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A UHF RFID Antenna Using Double-Tuned Impedance Matching for Bandwidth Enhancement

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Abstract—A broadband ultra-high-frequency (UHF) Radio Frequency Identification (RFID) antenna using double-tuned impedance matching theory is proposed. This paper presents a proximity coupled vertical meandered strip feed technique based on double-tuned impedance match which results in a wide bandwidth. This antenna mainly consists of a rectangular ground plane, a U-shaped radiation patch, and a suspended vertical meandered strip (VMS) by mesas of rotated Γ-shaped strip. The U-shaped radiation patch is fed by the VMS. The simulated and measured results show that the antenna has a very wide impedance matching bandwidth of 150 MHz (820–970 MHz) or 16.8% with the voltage standing wave ration (VSWR) less than 1.5 and achieves a high gain level about 8.5 dBi. Therefore, the proposed antenna can cover the entire UHF band of 840–960 MHz and is a good candidate for universal UHF RFID applications.

1. INTRODUCTION

After decades of development, radio frequency identification (RFID) technology has made great progress [1–3]. However, there are different frequency bands for UHF RFID application in different regions [4], such as 952–955 MHz in Japan, 840.5–844.5 MHz and 920.5–924.5 MHz in China, 866–869 MHz in Europe, and 920–926 MHz in Australia. Therefore, a UHF RFID antenna with wide frequency band is necessary. In order to broaden the bandwidth, a wide variety of methods have been reported. In [5], the stacked patch antennas with a sequentially suspended microstrip feed is proposed, which can operate at a wide bandwidth, but the cost is high, and the structure is complex. A horizontally meandered strip fed broadband patch antenna is proposed in [6], and it has a high profile. In [7], a low profile ring patch RFID antenna is proposed, and the impedance bandwidth and axial ratio bandwidth are about 3.5% and 0.65%. A wideband dual-frequency antenna is proposed in [8], but the bandwidth cannot cover all the UHF band with VSWR less than 1.5, and the gain is not high. A novel low profile wideband UHF antenna is proposed in [9], while the size is large, and manufacture of conic is difficult. In [10], the impedance bandwidth of the patch antenna is wide, while the measured gains are low in all the bands. In this paper, a double-tuned matching antenna is proposed to achieve a broadband performance for UHF RFID applications which can reduce the complexity of lumped tuning components. Meanwhile, it is simpler, wider and smaller than other traditional UHF RFID antennas. In addition, the antenna is easy to fabricate. Detailed design process and test results are presented in the following sections.

2. ANTENNA GEOMETRY AND EQUIVALENT CIRCUIT

2.1. Antenna Geometry

The geometry of the proposed broadband patch antenna with vertical meandered strip is shown in Fig. 1. The U-shape main radiation patch is made of aluminum material with thickness 1.5 mm which is

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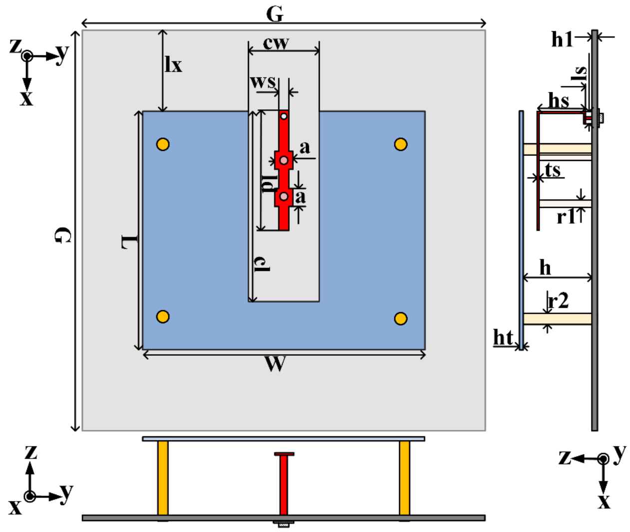


Figure 1. Geometry of the proposed antenna.

coupled-fed by the VMS. The ground plane is also made of aluminum material with a different thickness 2.0 mm. The height of air substrate is about 0.07λ. The VMS is fabricated by a long inductive copper strip with length 83 mm about $\lambda/4$ at the center frequency which is bent into a right angle two times in $-x$ axis direction at the position of distancing endpoint 4 mm and 27 mm. Meanwhile, it is put in the middle of the patch in y axis to obtain good impedance matching. The long copper strip is strongly inductive, and impedance performance is mismatched. Therefore, the strip line is bent parallel to the patch. On the one hand, the height of the antenna can be reduced; on the other hand, by using this double-tuning impedance match technique, the capacitance exists between the feed line and the patch which can weaken inductivity again. Moreover, the impedance bandwidth can be further improved compared to before.

