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A Broadband Modified T-Shaped Planar Dipole Antenna for UHF RFID Tag Applications

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Abstract—In this paper, we report a single layer modified T-shaped dipole antenna for UHF-RFID tag applications. The designed RFID tag antenna consists of a pair of T-shaped dipole strips loaded with four half discs patches and a tag chip placed in the center. The antenna's size is $80 \times 40 \times 1.6\,\mathrm{mm}^3$. Performance of the proposed design was investigated with simulations and measurements. The main feature of this design is that the RFID tag antenna can operate effectively at 868 MHz and 915 MHz frequency bands which make it broadband. The maximum reading range measured in an anechoic chamber is 4.25 m and 5.27 m at 915 MHz and 867.5 MHz, respectively. Furthermore, the RFID tag antenna can work on metallic plates when inserting a foam spacer between them. The final result has a simple configuration, low profile and can be suitable for practical applications dealing with free-space and metallic objects.

1. INTRODUCTION

In the past years, radio-frequency identification (RFID) technology, which uses radio waves to track or identify objects, has gained great attention among scientists and engineers all over the world owing to its immense applications in retail, inventory control, transportation, manufacturing and supply chain systems [1].

A UHF-RFID system, throughout the world, uses different frequency bands. For example, 902–928 MHz is used in North and South America, 840–845 MHz and 920–925 MHz in China, 866–869 MHz in Europe, 862–870 MHz in North Africa, and 950–956 MHz in Japan and some Asian Countries [2]. A typical RFID system is mainly composed of a reader, a tag that attached on objects, and embedded computer system. In a passive back-scattered RFID system, the reader transmits a modulated RF signal uniformly in all directions, and the tag, situated within the read-zone of the reader, receives the RF signal and generates a backscatter with identification data to the reader. A passive UHF-RFID tag usually includes an antenna and an RF chip which has a memory to store identification data [3]. For UHF-RFID systems, the input impedance of the RFID chip must be conjugately matched with that of the antenna impedance to achieve maximum power transfer.

In some real implementation, RFID tag antennas must be compact, light weight, and easy to fabricate for mass production. Furthermore, they have to be designed with an omnidirectional radiation pattern that facilitates communication with the reader regardless of their relative direction. Thus, when designing RFID tag antennas, the design process involves inevitable tradeoff among size, impedance and performance.

Up to now, numerous kinds of RFID tag antennas based on dipole or patch type designs have been proposed and tested in literature under different scenarios and environments [4–10]. However, to the

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best of our knowledge there are a few articles that provide antennas with broadband performance for UHF RFID tags to make them work globally. Hence, it is required to design suitable UHF RFID tag antennas.

In this paper, we propose a new modified T-shaped planar dipole antenna for UHF-RFID applications which is designed to meet the requirements of broadband, omnidirectional radiation pattern and reasonable compact size simultaneously. The proposed RFID antenna consists of a pair of T-shaped planar strips printed symmetrically on the same side of a dielectric substrate and separated by a 1 mm gap, and a RFID chip placed at the center. To have a good impedance matching between the antenna and the RFID chip, the technique of loading both T-shaped planar strips with two half discs patches at each end is applied. This design has a simple structure with one layer of dielectric. The performances of this RFID tag antenna supplemented with simulated and measured results are also presented and discussed.

2. RFID TAG ANTENNA DESIGN

The geometry of the proposed RFID tag antenna is shown in Figure 1, in which the unit of dimension is expressed in mm. The dimensions of this antenna, including a low-cost FR4 substrate with the relative dielectric constant of 4.4, loss tangent of 0.02 and thickness of 1.6 mm, are $80\,\text{mm} \times 50 \times 1.6\,\text{mm}^3$, which correspond to $(0.244\lambda) \times (0.1525\lambda) \times (0.004\lambda)$, where λ is the free-space wavelength at 915 MHz. The proposed design is fabricated (see Figure 2) using an LPKF Protomat S100 mill/drill unit. The radiator is printed on the top layer of the substrate, which consists of two identical T-shaped strips printed symmetrically on the same side of the substrate, as shown in Figure 1. It is well known that RFID chips are usually largely capacitive and need an inductive antenna; shorter dipoles are inherently capacitive [11]. Hence, in order to get an inductive behaviour of the input impedance of the antenna so that to satisfy the condition of the conjugate matching, four half discs patches were introduced at each end of the T-shaped strip as shown in Figure 1.

