Study of the Resonance Frequency Variation in UHF RFID Tags by Changing the Internal Dimensions of an Inlay

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Abstract. This paper aims to establish an analysis of the impact in the resonance frequency of a Radio Frequency Identification (RFID) inlay operating in Ultra High Frequency (UHF) by changing its internal dimensions. Obtaining the resonance frequency in terms of the S_{11} parameter is crucial in order to design RFID labels that meet specific requirements. The use of a Computer Aided Design (CAD) tool was considered to design the RFID inlay, while the simulations were performed using the MWS-CST Studio Student Edition software. Satisfactory results were met in order of verifying central frequency shifting as long as the internal dimensions of the inlay have been adjusted in two rounds of simulations. Additionally, it was possible to demonstrate a gain greater than 2 dB and 30 MHz bandwidth, showing that the tested conditions can be seen as a good starting point for future works to advance the studies in the context herein presented. The RFID tags designed in this paper benchmarks an antenna widespread in the RFID market. Meanwhile, the theoretical basis obtained by observing the antenna theory and analyzing the results has been used to contribute to all the process of building an RFID tag and stimulate the expansion of RFID technology worldwide.

Keywords: RFID · Tags · UHF · Resonance frequency · Radio frequency identification

1 Introduction

The Radio Frequency Identification (RFID) had its peak of popularization in the early 2000s; since then, this technology has been undergoing several improvements that ended up with the first interactions around the concept of the Internet of Things (IoT).

The success obtained in the most diverse market applications encourages the use of this technology in different scenarios and unexplored conditions. Thus, the popularization of technology has been growing since its first implementations, and, with that, investments in research and development in this area [1]. The use of RFID is quite diverse and is applicable for different market segments; among the most well-known

Y. Iano et al. (Eds.): BTSym 2020, SIST 233, pp. 750–758, 2021.
https://doi.org/10.1007/978-3-030-75680-2_83

applications are those that related to the retail and apparel segment, where RFID tags are applied to clothing items and respond to the infrastructure of readers and the software installed in a logistic distribution center or inside the stores.

Generally, a passive RFID tag has three main components: Integrated Circuit (IC), an antenna, also known as an inlay, and a substrate. The set operates by backscattering the Radio Frequency (RF) signals from a base station known as RFID Reader, which transmits a modulated signal and converts the voltage at the antenna terminals into Direct Current (DC), the energy is then transmitted from the reader to the tag that energizes the IC and sends back its information contained therein, thus changing the complex input impedance of the system [1].

One of the most important parameters to consider during an RFID tag development is the match between the antenna and the IC; usually, RFID tags are designed to answer the IC specifications; otherwise, it would be cost-wise unfeasible to develop a new IC for every particular application.

There are a few authors publishing different ways to develop an RFID inlay focusing on a specific market, including biotechnology [2], healthcare [3], RTLS (Real-Time Location System) [4, 5].

The regulations for UHF RFID frequencies depends on the countries or regions where the technology is being used; for example, in Europe, the local regulations permit the use of 866 MHz–869 MHz band, North and South America operate in 902 MHz–928 MHz, Japan and some Asian countries, from 950 MHz to 956 MHz. In addition, regulatory bodies are associated with the governments of the regions where communications are regulated; in Brazil, for example, ANATEL (National Telecommunications Agency, in Portuguese, Agência Nacional de Telecomunicações) manages and regulates the use of the frequency spectrum in telecommunications, and in Europe, the ETSI (European Telecommunications Standards Institute) [6–8].

This article aims to demonstrate the displacement of the resonance frequency in terms of parameter S_{11} in relation to the variation of the internal dimensions of an RFID inlay developed from a reference model used in this segment. The results obtained in this article aim to propose new constructive approaches in the scenario of RFID inlays in order to contribute to the viability of the technology in conditions that require specific characteristics.

This article is divided into four fundamental groups in which Sect. 1 presents a historical review of RFID technology, and Sect. 2 refers to the theoretical approach addressed as a baseline for the construction proposed here. Section 3 presents the development process applied to the methodology used in the simulations, as well as the premises and starting points that were taken into account in this article, while the conclusions and results can be found in Sect. 4, which includes a consolidation of the simulations performed and results obtained.

2 Theoretical Characteristics of Impedance Matching

In RFID projects, reading range, also known as reading distance, is given by the maximum distance that the RFID reader is able to decode the information contained in an RFID tag; this parameter, in many cases, defines the use of a certain label at the expense of others [1].

Some environmental conditions directly affect the efficiency of the reading range; most of these conditions are correlated with the resonance frequency matching and the bandwidth in which the system is propagating the RF waves, in addition, the orientation of the label, the immersion or contact with ionic and/or metallic environments are also amidst the conditions that induce RF distortions in the UHF band [9].

One of the most important parameters to consider when developing an RFID tag is the match between the antenna's impedances and the IC of an RFID tag. RFID tags are generally designed to meet the specifications of a market IC since the cost and complexity of developing a new IC for every single use case would be impracticable.

As in most antenna calculations, the reading range can be approximated by the Friis equation in free space, as shown in (1) where λ is the wavelength, Pt is the power transmitted by the reader, Gt is the gain of the transmission antenna, Gr is the gain of the receiving antenna, Pth is the power threshold necessary to supply the RFID inlay IC and τ is the transmission coefficient expressed by (2) [10].

By the qualitative analysis of Eq. (2) in which the impedance of the IC is given by $Zc = Rc + jXc$ and the antenna impedance by $Za = Ra + jXa$, it is clearly possible to verify that the maximum reading distance is obtained when the modules of Xa and Xc has the same values. The authors of [8] illustrate, on page 2, the contours of the correlation between Zc and Za.

The sensitivity of the RFID reader is typically higher compared to the sensitivity of the tag. In addition, the reading distance is determined by the thresholds of the responsiveness of the tag. It is important to notice that the reading distance is mainly influenced by the means of propagation and also by the type of material on which the label is operating [8].

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{PtGtGr\tau}{Pth}} \tag{1}$$

$$\tau = \frac{4RcRa}{|Zc + Za|^2}, 0 \leq \tau \leq 1 \tag{2}$$

Therefore, according to [10], it is possible to establish a correlation between the expected gain and the transmission coefficient. This type of analysis is essential to understand the compromise between gain, impedance, and bandwidth of an RFID tag.

3 Simulations and Results

3.1 Methodology

The simulations were carried out through practical experiments to verify the behavior of a RFID tag; thus, the development of the antenna was performed using the software MWS-CST Studio Student version that allows to design and simulate an antenna that meets the proposed requirements.

The antenna's development phase consists essentially of obtaining the best electromagnetic coupling ratio between IC and inlay. Thus, variations in the layout and dimensions of these inlays significantly alter the frequency response and the power radiated by the RFID tag, permitting to adjust the correlation between gain and resonance frequency to meet the proposed requirements.

Important factors such as the substrate on which the inlay will be deposited, the adhesive layers, the protective screening, and so the synthetic paper often used to print visual data were not considered in the experiments. Strictly speaking, only the direct response of the inlay and the interferences of the environment in which it was observed were considered.

The interferences of the environment in which the RFID tag is inserted are very relevant in the study of the behavior of RFID tags and can limit the choice of one type of tag over others as well as the communication protocol that governs the communication of data between an RFID tag and the reader infrastructure in which it communicates. The protocol used for RFID UHF communication is ISO 18006-C, which aims to standardize a series of requirements that, in addition to the frequency spectrum regulations of each country and/or region, enable the use of technology worldwide.

The results presented in this article were obtained through two simulation rounds that consisted of checking the parameter $S_{11,}$ and then the realized gain. The first round of simulations was performed with the original measurements of the inlay built from the reference model, while the second round was performed after some adjustments in the internal dimensions of the RFID inlay. The results and particularities of each of them will be described in this article.

The use S_{11} parameter was due to the fact that this parameter serves as a comparative reference for the central frequency of the antenna under development and its respective geometric adjustments. On the other hand, the realized gain is a very relevant measure that shows the relationship between the radiated power and the directivity of an antenna, since the energy radiated in a given direction must obtain a minimum efficiency in order to guarantee the information transmitted by the antennas meets the requirements from a given use case [11].

3.2 Reference Design

The starting point for the construction of the RFID inlay built for the simulations described in this article was based on the ALN-9770 model manufactured by the Alien Technology company, also known as “Bat” inlay [12].

The reason to choose this reference model is due to the fact that it is a very widespread label in the market, and it has a good efficiency in several environmental conditions, such as close to metallic environments and close immerse to ionic moisture [12].

As well as the reference of the contours and the layout of the inlay, the maximum dimensions defined for the model used in the simulations will also be based on the Alien “bat” label, that is, 83 mm × 32 mm [12]. In order to obtain a constructive safety margin, it was established that the maximum dimensions for the label under development in this article are 100 mm × 40 mm.

Two other parameters were established as constructive starting points for the design proposed in this article: the minimum reading sensitivity of −20 dBm and the Parasitic Capacitance at −0.21 pF; both values were taken from a commonly used IC in RFID applications for general purpose, the Monza R6 IC from Impinj manufacturer [13].

Taking into account the premises described, Fig. 1 illustrates the inlay used for the simulations presented in this article.

Fig. 1. Inlay under development used S_{11} and realized gain measurements.

3.3 Results Obtained

The starting point established for the dimensions defined in the antenna under development was based on the internal measurements of the Alien "bat" tag. Figure 2 presents the dimensions and the references that list the main measures that were taken into account during the simulations proposed here, and Table 1 presents the values of each dimension for the first round of simulations.

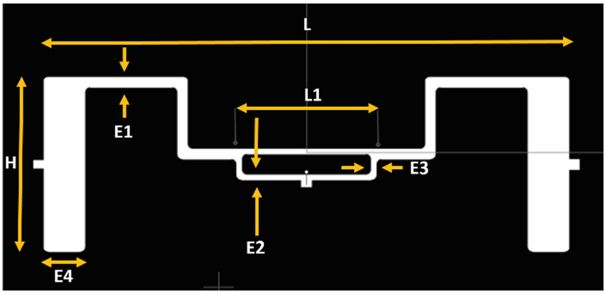

Fig. 2. Dimensions of main internal dimensions of the RFID inlay under development.

Table 1. Dimensions for designed inlay parameters in the first round of simulations

Dimensions	L	L1	E3	E4	H	E1	E2
Measure (mm)	98	12	0.9	16	34	0.9	0.9

Once the dimensions of each of the measures presented in Table 1 are defined, the goal of this first analysis is to understand what is the resonance frequency established by parameter S_{11} for this scenario. It is worth mentioning that the tests did not consider the application of the label on any type of surface; that is, the results obtained include the inlay applied only on the substrate in PEC.

Figure 3 illustrates the first simulation scenario considering the measures presented in Table 1. The first simulation round showed that the bandwidth for S_{11} at -10 dB varies between 925 MHz–939 MHz, and the S_{11} resonance occurs at 930 MHz at −22 dB.

Also, considering the measures established in the first round of simulations, the realized gain, as shown in Fig. 4, reached its maximum of 1.98 dB at 930 MHz, that is, at the same resonance frequency seen in S_{11}. Two complementary measures at 900 MHz and 915 MHz were taken of −2.07 dB and 0.49 dB, respectively, showing a positive trend of gain as it approaches the resonance frequency.

Mathematically, when analyzing the gain of 2 dB as a baseline for establishing the bandwidth for this configuration, a range of 30 MHz bandwidth could be seen.

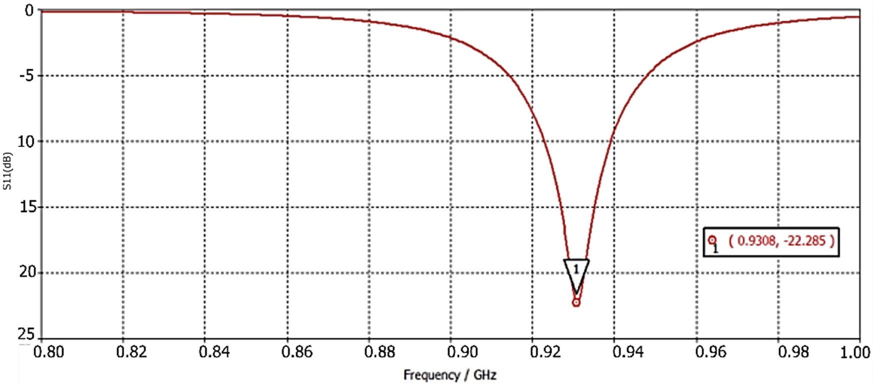

Fig. 3. Resonance frequency in S11 for the measurements established in Table 1.

