A Metallic Patch Antenna Using a Simple Short Probe for Improving Impedance Match Bandwidth

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Abstract ─ A metallic patch antenna using double-tuned impedance matching is presented in this paper. The antenna mainly consists of a rectangular ground plane, a radiation patch with U-slot and two short metal cylinders, with a size of 200mm×200mm×25.5mm. The two metal cylinders are used to connect the patch and the ground. With the common effects of the U-slot and the two metal cylinders, the impedance match has become better than before. Moreover, high harmonics and cross polarization are suppressed after loading two short pins. Measured results show that the antenna has a wide impedance bandwidth from 830 MHz to 970 MHz (16%) for voltage standing wave ratio (VSWR) less than 1.5, and a high gain level about 9.3dBi in a wide band. A good agreement is achieved between simulated and measured results. Therefore, the proposed metal antenna is a good choice for UHF RFID applications.

Index Terms ─ Cross polarization, high harmonics, short probe, UHF RFID applications, wideband.

I. INTRODUCTION

Broadband antenna with a small size is a hot topic for antenna designers and it is a pair of contradictory unity of opposites. As we all know, a traditional antenna has a narrow band since only one resonance has been used [1]. An effective approach to add a new resonance point has been adopted to improve the bandwidth. Firstly, a ring slot has been reported in paper [2], while the radiation pattern is not very good. Another capacitive coupled technology is presented to enhance the bandwidth in paper [3], but the gains are not satisfactory results. U-slot and other capacitive gaps have been used to enhance the bandwidth in papers [4-5]. A parasitic element is also used to increase the bandwidth in [6-7], while there are a few reports about improving the impedance match. Other broadband antennas [11-12] are also presented.

In this paper, a U-slot has been used to improve the bandwidth. After that, two metal cylinders are placed on the ends of the feeder symmetrically to improve the impedance match. Furthermore, the cross polarization and high order modes are also improved. The proposed antenna has a perfect impedance match bandwidth covering from 830MHz to 970MHz with desirable gains. It can be used for UHF RFID applications. Detailed design processes and test results are presented in the following chapters.

II. ANTENNA DESIGN AND ANALYSIS

Geometry for the proposed antenna and detailed design process will be presented in this section.

A. Geometry of the proposed antenna

Figure 1 shows the geometry and dimensions for the proposed antenna. The all-metal antenna is made of aluminum material. Air substrate is used to separate the ground with the radiation patch, which can improve the bandwidth. A single-probe is adopted as feeding structure installed at the center of radiation patch. Then, the bandwidth has improved by using a U-slot. Moreover, a good impedance match performance in a wide operating bandwidth is achieved by two metal cylinders. The antenna can be fixed by four dielectric cylinders. A prototype of the antenna is illustrated in Fig. 1, and the optimized parameters are as follows: W=200mm, L=200mm, W1=9mm, W2=8mm, W3=36mm, Wr=70mm, L1=126mm, L2=77mm, Lr=8mm, H=25mm, h1=1.5mm, h2=2mm.

B. Theoretical analysis

In this paper, multistage matching technology is used for broadening the bandwidth of antenna. In equation (1), the impedance matching equation is presented for guiding the design of broadband antenna

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where n is the tuned stage, and B_n is the optimal impedance bandwidth at the corresponding state. As we know, a single radiation patch antenna can be considered as a first-order resonant circuit as shown in Fig. 2 (a). Corresponding to the impedance equation, the value of n is equal to 1. The optimal bandwidth about B_1 is presented in equation (2). Furthermore, an optimal first-order resonant mode can be obtained by tuning the parameter of the antenna. In addition, the bandwidth for mid-band and edge-band are demonstrated in equations (4) and (5):

$$B_n(\tau)=\frac{1}{Q}\frac{1}{b_N\sinh(\frac{1}{a_n}\ln(\frac{1}{\tau}))+\frac{1-b_n}{a_n}\ln(\frac{1}{\tau})}. \quad (1)$$

