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Design of a miniaturized dipole RFID tag antenna

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Abstract

Objectives: This study introduces a new design strategy for an RFID Tag. **Methodology/Findings:** A low-profile meander line dipole antenna has been fabricated as a proof of concept due to its electrically small size and simple structure. Good agreement is achieved between the results obtained by this method and those calculated by simulations using CST. The antenna is designed to operate at a frequency of 915 MHz, allocated for UHF RFID. In order to ensure that the design has good performance, all of the antenna parameters are optimized. The results of antenna parameters such as radiation pattern, bandwidth, gain and return loss are also considered. This made it possible to achieve a reduction in size of the order of 40%. **Applications:** Meander line dipole antennas are useful as radio frequency identification (RFID) tag antennas because of their relatively high radiation efficiency and small size.

Keywords: UHF; RFID; tag; meander; dipole

1 Introduction

Radio Frequency Identification (RFID) systems generally consists of tags associated to each object to be tracked, a reader that requests/receives information from the tags, and a database that gathers the information to be processed.

A tag, also known as transponder, holds the data that is transmitted to the reader when the tag is interrogated by the reader[1,2]. The most common tags today include an antenna and an Integrated Circuit (IC) with memory, which are essentially microprocessor chips. According to the communication methods between tags and reader, there are three types of RFID tag, passive, active and semi-active. The main difference is whether the battery is encapsulated in the tag or not. The most popular tags today are passive tags, as these tags require no battery power and can be produced at very low cost. They get their power by harnessing the electromagnetic energy emitted from the reader. Active tags have their own power supply. They do not require energy provided by reader to energize them. Thus, active tags can automatically send a signal to the reader.

Compared with passive tags, active tags have longer working range and more complex application, but shorter operation life, bigger size and heavier weight. Semi-active tags are between active and passive tags, as they use power from an onboard battery to operate. However, they still need electromagnetic field generated by reader to ”wake up” and transmit the information stored in the tag back to the reader [1–3].

Passive RFID tags have been used in assets tracking and inventory management for many years. Considering tag costs are one of the key considerations in an RFID deployment, a passive RFID tag solution, which is no-battery, less expensive and with favorable form factor, is the most appealing choice for use.

Different systems use different frequency bands: Low Frequency BF (125 kHz, 135 kHz), High Frequency HF (13.56 MHz), Ultra High-Frequency UHF (860 – 950 MHz) and microwave frequency (2.45 GHz). The different frequency bands have different qualities [4]. There are four main factors that are influenced by the frequency: the operating range, the transfer rate, the ability to penetrate materials and the ability to withstand electromagnetic background noise. In this case, the initial RFID system is primarily targeted to general asset tracking systems.

Considering the environment conditions of the tags and comparing the properties of different passive RFID products available in the open market, UHF RFID is decided to be used in the presented solution [5–8].

The remainder of this paper is organized as follows: Section 2 presents the design and simulation of the proposed antenna dipole for the passive UHF RFID tag. Section 3 presents the experiment and design of the miniaturized dipole antenna of tag with meander line. The results are also described and discussed. Then, this paper will be present the fabrication of this antenna and compare the proposed antenna structures. Finally, a conclusion will be made in Section 4.

2 Design of a dipole antenna

The dipole antennas are widely used in radio systems compared to traditional line antennas thanks to their advantages (small volume, low weight and low cost), and they are much more suitable for sensitive applications (mobile receivers, vehicle radio receivers and RFID tags) [9].

A dipole antenna was deposited on a substrate of FR4 type of relative permittivity ε_r = 4.3, loss tangent of 0.0019, thickness h = 1.6 mm and size 146 × 26 mm^2. The desired resonance frequency was 915 MHz and effective length (L = $\lambda/2$). The excitation of this antenna is in the center of the dipole and powered with an impedance of 50 Ω. The other geometrical parameters of this antenna are shown in Figure 1, with L = 128 mm and W = 4 mm.

