RFID Based Probes for EM-Field Measurements

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***Abstract*— In this paper the use of RFID for EM field measurement is studied. A novel RFID antenna with high tuning capabilities is presented and measured, and it is used in combination with several RFID IC to measure the EM field along the H-plane of a horn antenna. A calibration procedure for the non-linear effects in RFID IC is introduced and used to correct the measured fields.**

I. INTRODUCTION

The field of sensors system has become lately quite active with a vast number of applications, examples of current sensors such as accelerometers [1], bacterial concentration sensors [2], and measuring systems for glucose levels in blood [3]. Most of the available embedable sensors have a certain limitation with regard to the communication of the information to the reader. Usually they have to be physically connected to a specific instrument in order to retrieve the measured parameters, and it can be done recovering the sensor, reducing its lifetime, or waiting until the battery has exhausted. Some of them have the possibility of a wireless interconnection, but their dimensions are not small enough to be considered effectively non-intrusive [4], [5], and usually they use an external battery, which in spite of impribing the range of coverage, it limits its lifespan. There is a requirement of embedable passive sensors and at the same time a growing number number of applications demand an accurate information about the existing field distribution around or inside complex media; in order to unite both requirements we are proposing the use of an RFID tag. The authors previously presented the possibility to use RFID tags in order to retrieve the field distribution [6]. In this paper an RFID antenna will be designed to be used in combination with a set RFID IC's in order to further validate the technique.

The structure of the paper is as follows: section II will explain the main characteristics of the designed RFID antenna and the tuning possibilities that it offers; section III will present an overview of the methodology to retrieve the EM field using RFID with a special focus on the calibration procedure; section IV will present the results for two different IC with the tuned RFID antenna, and finally the last section will draw some conclusions.

II. ANTENNA DESIGN

The antenna designed in this paper is based in the geometry shown in [7]. The concept has been modified in order to present a higher degree of tunability. The final design of the antenna can be seen in figure 1 with its main dimensions. It basically consists of a bow-tie antenna with two sets of stubs, one in parallel and the other in series at the feeding point. It is supported on a Rogers RO4003C substrate of thickness $1.5mm$. The antenna has a high degree of tunability without variation of its physical size, by the lengthening and shortening of the stubs. The stubs at the bottom of the figure, at the feeding point, offer a high control over the reactance of the antenna, because it is placed in series to the IC and so it keeps the resistive part of the impedance basically constant (from now on we will refer to them as inductive stubs); on the other hand the stubs on the top side of the antenna are placed in parallel to the antenna impedance, and therefor it will change both the resistive and reactive part of the total impedance (we will refer to them as resistive stubs). The design of the antenna has been adjusted using the Finite-Element Method commercial solver HFSS. Figures 2(a) and 2(b) present the impedance in a range of 800 MHz up to 900 MHz for different values of the inductive stub length (L_1) and the resistive stub (L_2). The effects that each stub has on either the resistance or the reactance, where the inductive stub can be cleary seen, the inductive stub allows to fine tune the impedance value while the resistive stub has a bigger impact in the physical resonance of the structure ($\Im m\{Z_{in}\} = 0$). The initial design shown in figure 1 has been fabricated and its input impedance measured using a monopole version of the antenna, and the corrected input impedance at $868MHz$ is $19 + j401\ \Omega$, which agrees with the simulates, as seen in figure 4 and therefore presenting a good matching with the input impedance of the RFID IC Philips SL3S1001FTT.

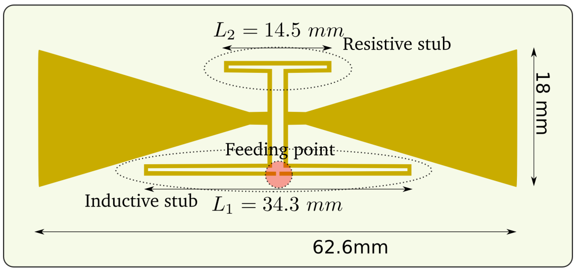
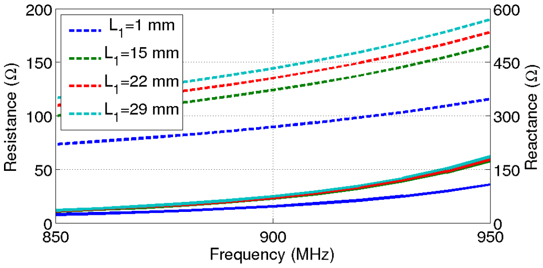
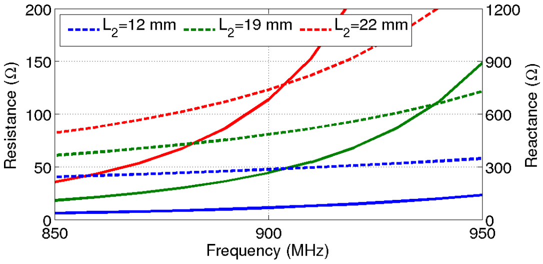


