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Design of RFID Coplanar Antenna with Stubs over Dipoles

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1. Introduction

Radio Frequency Identification system, initially projected for objects identification in large scale – a counterpart of the well-known barcode, has been expanding its horizons and has been used for the automation of several services such as tracking goods, credit card charging, supply chain controlling, and others. RFID systems consist on a Reader that interrogates an identification Tag and this, in turn, sends an identification code back to the Reader. Specifically, the passive RFID Tags take advantage of being free of batteries. It converts part of the incoming RF signal from the reader into power supply. Because of its versatility, lots of researchers have been investing on RFID, which, despite the 35 years old of the first patent, is still considered new and somewhat obscure. This chapter covers topics including the system surveying and the working basics of the RFID, especially the physical air interface between the RFID tags (the mobile part) and the so-called Interrogators, which are fixed part of the network. This chapter focuses on the project of 2.45 GHz planar antennas, with a gain higher than the commercial ones, in such a way that, when these brand new antennas are used in RFID tags, they increase the system efficiency. More coverage area can be achieved with these higher gain antennas, as well as lower power requirements of the Interrogators. Most of the necessary theory topics to project this antenna are shown. As well as the theory, measured and simulated results are presented such as: input impedance, frequency response, radiation pattern and gain, which could certainly be the starting point for future works.

With respect to academic research over RFID, it is increasing year after year. The number of publications in important periodicals is increasing in recent years. This happens due to its great applicability in many areas like, health, commerce, safety, etc. In recent years, it is becoming one of the most attractive areas in wireless applications. Figure 1 presents the number of publications about RFID from 2003 to 2009 in the IEEE (Institute of Electric and Electronics Engineers). As one can see, there is a considerable increase in recent years. This Figure shows only the most relevant publications according to the algorithm of the IEEE research in a sample space of 100 publications. In reality, the number of publications is in the order of tens of hundreds.

In general the RFID system publications can achieve different focus. These can be about development of antenna, chips identification, software control, etc. As usual, in all engineer systems, there is something to improve. The system still is a bit expensive, as an Interrogator may cost U$ 2,000.00. Another point is behind intersystem and intra-system interference, as it operates in the ISM bands (Industrial Scientific and Medical), free bands. Many others systems, operating in that band, can interfere with RFID systems.

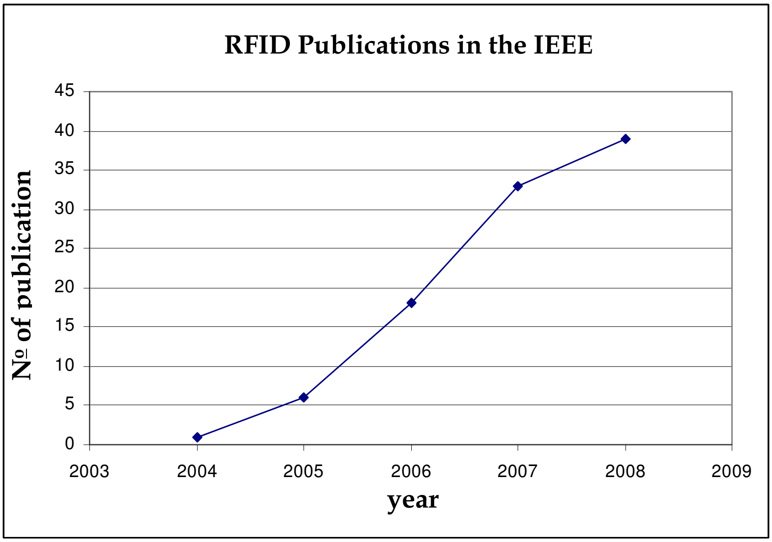

Fig. 1. RFID Publication in the IEEE. It is included publications over performance evaluation, development of news tools, new hardwares, etc.

