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Design of a Small Size, Low Profile and Low Cost Normal Mode Helical Antenna for UHF RFID Wristbands

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Abstract— **Emerging RFID applications in the UHF band in some cases require very specific antenna solutions. This contribution considers the identification and tracking of patients inside hospital facilities using wristbands, which impose strict tag size and cost limitations. We propose a solution for passive tags based on a normal mode helical antenna (NMHA) as an alternative to bulky and/or expensive solutions that can be found in the literature. The robustness of the resulting wristband will be assessed in a particular implementation by measuring the maximum read range for a variety of subjects with different physical constitutions.**

Index Terms— **Helical antennas, UHF antennas, RFID tags**

I. INTRODUCTION

ADVANCES in passive RFID technology in recent years have led to the emergence of many new applications in the UHF band. In some of these applications the tag must operate in the vicinity of materials (such as liquids, metal, human body…) that severely impair the performance of the dipole antenna of a typical UHF tag. In these cases, specific antenna designs are needed in order to meet the requirements of cost, size, profile, bandwidth and read range [1]-[6].

The application considered in this contribution is the identification and tracking of patients inside hospital wards in order to improve the quality of healthcare and safety. In this scenario, the antenna design must take into consideration the presence of the human body. Some of the current solutions for our application involve the use of combined technologies (RFID + WiFi) [7] or active RFID tags [8] which increase costs and/or network complexity and lead to bulky wristbands that consequently produce patient discomfort. Passive UHF RFID tags with patch type antennas have been also proposed in [9]-[11]. In [9]-[10], the antenna miniaturization is achieved through the use of a substrate of low loss and high permittivity; however, the final cost of these tags requires further reduction for mass implementation in hospitals. On the other hand, the solution in [11], although low cost, is too bulky to be used in a typical wristband.

In this paper we propose a normal mode helical antenna (NMHA) for wristbands in order to reduce both volume and cost. A low cost, bulky version of this antenna has already been shown to operate successfully on large metallic objects achieving read ranges around 15 m [12]-[13]. However, substantial changes in the design are required in order to adapt this concept to the particular requirements of our application: small size, low profile and heterogeneous operating environment.

Following the previous statements, the original contributions of our work are:

1. Design guidelines of a small NMHA for wristbands taking into account the vicinity of the human body. In particular, it will be shown that the tap feed proposed in [13] is actually not required in our application to conjugate match the impedance of commercial integrated circuits (ICs).
2. The evaluation of the read range of the prototype through turn on power measurements. A variety of subjects with different physical constitutions will be considered in order to demonstrate the robustness of our solution.

II. ANTENNA DESIGN

A. Working principle

A NMHA is achieved when its dimensions are small compared to the working wavelength. In that case, it can be approximated by a combination of N small loops and N short dipoles connected in series [14]. In free space, the far field contributions of such small loops and small dipoles are orthogonal and in time-phase quadrature, therefore, the resulting polarization will depend on the ratio between the area of the small loops and the length of the small dipoles.

When the NMHA operates on a metallic surface with the helix axis parallel to it, the far field contribution of the short dipoles is negligible compared to the contribution of the small loops. As a consequence, it can be understood as an equivalent magnetic current over a ground plane (similar to a patch antenna) and the polarization becomes essentially linear.

B. Specifications

The tag will operate in the UHF European band (865-868 MHz) and it will be designed to conjugate match the input impedance of the Alien Higgs-3 (AH3) integrated circuit (I.C.) whose impedance is $30 - j211\Omega$ at 867MHz [15].

The total available area for the tag in a typical wristband is 29 x 120 mm^2 [10]. A rigid substrate was selected as support

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for the NMHA to make sure that it will not be bent when placed on a patient wrist since this could cause a shift in the operating frequency. It should occupy the smallest possible volume so that the wristband is comfortable to wear.

RFID readers will usually be placed in the door frames to track the movement of the patients from one room to another; therefore, the minimum read range required is 2 m. The EIRP for the EU UHF band is 35 dBm and the sensitivity of the chip -18 dBm, then, from [16] we can determine that the realized gain of our antenna should be greater than -16 dB.

C. *Simulation model*

All the simulations have been carried out using the FEKO EM simulation software [17].

In our design, the human arm is modeled as a cuboid of 45 x 200 x 25 mm^3 with electrical permittivity $\varepsilon_r = 42$ and conductivity $\sigma = 0.99$ S/m [18].