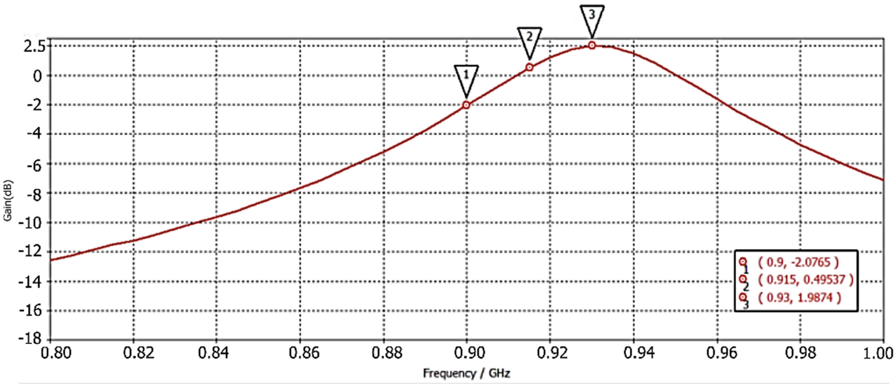

Fig. 4. Realized gain in dB for the measures established in Table 1.

The second round of simulations was carried out similarly to the previous condition, this time adjusting the values of the internal dimensions of the inlay under development for the measures corresponding to Table 2. For this new scenario, the dimensions E3 and E2 were changed, from 0.9 mm in the first round of simulations to 1.1 mm, and from 0.9 mm to 1.2 mm, respectively.

The region comprised of the E3 and E2 dimensions is known as the inductive loop; this area is very sensitive to changes in thickness and reflects directly in the S_{11} resonance frequency since it is in this region where the magnetic coupling occurs. As can be seen in Sect. 2, changes in the imaginary components of the input impedances can change the impedance matching between the IC and the inlay.

In order to enable a comparative analysis of the results obtained in the two rounds of simulations, for the second round, the same simulations were carried out in terms of the resonance frequency in S_{11} and the realized gain, as shown in Fig. 5 and Fig. 6 respectively.

Table 2. Dimensions for designed *inlay* parameters in the second round of simulations

Dimensions	L	L1	E3	E4	H	E1	E2
Measure (mm)	98	12	1.1	16	34	0.9	1.2

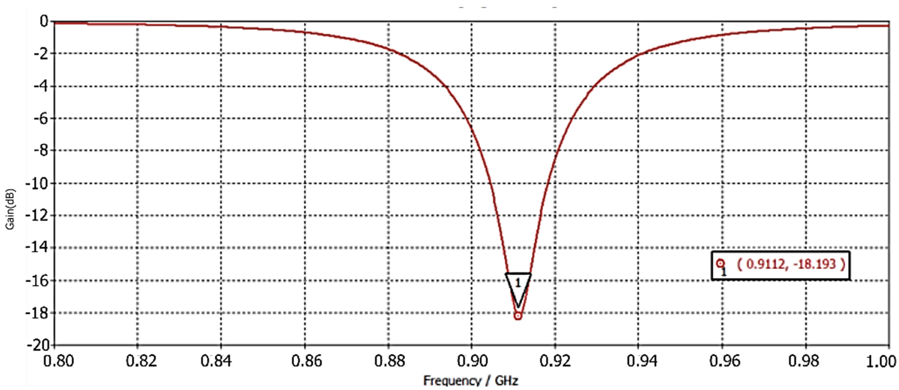

Fig. 5. Resonance frequency in S_{11} for the measures established in Table 2.

The second round of measurements showed that the resonance frequency in S_{11} is at 911 MHz and −18 dB and that a −10 dB range for S_{11} varies from 908 MHz–918 MHz, as shown in Fig. 5.

Still, for the second round of measurements, Fig. 6 shows the realized gain reaching its maximum point at 915 MHz and 2.0 dB; in this case, it has been shifted by around 4 MHz from the S_{11} resonance frequency. The two adjacent measures at 900 MHz and 930 MHz showed realized gain at 0.48 dB and 0.46 dB, respectively.

Establishing the same baseline reference at 2 dB of gain seen in the first round of simulations, the bandwidth was 8 MHz in this scenario.

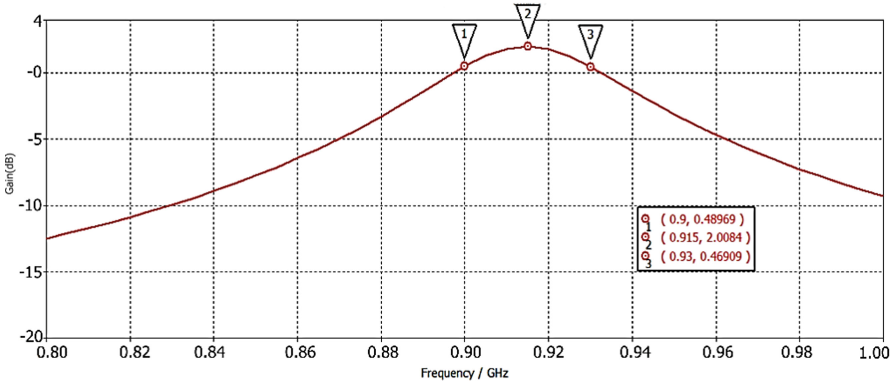

Fig. 6. Realized gain in dB for the measures established in Table 2.

4 Conclusions

The results from the simulations analyzed two different scenarios where there were adjustments on the internal inlay dimensions. Both scenarios have shown that there is a compromise between the measures of internal dimensions of an RFID inlay and its resonance frequencies as well as its realized gains.

In summary, the dimensional adjustments analyzed in Table 1 and Table 2 indicated that the resonance frequency shifted from the range close to 930 MHz to roughly 915 MHz. However, despite the average 2 dB maximum point of the realized gain in the two simulated situations, there was a significant loss in bandwidth in the second round of simulations, varying from 30 MHz to 8 MHz; such variation occurs due to the variation in the capacitive components of the input impedances of the RFID inlay.

Finally, it was possible to demonstrate that modifications of the dimensions in the thicknesses and lengths of the RFID inlay can be a good factor in order to get the desired frequencies and realized gains in a UHF RFID tag design.

However, further studies presented in this article can be driven in terms of knowing how the interaction of these dimensional adjustments affects or complements one another in order to obtain a gain that could be sustained by a larger bandwidth.

References

1. Nikitin PV, Rao KVS (2006) Theory and measurement of backscattering from rfid tags. IEEE Antennas Propag Mag 48(6):212–218
2. Chrysler A, Furse C (2016) Biocompatible, implantable UHF RFID antenna made from conductive ink. In: 2016 IEEE international symposium on antennas and propagation (APSURSI), Fajardo, pp 467–468
3. Amendola S, Lodato R, Manzari S, Occhiuzzi C, Marrocco G (2014) RFID technology for IoT-based personal healthcare in smart spaces. IEEE Internet of Things J 1(2):144–152
4. Ciftler BS, Kadri A, Güvenc İ (2017) IoT localization for bistatic passive UHF RFID systems with 3-D radiation pattern. IEEE Internet of Things J 4(4):905–916
5. Yu H, Chen J, Hsiang T (2015) Design and implementation of a real-time object location system based on passive RFID tags. IEEE Sens J 15(9):5015–5023

6. GS1 (2020) Regulatory status for using RFID in the EPC Gen2 (860 to 960 MHz) band of the UHF spectrum. [S.l.]
7. Agência Nacional de Telecomunicações. https://www.anatel.gov.br/institucional
8. European Telecommunications Standards Institute. https://www.etsi.org
9. Balanis CA (2005) Antenna radiation efficiency. In: Antenna theory: analysis and design, 3rd edn. Wiley-Interscience, New Jersey, pp 85–87
10. Rao KVS, Nikitin PV, Lam SF (2005) Antenna design for uhf rfid tags: a review and a practical application. IEEE Trans Antennas Propag 53(1):3870–3876
11. Balanis CA (2005) Gain. In: Antenna theory: analysis and design, 3rd edn. Wiley-Interscience, New Jersey, pp 65–69
12. ALIEN (2016) ALN-9770 “Bat” Battery Inlay. [S.l.]
13. IMPINJ (2020) Monza R6 Tag Chip Datasheet. [S.l.]