A Thin Folded Dipole UHF RFID Tag Antenna with Shorting Pins for Metallic Objects

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Abstract

A novel folded dipole type microstrip patch antenna designed for ultrahigh frequency (UHF) band radio frequency identification (RFID) tag is presented in this paper, which can be used on the metallic objects. The presented antenna is fabricated on a very thin Rogers 5880 substrate with a thickness of 0.508 mm. The structure consists of two folded dipole and two symmetrical shorting pins placed at both sides of feed point. An adjustable frequency response can be easy obtained via modify the location and radius of the shorting pins. The antenna has been analyzed by full wave simulations soft. The simulated bandwidth is about 67.2 MHz, which covers the Europe and North America UHF RFID frequency range. A manufactured prototype has been fabricated and measured to demonstrate the antenna performances. The simulation results agree with the measurement data well. The measured maximum reading range of the prototype can be reached 4.1 m in free space, and 3.2 m on a metal plate whose size is $150\times150\times8mm^3$.

Keywords: Folded dipole antenna, thin, RFID, UHF, tag

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1. Introduction

Due to an expanding number of applications in supply chain management, identification documents, event tickets, and contactless payments, the technology and influence of radio frequency identification (RFID) in the ultrahigh frequency (UHF) band (865.6—867.6 MHz for Europe, 902 —928 MHz for US and 952—954 MHz for Japan.) has gained much interest in recent years. The tag antenna consists of a radiating structure and RFID chip. The ability of the tag to communicate efficiently with the reader depends on antenna characteristics and channel properties [1]. So, the tag antenna is one of the essential components, and plays a key role in the overall RFID system performance factors.

In some practical applications, the UHF RFID tags need to be attached on electrically metallic objects' surface. But these metallic environments have a significant effect on nearby electromagnetic fields, and this effect changes antenna's radiation pattern, input impedance, radiation efficiency and resonant frequency. Therefore UHF RFID tags designed for metallic objects such as containers, notebooks, cars, gas cylinders and so on are particularly challenging. To overcome this problem, a tag antenna in structure including a ground plane can be viewed. Based on such considerations, several designs have been developed, such as inverted F-antenna (IFA), printed inverted F-antenna (PIFA) [2][3][4], patch-type antenna, and other structural deformation of these antennas [5][6][7]. Mo et al. [8] designed a tag can be used in metallic object with a size $74.5\times20\times3mm^3$. The tag uses an open stub line with a length 40mm. Genovesi et al. [9] proposed a folded dipole tag antenna with a size $125.5\times14\times1.5mm^3$. Chen et al. designed a PIFA array, which size is $130\times45\times0.8mm^3$ [10] and a patch antenna with a size $100\times50\times0.8mm^3$ [11]. The size of these solutions are not enough small and thin.

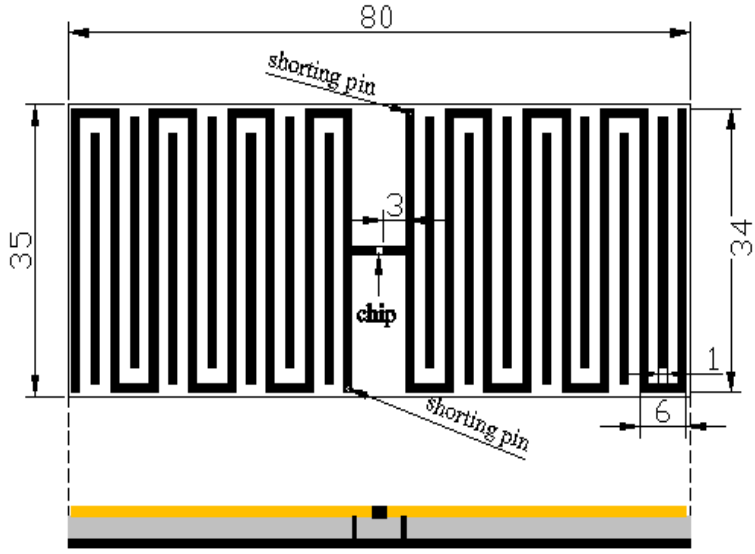
In this paper, a folded dipole planar UHF RFID tag patch antenna which can be used on the metallic object`s surface is proposed. The substrate of this antenna is common Rogers 5880 with a thickness of h=0.508mm. The proposed antenna configuration and the design concept used in this letter will be explained in Section II. Parametric studies and measurement of the proposed antenna are in section III. Finally, conclusions are drawn in Section IV.