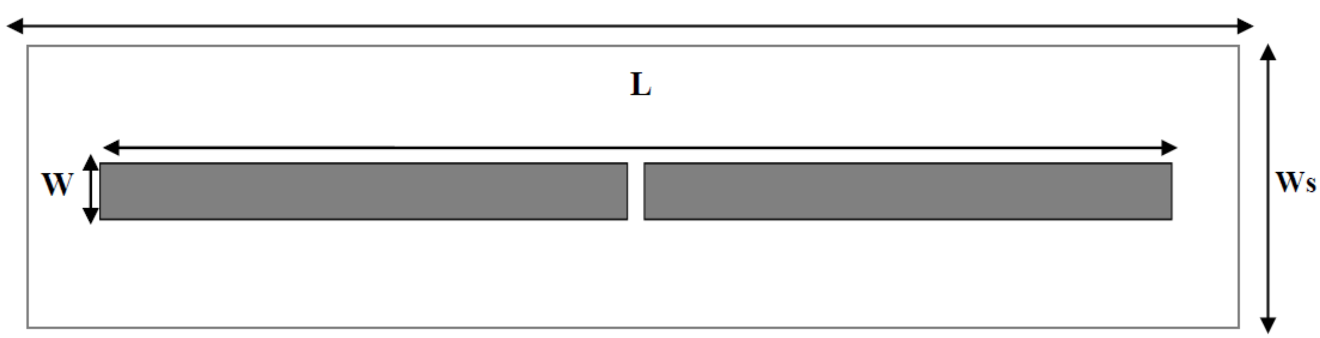

Fig 1. Design of the dipole antenna

Figure 2 presents the reflection coefficient S_{11} of the tag dipole antenna. A reflection coefficient S_{11} of -27 dB is achieved at the frequency of 915 MHz, along with a 100 MHz bandwidth (868-968 MHz).

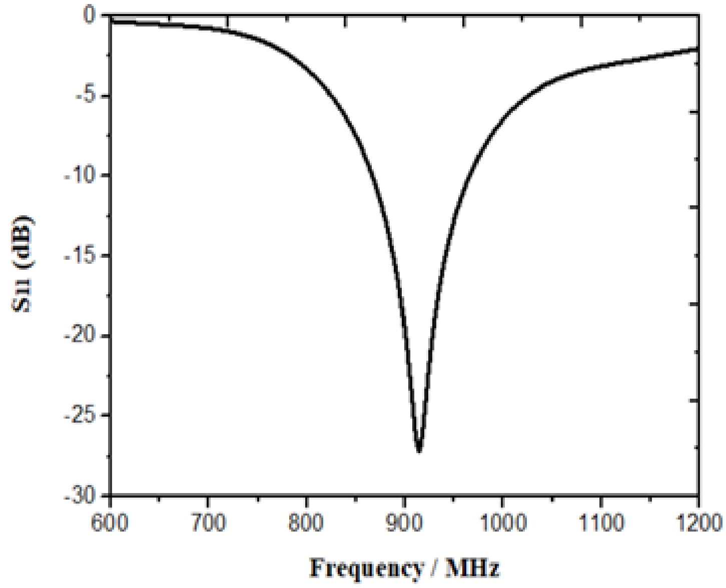

Fig 2. Reflection coefficient S11 of the dipole antenna

Figure 3 represents the radiation pattern in the xy and yz planes in polar coordinates. The directivity obtained is in the order of 2.01 dB.

