Flexible RFID tag for bottle labelling

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***Abstract*—This paper describes the design, manufacturing and range measurement of an UHF (ultra high frequency) RFID (radio frequency identification) tag to apply on a glass bottle filled with water. To achieve this, a free-space matched RFID antenna is studied and modifications are made in order reduce its size drastically and to turn it functional when applied to a bottle with water. Later, range measurement tests are made on the fabricated tag.**

***Index Terms*—RFID, tag, UHF RFID, RFID tags on bottles, impedance matching, antenna size reduction**

I. Introduction

RFID refers to a technology where digital data encoded in RFID tags is captured by a reader via radio waves. This is an automatic identification technology and is mainly used for identification of people or objects. A tag is attached to what is wanted to be tracked or identified and when it passes near a reader the tag responds to the reader's signal with information of the associated item.

The use of RFID on inventory control is best understood by analysing how we have been controlling inventory with bar codes over the past decades. As resourceful as the bar code technology is, RFID provides a better method that eliminates the requirement for line of sight scanning. RFID readers can be strategically placed on the production or inventory chains so that when the products pass near them, the energized tag reflects back the encoded data of its associated product even if it is not in line of sight with the reader.

Although the RFID has advantages when comparing to the bar code technology, it also has some handicaps.

The development of versatile and low-cost tags for the labelling of bottles remains a major challenge due to the unsatisfactory performance of the antennas when in presence of different liquids. A RFID tag may work perfectly well when applied to a package of cookies, but the same tag is unlikely to work when applied to a bottle with liquid in it. [1] implies that each tag has to be designed according to the product to which it will be applied on.

In the literature an embedded T-match dipole UHF tag antenna mounted on a winebottle neck with a 360-degree readable zone is shown [2]. Being mounted on the bottleneck causes the radio waves to pass through a smaller amount of wine, reducing or mitigating the loss introduced by the wine. This antenna yields read distance results between 5 to 8 m when the bottle is in an upstanding normal position, and 3 to 7 m when the bottle is upside down, having wine filling the bottleneck area. Both of these results are valid for a frequency range between 860 and 960 MHz. In [3] an antenna tag applicable in a new type of wine bottle closure is presented. This closure is composed of a thin metal sheet, a hollow internal plastic bladder and a plastic cover. The space in the internal bladder is used to place the RFID tag antenna. The antenna is a meander line monopole matched for 920 MHz, 2.6 cm long and 1.5 cm wide. A circular ground plane capable of fitting in the bottle closure is used to allow the antenna to radiate over the metal structure. Part of the monopole is bent over this ground plane in order to obtain low profile performance, creating an IFA (Inverted F Antenna). Reading distances of 1.5 m are achieved for this tag antenna when applied on the wine bottle closure.

This paper presents the design of a new RFID antenna to be placed on the widest part of a bottle filled with water. All the simulation will be performed with the CST MWS software [4]. The paper organization is as follows: Section II addresses the study of a free-space RFID matched antenna and all the design evolutions to make it functional when applied to the body of a glass bottle filled with water. Section III presents the practical tests performed on the constructed tag and results discussion. Final conclusions are presented in section IV.

II. Study and design of RFID antenna

A tag antenna, shown in figure 1 and presented in [5], is selected as base for this work. It is a meandered dipole with a T-match feed that facilitates the input impedance matching between the antenna and the tag's microchip, and was designed to operate in free space.

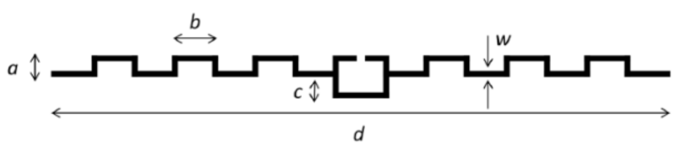

Fig. 1. Selected meandered dipole from [5].

TABLE I
Dimensions of selected RFID antenna from [5].