Fig. 1. Final antenna design, the two stubs that can be used to tune its impedance have been shown using a dotted encircling line over the,



(a) Inductive stub variation, $L_2 = 15mm$



(b) Resistive stub variation, $L_1 = 15mm$

Fig. 2. Impedance results from simulations using HFSS for different length of the tuning stubs. The straight line represents the resistance values, and the dashed line the reactance values

III. EM-Field measurement

The electromagnetic field distribution produced by an antenna can be measured in different ways; the first one consists in performing a direct measurement using a small antenna, probe, connected to an RF receiver, obtaining precise results as long as the probe is small enough. But to connect the probe to the RF receiver, bulky RF connections are needed, and those can not be used in every of the scenarios (inside of a body) and also do not offer the flexibility that is desirable; a different approach consists in an indirect measurement, where we will be measuring the signal reflected back from the EM probe and measured at the transmitting antenna (mono-static measurements); such a measurement setup present a high degree of flexibility, although it also requires to be able to identify the reflection from each probe with techniques such as the modulated scatterer technique (MST).

A. *MST theory*

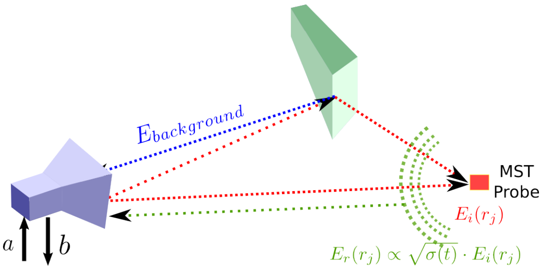


Fig. 3. Basic scenario of operation of the Modulated Scattered Technique, a complex scenario where there may be more than one interested reflection and where we are interested in retrieving a specific one, the one at the MST Probe

In the modulated scattered technique we measure the reflection produced by an RF-probe and captured at the interrogating antenna. Such reflection will be added to a set of different components to produce the total reflected signal at the antenna (b); the different components consist on the self-reflected signal of the antenna ($S_{11} \cdot a$), reflections coming from the background (b_{bgnd}), that we are not interested in, and the reflection coming from the probe of interest (b_j). Figure 3 shows a sketch summarizing this, therefore the signal we measure is:

$$b = a \cdot S_{11} + b_{bgnd} + b_j \qquad (1)$$

where b_j is proportional to the existing field at the probe ($E(r_j)$) and the complex reflection factor between the probe impedance and its load ($\left(\tilde{\rho}_L = \frac{Z_L - Z_{IC}^*}{Z_L + Z_{IC}^*}\right)$) as $b \propto (E(r_j))^2 \cdot \rho_L$. By taking two measurements for two different loads in our RF-probe, we can distinguish the unwanted reflections and so filter them out. In such a scenario, it can be probed that the differential reflection coefficient at the input ($\Delta\rho_T = \Delta b$), will be, [8], [9]

$$\Delta\rho_t(r_j) = \frac{Z_{tr}(r_j)}{2R_T} \underbrace{(\tilde{\rho}_{L1} - \tilde{\rho}_{L2})}_{\Delta\tilde{\rho}} \propto L_t^2 \Delta\sqrt{\sigma_L} \qquad (2)$$

where the term Z_{tr} is the transfer impedance and accounts for the field distribution. This formulation can be used for near field schemes as well as in far-field; in far-field a similar expression based on radar cross-section would be possible, as it is shown in the right hand side of the equation. The term L_t accounts for the losses due to the distance and position of the angular probe (they are in a power of 2 to take into account both the incident and reflection paths), as well as the radar cross section By moving the probe inside the area of interest, all the terms of equation (2) remain constant except for Z_{tr}. Therefore we are able to retrieve the relative field distribution. The fact that the principle of operation of RFID is based on the backscattering modulation, and hence it inherently switches between two impedances values when the tags communicates back to the reader, makes RFID tags a natural RF- probe to be used for field distribution measurements under the MST.