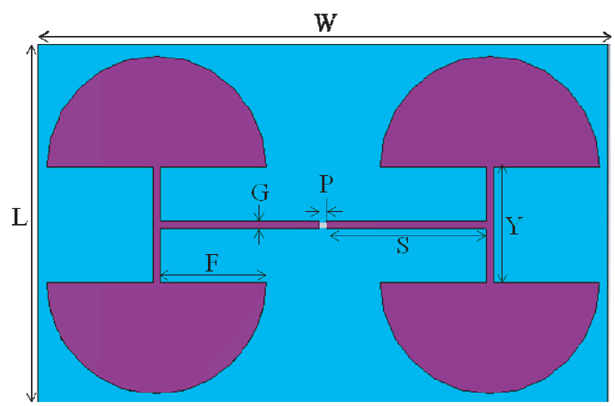

Figure 1. Configuration of the proposed RFID tag antenna.

The input impedance of the chip (MURATA-LXMS31ACNA) used in this work was measured using the same method reported in [12]. The obtained measured impedance chip is $Z_{\text{Chip (Measured)}} = 17.6\text{-j}100.9\,\Omega$ at 915 MHz, which is slightly different from the one given in datasheet ($Z_{\text{Chip (Datasheet)}} = 12\text{-j}107\,\Omega$) at 915 MHz [13]. Therefore, the input impedance of the antenna has to be $Z_{\text{antenna}} = 17.6\text{+j}100.9\,\Omega$, so that maximum power transfer can be reached. The RFID chip was placed in the separation distance between the two modified T-shaped strips with a dimension of 1 mm.

To quantitatively study the proposed antenna characteristics, a time domain solver within the commercial software package CST Microwave Studio, which is based on Finite Integration (FIT) Technique, was used to obtain numerical results. The final parameters of the realized RFID tag antenna are: $L = 50\,\text{mm}$, $W = 80\,\text{mm}$, $S = 22.4\,\text{mm}$, $Y = 16\,\text{mm}$, $P = 1\,\text{mm}$, $G = 1\,\text{mm}$, $F = 14.9\,\text{mm}$.

3. SIMULATED AND MEASURED RESULTS

To verify the obtained simulated results, the input impedance of the RFID tag antenna was measured using a Rohde & Schwarz ZVB 20 Network analyzer. Since the proposed design is a symmetric structure, one can use the image theory [14] to measure its input impedance according to the following procedure. First, the proposed design has been divided into two equal parts about the central symmetrical axis. Then, one part of the proposed design is mounted on a ground plane as shown in Figure 2 along with the antenna feeding circuit. The measured antenna is only one half of the actual antenna structure, and thus the correct input impedance of the antenna, which can be calculated using the equation below, is two times of the measured impedance value.

$$Z_{\text{imag}} = \frac{1 + S_{11\text{imag}}}{1 - S_{11\text{imag}}} Z_0 \tag{1a}$$

$$Z_A = 2 \times Z_{\text{imag}} \tag{1b}$$

where $S_{11\text{imag}}$ is the measured reflection coefficient, Z_{imag} the unbalanced impedance, Z_{A} the input impedance of the whole antenna, and Z_0 the impedance of a 50 ohm transmission line. It is worthwhile to mention that the conjugate matching is optimized by tuning the radius of the half discs.

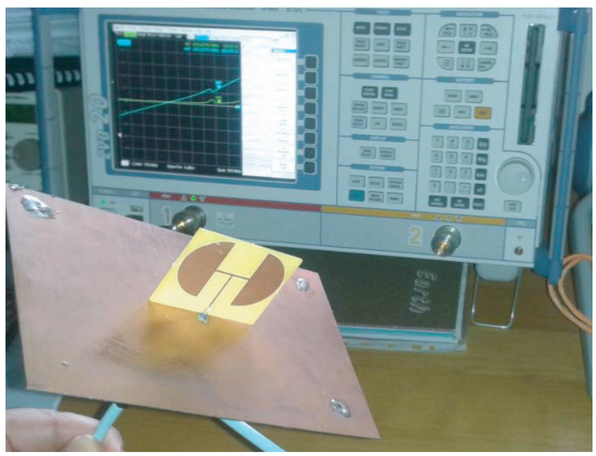

Figure 2. Measurement setup of the antenna input impedance by image theory.

Figure 3 shows the simulated and measured input impedances of the proposed design as a function of frequency. It can be clearly seen that the measured and simulated results are in good agreements. Indeed, at 915 MHz, the measured impedance of the antenna is $Z_{\text{ant (Measured)}} = (20.54\text{-j}131.12)\,\Omega$ which corresponds to a series resistance about 20.54 Ω and series capacitance about 1.32 pF, and the simulated impedance of the antenna is $Z_{\text{ant (Simulated)}} = (17.6\text{-j}100)\,\Omega$ which corresponds to a series resistance about 17.6 Ω and series capacitance about 1.74 pF. The small discrepancy can be attributed to the fact that the measurements were not taken in an anechoic chamber but in an ordinary room.

The backscattered time domain measurement setup depicted in Figure 4 was used to evaluate the minimum power activation (Power sensitivity) of the proposed design. This system consists of two horn antennas, a digital oscilloscope (Agilent DSO91204A), and a pulse generator (Picosecond Pulse LabsModel 3500). The whole system is controlled by homemade software based on Matlab. The transmitter and receiver horn antennas with a bandwidth between 2 GHz and 32 GHz provide a flat 17 dBi gain across the frequency range of 860 to 960 MHz. The receiver horn antenna gets the backscattered signal produced by the tag. The digital oscilloscope (Agilent Infiniium), which is connected to another horn antenna, measures the tag activation. The distance between the horn antenna and the RFID tag antenna in this setup is 0.5 m. The minimum power activation is presented in Figure 5. It can be clearly seen that the measured minimum power to activate the tag at 915 MHz is −7 dBm which is a little bit different from the one given by the manufacturer ($P_{\text{th}} = -8$ dBm) that does not take into account the presence of the antenna.

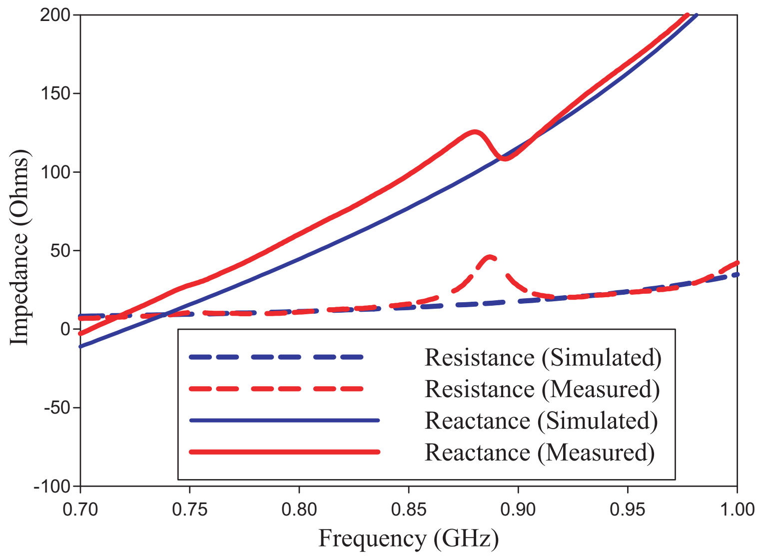

Figure 3. Measured and simulated input impedance of the proposed RFID tag antenna.

Figure 4. Experimental setup used in measuring the minimum power activation (power sensitivity).

Next, we measure, in an anechoic chamber, the reading range, which is the most important characteristic, to get an understanding about the practical performance of the proposed RFID tag antenna. The theoretical reading range can be obtained using Friis free space equation formula [3]:

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau}{P_{\text{th}}}} \tag{2}$$

where λ is the wavelength, P_t the power transmitted by the reader, G_t the gain of the transmitting antenna, G_r the gain of the receiving tag antenna, P_{th} the minimum (threshold) power to active the tag, and τ the power transmission coefficient.

The experimental reading range $r_{\max}$ is determined as follows [5]:

$$r_{\max} = d\sqrt{\frac{P_{\text{EIRP}}}{G_t P_{\text{th}}}} \tag{3}$$

where d is the distance between the RFID tag antenna and the transmitter antenna of the measurement system, P_{th} the minimum transmit power obtained from the measurement system to activate the tag, G_t the gain of Transmitting antenna, and P_{EIRP} the maximum output allowed transmitted power that is 3.28 W according to the European Telecommunications Standards Institute (ETSI) [2].