2. Antenna Design and Results

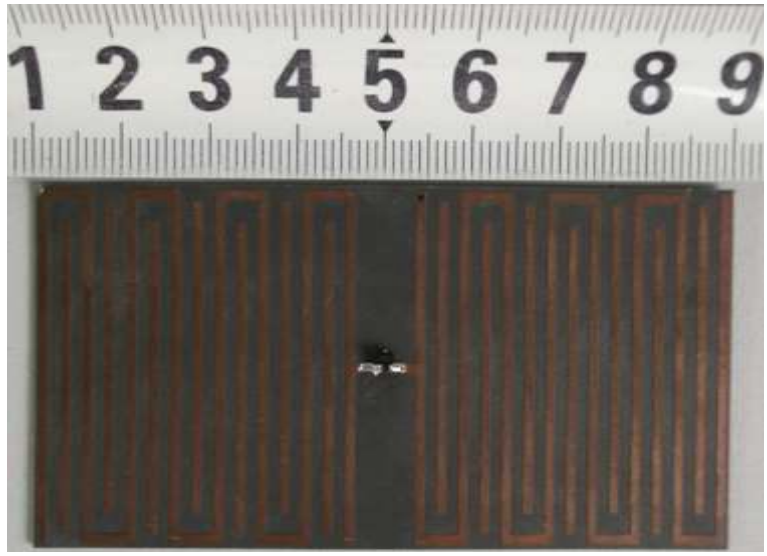
There are two approaches in the RFID metal tag design. First one is to reduce the interference from the metallic surface effect, for example, insertion of a high permittivity substrate or embedding of a high-impedance surface (HIS) ground plane. Another one is to arrange a conductive ground plane in the antenna structure to reduce the metallic surface effect in the antenna performances, for example, IFA, PIFA, or the common using patch-type antenna [12]. However, the first option increases the cost of manufacture. So, our design is based on the second solution.

The proposed antenna consists of two symmetric folded radiation units and a ground

plane, which configuration is shown in **Fig. 1(a)**. The radiation metallic patches are electrically connected to the ground plane through two symmetry metallic shorting pins which are placed at both sides of feed point. Filling the space between patches and ground with Rogers 5880 whose thickness is 0.508 mm, relative permittivity is 2.2, and dielectric loss tangent is 0.0009.



(a)



(b)

Fig. 1. Geometries of the proposed folded dipole planar patch antenna. (a) schematic diagram of the antenna. (b) Photograph of the antenna

The tag chip is placed between two radiation units and connects to both of them. The overall size of the antenna is 80×35×0.508mm^3. The detail geometries size of the tag antenna are shown in **Fig. 1(a)**.

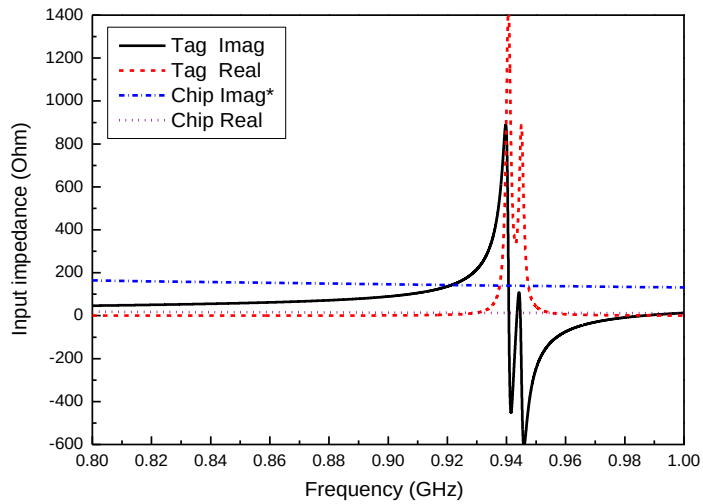


Fig. 2. The input impedance of the proposed antenna.

