Progress In Electromagnetics Research C, Vol. 38, 141–151, 2013

A SLIM WIDEBAND AND CONFORMAL UHF RFID TAG ANTENNA BASED ON U-SHAPED SLOTS FOR METALLIC OBJECTS

Tao Tang[1, 2, *] and Guo Hong Du[1]

[1]Electronic Engineering College, Chengdu University of Information Technology, Chengdu 610225, China

[2]CMA Key Laboratory of Atmospheric Sounding, Chengdu 610225, China

Abstract—A slim wideband patch antenna designed for the ultra-high frequency (UHF) band radio frequency identification (RFID) tag is presented in this paper, which can be mounted on flat or curved metallic surfaces directly. The presented antenna is fabricated on a very thin (only 0.5 mm) and low-cost PET substrate ($\varepsilon_r = 3.8$, $\tan\delta = 0.02$). The proposed design consists of tow coplanar patches radiation unities which are electrically connected to the metallic ground through two symmetrical shorting walls placed at both edge sides of the patches. Double symmetrical U-shaped slots are etched out to improve the antenna bandwidth. A perfect matching between antenna and tag chip can be easily obtained by varying the geometry parameters of the slots. The simulated bandwidth is about 97 MHz, which covers the Europe and North America UHF RFID frequency range. The measured maximum reading range of the proposed antenna can be up to 5 m when the tag is mounted on a metal plate whose size is $150 \times 150 \times 8\,\text{mm}^3$.

1. INTRODUCTION

Profiting from a rapid expanding of wireless 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 has gained much interest in recent years [1, 2]. The allotted band range

Received 10 January 2013, Accepted 25 March 2013, Scheduled 26 March 2013
* Corresponding author: Tao Tang (tangt@cuit.edu.cn).

of UHF for RFID system is different for each country, such as 865.6–867.6 MHz for Europe, 902–928 MHz for North America, and 952–954 MHz for Japan [3]. A RFID system consists of reader, tag and interface software. In which, the tag contains radiating antenna and a chip. The ability of the tag to communicate efficiently with the reader depends on the antenna characteristics and channel properties [4]. So, the tag antenna is one of the essential components and plays a key role in the overall RFID system.

RFID tags need to be attached to various objects with different shapes and material properties [5, 6]. In some practical applications, the 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 [7, 8]. Therefore, the design of RFID tag for metallic usage, such as containers, notebooks, and cars, is a challenge, especially when tags attached to those objects like bottle and gas cylinders which have a curved metallic surface.

In order to weaken the interference from metallic objects and to meet the conformal requirements between the tag antenna and the objects, a tag antenna in structure including a ground plane can be viewed, and the flexible substrate can be selected. Besides, some requirements in commercially should be taken into account in design process, such as the size of the antenna, sensitive read range, manufacturing cost, and impedance matching [8, 9]. Based on the above considerations, several designs have been developed [10–14]. However, the size of the tag antenna in these designs is not small or thin enough, e.g., $118 \times 43 \times 1.5\,\mathrm{mm}^3$ in [10]. A circular shape tag with high-permittivity ceramic ($BaTiO_3$) structure has been proposed in [11], and its diameter and thickness are 27.5 mm and 2.75 mm, respectively. Another $80 \times 25 \times 3.5\,\mathrm{mm}^3$ metal tag is designed in [12] and consists of an additional loop feed. Ref. [13] proposed a miniature tag for metallic objects ($32 \times 18 \times 3.2\,\mathrm{mm}^3$), whose size is minimized by using an unconnected conductive layer to increase the capacitance of the antenna, but this method reduces the antenna radiation performance. Besides, many of these designs suffer from narrow bandwidth (40 MHz, for example), and the rigid substrates in these designs cannot be suitable for conformal applications.

A multi-slotted tag with 1.6 mm thickness and 31 MHz bandwidth is proposed in [14], which also discusses how the bandwidth could be increased by incorporating multiple slots. A metal-mountable tag with a size $140 \times 50 \times 1.8\,\mathrm{mm}^3$ is designed in [15], which has a shorting wall at one edge side. Its read range is 4 m on copper plate. By replacing the

FR-4 substrate layer with paper substrate, it can be bent for conformal usage [16].