Parameter	a	b	c	d	w
Dimension [mm]	6.2	13.4	6.2	180.3	1.7

The dimensions of the antenna are represented in table I. The antenna's S_{11} parameter is presented in figure 2. It has a total length of 18 cm, which is not adequate to be applied to a bottle. Therefore, limits are set for the maximum dimensions of the antenna designed in this work. The limits for the imposed dimensions are 7 cm x 3 cm, in order to be possible to place the antenna behind the label of a bottle. It is then necessary to drastically reduce the size of this antenna while keeping it matched with the microchip. The microchip that is used in this paper is the SL3S1013FTB0 from NXP Semiconductors which has an input impedance of 27 - j234 Ω at 866 MHz [6].

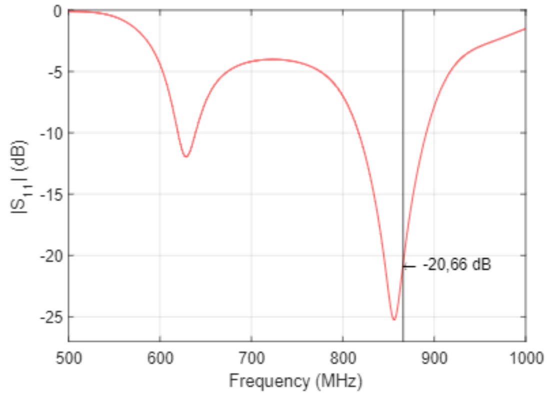

Fig. 2. Selected antenna S_{11} parameter.

To reduce the tag length, meander segments are removed from the dipole arms and the tip loading technique is used [7]. This technique consists of increasing the conductive surface at the end of the dipole, as shown in figure 3. This increases the number of charges that accumulate at the end of the antenna, and consequently its capacitance [7]-[8]. With this capacitance increase, the resonant frequency of the antenna lowers, since it is inversely proportional to the capacitance [8].

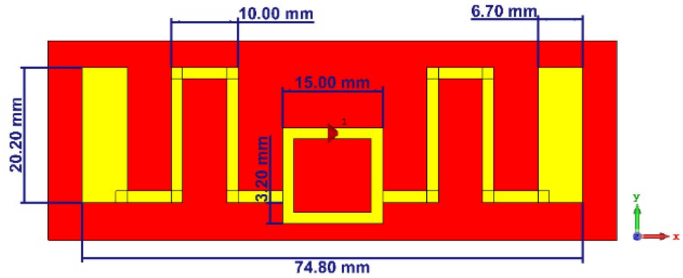

Fig. 3. Free space antenna size reduction.

The red block around the antenna represents the paper substrate. It is assumed that this is a conventional A4 sheet of printing paper and its thickness is 0.065 mm [9]. The paper properties were obtained from CST library and are $\varepsilon_R = 2.31$ and $tan\delta = 0$.

A reduction of almost a third in the antenna length is achieved, with the antenna having now a total length of approximately 7.5 cm. Its height has increased around 0.8 cm, having a total value of 2.02 cm. A great improvement is also achieved in the S_{11} parameter, which now has a value of -55.5 dB at 866 MHz, as can be seen in figure 4. Although the total length of the antenna is not yet within the established limits, it is decided to proceed with this antenna to test the introduction of glass and water due to the anticipation of the need to reduce its dimensions for later adaptation to the presence of these materials.

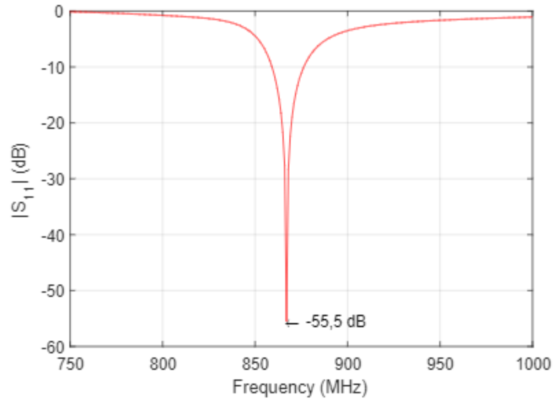

Fig. 4. Free space antenna S_{11} parameter.