B. *RFID for MST measurements*

As it has been previously stated, RFID becomes a natural probe for doing MST measurements. Moreover its powerless nature when using passive RFID tags, increases its possibilities because it reduces the requirement of cabling for powering up, although at the same time it introduces a new effect that needs to be taken into consideration. The power requirements of RFID tag ICs are fullfilled by means of a rectification of the incident field, the use of a rectifier introduces a non-linear effect in the IC input impedance, and as such the term $\Delta\tilde{\rho}$ from (2) will change depending of the power in the tag; in order to measure a field distribution we will need to apply an additional calibration procedure that will take into account the power dependence. This procedure will be outlined in the following paragraphs

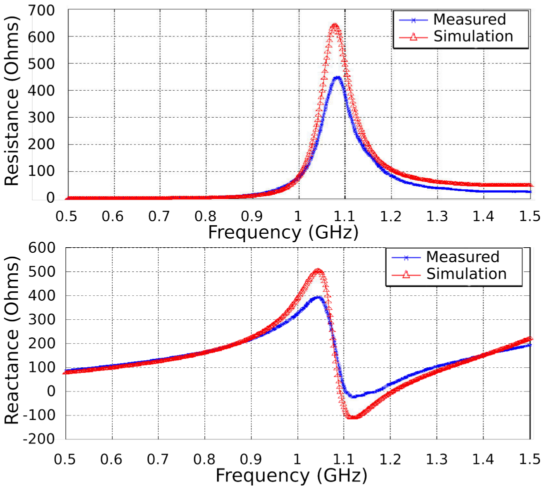


Fig. 4. Impedance measurements using a monopole version of the designed antenna. The results show the monopole results, and so the dipole version wuold present twice the values of the figure

In order to make this procedure as clear as possible we will comment it from a far-field point of view; let L_{tr} account for the attenuation of the field from the input antenna to the probe position; for a specific reference position (r_{ref}) and a given power (P_{ref}), the differential reflected signal (Δb) is:

$$\Delta b\left(P_{ref}, r_{ref}\right) = \sqrt{P_{ref}} \cdot L_{tr}^2(r_{ref}) \cdot \Delta s\left(P_{ref} \cdot L_{tr}^2(r_{ref})\right) \tag{3}$$

with $\Delta s = \sqrt{\sigma_1} - \sqrt{\sigma_2}$. By measuring the response for a set powers, and refering it to the reference signal, we can obtain a curve such as:

$$S = \frac{\Delta s\left(PL_{tr}^2(r_{ref})\right)}{\Delta s\left(P_{ref}L_{tr}^2(r_{ref})\right)} = \frac{\Delta b(P, r_{ref})}{\Delta b(P_{ref}, r_{ref})} \cdot \sqrt{\frac{P_{ref}}{P}} \tag{4}$$

where S is defined as the relative variation of Δs with respect to the variation of the power reaching the tag. This function can be fully characterized in a practical environment. This curve is used to solve the transcendental equation

$$\frac{\Delta b(P_{ref}, r_j)}{\Delta b(P_{ref}, r_{ref})} = \frac{L_{tr}^2(r)}{L_{tr}^2(r_{ref})} \cdot S\left(\frac{L_{tr}^2(r)}{L_{tr}^2(r_{ref})}\right) \tag{5}$$

to correct the non-linearity and to obtain the relative field distribution over the area of interest.

IV. EXPERIMENTAL RESULTS

The antenna designed in section II has been fabricated and measured. In order to measure its input impedance a monopole version of the antenna has been used, as it allows to measure its value using a conventional network analyzer (Agilent E8362B); the measured values for the input impedance are shown in fgure 4 compared with the results from the simulations.

The field distribution along the H-plane of a ridged horn antena with an aperture of $19 \times 27\ cm$ has been measured using two different RFID IC's, the NXP U.Code G2XM Hawk and the Alien Strap-On Higgs. The IC's have been connected to the designed antenna, that has been tunned to improve its performance. The measurement setup can be seen in figure 5, and it consists of the horn antenna acting as a transmitter, a Rohde SMJ100A vector signal generator, to generate the RFID *QUERY* signal and a Rohde FSL6 spectrum analyzer to capture the IQ signal reflected back from the RFID probe through the horn antenna and a directional coupler. The RFID probe is fixed in a motorized rail that moves the probe along a line in front of the aperture of the horn antenna. The frequency of operation has been $868MHz$