In this paper, a wideband UHF RFID tag patch antenna is proposed for metallic objects which have following characteristics: (1) thinness (only 0.5 mm); (2) wideband (about 97.1 MHz); (3) allow bending for conformal requirements; and (4) it can be directly mounted on metallic surfaces. The configuration of the antenna and simulation results will be explained in Section 2. Parametric studies and measurement results are given in Section 3. Finally, conclusions are drawn in Section 4.

2. ANTENNA DESIGN AND RESULTS

There are two approaches in the RFID metal tag antenna design. The first one is to reduce the interference from the metallic surface effect, for example, inserting of a high permittivity substrate or embedding of a high-impedance surface (HIS) ground plane. The other is to arrange a conductive ground plane in the antenna structure to reduce the metallic surface effect in the antenna performance [8, 17], for example, IFA, PIFA, or the commonly used patch-type antenna [18]. Our design is based on the second solution.

The proposed antenna consists of two symmetry rectangular metallic radiation patches with two symmetrical U-shaped slots and a ground plane. The configuration is shown in Figure 1(a). The radiation patches are separated by 4 mm gap. The tag chip ($1\times 1\,\text{mm}^2$) is placed between the two patches and connects to both of them. The radiation metallic patches are electrically connected to the ground plane through two symmetrical metallic shorting walls which are placed in each edge side. The substrate between patches and ground is PET ($\varepsilon_r = 3.8$, $\tan\delta = 0.02$) with the thickness 0.5 mm. The overall size of the antenna is $80 \times 31 \times 0.5\,\text{mm}^3$. Profiting from its thin and flexible PET substrate, the proposed tag is bendable (shown in Figure 1(c)). The detailed geometries parameters of the tag antenna are given in Table 1.

The selected Alien's Higgs_3 tag chip has an intrinsic impedance of $Z_c = 27 - j201\,\Omega$ at 915 MHz [19]. And a metal plate in size $150 \times 150 \times 8\,\text{mm}^3$ is considered in simulation model. The desired antenna input impedance has to be conjugately matched to tag chip to ensure adequate power transmission to the chip. The power transmission coefficient is defined as

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

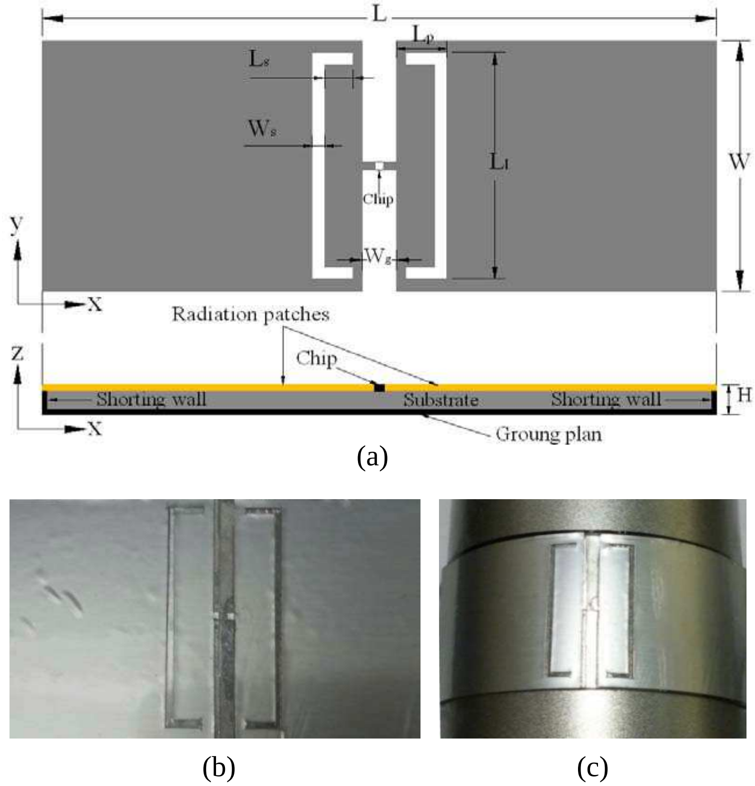

Figure 1. Geometries of the proposed tag antenna. (a) Schematic diagram of the antenna. (b) Photograph of the antenna. (c) On curved metallic surfaces.

Table 1. Detail geometries parameters of the antenna.