In order to test the effects caused by glass and water, planar blocks of these materials are now introduced. For simulation purposes it is defined that the length of these blocks is twice the length of the tag, with the height being three times the height of the tag. The glass material is already defined in CST library having $\varepsilon_R = 6$ and $tan\delta = 3.46e^{-12}$ at 866 MHz. The thickness defined for the glass block is 2 mm, being this the typical thickness of a glass bottle [10]. The water block is created with 10 mm thick. The dielectric properties of water in CST library are define having an $\epsilon_R = 78$ and $tan\delta = 0.423$ at 866 MHz. This simulation environment composition is shown in figure 5,

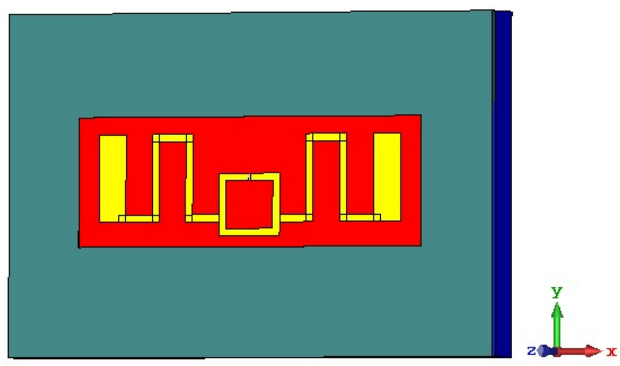

Fig. 5. Free space antenna with the glass and water blocks.

By introducing both of these materials it is noticeable in the graph of S_{11} parameter, figure 6, that the antenna is no longer matched, having the minimum value of $|S_{11}|$ of -8.6 dB at 1048 MHz.

It is then decided to create the model of a bottle body in the simulation environment, to which the antenna will be matched.

The bottle model has a height of 20 cm and a diameter of 7.1 cm. The antenna previously designed is placed on the bottle.

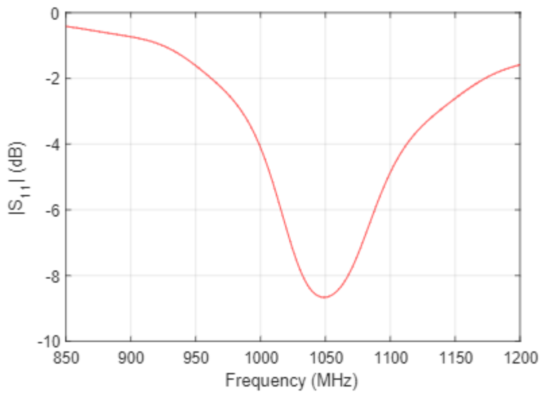

Fig. 6. Free space antenna S_{11} parameter with the influence of glass and water blocks.

New adjustments are made in order to retune the antenna to the desired frequency. The new dimensions are shown in figure 7 which resulted in the $|S_{11}|$ shown in figure 8. It has a minimum value of -14.53 dB at 868.5 MHz, and a value of -14.8 dB at 866 MHz. The input impedance is 38.5 + j229.6 Ω, which when compared with the impedance of the microchip still shows some deviation in the real part. The bandwidth has a value of 34 MHz, between 852 MHz and 886 MHz. The antenna applied on the bottle model is shown in figure 9.

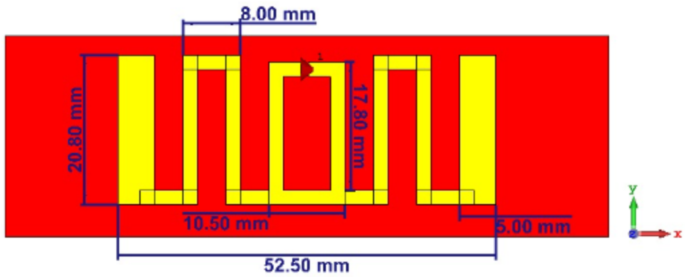

Fig. 7. Dimensions of the antenna applied on simulated bottle.