While $n=1$, $a_n=1$, $b_n=1$, the bandwidth is shown as following:

$$B_1=\frac{1}{Q}\frac{\pi}{\ln(\frac{1}{\tau})}=\frac{1}{Q}\frac{\pi}{\ln(\frac{VSWR+1}{VSWR-1})}, \quad (2)$$

$$Q=\frac{\omega_0 L}{R}, \quad (3)$$

$$B_{1MB}=\frac{1}{Q}\frac{2\tau^2}{\sqrt{1-\tau^2}}=\frac{1}{Q}\frac{VSWR-1}{\sqrt{VSWR}}, \quad (4)$$

$$B_{1EB}=\frac{1}{Q}\frac{2\tau}{1-\tau^2}=\frac{1}{Q}\frac{VSWR^2-1}{2*VSWR}. \quad (5)$$

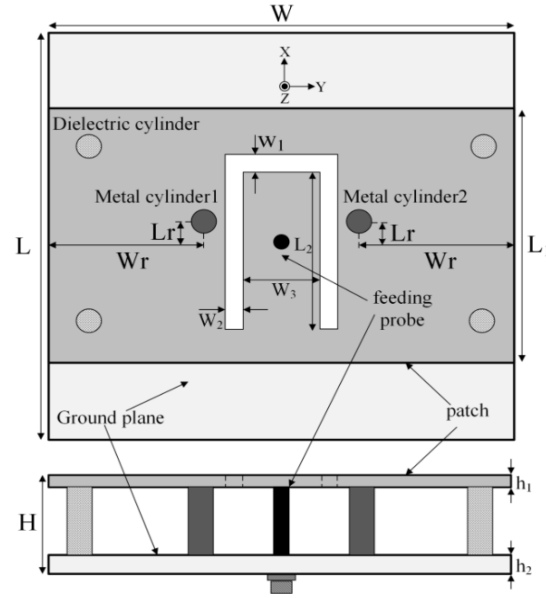


Fig. 1. Geometry of the proposed antenna.

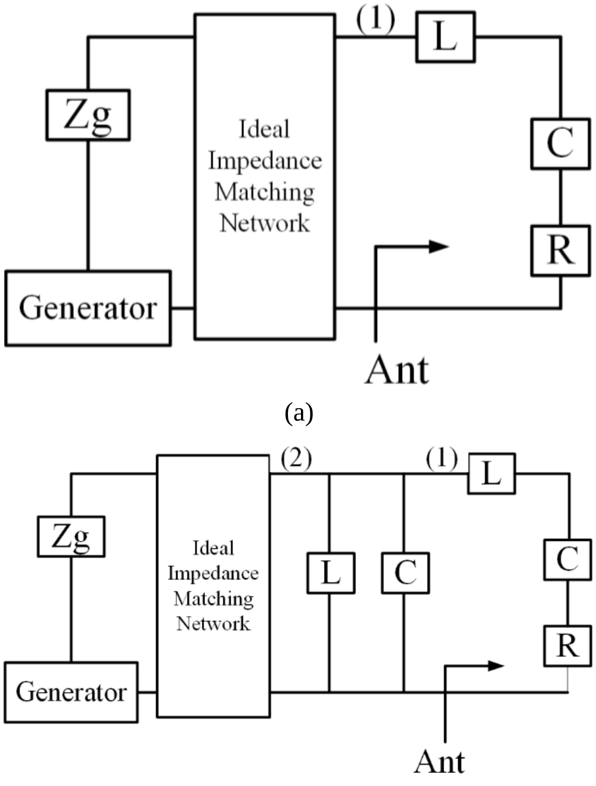
The relationship about reflection coefficients, phase and bandwidth about the double-tuned matching are shown in the following equations (6), (7), (8):

$$B=\frac{1}{Q}\tan(\varphi_{EB}), \quad (6)$$

$$\tau_1=\tan(\tfrac{\varphi_{EB}}{2}), \quad (7)$$

$$\tau_2=\tau_1^2, \quad (8)$$

φ_{EB} is the phase at the case of edge-band, τ_1 is the reflection coefficient of single tuning, τ_2 is the value of double tuning. The blue curve represents the mid-band and the red curve represents the case of edge-band. The equivalent circuit for double tuned match is presented in Fig. 2 (b). Firstly, the patch is acted as a series RLC circuits [11], then the gap of U type is etched on the patch, it can be replaced by a capacitor, approximately. After that, a pair of short pins are connected between the patch and the ground to further improve matching.