Total length (L)	Total width (W)	Overall height (h)	Slot length (L_l)
80 mm	31 mm	0.5 mm	26.5 mm
Slot width (W_s)	Slot short side length (L_s)	Distance between slot and gap edge (L_p)	Gap width between patches (W_g)
2.2 mm	3.4 mm	6 mm	4 mm

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

The input impedance of the proposed antenna is shown in

Figure 2. There are intersections between the tag impedance and the chip conjugate impedance around 920 MHz, and this indicates that the tag has a good conjugate match with the chip at this frequency. The power transmission and input reflection coefficient (S_{11}) are shown in Figure 3. It can be noted that the antenna has a wideband performance on the metallic surface (-10 dB bandwidth is 97.1 MHz, from 856.8 MHz to 953.9 MHz).

Figure 4 shows that the simulated radiation patterns of the antenna are placed in free space and the metal plate for x-z plane

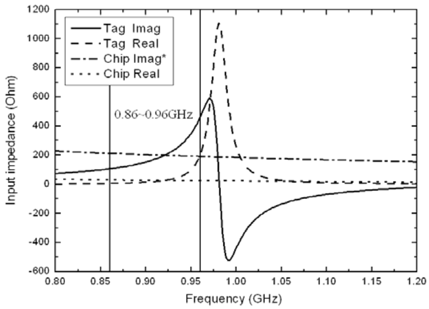

Figure 2. The input impedance of the proposed antenna.

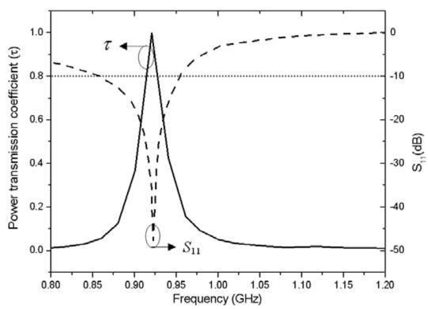

Figure 3. The power transimission coefficient and S_{11} of the proposed antenna on a $150 \times 150 \times 8\,\text{mm}^3$ metal plate.

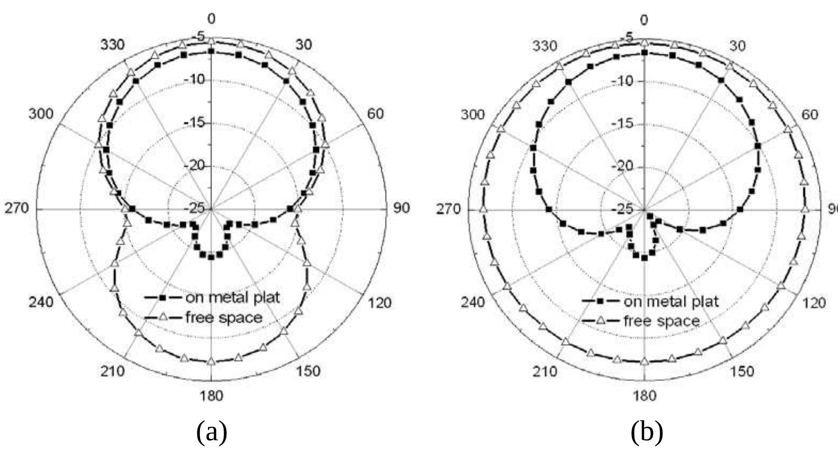

Figure 4. The radiation patterns at 915 MHz in free space and on a $150 \times 150 \times 8\,\text{mm}^3$ metal plate. (a) x-z plane ($\varphi = 0°$). (b) y-z plane ($\varphi = 90°$).

($\varphi = 0°$) and y-z plane ($\varphi = 90°$), respectively. And the back radiation in the direction $-z$ is decreased dramatically when the antenna is mounted on the metal plate.

3. PARAMETRIC STUDIES

The parametric studies are carried out to provide more design information for readers.

3.1. Effect of the Slots

Generally, the tag chip is capacitive in nature [20]. Accordingly, the antenna should be inductive for perfect matching. The slots created on metallic patches can help increasing inductance value of the antenna, and hence changing the slots dimension leads to the changes of antenna inductance.

