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Wireless interrogation of small animal phantoms with a miniature implanted UHF RFID tag

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Abstract—In this article, the RSSI measurement with a miniature implanted tag into a small animal phantom, intended to work in the European UHF RFID band is presented. The miniaturization of the radiating element while preserving its efficiency allows the reliable communication between an external interrogation device and the identification tag aimed to be implanted into a small animal. The paper first presents the design of the proposed antenna optimized by some new techniques to reduce its radiating performance and its efficiency [4] - [6].

Moreover, a total gain value between -17.5 dBi and -30.7 dBi is always obtained at the working frequency of 868 MHz. The measured reflection coefficients shows that a good matching (10 MHz - 20 GHz). The comparison between simulated and measured reflection coefficients shows that a good matching is always obtained at the working frequency of 868 MHz. Moreover, a total gain value between -17.5 dBi and -30.7 dBi is reached (Fig. 3 (b)). This gain seems acceptable given the dimensions of the antenna and the work previously presented [10], [11].
The objective of this section is to calculate the theoretical received power $P_{\text{rx reader}}$ by the reader when the antenna is implanted in the phantom model of a small animal. The reader antenna is placed in a confined space with reduced dimensions and has a limited gain around 3.2 dBi. The power emitted by the reader is 27 dBm and respects the ERC recommendations as the ISM band at 868 MHz imposes a maximum power of 500 mW (27 dBm) [12]. The power backscattered by the implanted tag and received by the RFID reader must be greater than its sensitivity (the minimum power required to detect the feedback signal of the tag) to guarantee the communication of the system. Thus, based on the reader’s performance, the attenuation parameters $A_m$ in the animal environment, the losses at the interface $L_{\text{int}}$ between the air and the animal environment, and considering that the model phantom is placed in the center of the reader antenna, we can express the received power by the reader by the following equation [13] - [15].

$$P_{\text{rx reader}} = \frac{P_{\text{tx reader}} G_{\text{tag}}^2 G_{\text{reader}}^2}{\sum L_{\text{int}} \sum A_m}$$  \hspace{1cm} (2)

Let us assume that $d_i$ ($i = 0, 1$) is the length of the propagation channel of the wave in each medium (Fig. 4). In this case, $d_0$ is the thickness of the air layer and $d_1$ is the equivalent thickness of the body layer of the animal. The attenuation of the medium $A_m$ is defined by the following equation:

$$A_m = \left(\frac{\lambda_1}{4\pi d_i}\right)^2 e^{-\alpha_i d_i}$$  \hspace{1cm} (3)

Where $\alpha_0 = 0$ is the attenuation constant in the air and $\alpha_1$ is the equivalent attenuation in the animal body:

$$\alpha_1 = \omega \sqrt{\mu_{\text{req}} \varepsilon_{\text{req}}} \left[ \sqrt{1 + \left(\frac{\sigma_{\text{eq}}}{\omega \varepsilon_{\text{req}}}ight)^2} - 1 \right]$$  \hspace{1cm} (4)

Moreover, we consider that the incident wave propagates through the different media as shown in Fig. 4 with different impedances that produce different losses $L_{\text{int}}$ at the interfaces, defined by the equations in [16]. The reflection coefficient $\Gamma_1$ can be expressed directly in terms of $\rho_i$ and $d_i$.

### III. LINK BUDGET CALCULATION

The objective of this section is to calculate the theoretical received power $P_{\text{rx reader}}$ by the reader when the antenna is implanted in the phantom model of a small animal. The reader antenna is placed in a confined space with reduced dimensions and has a limited gain around 3.2 dBi. The power emitted by the reader is 27 dBm and respects the ERC recommendations as the ISM band at 868 MHz imposes a maximum power of 500 mW (27 dBm) [12]. The power backscattered by the implanted tag and received by the RFID reader must be greater than its sensitivity (the minimum power required to detect the feedback signal of the tag) to guarantee the communication of the system. Thus, based on the reader’s performance, the attenuation parameters $A_m$ in the animal environment, the losses at the interface $L_{\text{int}}$ between the air and the animal environment, and considering that the model phantom is placed in the center of the reader antenna, we can express the received power by the reader by the following equation [13] - [15].