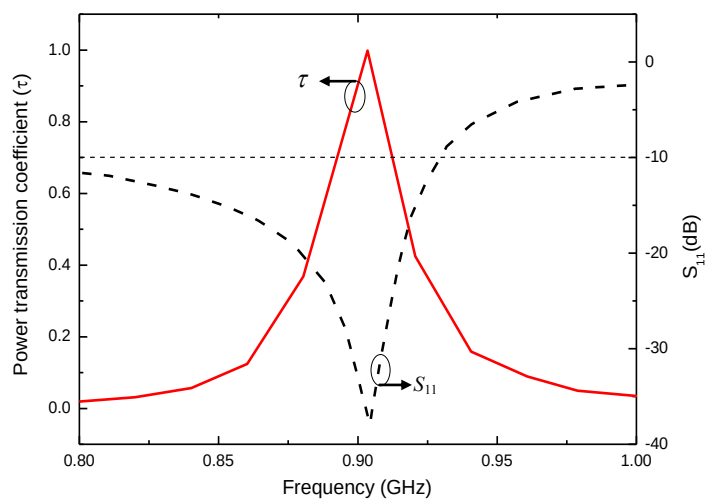


Fig. 3. The power transimission coefficient and $S_{11}$of the proposed antenna on the 150×150×8 mm^3 metal plate.

The selected Alien's Higgs 2 tag chip which has an intrinsic impedance of Z_c =14-j144 Ω at 915MHz, a metal plat in size 150×150×8 mm^3 is considered in simulation model. The desired antenna input impedance has to be conjugate matched to tag chip to ensure

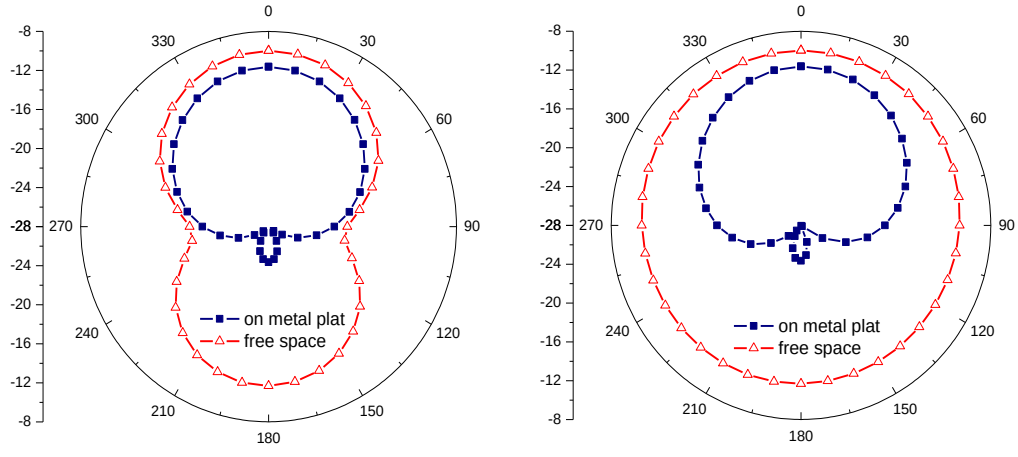
adequate power transmission to the chip. The power transmission coefficient defined as

$$\tau = \frac{4\mathrm{Real}(Z_a)\mathrm{Real}(Z_c)}{\left|Z_a + Z_c\right|^2}. \tag{1}$$

Where $Z_c=R_c+jX_c$ and $Z_a=R_a+jX_a$ are the input impedances of the antenna and the chip, respectively.

The input impedance of the proposed antenna is shown in **Fig. 2**. From **Fig. 2**, one can note that the antenna input impedance has a good conjugate match to the chip. The power transmission and input reflection coefficient (S_{11}) are shown in **Fig. 3**. It can be noted from S_{11} curve that the antenna has a wideband performance on the metallic surface (-10dB bandwidth is 67.2 MHz, from853.3MHz to 920.5 MHz).

Fig. 4 shows the simulated radiation patterns of the antenna, when it is placed in free space and mounted on the metal plate. From **Fig. 4**, one can see that the back radiation in the direction –z is decreased when the antenna is mounted on the metal plate.



(a) (b)

Fig. 4. The radiation patterns at 915 MHz in free space and on the 150×150×8 mm^3 metal plate.