2.2. Single Tuning Mid-Band Matching

The impedance-matching equation is shown in Formula (1), where B_n is the maximum fractional matching bandwidth, $B_n = (f_H - f_L)/f_0$, and n is the tuned stages. First, an equivalent circuit of a single tuning antenna is shown in Fig. 2. It describes the situation of single-tuned match. The reflection coefficient curve for Smith-chart is shown in Fig. 3. In Fig. 3, an ideal matching point is set; therefore, a point of zero reflection is achieved at the resonant frequency $f_0 = \sqrt{f_H f_L}$.

$$B_n(\tau) = \frac{1}{Q} \frac{1}{b_n \sinh\left(\frac{1}{a_n} \ln\left(\frac{1}{\tau}\right)\right) + \frac{1-b_n}{a_n} \ln\left(\frac{1}{\tau}\right)} \tag{1}$$

Based on above theory, when $n = 1$, $a_n = 1$, $b_n = 1$, the fractional bandwidth about single-tuned match is given in Formula (2) as following. And the fractional bandwidth about mid-band and edge-band is presented in Formulas (3) and (4).

$$B = \frac{1}{Q} \frac{\pi}{\ln\left(\frac{1}{\tau}\right)} = \frac{1}{Q} \frac{\pi}{\ln\left(\frac{\text{VSWR}+1}{\text{VSWR}-1}\right)} \quad \left(\text{where, } Q = \frac{w_0 L}{R}\right) \tag{2}$$

$$B_{1MB} = \frac{1}{Q} \frac{2\tau^2}{\sqrt{1-\tau^2}} = \frac{1}{Q} \frac{\text{VSWR}-1}{\sqrt{\text{VSWR}}} \tag{3}$$

$$B_{1EB} = \frac{1}{Q} \frac{2\tau}{1-\tau^2} = \frac{1}{Q} \frac{\text{VSWR}^2 - 1}{2\text{VSWR}} \tag{4}$$

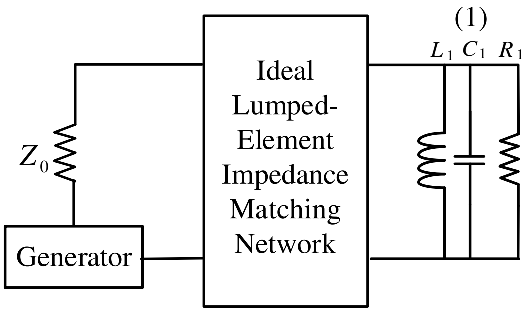


Figure 2. Equivalent circuit of the single tuning match.

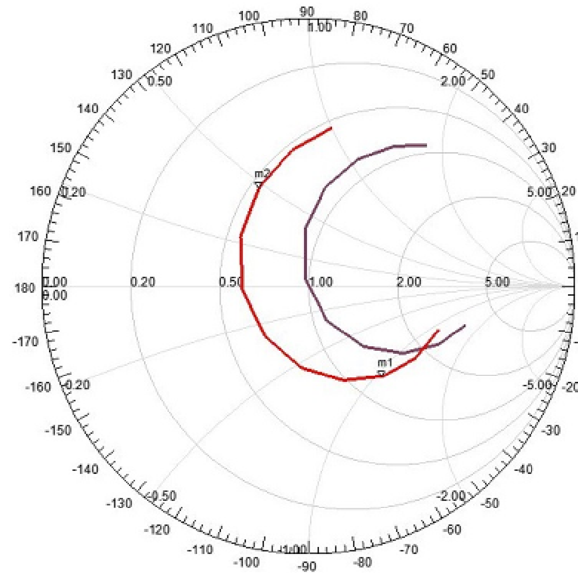


Figure 3. Optimum single-tuned matching.

The Smith chart of mid-band single-tuned match is shown in Fig. 3. The bandwidth is 44 MHz from 874 MHz to 918 MHz, with VSWR less than 1.5.

