PROJECT AND STUDY OF A BELT ANTENNA

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ABSTRACT

Body Area Networks (BANs) are telecommunications networks that operate in the vicinity of the human body. They have several applications but the proximity of the human body imposes a set of characteristics to be met. The wearable antennas (WA) are one of the elements of BANs and all its features take into account the scenario in which they operate.

This work aims to design and test a belt antenna. The buckle is used as a radiator, and the antenna is fed by a microstrip line with leather substrate. The antenna structure is optimized to operate in 2.45GHz and 5.8GHz Industrial, Scientific and Medical (ISM) bands. Given the possible scenarios of use and to check the mutual effects when the antenna is operating, the structure was simulated in the air and in the vicinity of a representative model of the human body. Efficiency, directivity, radiation patterns and Specific Absorption Rate (SAR) measures are other characteristics of the antenna obtained by simulation.

The results obtained in the laboratory indicate that the 2.45GHz and 5.8GHz ISM bands are covered by the operating bands of the antenna when tested in the air, but loses tuning in the 2.45GHz ISM band when working in the vicinity of the human body. The results obtained for the SAR estimations at 5.8GHz are according with Council of the European Union recommendation.

Index Terms— Belt antenna, wearable antennas, user interaction, specific absorption rate (SAR).

1. INTRODUCTION

Body Area Networks (BAN) are a recent concept in telecommunications, that refers to a set of elements designed to operate in the vicinity of the human body. There are several applications for BAN that comes from pure entertainment to medical questions. Wearable antennas are one of the important pieces of BAN.

One of the critical aspects of the BAN is in the proximity between the human body and the radiation elements of a BAN. The radiation levels should respect the human body and ensure that no harm is made to the person health. The maximum exposed levels are delimited for some commissions and in the European Union a recommendation was made [1].

The IEEE 802.15.6 standard is being created to establish a set of rules for this technology [2]. According to [2] the BAN elements should consume low power while communicating with each other to protect the human tissues, have approval from medical authorities to communicate in or near the human body and should respect the Specified Absorption Rate (SAR), among others. The primordial issue of this technology is, besides the network purpose, to ensure that it respects the human body health.

The wearable antennas have a lot of proposed solutions among the investigators. The most explored solutions are the antennas on textiles, also known as flexible antennas, and on the daily wearing objects.

In [3] P. Salonen et al. present a textile WLAN antenna. The antenna was tested in the vicinity of the human body but no SAR simulations or measurements were made. B. Sanz-Izquierdo et al. present a button antenna with dual band characteristics in [4]. The antenna is set on a jacket and the input reflection coefficient of the antenna is measured in the vicinity of the human body. This study does not present SAR estimation results.

The work that is here presented is based on a solution proposed by B. Sanz-Izquierdo et al. in [5], a belt antenna that is prepared to work in the 2.4GHz and 5GHz WLAN bands.

2. ANTENNA DESIGN

A belt antenna for use in ISM 2.45GHz and 5.8GHz bands has been designed inspired in [5], where some modifications were made towards a practical application scenario, considering a common human usage. The antenna is fed by a microstrip transmission line, and uses the belt 3.3mm thick leather as dielectric substrate.

The dielectric properties of the leather used on the antenna structure were obtained by standard measurement methods. Taking these results into account in all simulations the considered relative electric permittivity was $\varepsilon_r = 2.95$. In the design procedure all simulations were performed using CST™ Microwave Studio tools.

Front and back views of the antenna model and the built prototype are shown in Fig. 1.
3. ANTENNA ON AIR: SIMULATION AND MEASUREMENT RESULTS

In this section the results obtained by simulation and laboratory measurements for the antenna in the frequency band between 0.5GHz and 6GHz is presented. The antenna was also tested for its operating bands considering some changes in its structure and in the leather.

3.1. Simulated Antenna Input Reflection Coefficient $|S_{11}|$

The following sections present a set of simulations made to study the antenna robustness to some changes made in its original structure and properties.