In order to further illustrate the effect of the slots, a tag without U-shaped slots but with the same overall size ($80 \times 31 \times 0.5\,\text{mm}^3$) is analyzed firstly. The input impedance of the unslotted antenna is shown in Figure 5(a). In Figure 5(a), one can see that the antenna input impedance can never match chip impedance in the UHF RFID frequency range (860∼960 MHz). The power transmission coefficient is shown in Figure 5(b). The detailed performances of the proposed tag and unslotted tag are both given in Table 2. It can be noted

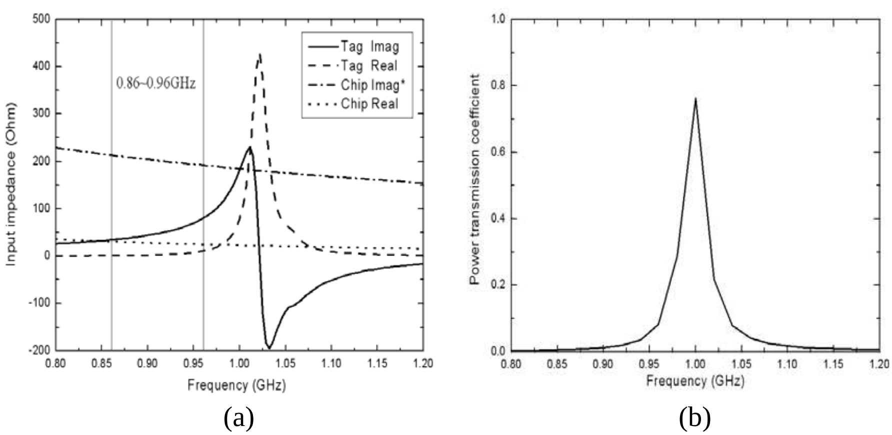

Figure 5. The input impedance and power transmission of the unslotted antenna. (a) Input impedance. (b) Power transmission coefficient.

Table 2. Antenna performance with different number of slots.

Tag type	Resonant frequency (MHz)	Input impedance at 915 MHz (Ω)	Bandwidth (MHz)	Gain at 915 MHz (dB)	Radiation efficiency
proposed tag	922.1	$20.7 + j198.6$	97.1	−5.86	7.32%
Unslotted tag	997.0	$3.3 + j49.4$	31.7	−4.24	12.83%

that the best working frequency of the unslotted 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, but this does not meet the design concept. Fortunately, as previously mentioned, we can achieve the miniaturization purpose by adding slots in the patches of the antenna. Bedsides, the slots can help to improve the bandwidth characteristics of the tag antenna.

If we create more symmetrical U-shaped slots for this tag antenna, we can find that with increasing of slots, the antenna has the following characteristics: (1) Decreasing in resonant frequency; (2) Decreasing in bandwidth: the bandwidth of proposed antenna with two symmetrical U-shaped slots is 97.1 MHz whereas in the presence of six slots the bandwidth decreases to 53.7 MHz; (3) Decreasing in gain and radiation efficiency. From these, we can deduce that creating more slots, the antenna size can be reduced but with other trade-off.

3.2. Effect of the Metal Plat

The proposed tag antenna can be also used in free space. Figure 6 shows the input reflection coefficient (S_{11}) of the antenna mounted on the $150 \times 150 \times 8\,\text{mm}^3$ metal plat and placed in free space. It can be noted from Figure 6 that the resonant frequency will be reduced when it works in free space (without metal plate).

We know that the metallic environment has a significant effect on antenna performance. The effects of the metallic environment are investigated by changing metal plat size, and the results are shown in Table 3. From Table 3, one can see that the size of the metal plate has little effect on antenna resonant frequency and bandwidth; the gain firstly increases and then decreases with the increasing of 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 has almost no effect on antenna performance.

Table 3. Antenna performance with different size of metal plat.

