaposed sub-loops (Fig. 2a,2b). Also the magnitude field is also improved with the multi-loop antenna compared to the conventional antenna (Fig. 2c,2d).

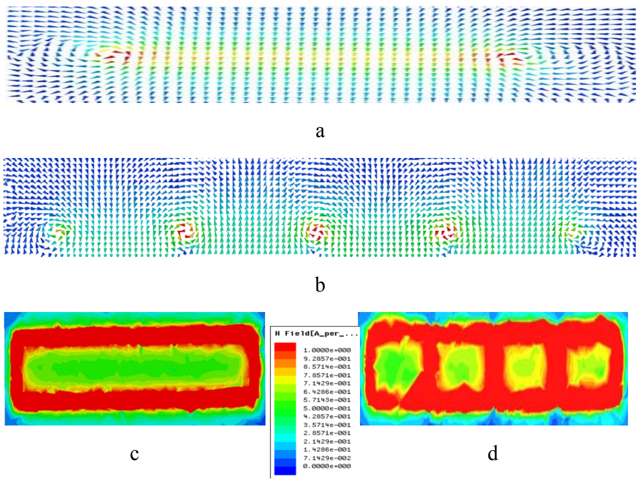


Fig. 2. Lines and magnitude of the magnetic field for conventional reader antenna (a, c) and the proposed multi-loop antenna (b, d)

A. Theoritecal study

HF RFID detection is based on load modulation. The performances are depending on the distance and positioning (lateral and angular) between the tag and the reader. In this study the evaluation of the performance is based on mutual inductance value in function of the position.

In conventional configuration, the mutual inductance is calculated by the Neumann formula as:

$$M = \frac{\mu_0}{4\pi}\left[\oint_{\Gamma_R} \oint_{\Gamma_T} \frac{\overrightarrow{dl_R}.\overrightarrow{dl_T}}{d} \right] \quad (1)$$

Where, Γ_R and Γ_T are the two circulations fed respectively by the currents I_R and I_T. d is the distance between each elementary displacement In the case of a multi-loops antenna design, the mutual inductance is the sum of the mutual inductances between the tag and each one of the sub-loops R_1, R_2 , R_3: and R_4

$$M = \frac{\mu_0}{4\pi}\left[\begin{array}{l} \oint_{\Gamma_{R_1}} \oint_{\Gamma_T} \frac{\overrightarrow{dl_{R_1}}.\overrightarrow{dl_T}}{d} + \oint_{\Gamma_{R_2}} \oint_{\Gamma_T} \frac{\overrightarrow{dl_{R_2}}.\overrightarrow{dl_T}}{d} \\ + \oint_{\Gamma_{R_3}} \oint_{\Gamma_T} \frac{\overrightarrow{dl_{R_3}}.\overrightarrow{dl_T}}{d} + \oint_{\Gamma_{R_4}} \oint_{\Gamma_T} \frac{\overrightarrow{dl_{R_4}}.\overrightarrow{dl_T}}{d} \end{array} \right] \quad (2)$$
$$= M_{R_1T} + M_{R_2T} + M_{R_3T} + M_{R_4T}$$

B. Simulations and measurements

The coplanar design is validated by (i) HFSS simulations of the mutual inductance, and (ii) RFID detection tests using commercial reader module, in parallel and perpendicular configuration. The two reader structures are realized with 6 mm width copper ribbon.