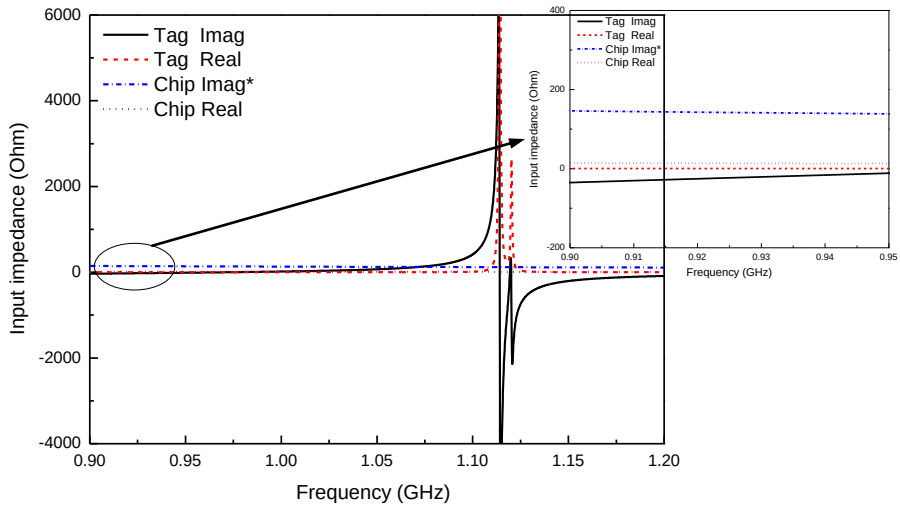
(a) x-z plane (φ=0°). (b) y-z plane (φ=90°).

3. Parametric Studies

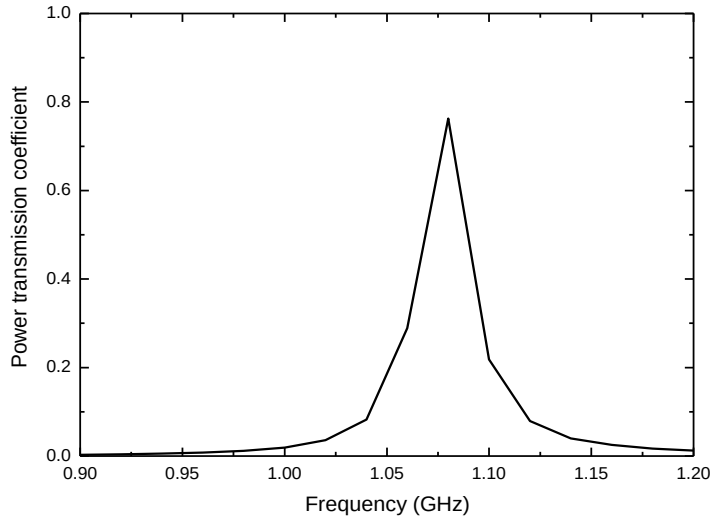
The parametric studies are carried out to provide readers with more design information. It is known that, the position and dimension of shorting pins will affect the antenna performance significantly.

In order to further illustrate the effect of the shorting pins, a non-shorting-pins antenna with the same overall size was analyzed firstly. The input impedance of the non-shorting-pins antenna is shown in **Fig. 5 (a)**. In **Fig. 5 (a)**, one can see that the antenna input impedance can never conjugate match to chip impedance in the UHF RFID frequency

range (860~960MHz). The power transmission coefficient is shown in **Fig. 5 (b)**. It can be noted that the best working frequency of the non-shorting-pins antenna is offset to larger frequency than the UHF RFID band. According to antenna theory, the antenna size should be extended to get a satisfying resonant frequency. So, the shorting-pins can achieve the purpose of antenna miniaturization.



(a)



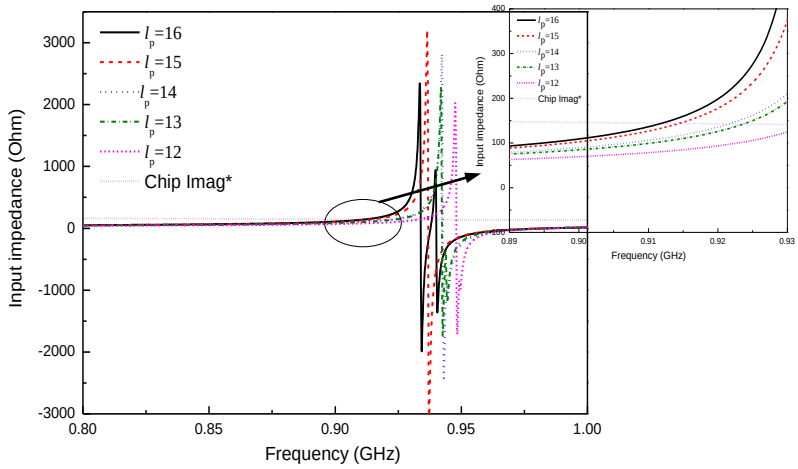
(b)

Fig. 5. The input impedance and power transmission of the unslotted antenna.