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$$\rho_0 = \frac{\eta_1 - \eta_0}{\eta_1 + \eta_0}$$  \hspace{1cm} (5)

$$\rho_1 = \frac{\eta_0 - \eta_1}{\eta_0 + \eta_1}$$  \hspace{1cm} (6)

$$\Gamma_1 = \frac{\rho_0 + \rho_1 e^{-j2k_1 d_1}}{1 + \rho_0 \rho_1 e^{-j2k_1 d_1}}$$  \hspace{1cm} (7)

$$L_{\text{int}} = |\Gamma_1|^2$$  \hspace{1cm} (8)

Where $\rho_i$ denote the elementary reflection coefficient to the left of the two interfaces, $k_i = 2\pi/\lambda_i$ is the wave number, $\lambda_i$ is the wavelength in each medium and $\eta_i$ is the characteristic impedance of each environment: $\eta_0$ and $\eta_1$ are the impedances of the air layer and of the animal body, respectively, and they are defined by:

$$\eta_0 = \sqrt{\mu_0/\varepsilon_0}$$  \hspace{1cm} (9)

$$\eta_1 = \sqrt{\mu_{\text{req}} \varepsilon_{\text{req}}/\varepsilon_0}$$  \hspace{1cm} (10)
The characteristics of the reader and its antenna are given in Table 1:

<table>
<thead>
<tr>
<th>Reader Parameters</th>
<th>Reader Sensitivity</th>
<th>Reader Trans. Power</th>
<th>Reader Antenna Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-82 dBm</td>
<td>27 dBm</td>
<td>3.2 dBi</td>
</tr>
</tbody>
</table>

The reader antenna inspired from [17], is presented in Fig. 5. It is made up of an annular ring slot, excited by a micro-strip line on the lower face of the substrate. The micro-strip/slot line transition is used in combination with a small open circle stub for the matching. A U-shaped slot stub is also used to miniaturize the whole diameter of the antenna and to obtain the circular polarization used in UHF RFID standard. The simulated and measured \( S_{11} \) coefficients for this antenna are given in Fig. 6. A good agreement is obtained and the antenna is well matched in the UHF band with a value of \( S_{11} \) around -13 dB at 868 MHz. Thus, with this radiating element, we obtain a received power \( P_{rx reader} \) between -34.5 dBm and -60.9 dBm for an emitted power of 27 dBm according to equation (1) when the model phantom is placed in the center of the antenna reader.

IV. RSSI MEASUREMENTS

Based on the previous section III, the RSSI theory value is expressed by the following equations:

\[
P_{rx\ tag} = P_{tx\ reader}G_{\text{reader}} \sum L_{\text{int}} \sum A_m \]  \hspace{1cm} (11)

\[
RSSI(dBm) = P_{tx\ tag\ (dBm)} - \sum Loss = P_{rx\ reader} \]  \hspace{1cm} (12)

For the measurements, a phantom body was realized by combining diethylene glycol butyl ether (44%) and de-ionized water (56%) [18], contained in a 60 ml polypropylene cylindrical flask having the dimensions and, more or less, the shape of the animal body (Fig. 7 (a)).

Fig. 7. (a) antenna prototype in the phantom model, (b) measurement set-up.

The implantable tag prototype (Fig. 7 (a)) has been tested with a RFID reader antenna connected to an Impinj Speedway Revolution R420 reader [19] able to interpret the data received from the implanted antenna as shown in Fig. 7 (b). The cage bottom surface has been divided into a coordinate model to control exactly the phantom model position (Fig. 5 and Fig. 8).

The software interface is implanted into a computer connected to the reader and allows us to control the whole system (Fig. 7). With these elements, the reader is able to detect the tag in the Plexiglas rack cage after a few seconds. Fig. 9 presents the measured values obtained for the two orientations of the phantom. As we can observe, the RSSI value is close to the maximum when the phantom model is above the center of the reader antenna. The small shift in the position compared to the center of the antenna is due to the asymmetry of the plastic casing of the phantom, the asymmetry of the antenna of the reader and uncertainties in the positioning. The influence of this asymmetry is logically more important for an orientation of the phantom along the Y axis than along the X axis.

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The measured average value of the RSSI varies between -48 dBm and -68 dBm, which is close to the theoretical values calculated previously. These results also prove the potential of the whole system to detect, identify and localize small animals equipped with such miniaturized implanted tags.

Fig. 9. RSSI measured values at 868 MHz when the phantom model is oriented along the X axis (a), Y axis (b) and moves along the Y axis.

V. CONCLUSION

In this paper, the antenna design of an implanted RFID tag dedicated to very small animals and intended to operate in the UHF RFID band is presented. The studies of the link budget and the RSSI measurement between the implanted antenna and the interrogating system in the specific environment of the project also show that the performance of the designed antenna allows its use in the intended application.

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