The antenna for the wristband is composed of three elements: NMHA, PET substrate and thin copper tape (Fig. 1). The NMHA consists of a copper strip wound around a low-cost FR4 substrate ($\varepsilon_r = 4.5$, tan $\delta = 0.02$, thickness 1.55 mm). The geometrical parameters that define the helix are depicted in Fig. 2. A PET substrate of thickness 0.14 mm is placed between the copper tape and the NMHA to avoid shorting them. The copper tape acts as a small thin ground plane that conforms to the wrist shape, its dimensions are 29 x 110 mm^2 and the thickness is 35µm. Simulations show as this copper tape improves realized gain in 2 dB.

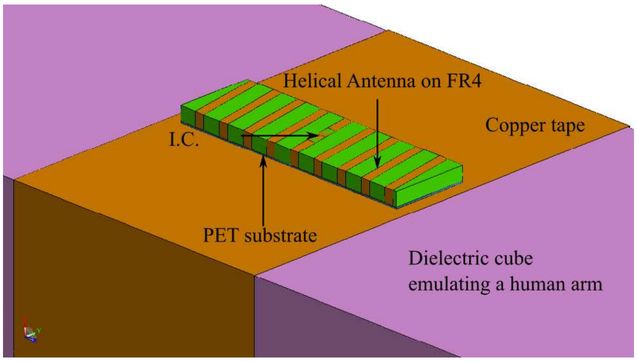

Fig. 1. Wristband geometrical arrangement.

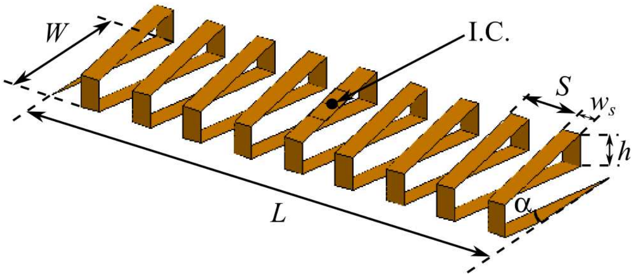

Fig. 2. Helix geometrical parameters.

D. *Design procedure*

Whenever it comes to design antennas for RFID tags in the UHF band, our goal is the complex conjugate matching of the I.C. input impedance. Since a NMHA is a small antenna, the volume (dimensions *L*, *W* and *h*) will be the maximum permitted by the application in order to maximize the gain. *L* and *h* are restricted by the width of the wristband and the thickness of the FR4 substrate respectively, so we set $L = 26$ mm and $h = 1.55$ mm. Next, we determine the minimum *W* that results in a gain greater than -16 dB. Fig. 3 shows the simulated gain pattern for $W = 8$ mm. It can also be verified that the gain does not change significantly with *N* and *S* so, in this first step, these values need not be adjusted accurately.

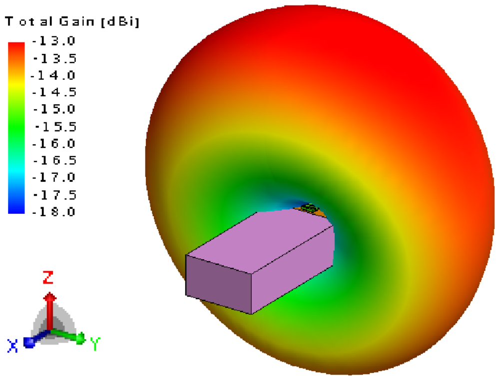

Fig. 3. Simulated gain pattern at 868 MHz ($L = 26$ mm, $W = 8$ mm, $h = 1.55$ mm, $w_s = 1$ mm, $S = 2.85$ mm and $N = 8.8$).

Once the antenna volume is determined, in the next step we find the length of the copper strip (L_T) that will allow us to compensate the reactance of the IC. For a helical antenna with rectangular section, L_T is related to the parameters of Fig. 2 through

$$L_T = N\left(\sqrt{4W^2+S^2}+2h\right) \qquad (1)$$

Additionally, the spacing between turns (*S*), the number of turns (*N*) and the strip width (w_s) must satisfy the constrain

$$L = NS + w_s \qquad (2)$$

Therefore, since w_s is small compared to *L*, for a given volume, we must find the combination of *N* and *S* that allows us to conjugate match the I.C. Fig. 4 shows the variation of the input impedance of a NMHA for different pairs of *N* and *S*. It must be noted that, in our design, the tap feed proposed in [13] is not required to conjugate match the I.C., thus reducing significantly the antenna volume.