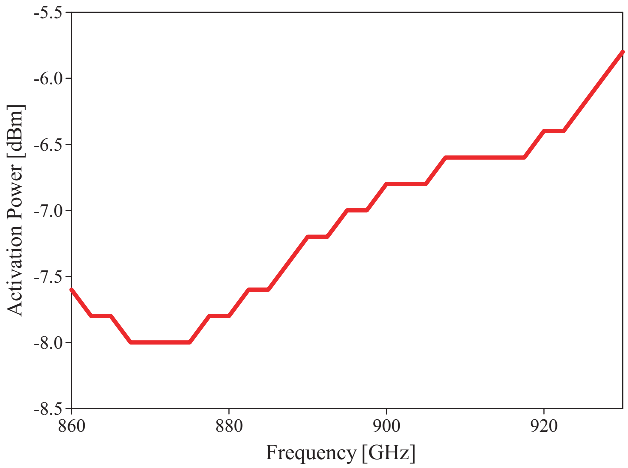

Figure 5. Activation power (P_{th}) of the proposed RFID tag antenna vs frequency.

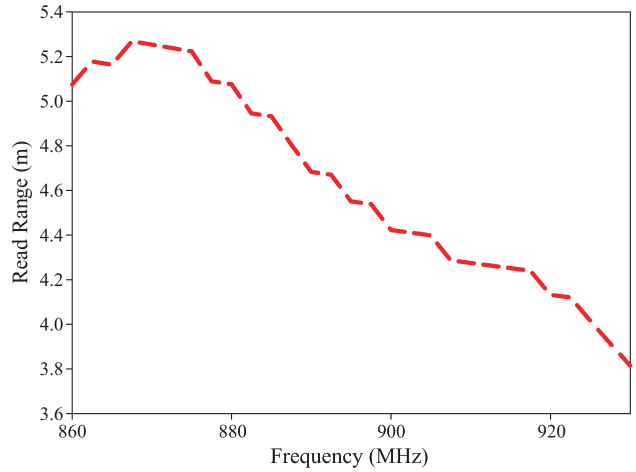

Figure 6. Measured range of the proposed RFID tag antenna.

Figure 7. Measured read range of the proposed RFID tag antenna.

The maximum reading range versus the frequency over the 860–930 MHz band is presented in Figure 6. The measurements were carried out in a fully anechoic chamber at LCIS-INP, Grenoble, France. At 915 MHz, the maximum reading range was found to be 4.25 m. This value of the reading range indicates that a good conjugate matching between the antenna and the RFID tag is obtained.

Figure 5 reveals that the proposed structure can work on a broad bandwidth from 860 MHz to 930 MHz, which covers the total band of North America (902–928 MHz) and Europe (865–868 MHz). It is worthwhile to mention that this obtained measured reading range is much higher than the ones previously presented [15, 16].

We have also measured the communication distance [17], maximum distance that an RFID reader can recognize, in an ordinary room using the reader unit manufactured by Alien Technology (ALR 9900+), which operates in the Morocco band (865.6–867.6 MHz) to verify the performance of the proposed design. The reader's output power is set to 2.0 W EIRP. The measurement setup of communication distance is illustrated in Figure 7.

It is found that when the RFID tag antenna was mounted directly on foam, the measured communication distance was found to be 7.5 m. Next, we have investigated the effect of metallic plate on the behaviour of the RFID tag antenna because it is well known that the characteristics of RFID tag antennas can be changed dramatically when they are placed near or onto metallic objects, especially in UHF band. Thus, we have measured the communication distance of the proposed design when it is attached directly or close to a metallic plate whose dimension is $30 \times 30\,\text{cm}^2$.