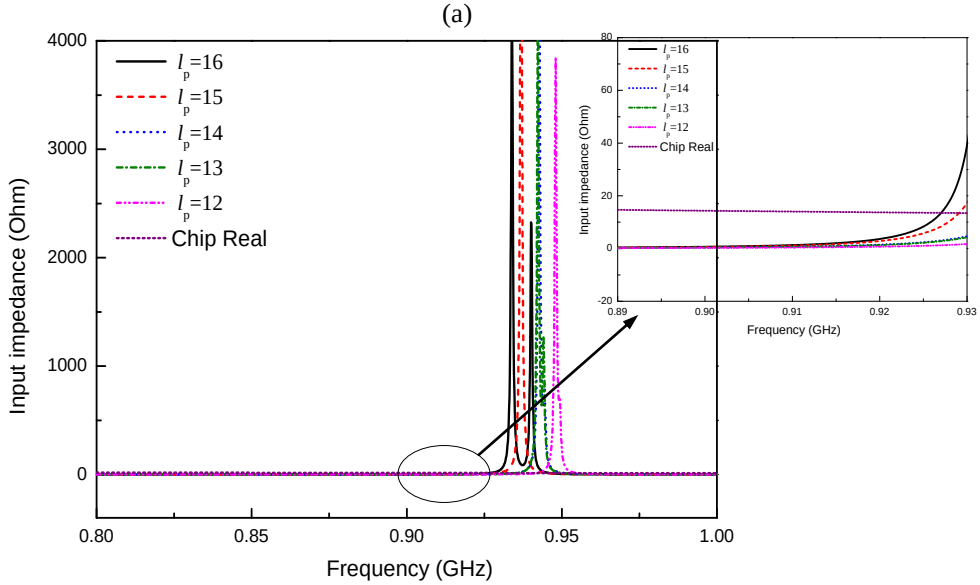
(a) input impedance. (b) power transmission coefficient.

We set l_p is the vertical distance between the symmetrical shorting pins and the midpoint of the antenna, set r is the radius of shorting pins. Firstly, the parameter of r=0.4mm was fixed,

and the affect of varying l_p on the antenna performance has been studied. **Fig. 6** shows the simulated antenna input impedance including imaginary part and real part against frequency as a function of l_p. From **Fig. 6**, one can note that the input impedance will increase as l_p increases, if l_p is less than a value, e.g. 12mm, the antenna input impedance curve never passes through the chip impedance value, and this implies that the conjugate match between the antenna and the chip in the case of l_p less than12mm will not be achieved.



(a)



(b)

Fig. 6. Input impedance against frequency with various l_p, (a) imaginary part. (b) real part.

The other antenna performance with different value of l_p are given in **Table 1**. From **Table 1**, we can see that the resonant frequency and bandwidth increases with the decreasing in the value of l_p, the gain, however, firstly increases and then decreases with the increasing in the value of l_p..

Next, we fix l_p=16mm, the influence of different radius of shorting pins r on the antenna performance was examined and the results are shown in **Table 2**. It is found that when the radius r changes the antenna resonant frequency curve has a slight change, that is to say, the changes of r has little effect on the antenna resonant frequency. The effect of radius r to input impedance has a similar conclusion. Simulation results do not show a clear effect relation to bandwidth and gain when the changes of r.

In order to illustrate the effect of parasitic patch to antenna performances, an antenna without parasitic patch has been analyzed. The simulation results show that both the gain and the bandwidth of the non-parasitic-patch antenna will be reduced.

In the above study, a metal plat in size 150×150×8 mm^3 is considered in simulation model. The proposed tag antenna can be also used in free space. **Fig. 6** shows the power transimission of the antenna mounts on the metal plat and places in free space.