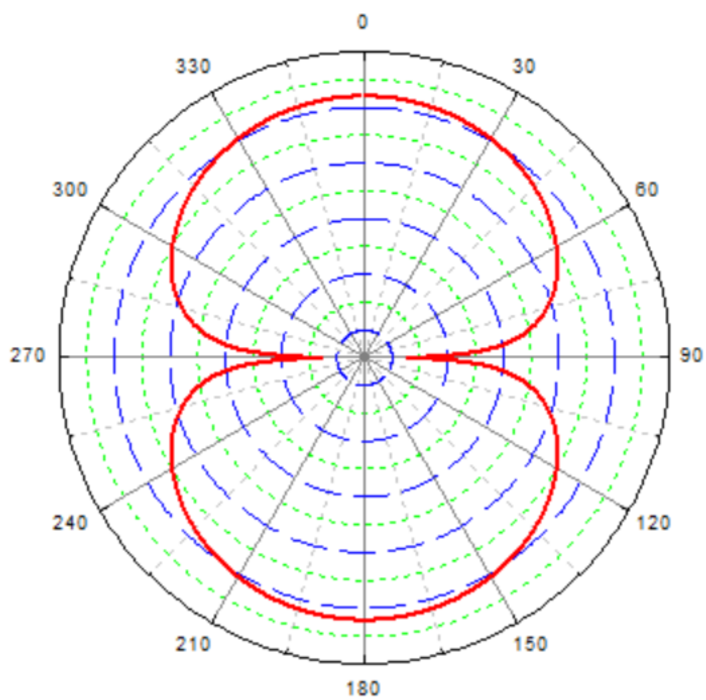

Fig 3. Simulated directivity of the dipole antenna

Figure 4 shows the gain of the designed antenna as a function of frequency, with 1.93 dB gain being registered at 915MHz.

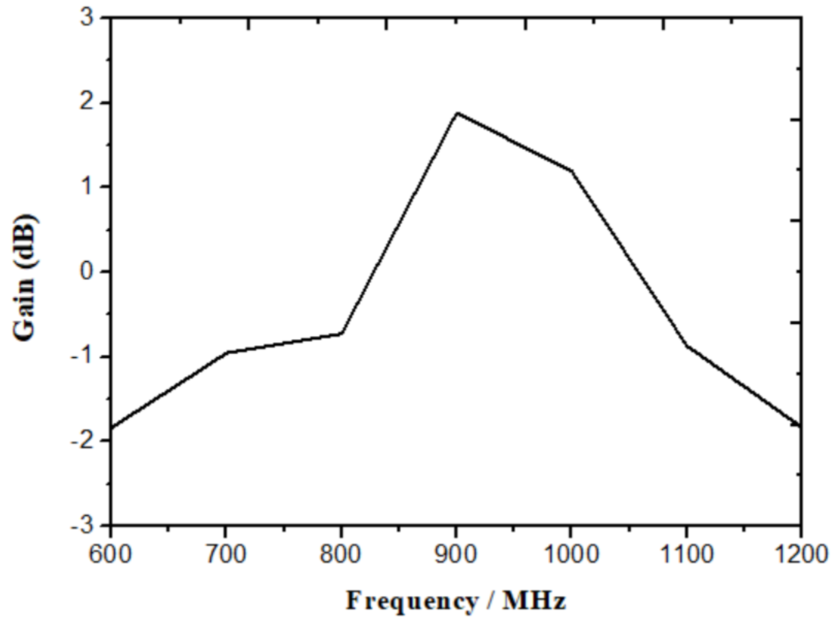

Fig 4. Gain of the simulated antenna as a function of frequency

3 Design of a meander dipole antenna

The use of the meander line dipole is one of the most used techniques for antenna miniaturization. The start point is a dipole antenna, then the same effective length (L = $\lambda/2$) is tried to be preserved while creating a folded path to occupy less space[10].

3.1 Parametric study

To obtain a good performance from a dipole, its length should be of the order of the half-wavelength, a good estimate is 0.47 times the wavelength[11]. The length of the resonant dipole can therefore be calculated with equation 1:

$$l_{\text{rad}} = 0.47\lambda = 0.47\frac{v}{f} \tag{1}$$

Where v represents the propagation velocity in the medium of the dipole strands. This speed depends on the effective dielectric constant of the medium surrounding the dipole. It is calculated from equation 2:

$$v = \frac{co}{\sqrt{\varepsilon_{eff}}} \tag{2}$$

Where c_0 is the speed of light in a vacuum and ε_{eff} is the effective dielectric constant of the surrounding medium[12], whose value is given by equation 3 for a value of W/h > 1:

$$\varepsilon_{reff}(W) = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{3}$$

Where W and h are, respectively, the width of the dipole and the thickness of the substrate with relative permittivity ε_r.

Being considered as a transmission line, the dipole's characteristic impedance Zc can be calculated with the following formulas, according to the value of the ratio W/h[13]:

For narrow lines (W/h <3.3):

$$Z_C = \frac{119.9\pi}{\sqrt{2(\varepsilon_r+1)}} \times \left\{ \ln\left(4\frac{h}{W} + \sqrt{16\left(\frac{h}{W}\right)^2 + 2}\right) - \frac{1}{2}\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)\left(\ln\frac{\pi}{2} + \frac{1}{\varepsilon_r}\ln\frac{\pi}{4}\right) \right\} \tag{4}$$

For wide lines (W/h> 3.3):

$$Z_c = \frac{119.9\pi}{2\sqrt{\varepsilon_r}} \left\{ \frac{W}{2h} + \frac{\ln 4}{\pi} + \frac{\ln\left(\frac{e\pi^2}{16}\right)}{2\pi} \cdot \left(\frac{\varepsilon_r - 1}{\varepsilon_r^2}\right) + \frac{\varepsilon_r + 1}{2\pi\varepsilon_r} \times \left(\ln\frac{\pi e}{2} + \ln\left(\frac{W}{2h} + 0.94\right)\right) \right\}^{-1} \tag{5}$$

From these equations, the different parameters presented in the structure of Figure 5 were calculated and are presented in Table 1. The antenna is etched on a substrate of the FR4 type of relative permittivity ε_r = 4.4, loss tangent of 0.0001 and thickness h = 1.6mm.

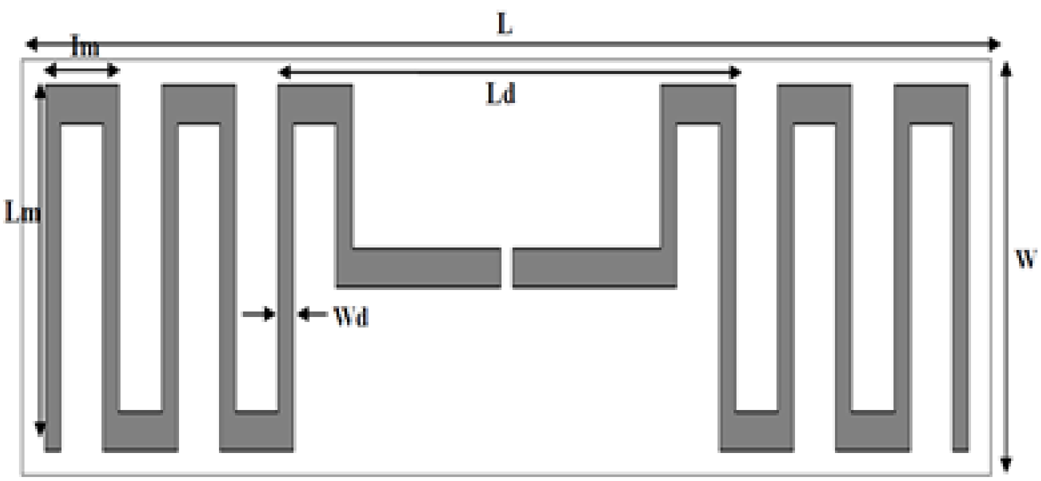

Fig 5. Meander dipole antenna design

Table 1. The miniaturized antenna dimensions

Parameters	L	W	Ld	Wd	Lm	Im
Dimensions (mm)	87.5	15	30.4	1.4	12.8	6.4

3.2 Simulation results

The simulation result of the proposed antenna is shown in Figure 6. The adaptation of the miniaturized meander dipole antenna is very good with a reflection coefficient of -37 dB at 915 MHz and a bandwidth of 50 MHz.