2.3. Double-Tuned Matching and Equivalent Circuit

The bandwidths and reflection coefficients about the double-tuned matching are shown in the following Equations (5)–(7).

$$\mathrm{QB} = \tan(\varphi_{EB}) \tag{5}$$

$$\tau_1 = \tan\left(\frac{\varphi_{EB}}{2}\right) \tag{6}$$

$$\tau_2 = \tau_1^2 \tag{7}$$

φ_{EB} is the magnitude of impedance phase at edge-band frequency, τ_1 the reflection coefficient of optimum single tuning, and τ_2 the reflection coefficient of optimum double tuning.

The equivalent circuit of double-tuned impendence match antenna is shown in Fig. 4. The radiation patch acting as the first resonator is replaced by a parallel RLC resonant circuit, and the values can be computed by the cavity model in [8]. The tuned feed strip can be seen as a lossless series resonator of LC circuit. Moreover, the gaps between the tuned strip and the radiation patch are capacitive coupling, which can be represented by a π-type capacitive network. The Smith chart about the double-tuned impedance match is shown in Fig. 5. As shown in Fig. 10, the bandwidth of simulation is 150 MHz from 820 MHz to 970 MHz with VSWR less than 1.5.

2.4. Simulated Surface Current Distribution

In order to further investigate the working mechanism. The simulated surface current distribution on the patch and double tuning feed line is shown. First, the single-tuning mid-band matching is shown in Fig. 6(a). There is only one resonance point at 900 MHz. Then, the surface current distributions on the proposed antenna are shown in Fig. 6(b) and Fig. 6(c). At low resonator frequency 860 MHz, the surface current is mainly focused on edge of the rectangular patch, and the equivalent length is the sum of $(W - cw)/2$ and L. The sum is 171 mm which is half wavelength of the low frequency. At high resonator frequency 925 MHz, the surface current is mainly focused on the incision as shown in Fig. 6(c). Moreover, the sum of $cw/2$, cl, and $(W - cw)/2$ is 164 mm which is half wavelength of the high frequency.

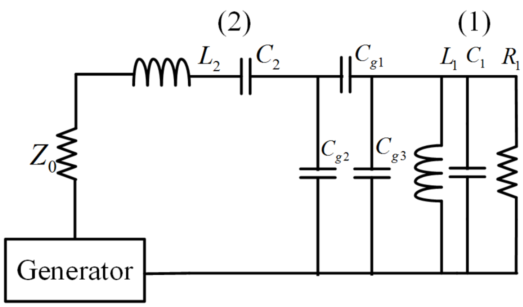


Figure 4. Equivalent circuit of the proposed patch.

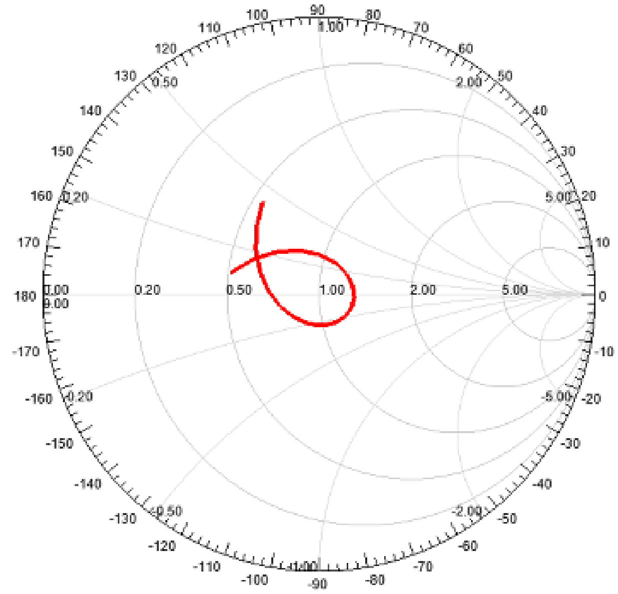
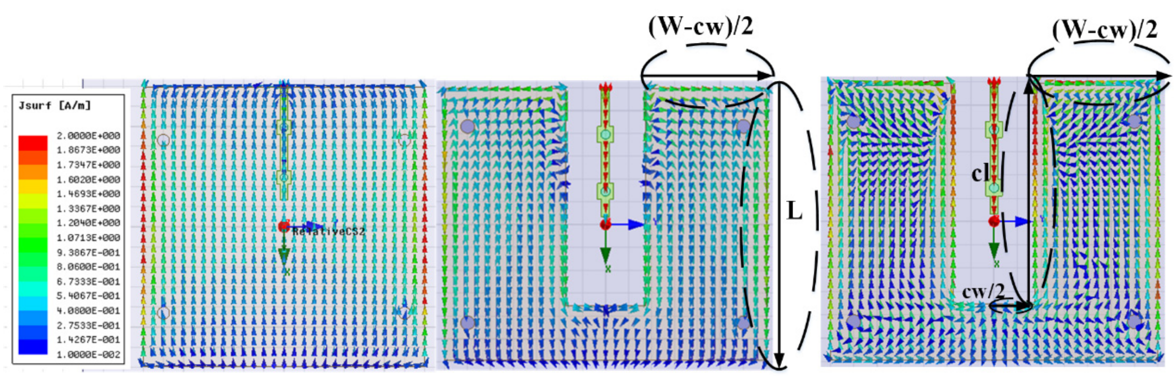


Figure 5. Smith chart of the proposed antenna.



(a) (b) (c)

Figure 6. The surface current distribution, (a) 900 MHz, (b) 860 MHz, (c) 925 MHz.

2.5. Parameter Analysis

In the previous section, the equivalent circuit about the double-tuned match is given, which helps the reader understand the double-tuned impedance match. In order to further study the performance of the antenna, several key parameters are under investigation. Parameter $y0$ is the length of the feed strip. The inductance increases with the growing length. The reflection coefficients of the different values about $y0$ are shown in Fig. 7, and the impedance matching bandwidth decreases with changing value of $y0$, and the value of $y0$ equal to 56 mm is suitable. The capacitive couple between the patch and feed strip is also affected by the height of the tuned strip $h2$, as shown in Fig. 8. When decreasing or increasing the value of cw, the capacitive coupling between the radiation patch and the tuned feed strip also changes as shown in Fig. 9.

Based on the analysis about the parameters of above simulations curves and with the help of simulation by HFSS 15, the proposed antenna is optimized and designed. The optimized dimensions are listed as follows (unit: mm): $G = 200$, $L = 119$, $W = 136$, $cl = 95$, $cw = 35$, $lx = 55$, $ws = 3.5$, $a = 7$, $ts = 0.2$, $ls = 4$, $ld = 56$, $hs = 23$, $h1 = 2$, $h = 28$, $ht = 1.5$, $r1 = 2$, $r2 = 3$, respectively.

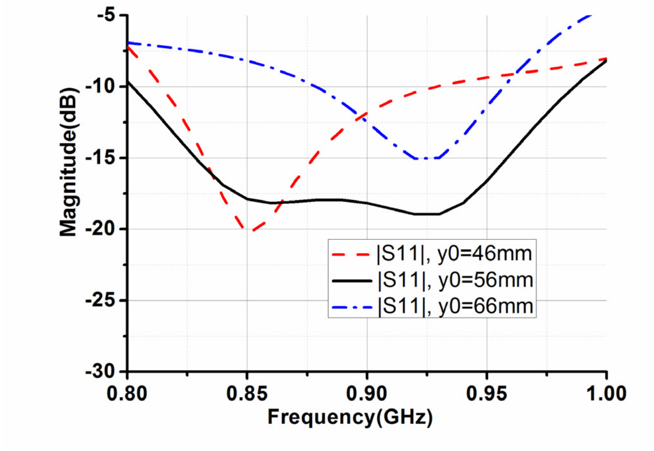


Figure 7. Reflection coefficients for different $y0$.

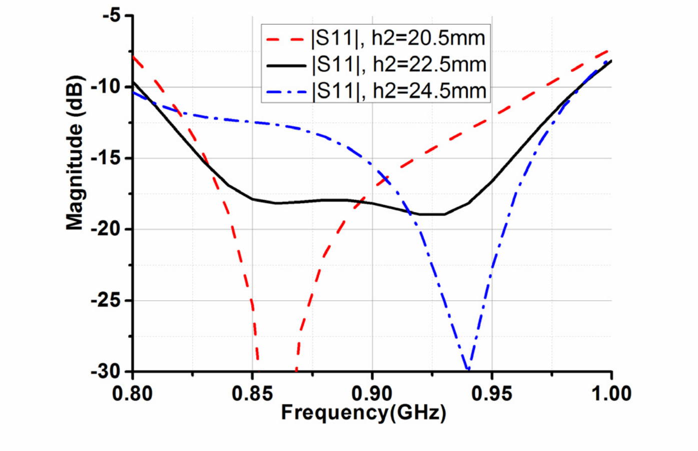


Figure 8. Reflection coefficients for different $h2$.