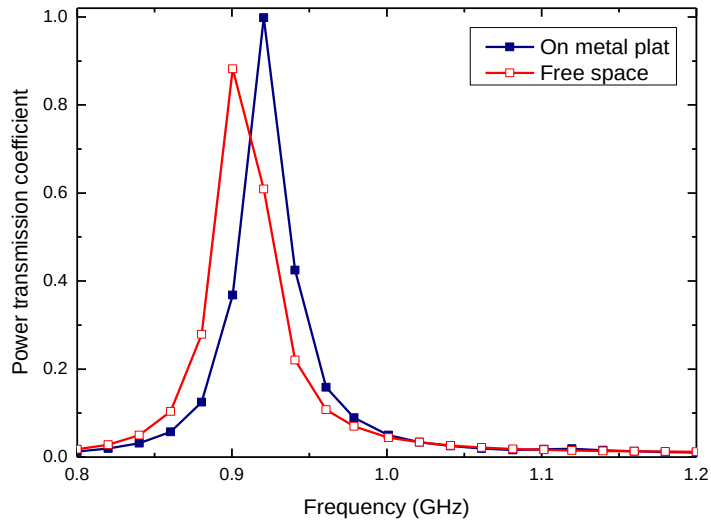


Fig. 6. The comparation of power transimission coefficient for the proposed antenna in free space and on a 150×150×8 mm^3 metal plate.

Table 1. Antenna performances with different value of l_p

value of l_p	resonant frequency(MHz)	Bandwidth(MHz)	Gain at 915MHz(dB)
12	933.5	33.7	-12.187
13	924.2	34.4	-12.017
14	922.1	47.5	-11.154
15	914.7	49.7	-11.257
16	912.1	66.9	-11.424

Table 2. Antenna performances with different value of r

value of *r*	resonant frequency(MHz)	Bandwidth(MHz)	Gain at 915MHz(dB)
0.20	911.8	56.4	-11.367
0.25	906.5	63.2	-11.809
0.30	908.1	60.9	-11.450
0.35	913.6	45.9	-10.857
0.40	907.6	66.8	-11.854

As we know that the metallic environment has a significant effect on antenna performances. The effects of the metallic environment are investigated by changing the metal plat size and the results are shown in **Table 3**.

Table 3. Antenna performances with different size of metal plat

Size of metal plat	resonant frequency(MHz)	Gain at 915MHz(dB)	Front-back ratio(dB)
100×100×8mm^3	904.4	-11.31	4.76
120×120×8mm^3	909.0	-10.57	7.22
140×140×8mm^3	908.4	-11.39	9.42
160×160×8mm^3	908.2	-11.48	10.89

From **Table 3**, we can see that the size of the metal plate has little effect on antenna resonant frequency; the gain firstly increases and then decreases with the increasing in the size of the metal plate; and the backward radiation decreases with the metal plate size increasing. The study also showed that the thickness of the metal plate has almost no effect on antenna performances.

In order to demonstrate the characteristics of the proposed RFID tag, a prototype has been fabricated, which is shown in **Fig. 1(b)**. The dimensional parameters of implemented antenna are finally fixed as l_p=16.5mm, r=0.35mm, and the other parameters as shown in **Fig. 1(a)**.

As we know that the traditional antenna measurement techniques can not be directly applied to RFID tag, so, Rahmat-Samii proposed the differential probe method [13]. Using the differential probe method, we measured the input reflection coefficient S_{11}. **Fig. 7** shows the measured and simulated reflection coefficient curves of the implemented antennas. As a comparison, the simulated reflection coefficient of the proposed tag placed in free space is also illustrated in **Fig. 7**. From **Fig. 7**, we can note that the -10dB bandwidth of the proposed tag has good performance in Europe (865.6—867.6 MHz) and North America (902—928 MHz) UHF band.

In some actual industrial applications, we need to quickly estimate the reflection coefficient of the antenna rather than accurate measurement. In order to meet this actual need, we proposed a new and simple “resonance method”. In the resonance method, a simple hand-made half-wave monopole antenna at 915MHz is employed to estimate the reflection coefficient of the tag antenna by the resonance between the half-wave monopole antenna and tag antenna. The configuration of the measurement platform is showed in **Fig.**

8. The measurement was performed by using Rohde-Schwarz vector network analyzer R&S ZVL. The 150×150×8mm^3 metal plate is used to imitate the metallic using environment.