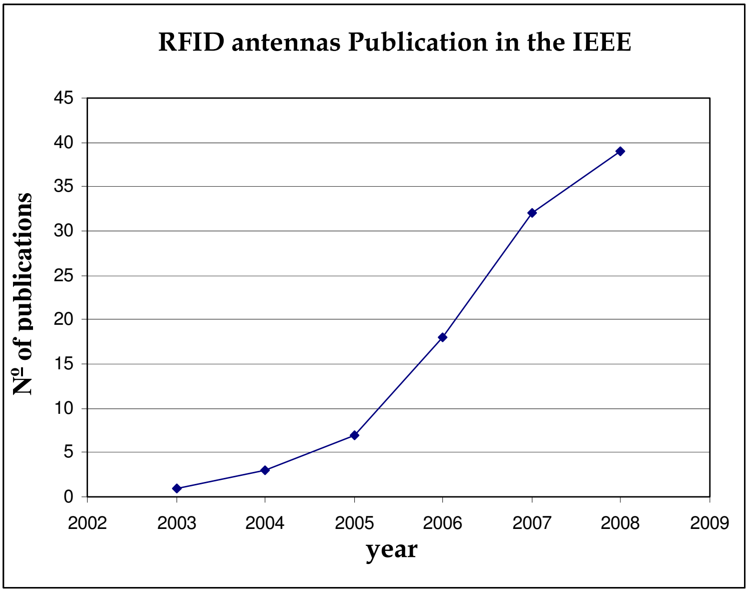

Fig. 2. Number of publications specifically for RFID antennas in the IEEE, in a sample space of 100 publications.

For a matter of power saving, design of high gain antenna can be necessary in the case of longer distance reading. On the other hand, some specific radiation patterns are suitable for grouped tags, avoiding the interfering effects. Besides, some Interrogators antenna arrays, can optimize the system power consume and/or optimize the number and position of the Interrogators, decreasing both the cost of implementation and the maintenance. It is clear that there is no any unique solution for whole problems, and perhaps, a particular solution for a particular problem. Figure 2 also shows an increase in the number of publications specifically for RFID antennas from 2002 to 2009 in the IEEE. These are only publications in the IEEE, there are other important periodicals, conferences, meeting, symposiums, etc. about RFID all over the world. Certainly, in this research area there is much work to do about optimization and cost reduction.
As the antenna design is one of the most important parts of RFID system development, it becomes necessary to see some basic concepts, analysis, and characterization of antennas used in RFID applications.

2. Important concepts

As predicted by Friis (Balanis, 1982) in (1), the reading range *r* is a function of the following parameters: wavelength in the free space λ, EIRP power $P_t \cdot G_t$, tag antenna gain G_r and the minimum required power for activating the RFIC chip P_r (Karthaus & Fischer, 2003). RFIC operating with 16.7μW minimum power level (Karthaus & Fischer, 2003) and indoor Reader EIRP of 27dBm, gain improvements on the tag antenna could increase the reading range of the system. Figure 3 shows the system reading range as a function of the antenna gain. According to (Karthaus & Fischer, 2003), (Finkenzeller), passive RFIC tags have generally negative input reactance and may have low input resistance. The impedance of the RFIC and the antenna must be matched each other (Finkenzeller).

$$r = \frac{\lambda}{4 \cdot \pi} \sqrt{\frac{P_t \cdot G_t \cdot G_r}{P_r}} \quad (1)$$

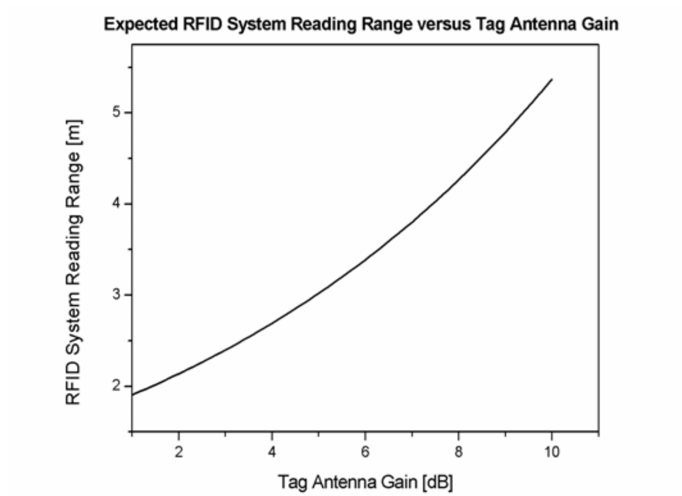

Fig. 3. Reading range versus tag antenna gain.