Size of metal plat	resonant frequency (MHz)	Gain at 915 MHz (dB)	Front-back ratio (dB)	Bandwidth (MHz)
Free space	904.5	−5.58	1.03	96.9
$80 \times 80 \times 8\,\text{mm}^3$	922.6	−7.31	3.45	88.9
$100 \times 100 \times 8\,\text{mm}^3$	934.7	−4.91	5.95	97.6
$120 \times 120 \times 8\,\text{mm}^3$	930.7	−4.87	8.16	89.5
$140 \times 140 \times 8\,\text{mm}^3$	926.6	−5.41	9.88	92.6
$160 \times 160 \times 8\,\text{mm}^3$	920.6	−5.99	11.75	93.8

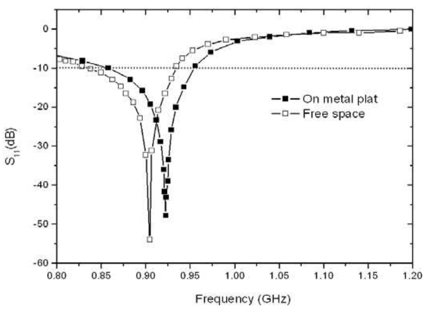

Figure 6. The comparation of input reflection coefficient (S_{11}) for the proposed antenna in free space and on a $150 \times 150 \times 8\,\text{mm}^3$ metal plate.

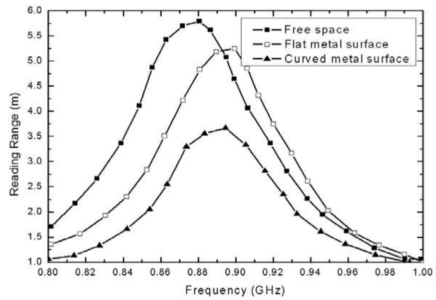

Figure 7. Measured read range of the proposed antenna on flat and curved metallic surfaces (bending radian is about 25 degree) and in free space.

3.3. Effect of the Bending Angle

Due to its thin and flexible substrate, the proposed design can be used for conformal applications. The bending radian is a key parameter in conformal use. The effect of the bending radian is given in Table 4. As shown in Table 4, both the resonant frequency and gain decrease with increasing bending radian, and the antenna performance will deteriorate if the bending radian is greater than 35 degree.

In order to demonstrate the characteristics of the proposed tag antenna, a prototype has been fabricated, which shown in Figure 1(b). The read range of the prototype was tested by Tagformance Lite [21]. A line polarization antenna, which has the same polarization feature with the proposed tag is equipped for reader, the output power of the

Table 4. Antenna performance with different bending radian.

Radian radian (degree)	resonant frequency (MHz)	Gain at 915 MHz (dB)	Bandwidth (MHz)
5	932.7	−5.41	81.2
10	928.6	−5.56	84.8
20	918.6	−6.18	87.3
25	902.5	−6.43	80.5
30	896.7	−6.79	74.2
35	876.4	−7.59	70.2

reader is fixed in 36 dBm (EIRP 4 W) [22]. The test results of the read range is shown in Figure 7.

As Figure 7 shows, the maximum reading range can be up to 5.8 m in free space. When it is mounted on the $150 \times 150 \times 8\,\text{mm}^3$ flat metal plate, the reading range can be stable up to 4 m in a wide frequency range, and the maximum read range can be up to 5 m. While on a curved metal surface (the bending radian is about 25 degree), the maximum reading range can be up to 3.7 m which can be noted from Figure 7 also.

4. CONCLUSIONS

A novel slim patch antenna for UHF RFID tag has been designed, which can be used for metallic object. It only has 0.5 mm in thickness. The operation frequency band covers the Europe and North America UHF RFID band range and guarantees a good match with the chip reactance. The measured results demonstrate that the reading range is larger than 5 m in free space and 4 m on metal surface. It can be affixed to the curved metal surface due to its flexible feature.

ACKNOWLEDGMENT

We would like to thank anonymous reviewers. Special thanks to XERAFY Co. Ltd for the measurement work. This work was supported by the National Natural Science Foundation of China (No. 61201095) and the Sichuan Education Department research projects (No. 13ZB0076), the CUIT Foundation for scientific research personnel (No. J201202), as well as the Scientific Research Foundation of CUIT (No. KYTZ201211).

REFERENCES

1. Amin, Y., Q. Chen, H. Tenhunen, and L. R. Zheng, "Performance-optimized quadrate bowtie RFID antennas for cost-effective and eco-friendly industrial applications," *Progress In Electromagnetics Research*, Vol. 126, 49–64, 2012.
2. Li, X. and J. Liao, "Eye-shaped segmented reader antenna for near-field UHF RFID applications," *Progress In Electromagnetics Research*, