

Enhancing UHF RFID Performance on Human Skin: Design and Simulation Strategies

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Abstract - This work describes the procedure for the design and fabrication of body mounted Radio Frequency Identification (RFID) tags. Tags of this nature usually face various challenges due to the unique nature of the body which interferes with normal tag operation. In this work, examines various issues the human body can present to the operation of body mounted RFID tag such as detuning and loss of power due to energy absorption by the water molecules present in the body. Various considerations for the design of a functional RFID that operates optimally when placed directly on the human skin are presented. A slot design was used to demonstrate how an accurate prototype can be developed when design and simulation guidelines are adopted. Simulation and measured results show a high degree of agreement.

Keywords: Enhancing UHF, UHF RFID Performance, Human Skin, Radio Frequency Identification, Mounted RFID tag.

I. Introduction

Radio Frequency Identification (RFID) belongs to the family of contactless identification system which includes bar codes and QR codes. However, unlike barcodes and QR codes, RFID does not require line of sight operation hence has higher speed, higher capacity and potential for more applications beyond the conventional asset tracking. These added functionalities include sensing purposes [1] and medical applications [2]. RFID technology is one of the fastest growing sectors of radio communication industry with an estimated current (2021) market size of \$10.7bn and a projected size of \$17.4bn by 2027 at a CAGR (cumulative annual growth rate) of 10.2% [3].

Increasingly, tags that are able to operate on the human skin are gaining more research interest because of their immense potential applications. However, because of the dielectric properties of the human body, the challenge of getting these tags to work on the human skin is something that needs to be surmounted. Researchers therefore continuously seek to design tags which can operate on the human skin without the need to employ methods to physically decouple the tag from the skin. This work aims to present methods and

considerations for designing tags capable of seamless operation on human body.

II. Operation of RFID System

The basic components of an RFID System are the RFID Tag and the RFID reader – which consists of the application specific integrated circuit (ASIC) and the tag antenna. The operation of this system depends on the coupling of the tag and the reader. For UHF RFID, the nature of this coupling is referred to as backscattered coupling. Backscattering is the concept where the tag reflects the radio signals coming from the reader back in the direction of the reader. The level of energy reflected back to the reader depends on the strength of resonance which in turn determines the radar cross section (RCS) of the tag. Figure 1 shows the interaction between the reader and tag.

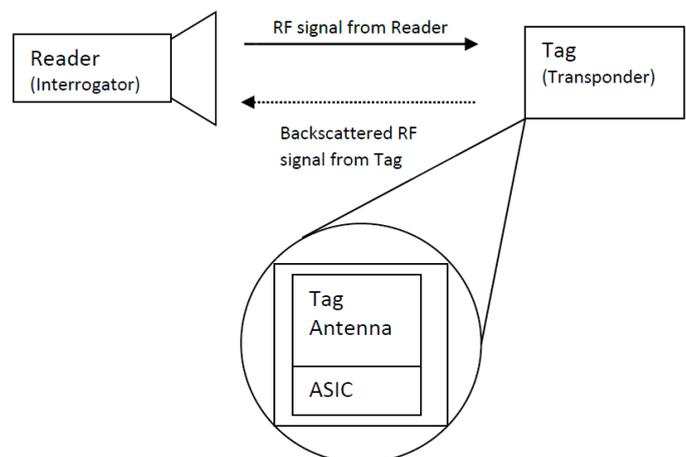


Figure 1: UHF RFID system

This reflected signal is modulated with a form of amplitude shift keying (ASK). This modulation is achieved by the chip switching its impedance match with the antenna between a well matched state (low reflection) and a completely unmatched state (high reflection). This switching is done in accordance with the bit stream being sent. The maximum possible communication distance between tag and reader is known as the read range and can be estimated using a modified Friis free space formula [4]:

$$r = \frac{\lambda}{4\pi} \sqrt{\frac{P_{reader} G_{reader} G_{tag} \tau}{P_{th}}} \quad (1)$$

Where λ is the wavelength, P_{reader} is the power transmitted by the reader, G_{reader} is the gain of the reader antenna, P_{th} chip threshold power, G_{tag} is the gain of the receiving tag antenna and τ is the power transmission coefficient given by:

III. Human Body and RFID Tag

The human body presents a challenging environment for the operation of RFID tags. These challenges are two-fold as identified by Kellomäki[5]. The first is the dielectric loading provided by the body which alters the electrical behaviour of the tag by increasing the electrical length of the antenna. The effect of this is that the tag is detuned (shifted from its original designed frequency) and also has its impedance lowered. The second effect of the body on the tag is the issue of the absorption of the RF energy from the reader signal by the water molecules present in the human body. This lowers the radiation efficiency because limited power is available to the tag for effective operation.