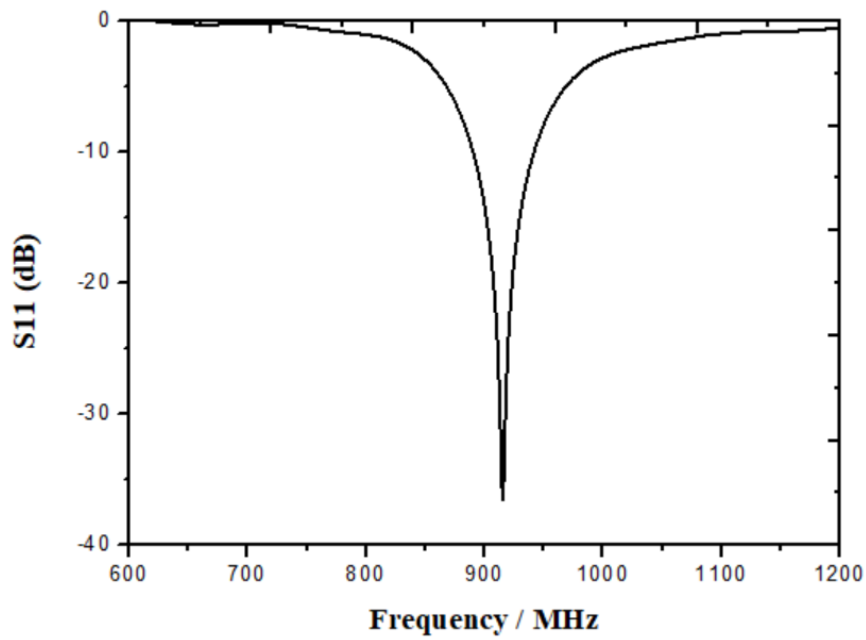

Fig 6. Simulated reflection coefficient S_{11} of the proposed meander antenna

The radiation pattern for this design is shown in Figure 7, and it can be seen that the directivity value of this antenna is 1.6 dB at 915 MHz.

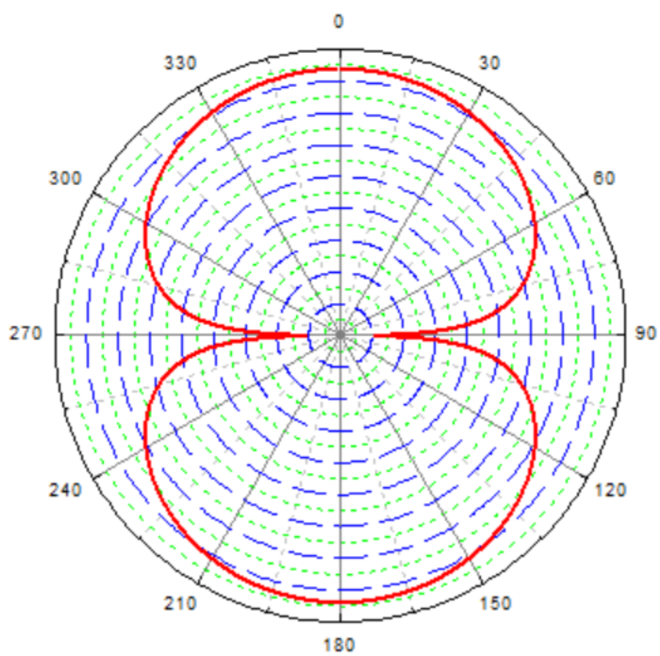

Fig 7. Simulated the radiation pattern for directivity

Figure 8 shows the gain as a function of frequency, and the gain is in the order of 1.32 dB.

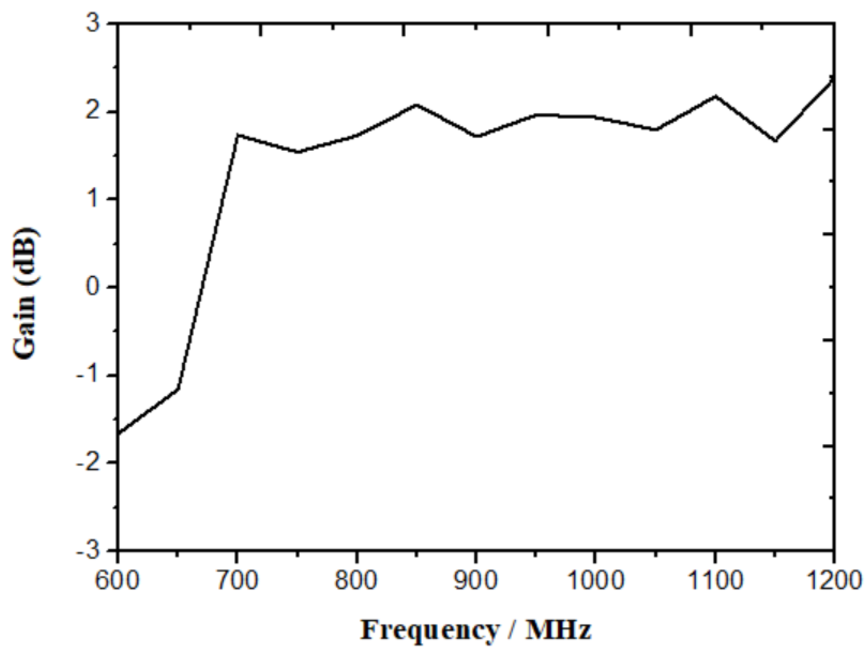

Fig 8. Simulated gain of the meander antenna as a function of frequency

Comparing the dipole antenna to the meander line dipole antenna, it is possible to see that the size is considerably reduced. Also, it is possible to note that the reflection coefficient reaches -37 dB and the gain suffers little change at 915 MHz.