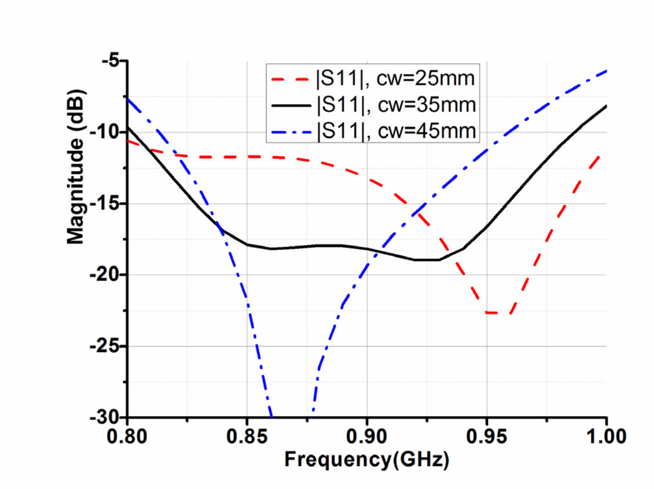


Figure 9. Reflection coefficients for different cw.

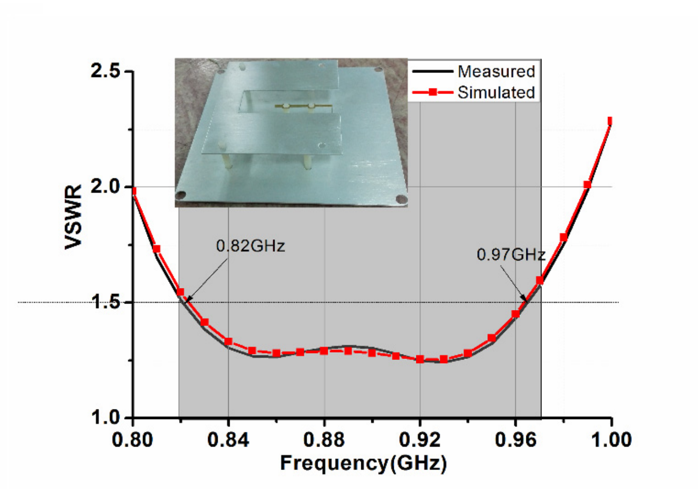


Figure 10. Simulated and measured VSWR for the antenna.

3. EXPERIMENTAL RESULTS AND COMPARISONS

3.1. Experimental Results

A prototype of the antenna is fabricated and shown in Fig. 10. The VSWR of the proposed antenna is measured by a WILTRON 37269A vector network analyzer. The simulated and measured VSWRs of the proposed antenna are also shown in Fig. 10. The bandwidth for VSWR less than 1.5 is 150 MHz, ranging from 820 MHz to 970 MHz. Good agreement is achieved between the simulated and measured results. Excellent two order tuning matching of the antenna is realized, and the bandwidth is wider than single-tuned impedance match antennas.

Figures 11–13 show the simulated and measured co- and cross-polarization patterns of the proposed antenna in the working band. It is clear that stable radiation patterns are realized in the whole operating frequency band in x-z and y-z planes. The simulated and measured gains for the proposed antenna are shown in Fig. 14, which distribute in the range of 8.2–8.6 dBi. Moreover, the simulated and measured efficiencies for the proposed antenna are shown in Fig. 15. The gains and efficiencies for the proposed antenna can satisfy the requirements in the entire UHF band.