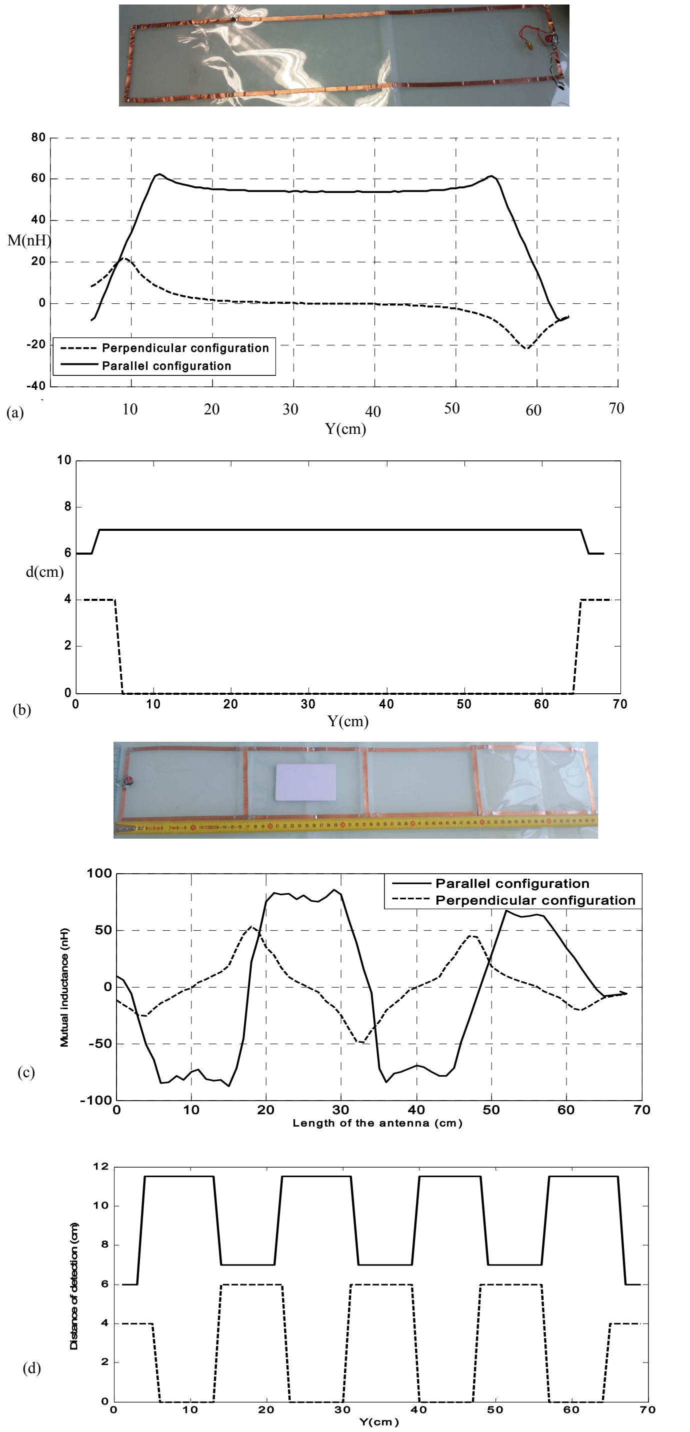


Fig. 3. Mutual inductance (a, c) and distance od detection (b, d) for conventional and multi-loop antenna in parallel and perpendicular configuration

The inductances and quality factors are respectively 0.93 uH and 28 for the conventional loop, 1.44 uH and 31 for the multi-loop antenna. The tag is a commercial card corresponding to a simulated rectangular coil of 8x5cm with an inductance of 21.5 nH.

The mutual inductance and detection range are evaluated in function of the tag positioning. In conventional antenna the maximum values of mutual inductance is seen at its edges. While at the surface of the conventional antenna, the mutual inductance has fixed values: 55 nH in parallel configuration and zero in perpendicular configuration. The tag detection is then performed at a distance of 4 cm above the surface of the reader antenna in parallel configuration, while in perpendicular configuration the tag is detected only above the edges of the antenna from a distance of 2.5 cm.

The mutual inductance is improved by the proposed design in both parallel and perpendicular configuration. The maximum values are seen above the common zones between the juxtaposed sub-loops, herein, the range detection is maximized up to 11.5 cm in parallel configuration and 6 cm in perpendicular configuration.

The perpendicular configuration is not optimized using the coplanar structure because the tag is not detected above the surface of the sub-coils. To overcome this drawback, we proposed then, to use the 3D model antenna in step 2.

III. STEP 2:3D STRUCTURE

A. *Magnetic field*

Previously, the concept of multi-loops antenna has been validated. In this part, the multi-loop antenna is conformed onto a tube external surface to provide a 3D structure. Each juxtaposed sub-loop is fed with opposite phase current.