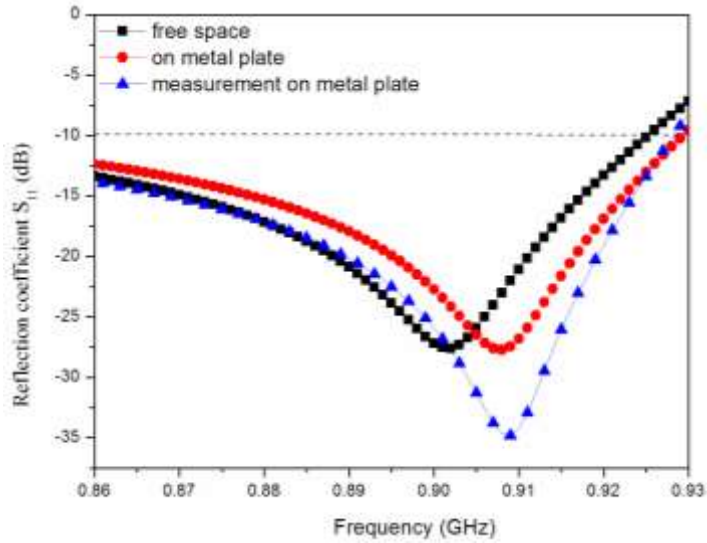


Fig. 7. Measured and simulated reflection coefficient of the proposed antenna.

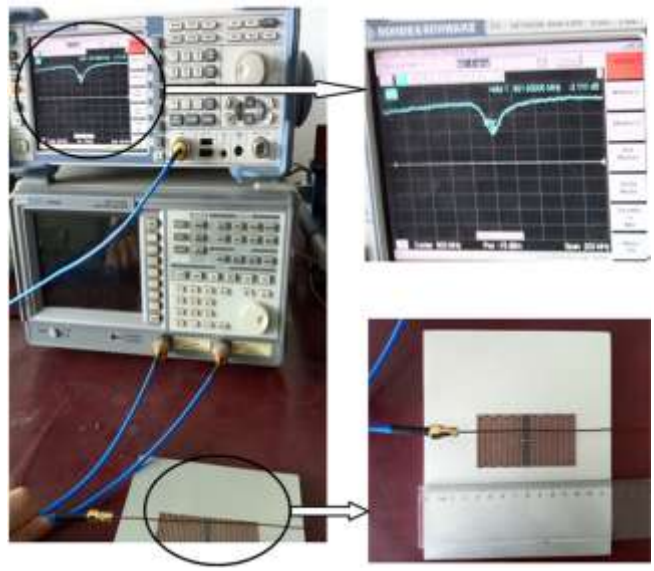


Fig. 8. Configuration of RFID tag measurement platform.

The reading range of RFID tag antenna is an important design goal. The estimated reading

range of the tag can be calculated as [14]

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

Where p_t is the output power of the RFID reader transmitter and G_t is the gain of the reader, λ is the wavelength in free space, G_r is the tag antenna gain, p_{th} is the chip power threshold sensitivity, τ is the power transmission coefficient as Eq. 1 shows.

Fig. 9. The reading range testing platform.

To evaluate the reading range of the proposed tag, experimental tag-reading-score tests were performed. The ALIEN ALR-8800 reader [15] is used in here to recognize the maximum reading range of the proposed tag. The output power of the reader antenna is fixed in 36dBm (EIRP 4W) [16]. In experimental test environment, the reading range is roughly determined as the maximum distance at which the tag can be recognized by the RFID reader [11]. The reading range testing platform is showed in **Fig. 9**. The reading range of the fabricated tag was first measured in free space. In free space the maximum reading distance can be up to 4.1m. And then, the reading range was measured for the antenna mounted on metal plates. In this case, the maximum reading distance is about 3.2 m. The reduce in the reading range can be explained by the result of the surface current distribution for the antenna mounted on the 150×150×8mm^3 metal plate. The surface current distribution will cause some canceling effects in the radiation patterns,

resulting in the degradation of the reading range.

4. Conclusion

A novel slim folded dipole planar patch antenna which can be used on metallic object`s surface has been designed in this paper. It has only a thickness of 0.508 mm. It operates within the Europe and North America UHF band and guarantees a good conjugate match with the chip reactance. Measurement results demonstrate that the reading range is larger than 4 m in free space. When it is mounted on the metallic surface, the reading range can still be larger than 3 m.