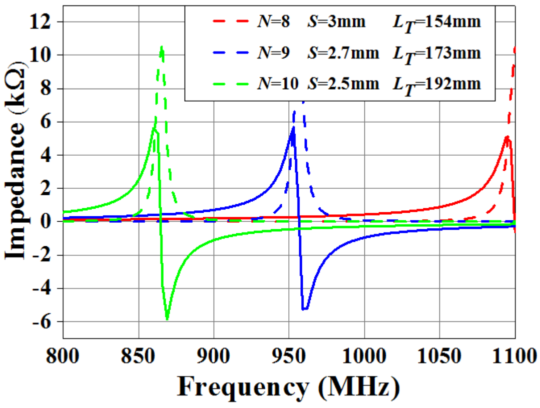

Fig. 4. Simulated input impedance for a NMHA of dimensions $L = 25.6$ mm, $W = 8$ mm, $h = 1.55$ mm, ws = 1 mm. Dashed lines and solid lines correspond to the real part and imaginary part, respectively.

As expected, an increase of h improves the maximum gain (Fig. 5). However, according to (1), L_T will also increase shifting the impedance response to lower frequencies, therefore, N and S must be readjusted in consequence to keep the same operating frequency.

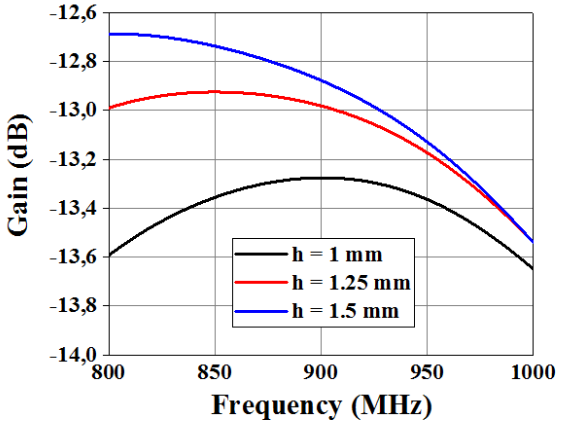

Fig. 5. Simulated antenna gain for a NMHA of dimensions L = 25.6 mm, W = 8 mm, S = 2.7 mm, N = 9, w_s = 1 mm and different values of h.

III. MEASUREMENTS

After a few iterations of the design guidelines proposed in the previous section we obtained the prototype shown in Fig. 6 for the AH3 I.C. The copper strip length (L_T) is tuned after fabrication for an optimal impedance matching.

Fig. 6. Fabricated antenna prototype. Dimensions are L = 26 mm, W = 8 mm, h = 1.55 mm, w_s = 1 mm, S = 2.85 mm and N = 8.8.

A. *Input impedance*

The input impedance measurement of the balanced antenna is carried out following the procedure detailed in [19]. Fig. 7 shows an image of the measurement set up.

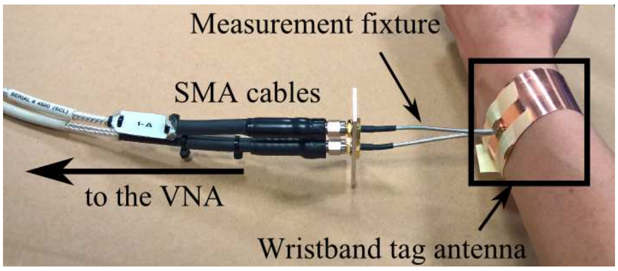

Fig. 7. Impedance measurement set up.

The measured antenna input impedance and the AH3 input impedance are displayed in Fig. 8. Although real part is not perfectly matched in the EU UHF band, the imaginary part is cancelled so the resulting maximum power transmission coefficient [16] is τ = –0.6 dB (Fig. 9). Therefore, gain and realized gain will be approximately the same at this band.

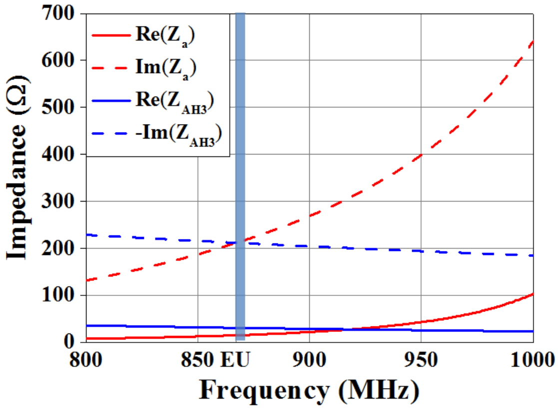

Fig. 8. Measured input impedance of the antenna (Z_a) and AH3 I.C. input impedance (Z_{AH3}).