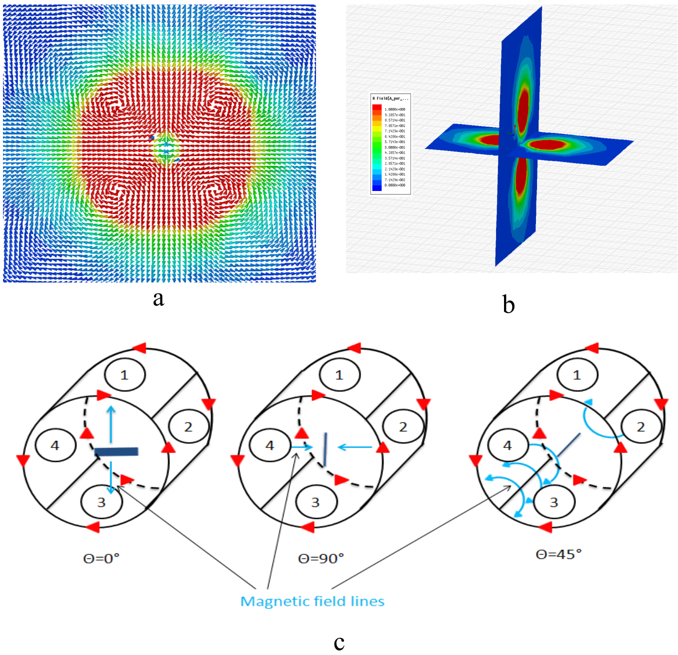


Fig.4. Lines (a) and magnitude (b) of the magnetic field and angular orientation of the tag inside the tube (c)

At the common zones, the magnetic field lines have a distribution in which the field line follows a circle, as seen in Fig. 4.a. The generated magnetic field distribution by the sub-loop "in face to face visibility" is directed outside the tube (i. e. loop 1 and 3), and towards the center of the tube (loops 2 and 4 in Fig4c). The structure permits the maximization of the magnitude of the magnetic field inside the tube but its center the magnetic field has minimum values (Fig 4.b). The tag is fixed at the center of the tube. In Fig. 4c, different angular tag orientations are reported (0°<θ<360°).

-For θ=0°: the tag is parallel to the sub loops 1 and 3 and perpendicular to the sub-loops 2 and 4.

-For θ=90°: the tag is parallel to the sub loops 2 and 4 and perpendicular to the sub-loops 1 and 3.

-For θ=45°: the tag is parallel to the common zones between sub-loops 1 and 4 and sub-loops 2 and 3, also the tag is perpendicular to the other common zones between sub-loops 1 and 2 and 3 and 4.

The mutual inductance between each sub-loop and the tag is reported in Fig. 5. According to the angular misalignment, the mutual inductance has maximum values when the tag is parallel to each one of the sub-coils and zero values the tag is perpendicular to the surface of the sub-loop.

-Sub-loops 1 and 3 are optimized for θ=0°, 180° and 360° (maximum values of mutual inductance: 10nH), however when θ=90°, 270° the mutual inductance has zero values.

-Sub-loops 2 and 4 are optimized for θ=90° and θ= 270° (maximum values of mutual inductance: 10nH) , however when θ=0°, 180° and 360°, the mutual inductance has zero values.

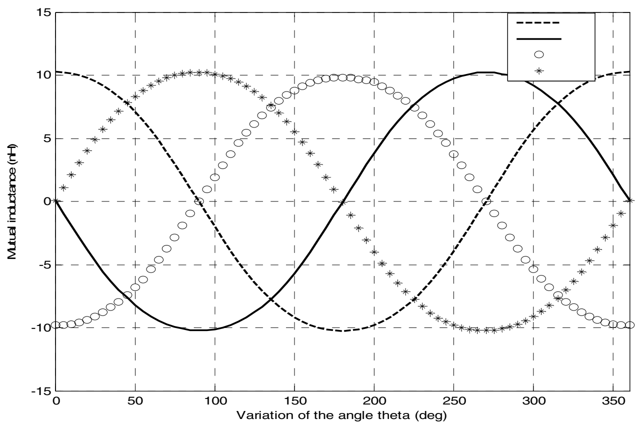


Fig.5 Mutual inductance between the tag and the different sub-loops according to the angular tag orientation