(a)

(b)

Fig. 2. (a) Equivalent circuit of the single tuning match, and (b) equivalent circuit of the proposed patch antenna.

In the end, the processes of the double tuning match are presented in the smith chart as shown in Fig. 3. Fractional bandwidth can be calculated by the following equations (9) and (10). The value of B1 and B2 are about 6% (40 MHz) and 16.8% (140 MHz), respectively, with VSWR less than 1.5:

$$B_n=(f_H-f_L)/f_0, \quad (9)$$

$$f_0 = \sqrt{f_H f_L}\,. \tag{10}$$

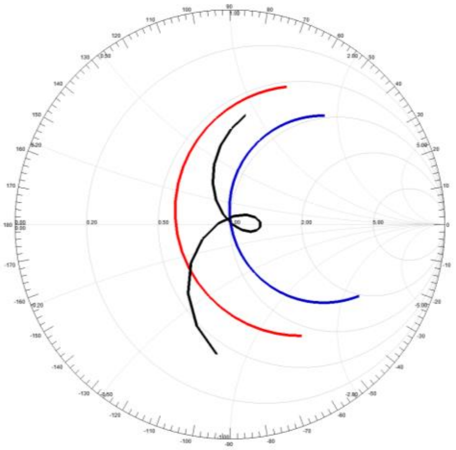


Fig. 3. Smith chart of double tuning match.

III. RESULTS AND DISCUSSION

The prototype of the antenna is fabricated which is shown in Fig. 4. The Key-sight E5080A vector network analyzer is used to measure the scattering performance. Simulated and measured S parameters are illustrated in Fig. 4. It is seen that the S11 is less than 15dB ranging from 830 MHz to 970MHz. A good agreement is obtained between the simulated and measured results. Figure 5 shows S parameters of the antennas with and without two metal cylinders, and the high harmonics have been suppressed with and without metal cylinders. Moreover, it can be observed that a good impedance matching is obtained by using a pair of short pins. The short probes can act as LC resonance elements, and a double-tuned impedance matching has been got, therefore the bandwidth of the proposed antenna has improved.

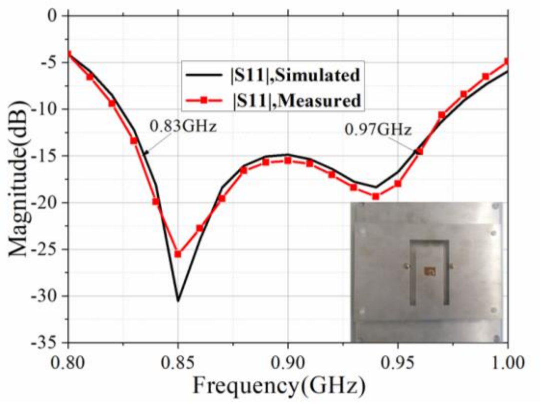


Fig. 4. The value of simulated and measured S11.

In order to further investigate the performance of suppressing cross polarization by using the metal cylinder, the main polarization and cross polarization in XOZ plane and YOZ plane are shown in Fig. 6. The cross polarizations with metal cylinder decrease 10dB and 5dB, in XOZ and YOZ plane, respectively. Therefore, the cross polarization has been suppressed with two metal cylinders obviously.

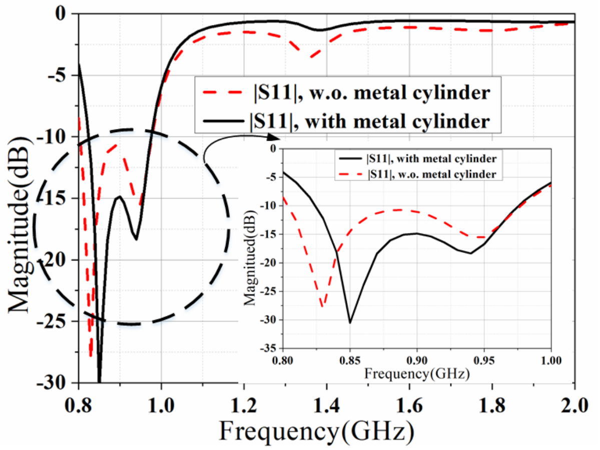
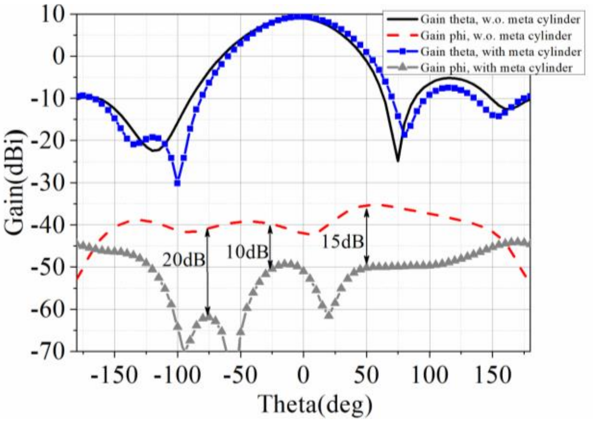
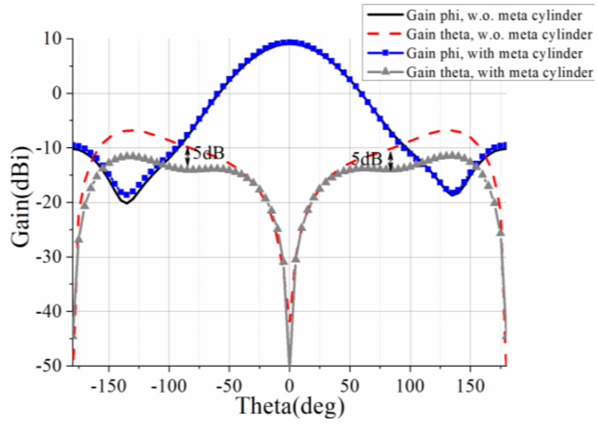


Fig. 5. S parameter of the antennas with and without metal cylinders.



XOZ-plane



YOZ-plane

Fig. 6. Main polarization and cross polarization in XOZ and YOZ plane.

Parameter analysis has been shown to describe the design mechanism of the wideband RFID antenna. In Figs. 7-9, the S parameter for the proposed antenna with different values of W3, h, Wr are shown, respectively. Figure 7 illustrates the effects of the size of the U slot. It is found that the low frequency changes fiercely with high frequency invariance. In Fig. 8, the impedance match performance has improved with the distance of the two short pins changing, while the dual resonant frequencies are almost unchanged. In Fig. 9, as the value of h changes from 21mm to 31mm, both of the dual resonator frequencies shift down to the low frequency, while the bandwidth of the antenna changes slightly.

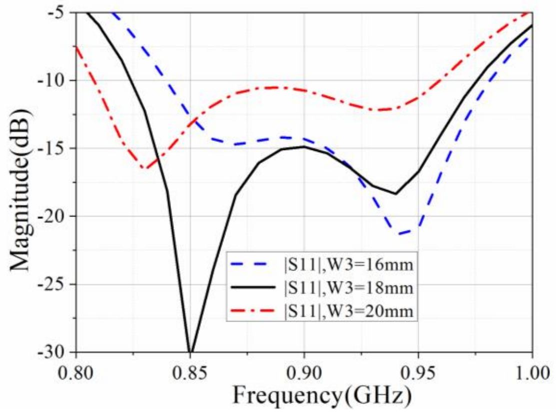


Fig. 7. Influence of U slot on the value of S11.

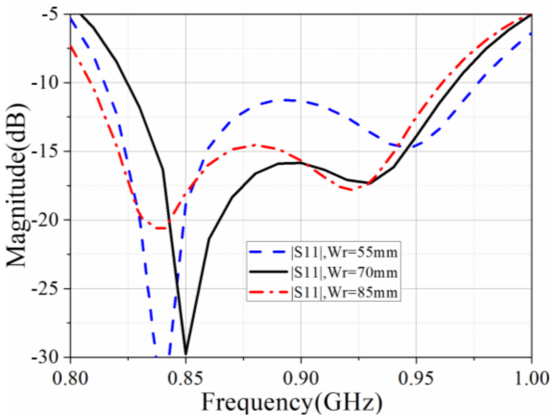


Fig. 8. Influence of two short pins on the value of S11.

The radiation patterns, gains and efficiencies are tested by using a SATIMO system. Figures 10-12 show the measured and simulated far field radiation patterns for XOZ-plane and YOZ-plane at 840MHz, 900MHz, and 950MHz in the desired band. It is clear that stable radiation patterns are obtained, and 3 dB beam width are both 65◦ for XOZ and YOZ plane.

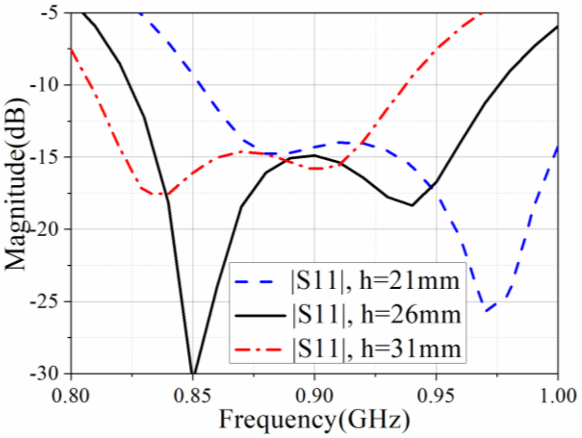


Fig. 9. Influence of height on the value of S11.

The simulated and measured gains and efficiencies of the proposed antenna are shown in Fig. 13 and Fig. 14. It is found that the gains of the proposed antenna are more than 9dBi in the desire band. Meanwhile, the simulated and measured efficiencies of the proposed antenna are more than 80%. Therefore, it can satisfy the traditional requirement in the whole UHF band.

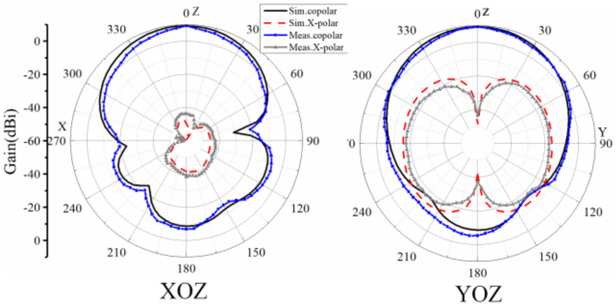


Fig. 10 Simulated and measured radiation patterns for XOZ plane and YOZ plane at 840MHz.

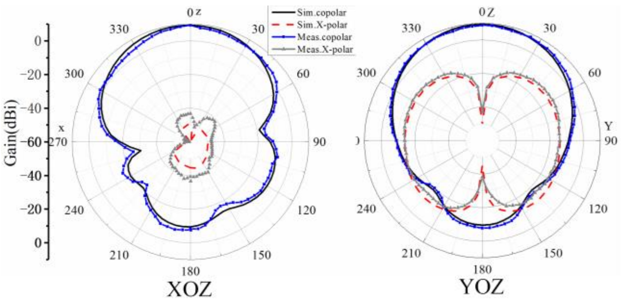


Fig. 11. Simulated and measured radiation patterns for XOZ plane and YOZ plane at 900MHz.

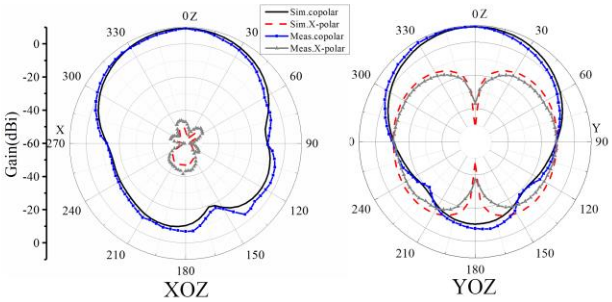


Fig. 12. Simulated and measured radiation patterns for XOZ plane and YOZ plane at 960MHz.

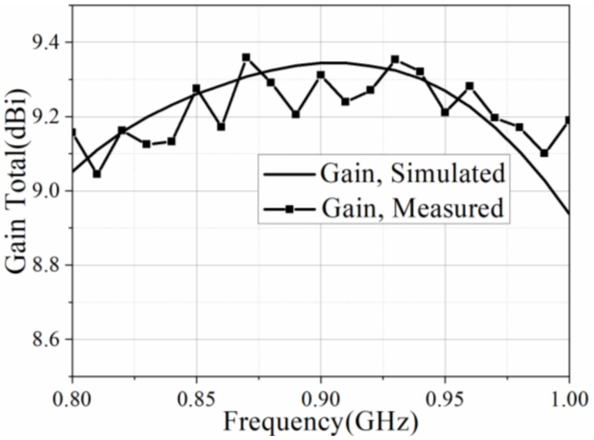


Fig. 13. Simulated and measured gains for the proposed antenna.

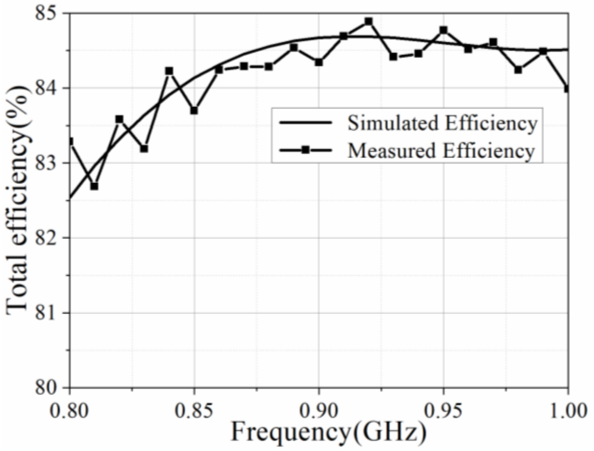


Fig. 14. Simulated and measured efficiencies for the proposed antenna.

The sizes, gain performance, and the bandwidth of the proposed RFID antenna have been compared with several other antennas in Table 1. By observing these data, all the performances of the designed antenna are superior to those of other reference antenna. Accurate comparative data are as follows.

Table 1: Performance of several other antennas

ANT	BW(VSWR<1.5) (MHz)	Gain (dBi)	Height
Ref. [8]	1620-1800 (10.53%)	7	0.125λ
Ref. [9]	2170-2580 (17.2%)	7.3	0.08λ
Ref. [10]	818-964 (16.3%)	3.5	0.125λ
Ref. [6]	4200-5400 (25%)	7	0.14λ
Prop.	830-970 (16.8%)	9.2	0.06λ

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No conflict of interest exits in the submission of this manuscript. All authors have seen the manuscript and approved to submit to your journal.

V. CONCLUSION

A wideband metal patch antenna basing on double-tuned impedance match is proposed. Owing to the common effect of the short probes and the U slot, the impedance matching bandwidth is improved ranging from 830MHz to 970 MHz (S11<-15). Moreover, high harmonics and cross polarization have been suppressed with the effect of metal cylinders. A good radiation performance has been obtained for the proposed antenna. Gains is more than 9dBi in the desired band, and the efficiencies are about 80%. Moreover, the radiation patterns are satisfying in a wide band, and 3-dB beam width are both 65◦ in XOZ and YOZ plane. Therefore, stable gain, low cost, compact structure, and easy manufacturing make the proposed antenna become a good candidate for UHF RFID applications.

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