In the first case, when the RFID tag antenna is mounted directly on the metallic plate, we lost the communication between the reader and the RFID tag antenna even we change the distance between them. However, Figure 8 shows that the communication distance increases as the foam separation

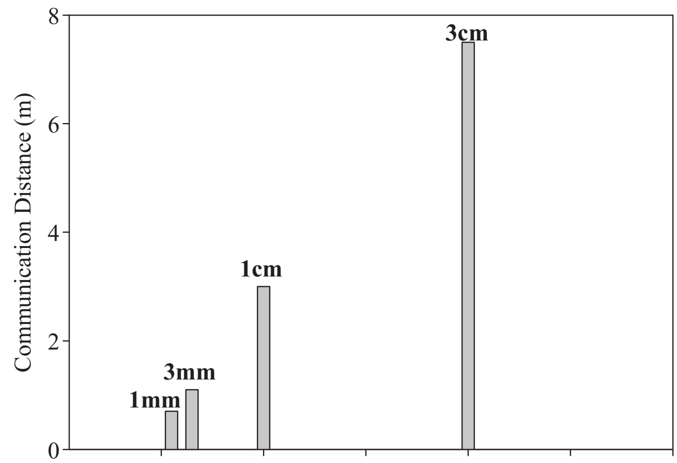

Figure 8. Measured read range of the proposed RFID tag antenna with different foam separation.

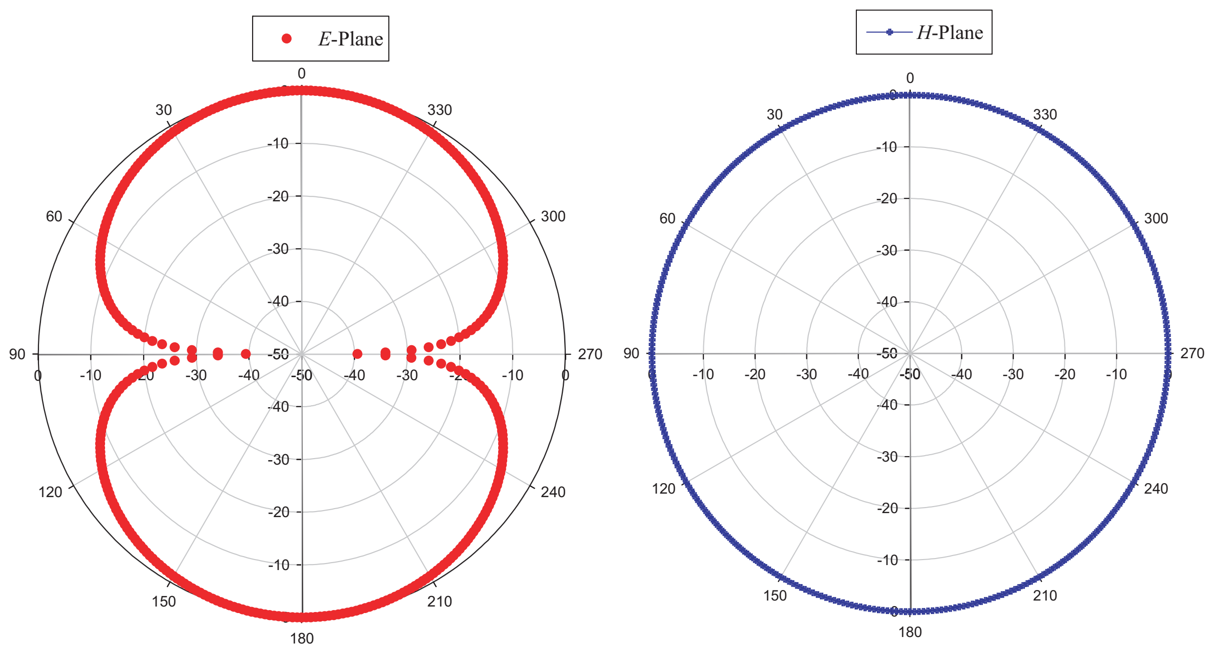

Figure 9. Simulated E-plane and H-plane far-field radiation patterns of the proposed RFID tag antenna.

(whose relative permittivity is 1) increases. For instance, when the thickness of foam separation is 3 cm, we find that the communication distance is 7.5 m, which makes it suitable to be installed in a recessed cavity in metallic objects such as vehicles, and metallic containers.

The radiation patterns and the realized gain of this RFID tag antenna were also investigated numerically, because a conventional anechoic chamber is not capable to achieve accurate measurements for any RFID tag antenna that is not matched to 50 Ω. In Figure 9, the simulated 2-D radiation pattern plots in the two planar cuts are presented for the x-z plane (E-plane) and y-z plane (H-plane). It is clearly seen that the proposed RFID tag antenna has a dip at 0° due to the current of the both dipole arms (look like a dipole).