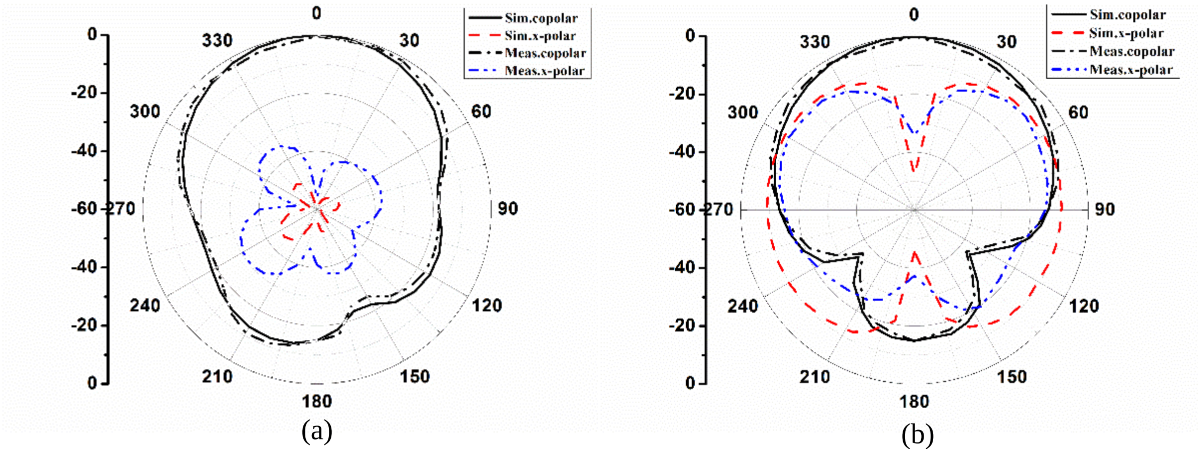


Figure 11. Simulated and measured radiation patterns of the proposed antenna at 860 MHz. (a) x-z plane, (b) y-z plane.

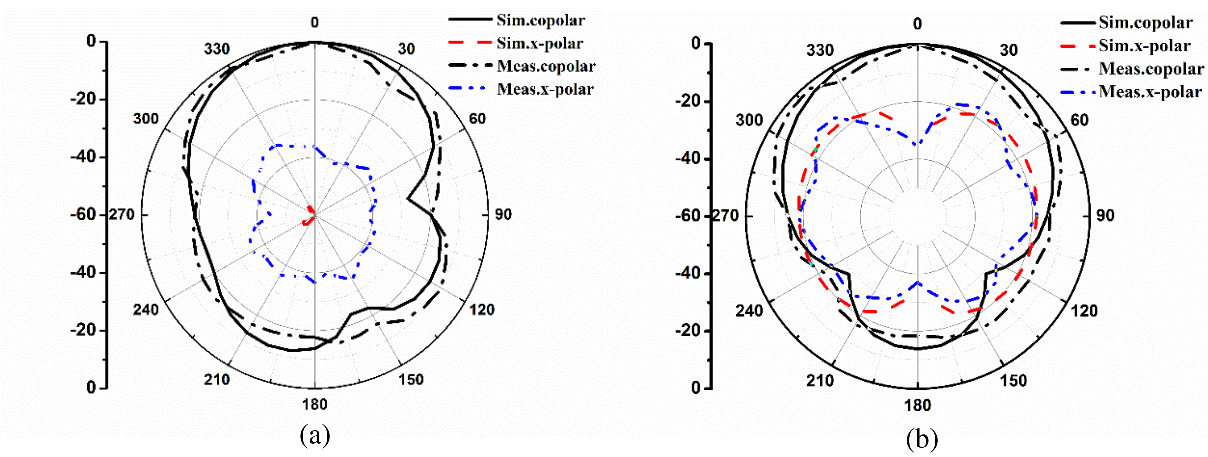


Figure 12. Simulated and measured radiation patterns of the proposed antenna at 900 MHz. (a) x-z plane, (b) y-z plane.