3.3 Realization of a miniaturized dipole antenna

It is of significant importance to note that the proposed antenna has a very large percentage reduction in size. Meanwhile, on one hand, it was shown that the designed structure has radiation parameters (gain, directivity) suitable for RFID applications, and on the other hand, the proposed antenna has no complex geometric shape, which facilitates its fabrication. The finished dipole tag antenna is presented in Figure 9.

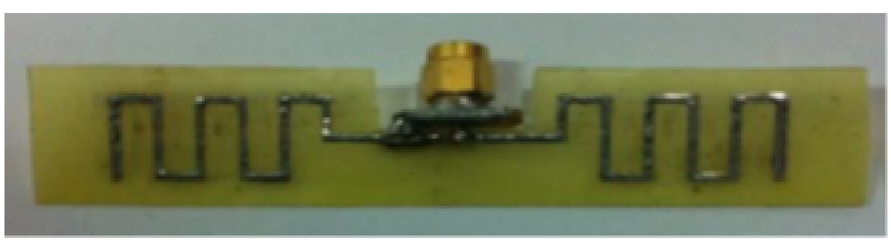

Fig 9. Realization of the miniaturized dipole tag antenna

Figures 10 and 11 show the reflection coefficient S_{11} of the miniaturized tag antenna. The measurement of the reflection coefficient is in the order of -15 dB at the resonance frequency 915 MHz, and it has a bandwidth of 70 MHz.

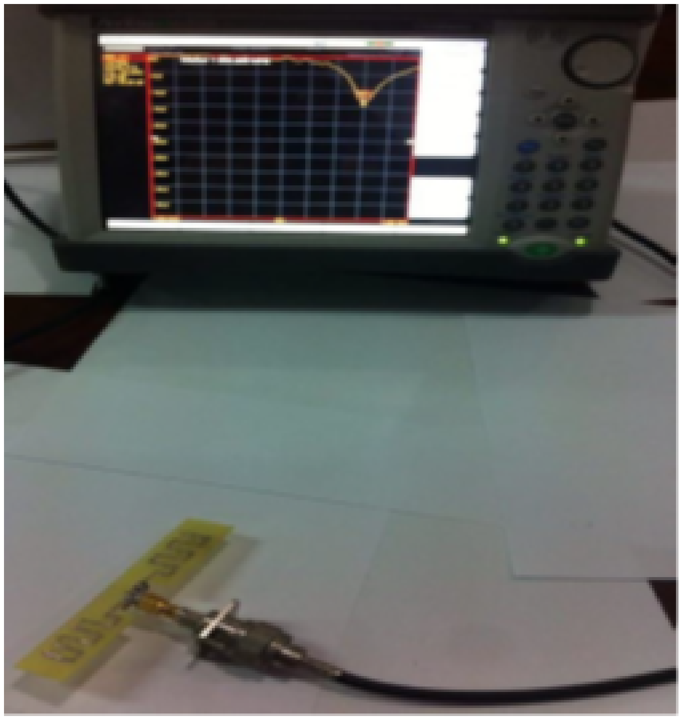

Fig 10. Reflection coefficient measurement setup and results for the miniaturized dipole antenna