References

[1] H. G. Cho, N. R. Labadie, and S.K. Sharma, "Design of an embedded-feed type microstrip patch antenna for UHF radio frequency identification tag on metallic objects," *IET Microw. Antennas Propag.*, vol.4, no.9, pp.1232–1239, Sep.2010. Article (CrossRef Link)

[2] M. Hirvonen, P. Pursula, K. Jaakkola, and K. Laukkanen, "Planar inverted-F antenna for radio frequency identification," *Electron. Lett.*, vol.40, no.14, pp.848–850, Jul.2004. Article (CrossRef Link)

[3] H. Kwon and B. Lee, "Compact slotted planar inverted-F RFID tag mountable on metallic objects," *Electron. Lett.*, vol.41, no.24, pp.1308–1310, Nov.2005. Article (CrossRef Link)

[4] B. Yu, S. J. Kim, B. Jung, F. J. Harackiewicz, and B. Lee, "RFID tag antenna using two-shorted microstrip patches mountable on metallic objects," *Microw. Opt. Technol. Lett.*, vol.49, no.2, pp.414–416, Feb.2007. Article (CrossRef Link)

[5] L. Ukkonen, D. Engels, L. Sydanheimo, and M. Kivikoski, "Folded microstrip patch antenna for RFID tagging of objects containing metallic foil," in *Proc. of 2005 IEEE Antennas and Propagation Society Int. Symp.*, vol.1B, pp.211–214, 2005. Article (CrossRef Link)

[6] L. Ukkonen, M. Schaffrath, D. W. Engels, L. Sydanheimo, and M. Kivikoski, "Operability of folded microstrip patch-type tag antenna in the UHF RFID bands within 865–928 MHz," *IEEE Antennas Wireless Propag. Lett.*, vol.5, no.1, pp.414–417, Dec.2006. Article (CrossRef Link)

[7] B. Lee and B. Yu, "Compact structure of UHF band RFID tag antenna mountable on metallic objects," *Microw. Opt. Technol. Lett.*, vol.50, no.1, pp.232–234, Jan.2008. Article (CrossRef Link)

[8] Lingfei Mo, and Chunfang Qin, "Planar UHF RFID tag antenna with open stub feed for metallic objects," *IEEE Trans. Antennas Propag.*, vol.58, no.9, pp.3037–3043, Sep.2010. Article (CrossRef Link)

[9] S. Genovesi, and A. Monorchio, "Low-profile three-arm folded dipole antenna for uhf band RFID tags mountable on metallic objects," *IEEE Antennas and Wireless Propag. Lett.*, vol.9, pp.1225–1228, 2010. Article (CrossRef Link)

[10] H. D. Chen, and Y. H. Tsao, "Low-Profile PIFA Array Antennas for UHF Band RFID Tags Mountable on Metallic Objects," *IEEE Trans. Antennas Propag.*, vol.58, no.4, pp.1087–1092, Apr.2010. Article (CrossRef Link)

[11] H. D. Chen, and Y. H. Tsao, "Low-Profile Meandered Patch Antennas for RFID Tags Mountable on Metallic Objects," *IEEE Antennas and Wireless Propag. Lett.*, vol.9, pp.118–121, 2010. Article (CrossRef Link)

[12] S. L. Chen, and K.H. Lin, "A Slim RFID Tag Antenna Design for Metallic Object Applications," *IEEE Antennas and Wireless Propag. Lett.*, vol.7, pp.729–732, 2008. Article (CrossRef Link)
[13] T. Koskinen, H. Rajagopalan, and Y. R. Samii, "Impedance measurements of various types of balanced antennas with the differential probe method," in *Proc. of 2009 IEEE International Workshop on Antenna Technology*, pp.1-4, Mar.2009. Article (CrossRef Link)
[14] B. Lei, J. X. Li, L. H. Mao, "Folded microstrip patch-type tag antenna mountable on metallic surfaces," in *Proc. of 2011 International Conference on Control, Automation and Systems Engineering*, pp.1–3, Jul.2011. Article (CrossRef Link)
[15] Skyetek Embedded RFID Readers, Available from: http://www.skyetek.com. Access Date: Dec.2009.
[16] P. V. Nikitin and K. V. S. Rao, "Lab VIEW-based UHF RFID tag test and measurement system," *IEEE Trans. Ind. Electron.*, vol.56, no.7, pp.2374-2381, Jul.2009. Article (CrossRef Link)

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