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RFID System for Respiratory Rate Monitoring

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Abstract. In this work, an RFID system was developed to monitor the respiratory rate. This monitoring was based on variations in the Received Signal Strength Indicator (RSSI) by the reader due to respiratory movements. In some breath measurement configurations, the maximum read range was greater than 1 m, which is the distance considered in the measurement configurations described in some scientific papers. The RSSI data, obtained by reading the RFID tag, were processed using the Daubechies wavelet of order 3 (db3) and considering three levels of signal decomposition. Less noisy breathing signals were obtained in the measurements with the participant seated and the RFID tag with the polyethylene foam on the abdomen. The respiratory frequencies acquired from the variations of the RSSI parameter were validated by comparison with the results obtained using a vital signals monitor.

1 Introduction

Vital signals are indicators of the health status of patients, providing relevant information about the body's functions. The monitoring of these signals allows the identification of health problems and a faster intervention by professionals in the area, in order to stabilize the patient's clinical condition, and to evaluate the results obtained after the intervention [1].

Respiratory rate is the least registered vital signal, despite being an important indicator of serious diseases, such as prognosis of cardiac arrest, abdominal pathology or sepsis [2]. In addition, with respiratory rate monitoring, sudden infant death syndrome (SIDS) [3], chronic obstructive pulmonary disease (COPD), obstructive sleep apnea syndrome (OSAS), Rett syndrome and asthma attacks can be detected [4]. Thus, it is possible to verify the importance of monitoring this vital signal, especially in critical cases, in which emergency care is crucial.

Some equipment used to monitor respiratory function is uncomfortable, requires devices attached to the body, and can even be invasive [5-6]. Among the methods for this monitoring, there are those that evaluate the temperature of the exhaled air, since it has been proven that the increase in the temperature of the exhaled air is related to the inflammation of the airways and to the increase in vascularization that is characteristic of the lung cancer [4, 7]. Some of these methods involve the use of masks or cannulas, non-contact infrared technology that requires expensive computer infrastructure and tools, or wireless systems with the sensor located in the region below the nose [7]. A wireless system has also been developed whose monitoring is based on the humidity of the exhaled air [4]. Other forms of monitoring use devices with sensors, such as a narrow chest strap, and some wireless technologies require custom Doppler radios, which are not readily available on the market [4, 6]. Therefore, it is observed that some of these methods can cause discomfort for the patient, are of high cost or are not easily accessible.

The use of technologies that provide this monitoring continuously associated with patient comfort is of great interest. Therefore, Radio Frequency Identification (RFID) technology is an alternative to existing technologies, since it allows this continuous monitoring through wireless communication, in a non-invasive way, and the use of flexible substrates can provide comfort to the individual. In addition, passive RFID tags do not require an internal battery for their operation, which contributes to both reducing weight and reducing costs and increasing their useful life.

In this work, the RFID UHF system that was developed for monitoring the respiratory rate is presented, and it is possible to determine the value of this frequency from the variation data of the Received Signal Strength Indicator (RSSI). Section 2 presents the tag design with the simulation results obtained after optimization of the tag presented in [8], as well as the made tag. In Section 3, the measurement settings are described, the respiratory signals obtained from reading the tags, that is, the RSSI variation signals due to respiratory movements, as well as the respiratory frequency results obtained from these variations of the RSSI and with the vital signals monitor. Finally, the conclusions are drawn in Section 4.

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2 Passive and flexible RFID tag design

2.1 Simulations

The RFID tag consists of an improvement of that presented in [8], with alteration of the L3 dimension of the port to facilitate the soldering of the chip and adjustments in other dimensions in order to achieve a resonance frequency close to 915 MHz with a lower value of the coefficient of reflection (S_{11}). Its simulation was also carried out using the ANSYS® Electronics Desktop™ software.

The tag can be seen in Fig. 1 (a) with its respective layers. The dimensions of its constituent parts are shown in Table 1 and indicated in Fig. 1 (b) and Fig. 1 (c). The distance between the CSRRs (Complementary Split Ring Resonators) cells is 1.1 mm and between the folded dipole antenna and the CSRR structure is 1 mm. Its total dimension is 63.9 x 107 mm².