In light of the aforementioned, design of tags for the purpose of use on the human body takes into consideration design approaches and techniques which aim at minimizing or eliminating these effects.

IV. Design Concept

The design of body mounted RFID tags starts with the proper selection of a tag design. The design should limit the amount of RF energy (fringing fields) in the direction perpendicular to the skin (flowing into the skin). This helps to limit the detrimental effect of absorption and dielectric loading earlier mentioned. Slot designs have been identified to provide one of the best performances on the human body especially for low profile antennas [6], [7].

4.1 Slotted Antennas and Performance on the Human Body

According to research presented in [8], slot antennas are a top choice for wearable RFID tags. One of the reasons for this is that they effectively address the challenges presented by the electrical properties of the human body. As mentioned earlier, the human body has a high dielectric value. Added to this, it also has high water content. What slotted antennas are able to do is to concentrate electrical currents around the slot. The result of this is that energy is directed outwards on the conductive surface of the tag instead of downwards into the skin[6]. This feature ensures a stable resonance frequency in the designed and intended resonance frequency. This concept is shown in the surface current plot shown in figure 2.

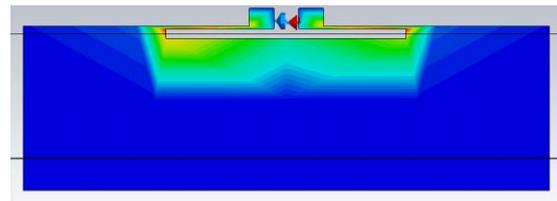


Figure 2: Simulated Surface Current Plot

Additionally, tuneability is also another desirable feature of these tags. This feature of slotted antennas allows designers to easily adjust the slot dimensions and the overall dimensions of the tag to match the impedance of the tag to the impedance of the application specific integrated circuit (ASIC) chip and also to adjust the resonance frequency of the tag for specific conditions[9]. By this, the parameters of the tag would be independently adjusted as desired. For instance, the length of slot in the tag shown in figure 2 controls mainly the resonance frequency of the tag and while its width controls the tag's impedance. The tag dimensions can also be used to influence its gain. A further advantage of such a feature is that the tag can then be adjusted for use on different parts of the body or to maintain performance in different conditions like movement and in the presence of moisture. The compactness of these designs also makes them physically appealing for applications such as integration into textiles, skin-adherent materials, user comfort and practicality.

Finally, slotted antennas are well suited for cost-effective fabrication techniques like screen printing, etching and embroidery which are ideal for wearable applications. They have been used in healthcare and IoT with satisfactory read range[10], [11].

V. Simulation Procedure

The accuracy of the simulation is very important for ensuring a prototype with the desired characteristics and electromagnetic behaviour is fabricated. Apart from using suitable simulation parameters (depending on the simulator used), there should also be use of a model which has as close as possible, similar dielectric (conductivity and permittivity) properties as an actual human skin (body). Also, accurate physical representation of the body is necessary and so it is important that the various layers of the body (skin, fat, muscle and bone) are accounted for.

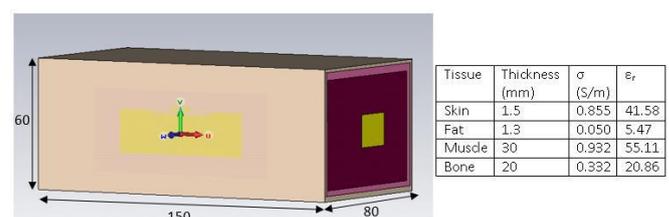


Figure 3: 3D Human Body Model

Electromagnetic simulators provide various models for the human body these could be homogenous models, voxel based models [12], multi-layered models [13]. Each of these models has frequency-dependent electrical properties like permittivity and conductivity. These values are to be set at the frequency of interest of the UHF RFID tag (860 – 960 MHz) to ensure accuracy.