If we assume that the antenna gain is approximately constant in a frequency range of a few tens of MHz (Fig. 5), the antenna bandwidth can be estimated from the power transmission coefficient. Fig. 9 shows as the bandwidth for a power transfer coefficient better than -1 dB, which represents a reduction of the maximum read range of 10%, is 17 MHz. This is more than enough to cover the 3 MHz of the EU UHF band.

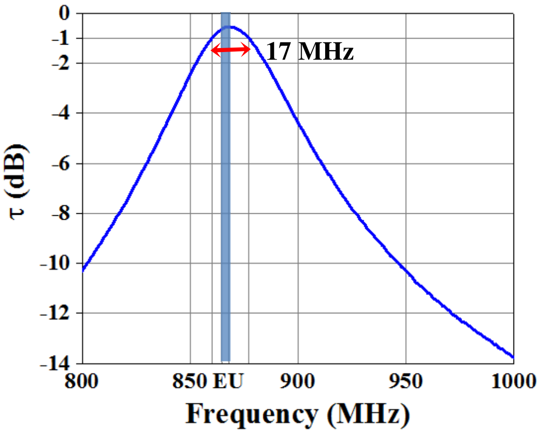

Fig. 9. Measured power transmission coefficient of the fabricated tag antenna.

B. *Turn on power*

Since antenna gain measurements are difficult to carry out in a real application scenario, we use the turn-on power measurement in the European band (865-868 MHz) to evaluate the performance of our wristband. In our setup, a commercial R220 reader from Impinj [20] is connected to an 8.5 dBic antenna [21]. The turn-on power measurement is repeated for four different subjects with different wrist sizes, in this way we assess the robustness of the solution for different physical constitutions. Three arm positions have also been considered (Fig. 10) in order to evaluate different positions in which a patient can be found on entering the line of sight of the reader antenna.

From the turn-on power at a fixed distance, the wristband read range is then calculated [16]. Results for the AH3 I.C. are summarized in Table I showing that the minimum specified read range is obtained in all cases.

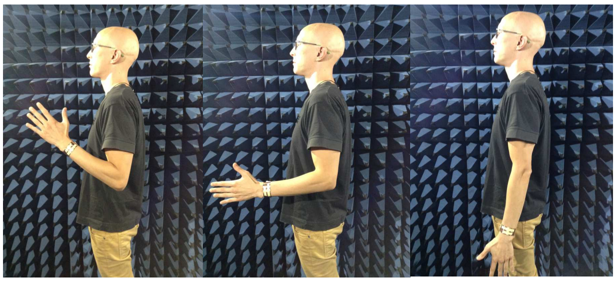

Fig. 10. Three different arm positions for the turn-on power measurement: P1, P2 and P3 from left to right.

TABLE I. TAG PERFORMANCE (READ RANGE)

Subject	Wrist size (cm)	Read Range (m)		
		P1	P2	P3
#1	13.5	2.2	2.8	2.5
#2	16.5	2.4	2.1	2
#3	18	2	2	2
#4	20	2.2	2.2	2

Measurements have also shown that the read range is kept around 2 meters while the wrist is not turned more than 45° with respect to the arm positions defined in Fig. 10.

C. *Discussion*

In [10] the use of patch antennas in wristbands to obtain a low profile antenna was considered. In that work, a thin flexible copper tape was also used as a ground plane for the patch antenna. In Table II the design proposed in this paper is compared to [10] in terms of volume and read range.

TABLE II. TAG PERFORMANCE COMPARISON

	Substrate	***Dimension (mm)***			***Read Range (m)***
		length	***width***	***thickness***	
NMHA	FR4	29	8	1.8	2.2
Patch Antenna [10]	AD1000	29	36.3	0.8	2.1

The first thing to notice in table II is that read ranges are practically the same. Although the NMHA thickness is approximately twice the patch antenna thickness, the NMHA volume has been reduced by half so now it is more comfortable to wear. Another important advantage of the NMHA design is that the use of FR4 significantly lowers fabrication costs.

IV. CONCLUSIONS

A NMHA design for passive UHF RFID wristbands has been presented. This solution is very versatile, following the basic guidelines given in the paper, our design can be easily adapted to conjugate match different IC's that can be found in the market.

In a hostile environment (human body) that severely impairs antenna performance, the proposed NMHA implementation meets the strict application requirements (low cost, low profile and small size) while ensuring the minimum read range of 2 meters.

Turn on power measurements with different wrist sizes and arm positions have demonstrated robust performance that is not significantly affected by the physical constitution of the patient.

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