Inside the tube (Fig.6), the mutual inductance corresponds to the sum of absolute values of the mutual inductances between each sub loop and the tag coil. The mutual inductance has minimum values of 20 nH and maximum values of 30.5 nH:

-For θ=0 °, 90°, 180°, 270° and 360°: the mutual inductance corresponds to the sum of the mutual inductances between the visible sub-loops. When the tag is perpendicular to two sub loops, the two other sub loops are parallel to the tag surface, then, the 3D structure eliminate theoretically all possible zero mutual inductance.

-For θ=45 °, 135°, 225° and 315°: the mutual inductance has maximum values of 30.5 nH. It corresponds to the sum of the mutual inductances between visible common zones

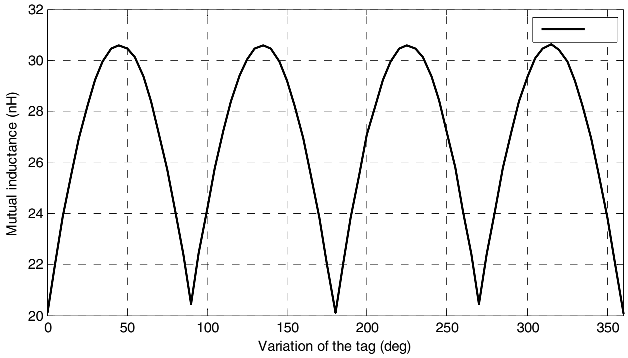


Fig.6. Mutual inductance between the tag and the 3D antenna according to the angular tag orientation

The mutual inductance is then optimized with the 3D structure for all angular misalignment of the tag.

IV. Experimental validation

The 3D design is realized with a tube of 20 cm diameter. The tag is positioned at the center of the tube at a distance of 10 cm from the structure. The tests of detection are done inside and outside of the tube.

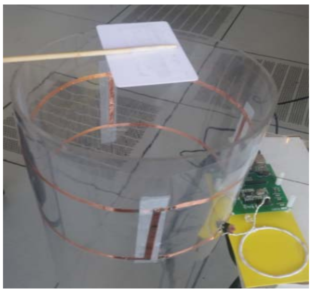
-Compared to the coplanar design, where only parallel configuration ensures tag detection above the reader antenna and where all the other angular configurations present null zones detection, this proposed design permits tag detection, inside the tube, in all possible angular orientations of the tag (0°<θ<360°) (Fig. 7a). It can be fruitfully used in practical for tracking applications like as animals or objects.

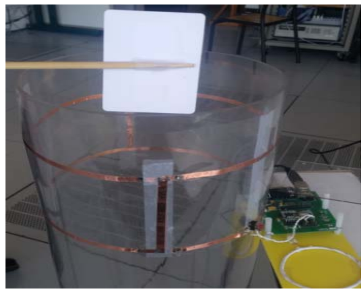
Outside the tube, the maximal distance of detection is respectively 25 cm when the tag is parallel to the tube (Fig. 7b) and 19.5 cm when the tag is perpendicular to the edges of the tube (Fig. 7c). The distance of detection is then improved up to 14 cm (from 11 cm to 25 cm) in parallel configuration and 13.5 cm in perpendicular configuration (from 6 cm to 19.5 cm). Inside the tube, the detection is also performed in different configuration, more precisely in parallel configuration the tag is detected at the concave surface of the tube, the design can then be used for maximizing range detection.

V. Conclusion

In this paper a new 3D HF RFID reader antenna is reported. The design is based on multi-loops antenna loaded by opposite phase currents (complementary principle). The coplanar design improved tag detection but especially for parallel configuration.. The proposed 3D design antenna which is a coplanar design conformed onto a tube surface, allow tag detection in any angular orientation of the tag inside the tube.

a





b c

Fig.7. Realized 3D design with the tag inside the tube (a), parallel to the tube (b) and perpendicular to the edges of the tube (c)

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