Depending on the computing capacity of your computer system, you could use any of these models. However, if there are limitations to your systems capabilities, a homogenous model could be best suited for you. The values of the various layers of the model are already preloaded on the simulators. However, you could make your own model with the different layers of the body and also assigning to them, the dielectric properties which are available in literature as shown in figure 3. To make a homogenous system, the assigned dielectric value of the model will be the average of the constituent layers of the human body. While this could come with an accuracy trade-off, it provides a less computing burden alternative.

5.1 Simulation Parameters

Some simulation parameters are presented below:

- *Frequency Range:* Ensure that the frequency of the simulation is set to cover the desired frequency range of UHF RFID (typically 860 – 960 MHz)
- *Material Properties:* The dielectric properties of tissues are frequency depended, ensure you are using the right values for the UHF RFID frequency band.

- *Boundary Conditions:* Use open boundaries or perfectly matched layers to simulate free space. This minimizes reflections.
- *Mesh Settings:* A fine mesh is essential for simulation accuracy. Use fine mesh near the tag and body interfaces. Adaptive meshing can also be used to ensure accuracy. If computing limits is a concern, use mesh setting that ensure that at least a mesh line passes through the smallest dimension of the tag.
- *Solver Settings:* Time harmonic solvers for steady-state analysis is employed by electromagnetic simulators with some utilizing the Finite Integration Technique (FIT) while others make use of the Finite Element Method (FEM). For RFID simulations, the transient solver is suitable for time-domain analysis, while the frequency-domain solver is used for steady-state analysis, aligning with the user’s focus on resonance frequency (e.g., 865-868 MHz).

VI. Simulation Results

Implementing the above guidelines and procedures we were able to obtain an accurate simulation which corresponded with measured results. Figure 4 shows the measured and simulated resonance frequency. The measured result indicated a peak frequency at the designed frequency of 865 – 868 MHz which corresponds to the simulated EU UHF RFID frequency band.

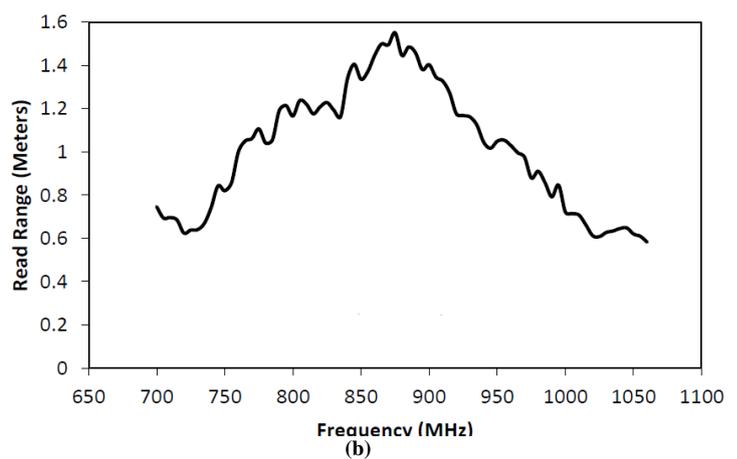
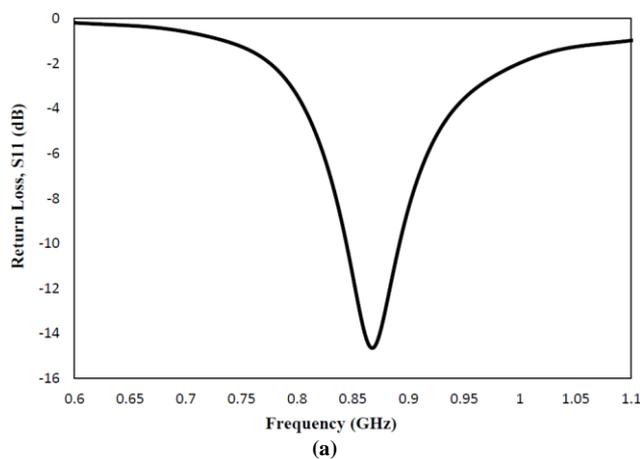


Figure 4: Simulated (a) and measured (b) tag resonance frequency

VII. Conclusion

This work has presented the key considerations for the design of tags capable of working in very close proximity of the human body. These considerations include the influence of the human body on the operation of tags of this nature and

possible features of tags which could help reduce these effects. Approaches to ensure accurate simulation results were also introduced. Results show good agreement between simulation and measurement when these approaches were taken.

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