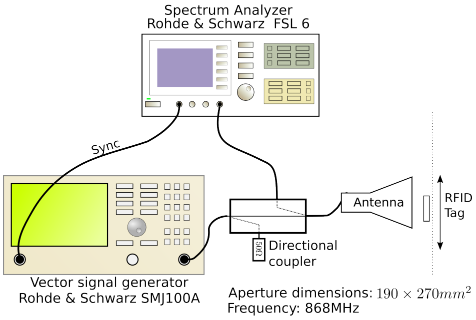


Fig. 5. Measurement setup for doing the EM-field measurements using RFID

The measured RFID signal can be seen in figure 6, which

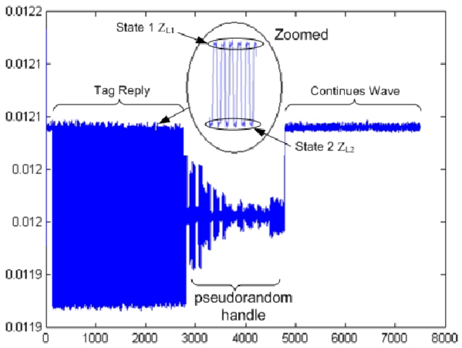


Fig. 6. Response from one of the RFID IC at the central position of the horn

corresponds to the first response from an RFID tag, and where the two states can be clearly distinguised. The measurement of such a signal for a set of input power levels allows to construct a curve to be used in the calibration procedure as previously explained; in figure 7 the non-linear curve for each RFID IC's is presented.

By moving the RFID antenna in front of the horn antenna we can measure the response for a set of positions, and after the calibration procedure the relative field distribution is obtained. Figure 8(a) and 8(b) show the reconstructed field along the H-plane of the horn antenna for both IC. We can observe a good agreement between the measured field for both of the IC, in spite of the difference in their non-linear response. At the same time, it should be noted the remarkably good agreement between the mangitude of the measured field and the simulated field obtained through the Method of Moments.

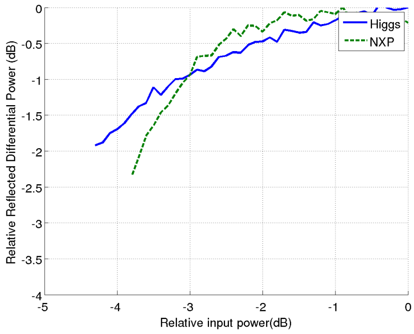


Fig. 7. This figure shows the differential response for a give position (center of the horn) and a set of power for both IC, we can clearly see that both of the circuit present a non-linear behaviour, where the variation is not linear with the input power, this curve will be used to correct the measured fields

V. CONCLUSIONS

In this paper a new antenna design for RFID tags with a high degree of tunability has been introduced. Also we have shown the capability that RFID tags present for EM-Field measurements. An initial formulation for the calibration of the non- linear response of the RFID IC has been proposed, and used in the measurement of the H-plane field distribution at the aperture of a ridged horn antenna.

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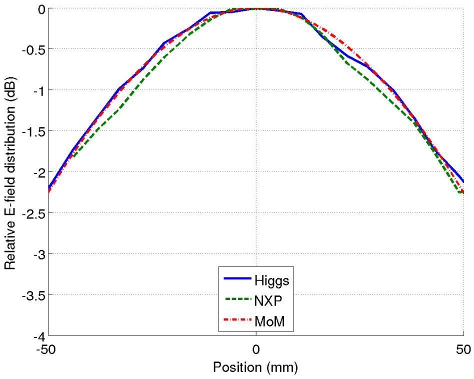
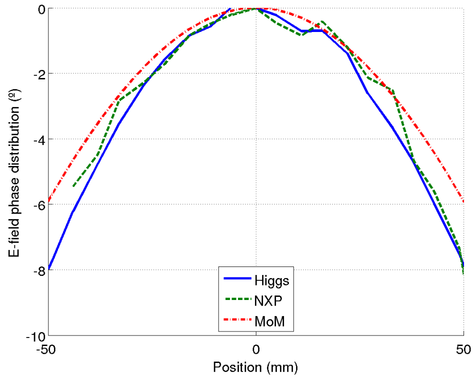


(a) Magnitude



(b) Phase

Fig. 8. Measured relative field distribution along the H-plane of the horn antenna, using two different RFID IC with the same antenna design, (a) shows the magnitude and (b) the phase

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