3.1.1. Changes in Leather Dielectric Properties

The laboratory measurements of the dielectric leather properties may not be precise. Therefore the design structure was tested considering different dielectric properties for the leather to check the possible impacts on the operating bands of the antenna.

The results obtained in the simulations for leather with different $\varepsilon_r$ are shown on Fig. 3. Fig. 4 are presents the results obtained in simulations for a leather with losses.

For the lowest frequencies, no significant changes occur for the changes in the $\varepsilon_r$ or in the $\tan \delta$, when comparing with the original leather ($\varepsilon_r = 2.95$ and $\tan \delta = 0$).

3.1.2. Microstrip line not adapted to 50Ω

The microstrip line width, $L_m$, was calculated to obtain a 50Ω impedance. To test the effects caused by a variation on the microstrip line width, some simulations were made. It was considered a decrease or an increase of 20% in the $L_m$ parameter. The results are shown in Fig. 5. For the lower frequencies the $|S_{11}|$ presents no significant changes, since the ISM 2.45GHz operating band is covered in all cases. The antenna loses tuning in the ISM 5.8GHz band, when the $L_m$ parameter increases 20%.

3.1.3. Antenna behavior when the belt is tightened

The regular wearing scenario for this antenna assumes that the belt is tightened. A strip of the same leather with 218mm long and 1.6mm thickness was used to emulate an extension
Fig. 4. Simulated input reflection coefficient. Leather with losses. For all cases $\varepsilon_r = 2.95$: (a) $\tan \delta = 0$ (original leather); (b) $\tan \delta = 0.16$, at 2.45GHz, (c) $\tan \delta = 0.16$ at 5.8GHz.

Fig. 5. Simulated input reflection coefficient. Microstrip line not adapted to 50Ω. Microstrip line width: $L_m$. (a) $L_m = 8.53mm$ (original structure); (b) $L_m = 6.82mm$; (c) $L_m = 10.23mm$.

Fig. 6. Simulated input reflection coefficient for the antenna on air. The belt is: (a) untightened; (b) tightened.

Fig. 7. Prototype measurements scenario for the antenna on air. (a) Untightened belt; (b) tightened belt.

3.2. Measured Antenna Input Reflection Coefficient $|S_{11}|$

Two prototypes for the designed antenna were built. The prototype 1 has a $(51 \times 51.7)mm$ buckle with a 3mm diameter wire, and the prototype 2 has a $(50.05 \times 53)mm$ buckle with a 3.2mm diameter wire. The buckle dimensions, $(f_x \times f_y)$, are represented in Fig. 1. The antenna input reflection coefficient $|S_{11}|$ was measured using a HP 8720A vector network analyzer, as shown in Fig. 7. The measurements were made for the belt untightened and tightened. The obtained results are presented in Fig. 8. For the lower frequencies the simulated and measured results are similar, but for the higher frequencies the differences are visible.
4. ANTENNA IN THE VICINITY OF THE HUMAN BODY: SIMULATION AND MEASUREMENT RESULTS

A three-dimensional human model created using 3D Studio and Poser software was imported to CST to simulate the antenna in the vicinity of the human body. This model was considered homogenous with density of 1000 kg/m³, relative electric permittivity of $\varepsilon_r = 45.6$ and electric loss tangent of $\tan\delta = 0.23$. The used model has 1.77 m high and around 65 kg. The dielectric properties were calculated considering an average human model with 85% muscle and 15% fat, and according the available data in [6]. To obtain the results for the simulated antenna input reflection coefficient it was used a simplified model of the human body, and the far field gain radiation patterns are obtained considering the complete model. On Fig. 9 are shown the two simulation models.

The two built prototypes were tested in laboratory for two different users according the following Measurement Scenarios (MS):

- **MS 1**: User standing up. No contact forced between the jeans button and the metal buckle.
- **MS 2**: User standing up. Contact forced between the jeans button and the metal buckle.
- **MS 3**: User sitting. No contact forced between the jeans button and the metal buckle.

Prototype 1 was only tested for User 1 in MS 1 and 2. Prototype 2 was tested in all the described measurement scenarios. In Fig. 10 is shown the Prototype 2 worn by the two users in the laboratory measurements.

4.1. Simulated Antenna Input Reflection Coefficient $|S_{11}|$

The results for the simulation with the antenna on air and in the vicinity of the human body considering the simplified...
model, are in Fig. 11. The results for these two cases are similar. The ISM 2.45GHz operating band is covered in both simulations.

Fig. 11. Simulated input reflection coefficient for the antenna: (a) on air; (b) in the vicinity of the human body (simplified model).

4.2. Simulated Radiation Patterns

The simulated radiation patterns obtained for the two models with the body and for the antenna on air (tightened belt) are shown in Fig. 12, Fig. 13 and Fig. 14. These results show that the radiation characteristic is affected when the antenna is near the human body. In all cases, an overall reduction in radiation is observed specially when the radiation characteristic intersects the human body.

Fig. 12. Far field gain radiation pattern for the XY plan. (a) 2.45GHz; (b) 5.8GHz; (c) belt model.

4.3. Measured Antenna Input Reflection Coefficient $|S_{11}|$

The measurements on laboratory consider the scenarios described in the beginning of this section. The measured results for the MS 1 and MS 2 scenarios are in Fig. 15. Considering that the antenna is tuned for the frequencies where $|S_{11}| < -10dB$, the ISM 2.45GHz band is not covered by any prototype in any scenario. However the ISM 5.8GHz operating band is covered for all cases. Considering that the antenna is tuned for the frequencies where $|S_{11}| < -6dB$ the antenna (both prototypes) cover all the bands between 1GHz and 6GHz. There are no major differences between the MS 1 and MS 2 results, which allows to conclude that a possible contact between the belt central wire and a metal button causes no significant perturbation in the antenna performance.

On Fig. 16 are presented the results for the MS 3 in comparison with the obtained in the MS 1. For user 1 the results are similar in both measurement scenarios, and for the user 2 some changes are visible around the 2GHz. Although the input reflection coefficient is still below the -10dB for this band. In the MS 3 scenario the ISM 2.45GHz band is not covered in both users measurements considering that the antenna is tuned for the frequencies where $|S_{11}| < -10dB$, but, as before, all bands between 1GHz and 6GHz are covered considering that the antenna is tuned when $|S_{11}| < -6dB$.

5. SPECIFIC ABSORPTION RATE RESULTS

The results for the specific absorption rate were also simulated in CST. This results are presented on Fig. 17 for the simplified model, and in the Fig. 18 for the complete model.

The European Union Council recommendation [1] for the localized SAR (10g) in the torso is a SAR below 2W/kg. The simulated results for the simplified and complete model
Fig. 15. Measured input reflection coefficient. Prototype 1 - User 1: (a) MS 1, (b) MS 2. Prototype 2 - User 1: (c) MS 1, (d) MS 2; - User 2: (e) MS 1, (f) MS 2.

Fig. 16. Measured input reflection coefficient (prototype 2). (a) Tightened belt on air. User 1: (b) MS 1, (c) MS 3; User 2: (d) MS 1; (e) MS 3.

present maximum SAR points above this limit, at 2.45GHz. At 5.8GHz, the SAR obtained for the simplified model e also above the limit, but for the complete model the obtained value, 0.757W/kg, is in the recommendation limits.

The maximum SAR point for all the simulations is near the antenna feeding area. The absorption area is only in the torso around the antenna.

6. CONCLUSIONS

A microstrip fed belt antenna, using leather as substrate, was designed and tested in wearing scenario including the influence of the human user. Measurements have shown that the antenna can be used in the ISM 2.45GHz and 5.8GHz, considering that the antenna is tuned for the frequencies where $|S_{11}| < -6dB$. The maximum SAR (10g) obtained for the complete model at 5.8GHz is in the recommendation limits.

For more detailed results check the Master’s thesis of this work [7].

This work presents the design and study of a wearable antenna on a belt. Given the results the next step would be to study how the antenna would behave as part of a BAN and analyze the propagation conditions and connectivity between the antenna and, for example, a set of sensors located in different body sites.
7. REFERENCES