3. Tag antenna design

Let us see the design step by step. It consists of two λ/2 folded dipole array fed by λ/4 Transmission Line (TL) sections. Each folded dipole works like a load for a λ/4 transmission line (TL). As described in (de Melo et al., 1999), two loaded λ/4 TL are connected at the position A-A´. This yields to array of two planar dipoles. The transmission lines TL, as shown in Figure 4, of length λ/4 works like an impedance transformer for the required input impedance at the feeding points A-A′. From Figure 5, one can see the load in the shape of a planar folded dipole.

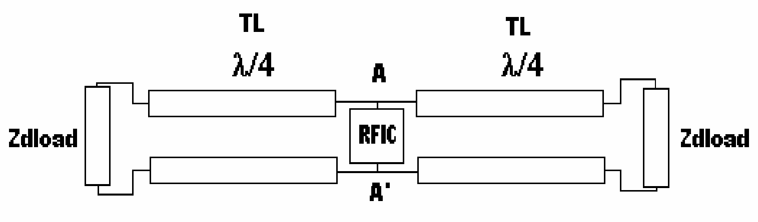

Fig. 4. Loaded CPS transmission lines.

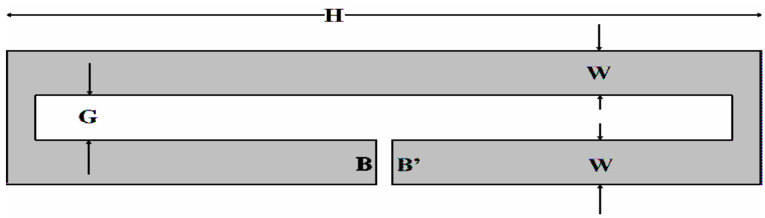

Fig. 5. Load in the shape of a dipole.

The transmission lines are connected together at the terminals A-A′, as shown in Figure 4. Arrays of radiating elements produce higher gain than isolated elements (Balanis, 1982). This fact allows this antenna to be useful when farther reading ranges are required. Because its symmetry related to the central plane, only half the antenna is analyzed and the results are further corrected in order to represent the whole antenna. With the dimensions described in Table 1 (Condition 1), the input impedance of one dipole can be calculated using quasi-static equations of conformal mapping (Lampe, 1985), (Nguyen, 2001), (de Melo et al., 1999) and such impedance is referred to as Z_{dipole}. It is the load impedance for the transmission line.

In practice it is not simple to obtain the dipole impedance, taking into account the real values of the geometrical parameters. The known usual expressions are suitable for ideal conditions and do not take into account some parameters, like width D, shown in the Figure 6. Another example is the gap *G* created in one of the strips for the signal feeding. Besides, the lower strip becomes smaller, comparing with the upper one. However, the expressions, published by (Lampe, 1985) still may be used to have an idea of the dipole behavior with variation of line width, space between strips, etc. To obtain the dipole impedance $Z_{dipole} = R_d + jX_d$ some simulations were carried out using the full wave simulator CST, varying the dipole geometric parameters.

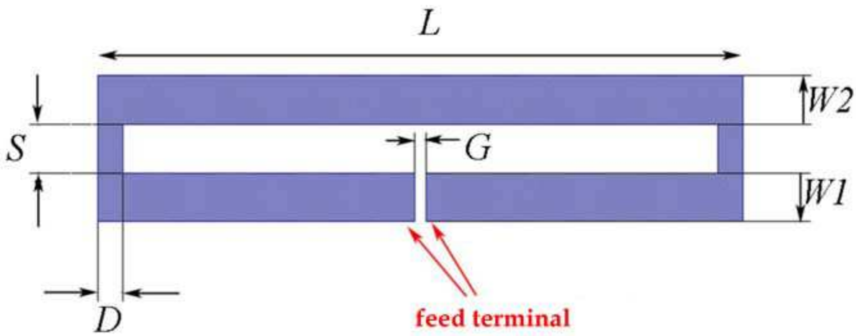

Fig. 6. Dimensions and parameters of the coplanar strip folded dipole.

Figures 7(a) and 7(b) present the real and imaginary part of the input impedance as a function of W1, respectively. Figures 8(a) and 8(b) present the real and imaginary part of the input impedance as a function of W2, respectively. Following the same idea, Figures 9 and 10 present the input impedance variations with S and D dimensions, respectively.

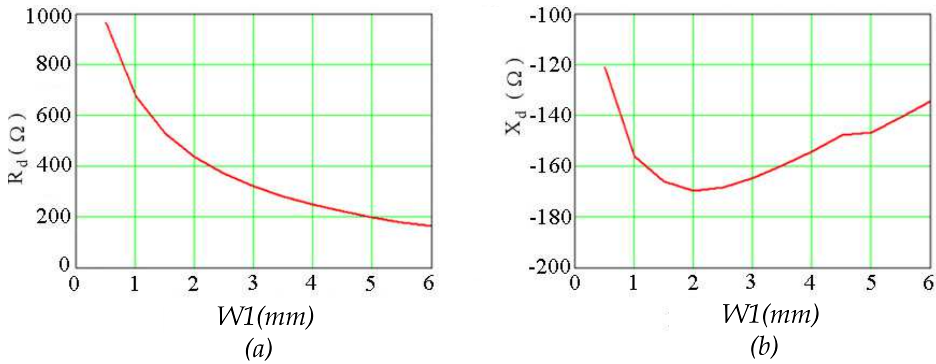

Fig. 7. Input impedance as a function of W1. (a) is the real part and (b) is the imaginary part.

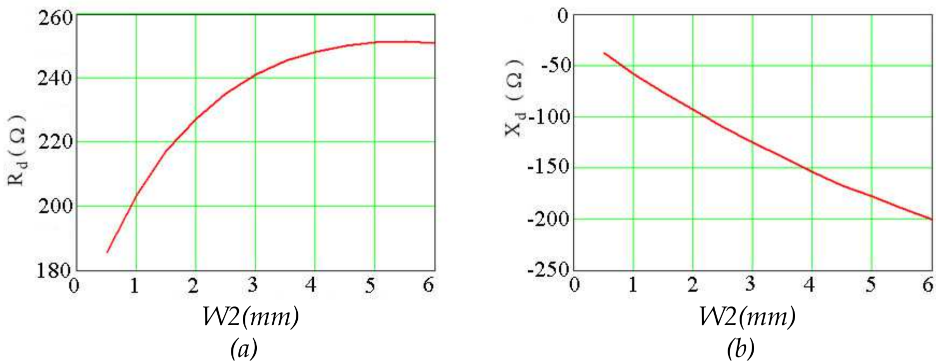

Fig. 8. Input impedance as a function of W2. (a) is the real part and (b) is the imaginary part.

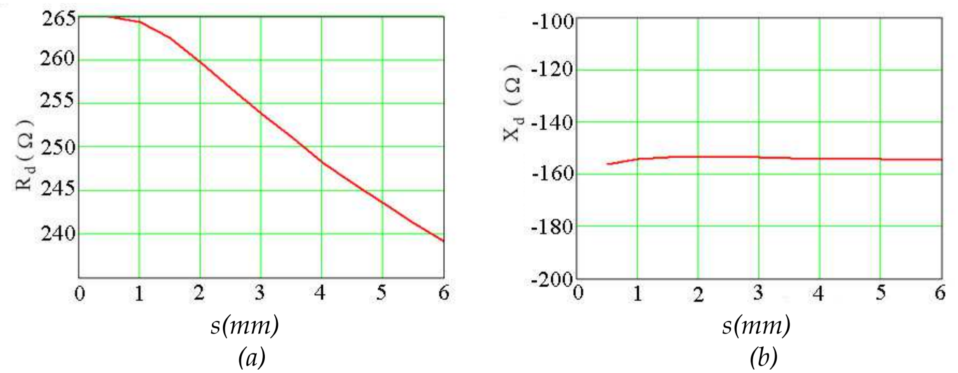

Fig. 9. Input impedance as a function of *s*. (a) is the real part and (b) is the imaginary part.