This dip is compensated in the y-z plane which becomes omnidirectional. To get more insight into the radiation mechanism of the proposed design, Figure 10 shows the simulated current density

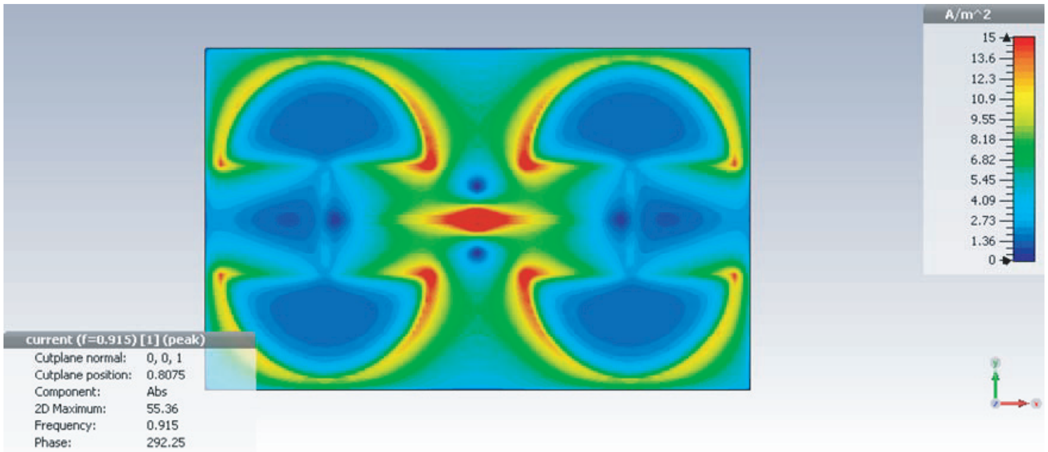

Figure 10. Simulated current density of the proposed design at 915 MHz.

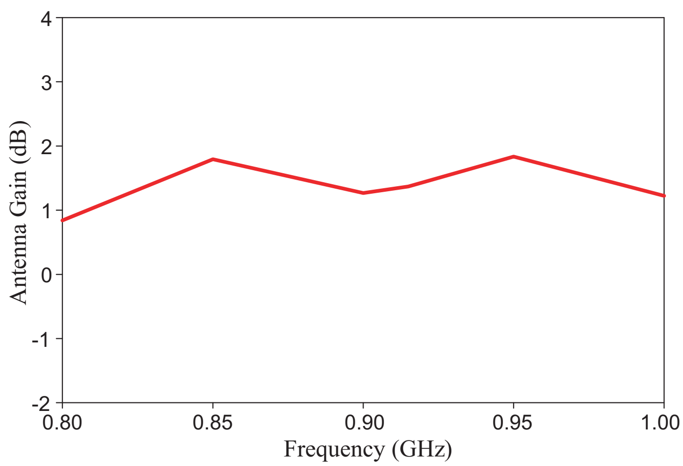

Figure 11. Simulated gain of the proposed RFID tag antenna as function of frequency in free space.

distribution at 915 MHz. This figure reveals that the currents concentrate mainly over the area of the dipole antenna. Thus, we can conclude that the major radiation comes from the arms of the dipole antenna and not from the half discs which have a little effect on the H plane pattern.

The simulated gain around the resonance frequency is presented in Figure 11. The maximal gain is approximately 1.46 dB at 915 MHz.

4. CONCLUSIONS

In this work, a single layer modified T-shaped tag dipole antenna is presented whose performance is tolerant to various materials such as metallic objects. To obtain an inductive behaviour of the input impedance of the proposed structure to get a good conjugate matching with the chip, the radius of the half discs has been properly chosen by using an electromagnetic simulator. The maximum reading range measured in anechoic chamber is 4.25 m and 5.27 m at 915 MHz and 867.5 MHz, respectively.

The experimental results also demonstrate that the proposed design can work on metallic plates when there is foam layer between the RFID tag antenna and the metallic plate. The simulated and measured results show very good performance. It has a simple configuration with low cost, low profile, and easy fabrication.

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