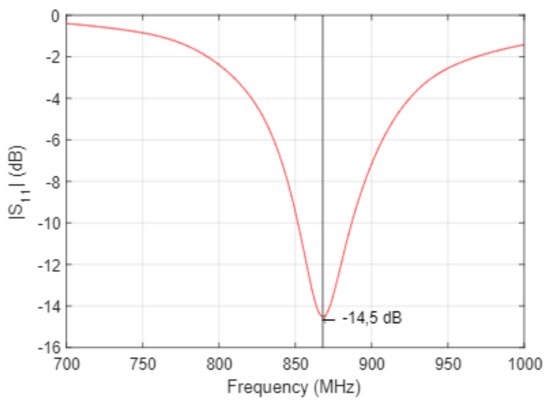

Fig. 8. S_{11} parameter of the antenna applied on simulated bottle.

The 3D gain radiation pattern of the antenna can be seen in figure 10 and the polar representation in 2D of its radiation

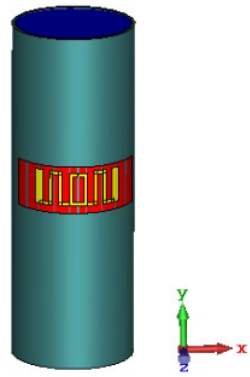

Fig. 9. Antenna applied on simulated bottle.

pattern is shown in figure 11. The antenna has not a directive pattern diagram which is a feature desired for this kind of RFID applications. Figure 12 displays the antenna's current density. As can be seen, it follows the typical current distribution of a dipole, with it's highest value at the center (near the feeding point) and decreases as it approaches the dipole ends.

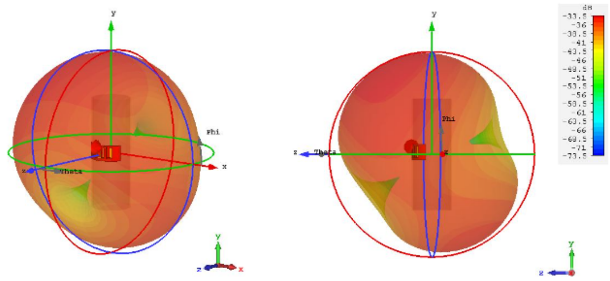

Fig. 10. Antenna's 3D gain radiation pattern.

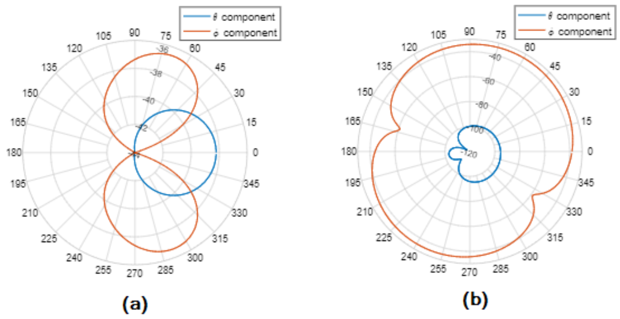

Fig. 11. 2D radiation pattern (antenna gain): (a) XZ plane, (b) YZ plane.

III. Tag Range Measurment

To perform read range tests, the Alien ALR 8800 RFID reader [11] is used. Several tests are carried out in a controlled environment to obtain the maximum tag reading distances. A small anechoic chamber is used to eliminate as many reflections as possible in order to make measurements free space like (see figure 13). The antennas of the RFID reader

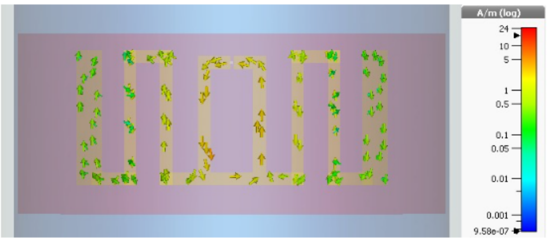

Fig. 12. Antenna's current density.

are mounted on a platform that can be moved horizontally and vertically, thus allowing for the distance and alignment tests. The range measurement setup can be seen in figure 13. Two tags were built from the antenna designs previously presented, one for free space and one to be applied on a bottle.

Fig. 13. Range measurements environment setup.

Three types of tag read distance measurements are performed: free space measurement, measurement with tags applied to empty glass bottles and measurement with tags applied to glass bottles with water. In addition to the two constructed tags, a commercial RFID tag is also used in these measurements in order to make a comparison of the designed tags. Table II shows the results of these measurements tests.

TABLE II
PERFORMANCE COMPARISON BETWEEN THREE RFID TAGS.

Tag	Free Space	Empty Bottle	Full Bottle
Free Space Tag	157 cm	28 cm	12 cm
Bottle Tag	90 cm	184 cm	30 cm
Commercial Tag	240 cm	20 cm	Not read

It can be concluded that the tag designed for a free-space scenario showed a good reading distance of about 1.5 m. Surprisingly, the reading at 30 cm in free space of the bottle tag was achieved. Still, the commercial tag showed the longest reading distance. When the tags are applied to an empty bottle, a degradation of the reading distances of the free space tags is clearly noticeable, thus showing that the glass causes degradation of the performance of the tags. For the bottle tag there is a significant improvement, reaching a distance of 184 cm. The influence of water is also quite noticeable when placing the tags in a glass bottle filled with water. The commercial tag is no longer readable in this scenario. The bottle tag reaches a good reading distance of 30 cm.

IV. Conclusion

A UHF RFID antenna tag to be applied on a glass bottle filled with water was presented. For this, it was necessary to drastically reduce the size of the tag in order to be able to have an antenna within the imposed size limits. When the tag was applied to a bottle, empty or full of water, it showed reading distances of 184 cm and 30 cm, respectively. These range measurements validated the good performance of the proposed tag antenna.

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References

[1] Wu, N.C. Nystrom, M.A. Lin, T.R. Yu, H.C.. (2006). Challenges to global RFID adoption. Technovation. 26. 1317-1323. 10.1016/j.technovation.2005.08.012.
[2] J. Xi and T. T. Ye, "Conformal UHF RFID tag antenna mountable on winebottle neck," Proceedings of the 2012 IEEE International Symposium on Antennas and Propagation, 2012, pp. 1-2
[3] Z. Hu and P. H. Cole, "Bottle packaged wine product detection by UHF RFID systems," 2010 International Conference on Electromagnetics in Advanced Applications, 2010, pp. 301-304
[4] "CST Studio Suite Electromagnetic field simulation software", www.cst.com
[5] H. M. O. de Miranda, "Sistemas RFID UHF", Universidade de Aveiro, 2015
[6] "SL3S1003_1013 Product Datasheet". [Online]. Available: https://www.mathworks.com/matlabcentral/fileexchange/12491-mimo-rayleigh-fading-channel-capacity (visited May. 2020)
[7] T. Hu, C. Liu and Z. Wang, "Design and analysis of UHF tag antenna structure," 2011 China-Japan Joint Microwave Conference, 2011, pp. 1-4.
[8] N. M. Faudzi, M. T. Ali, I. Ismail, N. Ya'acob, H. Jumaat and N. H. M. Sukaimi, "UHF-RFID tag antenna with miniaturization techniques," 2013 10th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, 2013, pp. 1-5
[9] "The Thickness of Printing Papert". [Online]. Available: https://www.zxprinter.com/support/paper-thickness.html (visited Feb. 2020)
[10] Liu, Qi et al. "A Versatile Flexible UHF RFID Tag for Glass Bottle Labelling in Self-Service Stores." IEEE Access 6 (2018): 59065-59073.
[11] "ALR-8800 ENTERPRISE RFID READER". [Online]. Available: http://www.srdinfotech.com/RFID/pdf/UHF/ALIEN/ALIEN_ALR-8800.pdf (visited Jan. 2021)