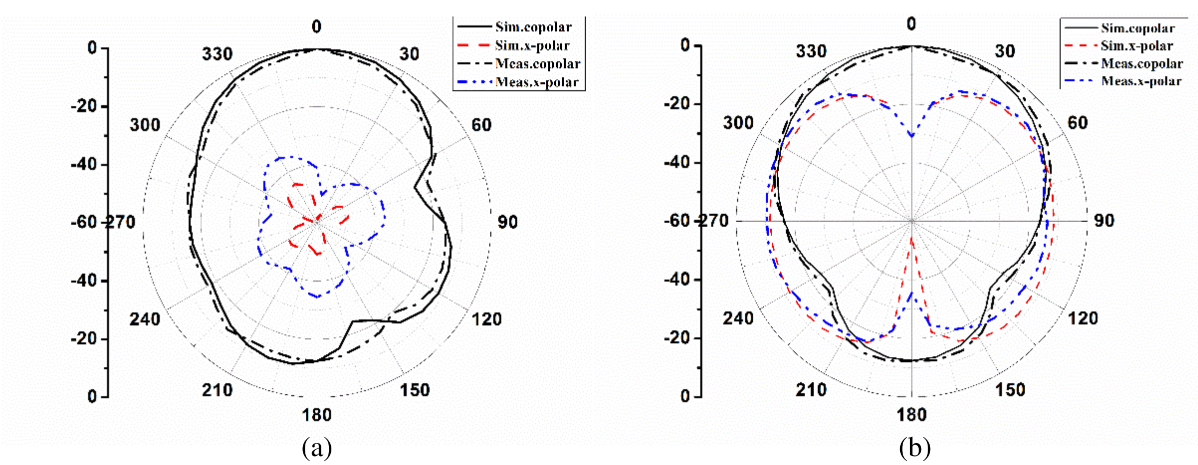


Figure 13. Simulated and measured radiation patterns of the proposed antenna at 960 MHz. (a) x-z plane, (b) y-z plane.

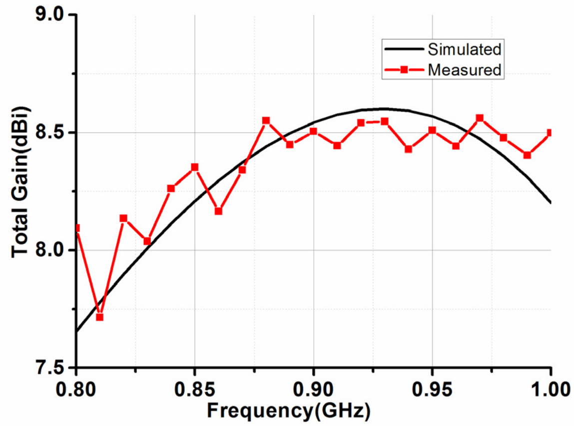


Figure 14. Simulated and measured gains of the proposed antenna.

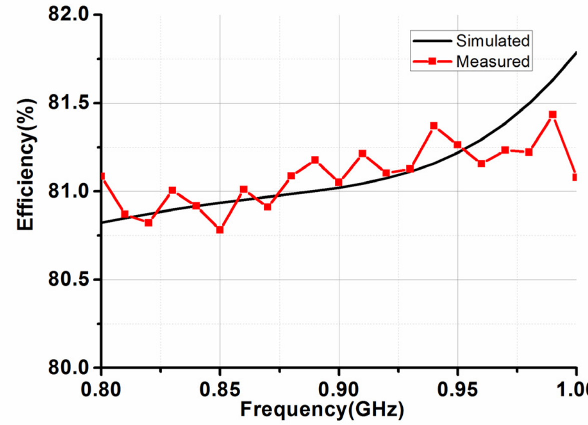


Figure 15. Simulated and measured efficiencies.

3.2. Comparison of the RFID Antennas

The sizes, gains, half power beamwidth, and bandwidth of the proposed antenna are compared with those of some antennas in Table 1. The bandwidth of the proposed antenna is wide compared to the reference antennas. Above all, the size of the proposed antenna is smaller than other antennas. Meanwhile, the VSWR of the proposed antenna is very smooth about 1.25 over the entire bandwidth, and an excellent double-tuned optimized match is displayed.

Table 1. Comparison between proposed antenna and reference antennas.

ANT	BW (VSWR $<$ 1.5) (MHz)	Max Gain (dBi)	Half Power Beamwidth	Size $(L \times W \times H)$ mm^3
Ref. [5]	758–983 (25.85%)	8.6	67	$250 \times 250 \times 36.5$
Ref. [6]	818–964 (16.39%)	8.6	-	$250 \times 250 \times 38$
Ref. [12]	837–963 (14%)	7.3	-	$250 \times 250 \times 36$
Ref. [13]	901–930 (3.17%)	7.8	70	$250 \times 250 \times 48$
Ref. [14]	835–955 (13.4%)	7.0	90	$200 \times 200 \times 29.8$
Ref. [15]	840–900 (6%)	5.5	100	$160 \times 160 \times 33$
Proposed	820–970 (16.76%)	8.5	75	$200 \times 200 \times 28$

4. CONCLUSION

A broadband UHF RFID antenna with double-tuned impedance match is proposed. Using the VMS double-tuned feed technique, excellent two-order tuning smith matching chart is achieved, and the profile of the antenna is reduced to 0.07λ. The measure results show that the antenna has an impedance bandwidth (VSWR < 1.5) of 758–983 MHz (16.8%), and gains and efficiencies also have satisfactory results. Stable gains, compact structure, and easy manufacture make the proposed antenna a good candidate for the UHF RFID applications.

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