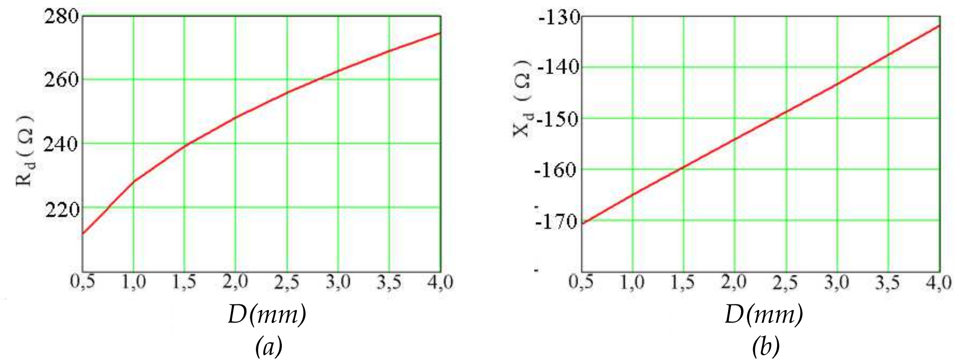

Fig. 10. Input impedance as a function of *D*. (a) is the real part and (b) is the imaginary part.

The half-antenna input impedance at the plane A-A′ (Figure 4) is given by the usual equation for transmission lines (Chang, 1992):

$$Z_{in} = Z_0 \frac{Z_{dipole} + Z_0 tanh(\gamma L)}{Z_0 + Z_{dipole} tanh(\gamma L)} \qquad (2)$$

where γ is the propagation constant of the wave, L is the transmission line section length and Z_0 is the characteristic impedance of the transmission line. The value of Z_0 is also calculated by quasi-static conformal mapping equations.

Figure 11 shows a coplanar folded dipole design. This structure is more suitable for matching with only the real part of the input impedance. Figures 12(a) and 12(b) present the real and imaginary part of the input impedance as a function of the length of the stub *l*, respectively. The imaginary part goes from negative to positive values as the length *l* increases from 0(mm) to 20(mm). For a fixed value of *l*, Figures 12(a) and 12(b) can be used for impedance match between the antenna and the chip or between the antenna and the network analyzer. Note that the input impedance also can change with the spacing g, the width k and the distance H.

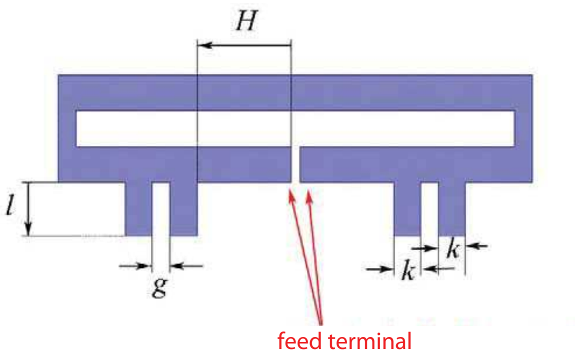

Fig. 11. Dimensions and parameters of the coplanar strip folded dipole.

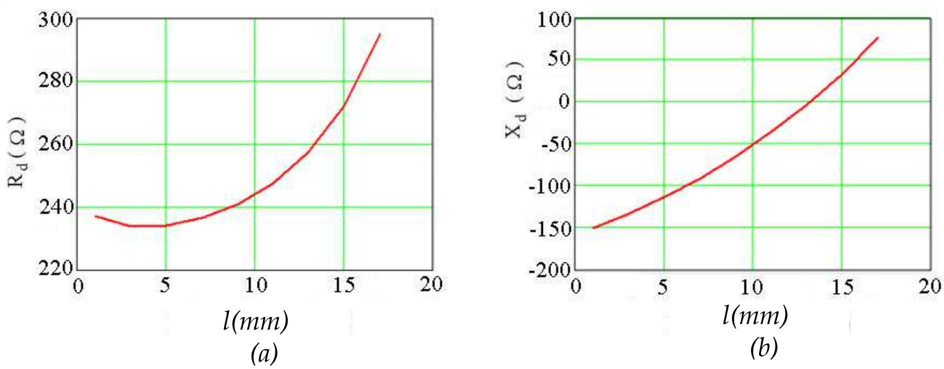

Fig. 12. Input impedance as a function of *l*. (a) is the real part and (b) is the imaginary part.

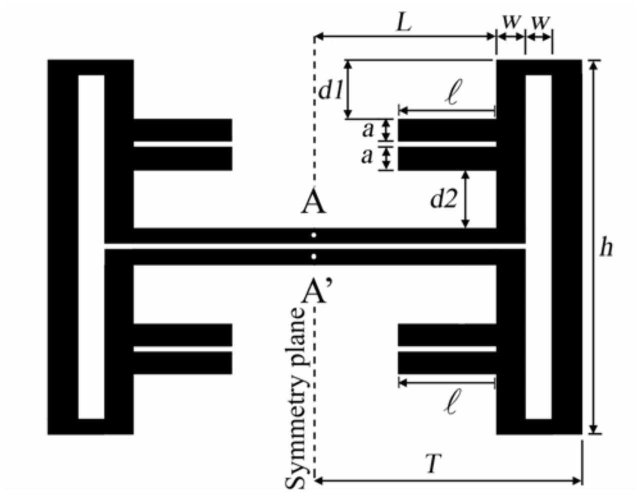

Fig. 13. Antenna layout. The stubs are placed over the dipoles.

Dimensions	Condition 1	*Condition 2*
h	53 mm	*53 mm*
w	4 mm	*4 mm*
a	3 mm	*3 mm*
d1	8.5 mm	*8.5 mm*
d2	8.5 mm	*8.5 mm*
L	26.5 mm	*26.5 mm*
T	38.5 mm	*38.5 mm*
ℓ	**0 mm**	***14 mm***

Table 1. Dimensions of the antenna

Note that all dimensions have the same value for condition 1 and 2, except for ℓ. The ℓ = 0 mm means no stubs. For all dimensions described in Table 1 - condition 1, the input impedance of half the antenna is $Z_{in} = 100 + j100\Omega$. Because its symmetry, the impedance of whole antenna at the plane A-A´ is to be $Z_{ant} = \frac{Z_{in}}{2}$. In other words, $Z_{ant} = 50 + j50\Omega$. The imaginary part of Z_{ant} can be significantly decreased by placing planar stubs over the dipoles. On the other hand, the real part of Z_{ant} is slightly altered. Those facts are important when purely real impedance is needed. That is the case when stubs of length ℓ = 14mm are added to the dipoles (Table 1 - Condition 2). At that length, the above described impedance becomes $Z_{ant} = 49\Omega$ and the imaginary part is no longer seen.

4. Fabrication measurement and simulation

The antenna described in the previous section was simulated with a full wave EM software. The fabricated antenna with stubs over the dipoles is shown in Figure 14. It was implemented on a RT6002 substrate of thickness 1.5mm, relative dielectric permittivity $\varepsilon_r = 2.94$ and loss tangent δ = 0.0012. Simulations were taken in the 1.5 – 3 GHz range. Calculations of input impedance were taken at 2.45GHz, which is the central frequency of the free 2.4GHz part of the spectrum. Figure 15, 16 and 17 show the comparison between simulated and measured results and good agreement can be noticed. Figure 18 and 19 show the radiation pattern and the gain of this proposed antenna at 2.45GHz. The antenna lies in the plane $\theta = 90°$ and has its printed strips at the right-hand side. The maximum gain is increased over the direction perpendicular to the antenna plane. Still from Fig. 7, one sees that the highest simulated gain reaches 5.97dB over an isotropic radiator. The measured gain reaches 5.6dB, which is very close to the simulated one. These values are at least twice higher than the gain of an ordinary dipole (Finkenzeller). Simulated results show how the stub length can modify the Z_{dipole} and the antenna input impedance Z_{ant}, as a consequence. Thus, it is possible to choose some suitable stub length for the desired antenna input impedance. For example, for ℓ = 14 mm, one finds the simulated antenna input impedance of $Z_{ant} = 50 + j7\Omega$. It is very close to that one of 49 Ω, expected in the section before. On the other hand, the measured value of the new antenna is $Z_{ant} = 48 + j7\Omega$.

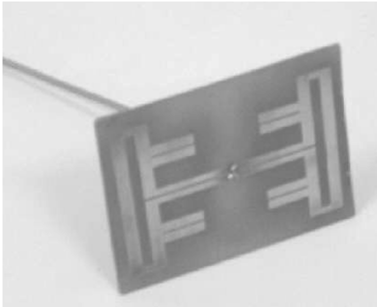

Fig. 14. The printed antenna.

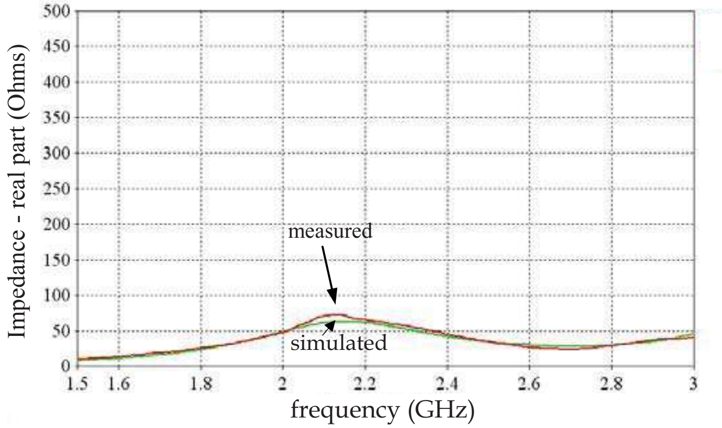

Fig. 15. Simulated and measured real part of the impedance.

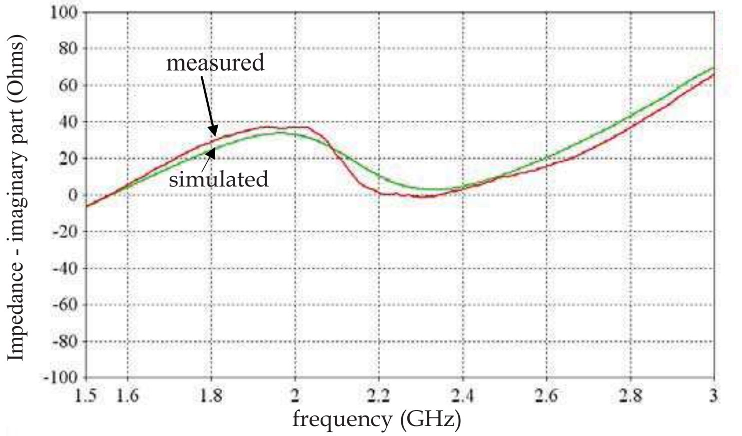

Fig. 16. Simulated and measured imaginary part of the impedance.

In the Figure 16 one notices a slight difference between the simulated and measured responses, at the central frequency. This may be explained due to a possible coupling between the two radiator elements.

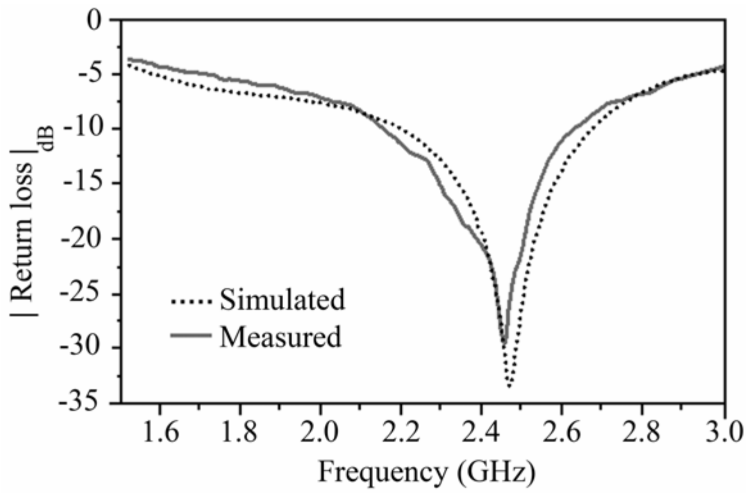

Fig. 17. Comparison of the simulated and measured return loss for the antenna shown in Figure 14.

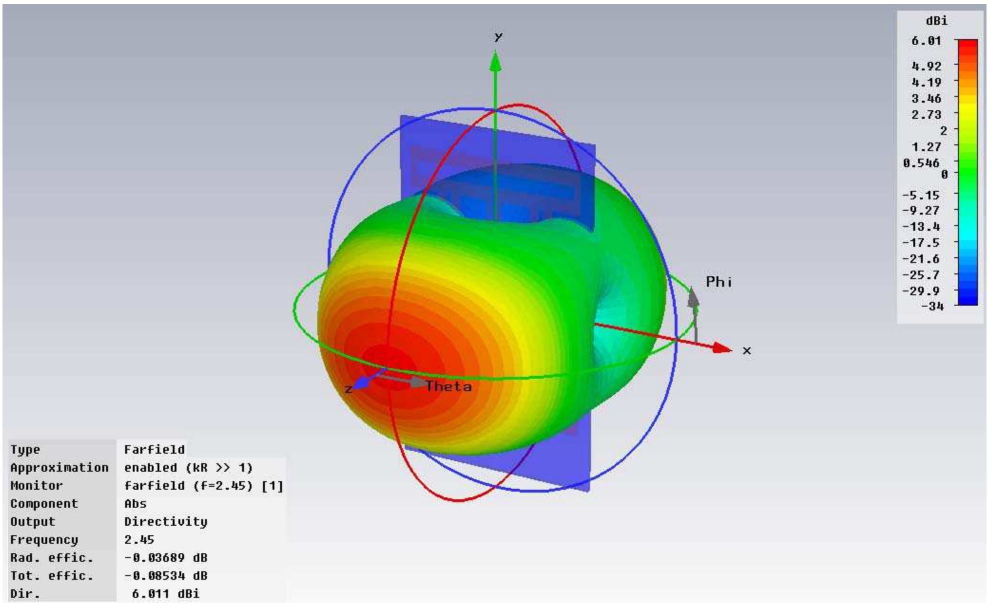

Fig. 18. Simulation results of radiation pattern, directivity, gain and radiation efficiency for the antenna in Figure 14.

For the gain calculation of the antenna in Figure 14, one takes the value from Figure 18. Directivity D = 6,011 dB and radiation efficiency η = 0,003689. Thus, one finds G = 6,011-0,003689 ≅ 5,97dB.

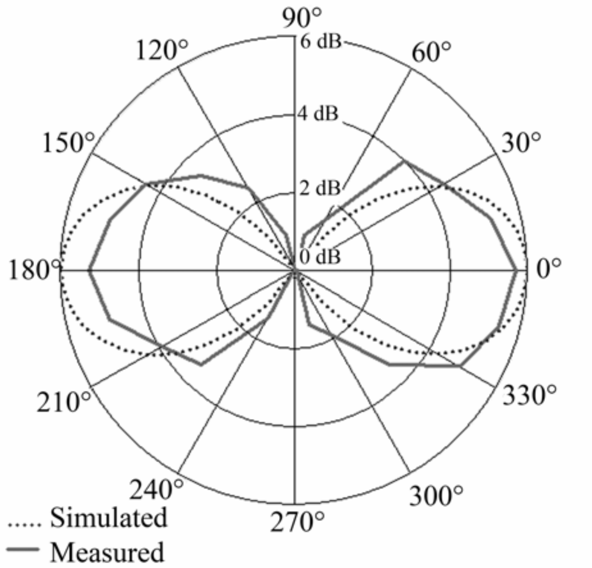

Fig. 19. Simulated and measured antenna gain over an isotropic antenna: 5.97dB and 5.6dB, respectively.

5. Conclusion

Good agreement between simulated and measured responses is seen. The reading range of RFID Tags can be increased by 41 % when this antenna is used. Stubs over the dipoles are a very useful tool when impedance adjustments are needed. This antenna has good performance comparing with the commercial versions available and seems to be promising as far as RFID applications are concerned. For the future some improvements can be carried out over the design. Decrease the whole size, modeling equation approach for the gaps, discrete elements equivalent circuit elaboration and insertion of this antenna into an active RFID system.

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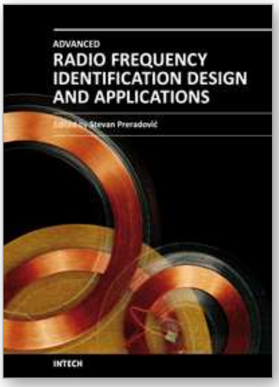

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Radio Frequency Identification (RFID) is a modern wireless data transmission and reception technique for applications including automatic identification, asset tracking and security surveillance. This book focuses on the advances in RFID tag antenna and ASIC design, novel chipless RFID tag design, security protocol enhancements along with some novel applications of RFID.