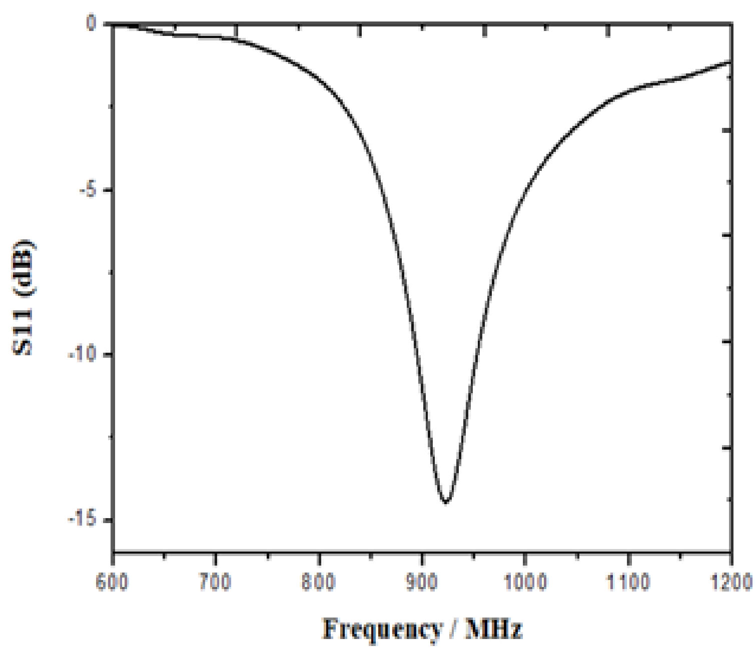

Fig 11. Measured reflection coefficient of the miniaturized dipole antenna

3.4 Comparison of the results obtained

In this article, a miniature antenna for a passive RFID tag was presented. Figure 12 contains a comparative study of the obtained results, presenting the measured (red) and simulated (black) reflection coefficients of the miniaturized tag antenna which show a resonance frequency of 915 MHz.

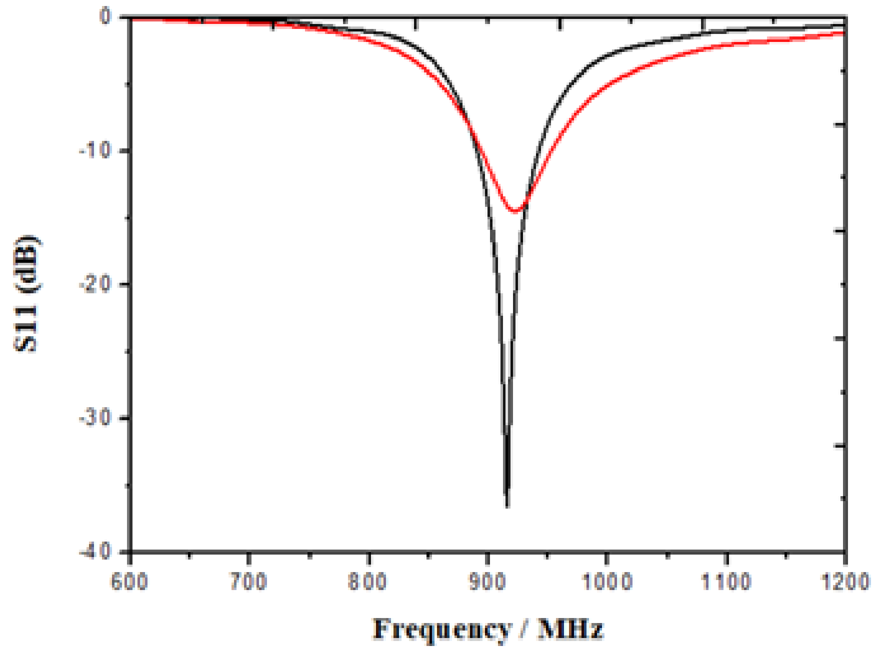

Fig 12. Measured (red) and simulated (black) reflection coefficient S_{11} of the miniaturized dipole antenna

Table 2 presents a comparison between the studied structures and the obtained results.

Table 2. Comparison of the antennas

Antenna structure	Gain (dB)	S11 (dB) at 915 MHz	Bandwidth (MHz)	POM
Dipole Antenna	1.93	-27	100	-
Miniaturized dipole antenna (simulation)	1.32	-37	50	40%
Miniaturized dipole antenna (measurement)	-	-15	70	40%

POM: Percentage of miniaturization

4 Conclusion

The study presented in this article allowed to greatly miniaturize an antenna without significantly impacting its directivity and gain, which are essential for passive RFID applications. The technique used for this design was the dipole antenna meander, and it allowed they for a reduction of the size of the antenna by about 40%. This study was validated through a comparison of measurement and simulation data, which were in agreement, and the fabrication and measurement of the reflection coefficients showed the effectiveness of this antenna, which can be used to make RFID tags considerably smaller without hindering their performance.

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