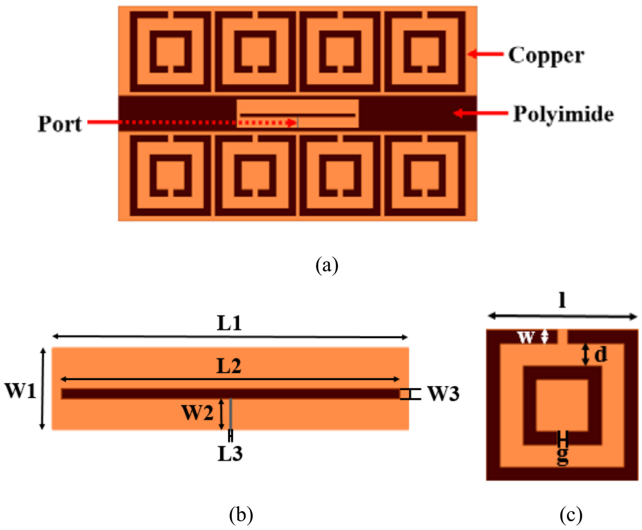

Fig. 1. Simulated RFID tag: (a) tag layers, (b) dimensions of the folded dipole antenna, (c) dimensions of the CSRRs cells.

Table 1. Dimensions of the RFID tag in [mm].

L1	L2	L3	W1	W2	W3
36.3	34.4	0.2	8.7	1.1	3.3
	l	w	d	g	
	24.2	2.2	3.6	1.6	

With this tag, it was possible to obtain a reflection coefficient of -49.99 dB at the operating frequency (915 MHz), as shown in Fig. 2. In Fig. 3, the antenna input impedance at this frequency is observed, with Za = (11.45 + j199.2) Ω. In this way, it is noticed a very good conjugate matching with the chip impedance (Zc = 12.7-j199 Ω for the NXP SL3S4021 chip at 915 MHz [9]).

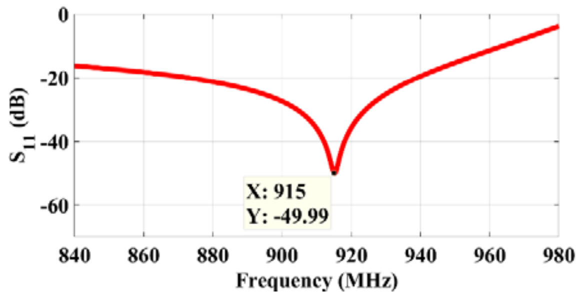

Fig. 2. Reflection coefficient (S_{11}) of the simulated tag.

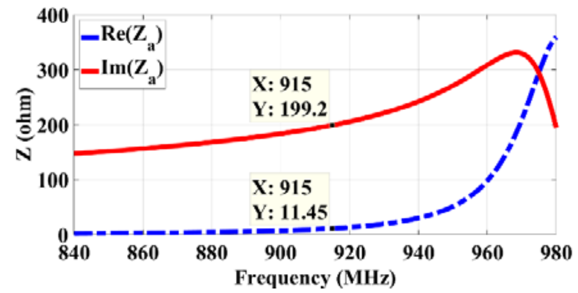

Fig. 3. Input impedance of the simulated tag.

Fig. 4 and Fig. 5 show the radiation patterns of the tag. It is possible to check the maximum positive gain value (5.47 dBi). In addition to this parameter, a maximum directivity value of 6.28 dB and a radiation efficiency of 82.98% were obtained.

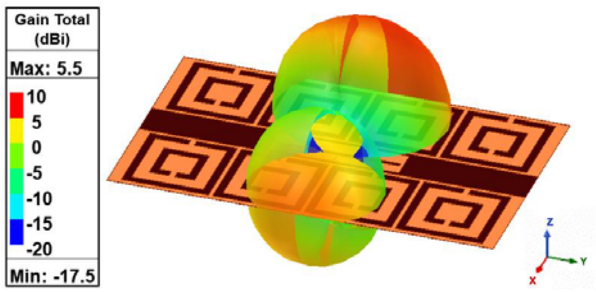

Fig. 4. 3D radiation pattern of the simulated tag.

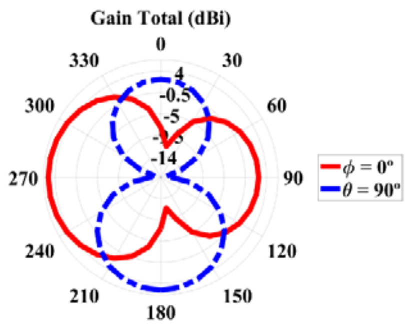

Fig. 5. 2D radiation patterns of the simulated tag.

The average Specific Absorption Rate (SAR) on the tag substrate was also simulated, as can be seen in Fig. 6, in order to certify that the limits specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) were being met. As the limits established by ICNIRP for public and occupational SAR for the trunk are 2 W/kg and 10 W/kg [10], respectively, it is noted that the value obtained meets these requirements.

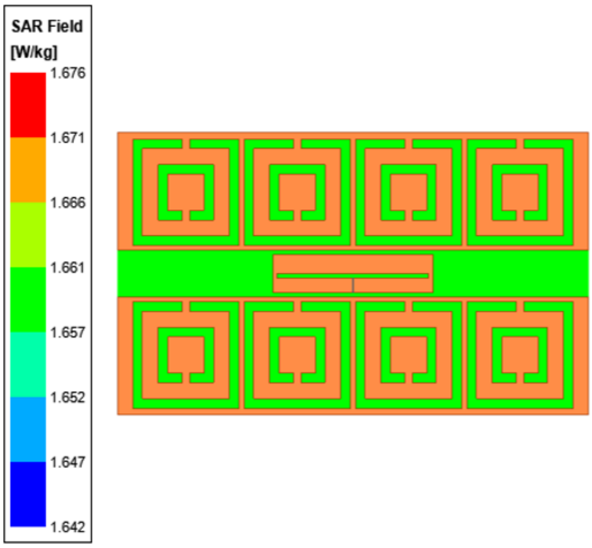

Fig. 6. SAR behavior on the RFID tag substrate at the frequency of 915 MHz.

The maximum read range for this tag, calculated using the Friis equation [11], is 24.60 meters at 915 MHz.

2.2 Fabrication

The RFID tag was made using the corrosion process of the copper face of the polyimide laminate using an iron perchloride solution. For this, the adhesive of the tag layout was pasted on this conductive layer, in order to prevent corrosion of the copper located under it. Subsequently, the substrate was cut and part of the adhesive to remove the chip was removed. To avoid cutting the copper located on the structure's margins by the manual manufacturing process, a margin of the substrate was left and the total dimension of the structure was 64 x 108 mm². The made tag is shown in Fig. 7.

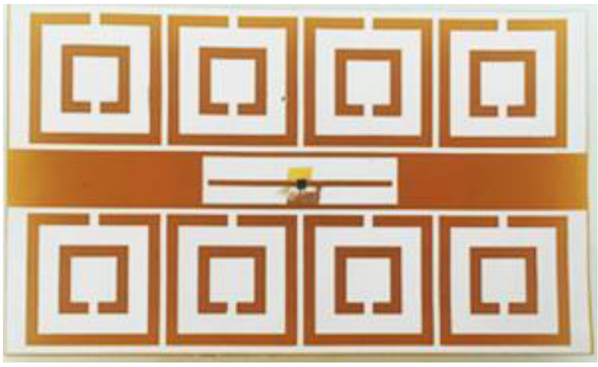

Fig. 7. Manufactured RFID tag.

3 Results and analysis of measurements

3.1 Experiments Setting

The configuration of the tests to obtain the respiratory rate is shown in Fig. 8. In these tests, the RSSI measurements from the reading of the RFID tag on the abdomen and the measurements with the Lifemed LIFEtouch.10 vital signals monitor were performed simultaneously for later validation of the respiratory rate results obtained by the RSSI variations. The 5-lead ECG cable was used on the multiparametric monitor and the electrodes were glued to the body in the positions indicated in Fig. 8 and also on the legs.

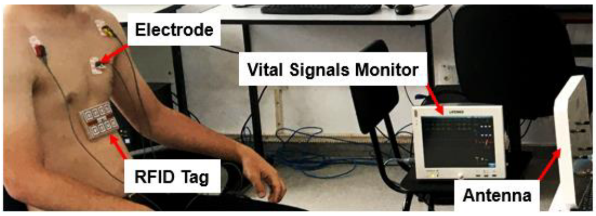

Fig. 8. Measurement setting.

As it was not possible to read the tag placed directly on the abdomen due to the influence of the human body on its performance, a 11 mm layer of polyethylene foam was inserted between the RFID tag and the body, which reduces the influence of the body on the performance of the tag. The foam was adhered to the polyimide substrate and to the human body by means of a thin double-sided tape, which does not cause damage to the skin.

In addition, the position of the tag on the abdomen was varied between the positions shown in Fig. 9, in order to observe in which position it is possible to obtain a greater range read of the tag and a better signal of breathing. Position 1 corresponds to the top edge of the tag placed just below the sternum and position 2 with it placed approximately four fingers below the sternum. The position of the individual was also varied, making measurements with him sitting and standing.

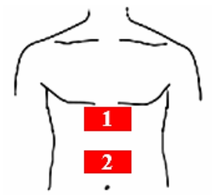

Fig. 9. RFID tag positions on the human body (adapted from [1]).

In those tests, the Intermec IF2 network reader was used and the Laird PAL90209H antenna was connected to it. This antenna has a gain of 9 dBic and operates in the frequency range of 902-928 MHz, which includes the operating frequency of the 915 MHz tag.

To carry out those measurements, the project was submitted to the Research Ethics Committee of the Hospital Universitário Alcides Carneiro (CEP-HUAC) for evaluation and was approved in accordance with the opinion number 3.742.182 and Presentation Certificate for Ethical Appreciation (CAAE) number 21811419.3.0000.5182.

3.2 Results and Analysis

The maximum read ranges after varying the distance between the tag and the antenna connected to the RFID reader are presented in Table 2. According to this table, it can be noted that it was possible to achieve greater range with the tag in position 1 and the participant

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standing. It is also noticed that all distances were greater than 20 cm, respecting the requirement of a minimum distance of 20 cm between the transmitting antenna and the human body of the Federal Communications Commission (FCC) [14].

Table 2. RFID tag maximum read range.

Position Tag	Participant's Position	Maximum Read Range (m)
1	Seated	1,09
2	Seated	0,865
1	Standing	1,23
2	Standing	1,05

The difference between the maximum read ranges obtained in the measurements and the value obtained from the simulation data (24.6 m), may be, among other factors, due to flaws in the manual manufacturing process and the influence of the human body on the performance of the RFID tag.

In some configurations, however, the read range was greater than 1 m, which is the distance considered in some works found in the literature, as can be seen in Table 3.

Table 3. Comparison between some works that use RFID technology to monitor breathing.

Reference	Year	Substrate	Read Range (m)
[12]	2016	Mix of wool and lycra and 55 mm polyethylene foam	1.00
[13]	2017	Fabric	1.00
[6]	2017	-	6.00
[4]	2017	Polyimide and polyurethane film	0.60
[3]	2018	-	1.00
[7]	2018	Bio-silicone membrane	0.50
This work	2020	Polyimide and 11 mm polyethylene foam	1.23

Because the signals received by the reader from reading RFID tags are quite noisy, it was necessary to process these signals to filter out noise. For that, the MATLAB software toolbox dedicated to the Wavelet Transform was used, which presents, among its applications, noise attenuation. Daubechies wavelet of order 3 (db3) was applied considering three levels of signal decomposition, which allowed the visualization of RSSI variations with respiratory movements and, consequently, the calculation of respiratory frequency from the number of signal peaks.

The measurements were carried out over a period of 2 minutes, however, as the respiratory rate corresponds to the number of respiratory cycles in 1 minute, only the data from the time interval in which it was possible to achieve better results was considered.

In Fig. 10, it is possible to observe the signals obtained when considering the seated participant. For the tag in positions 1 and 2, a respiratory rate of 20 rpm (breaths per minute) was obtained. The RSSI values varied between -60.3 dBm and -63 dBm for the tag in position 1 and between -59.5 dBm and -62 dBm for the tag in position 2.

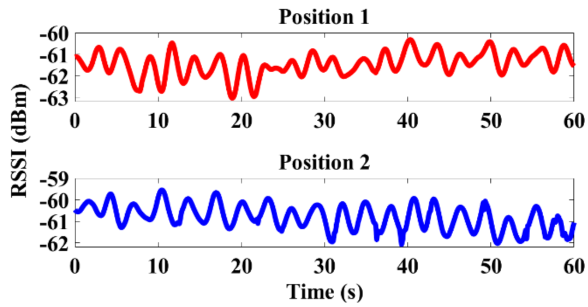

Fig. 10. Breathing signals obtained from reading the RFID tag with the 11 mm polyethylene foam and the participant seated.

The results for the standing participant, on the other hand, can be seen in Fig. 11. Note that the respiratory rate is approximately 20 rpm for the tag in position 1 and 19 rpm with it in position 2. Furthermore, in the measurement with the tag in position 1 on the abdomen, a variation of the RSSI was obtained between -58.3 dBm and -62.7 dBm, and, with it in position 2, this variation was between -64 dBm and -65.4 dBm.

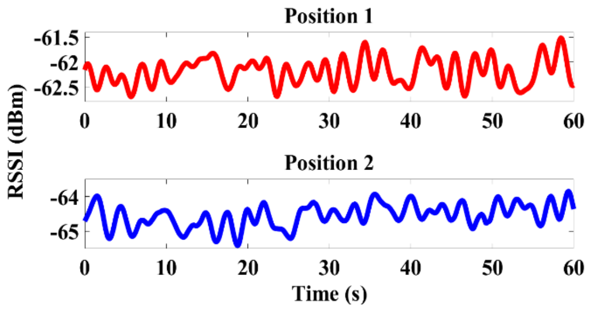

Fig. 11. Breathing signals obtained from reading the RFID tag with the 11 mm polyethylene foam and the participant standing.

According to the signals in Fig. 10 and Fig. 11, it is clear that, after processing, a less noisy result was obtained with the tag in position 2 and the participant being seated. However, in the other configurations it is also possible to verify variations of the RSSI with the respiratory movements.

In order to validate the values of the respiratory frequencies obtained from the variations of the RSSI, a comparison was made with the results obtained using the multiparametric monitor. Table 4 shows the values obtained from the RSSI variations and the frequency range in which the respiratory rate obtained through the signal monitor varied during the measurement. It is verified that the frequency obtained from the RSSI data are within the range of variation of the frequency obtained using the multiparametric monitor, thus validating the results of these measurements.

Table 4. Respiratory rate values obtained from RSSI variations and through the vital signals monitor.

Position Tag on the Abdomen	Participant's Position	Respiratory Rate Measured from Changes in RSSI (rpm)	Range of Respiratory Rate Variation with the Vital Signals Monitor (rpm)
1	Seated	20	15-22
2	Seated	20	16-22
1	Standing	20	20-22
2	Standing	19	17-21

4 Conclusion

In this work, a UHF RFID system for monitoring respiratory rate was developed, using a passive and flexible RFID tag. In the results of simulations of the tag, a maximum positive gain value of 5.47 dBi was observed and it was found that the average simulated SAR complies with the limits established by ICNIRP, ensuring its use on the body. Regarding the monitoring of respiratory rate, the possibility of this monitoring was verified through the variation of RSSI data obtained from the reading of the tags by the RFID reader. A better result was achieved in the measurement with the participant in the sitting position and the tag with the polyethylene foam on the abdomen. The respiratory rate data obtained from the RSSI variation were validated by comparison with the results obtained by the vital signals monitor. Regarding the maximum read range, it was noted that it was possible to obtain a range greater than 1 m in some configurations, this distance used in the measurements presented in some papers in the literature.

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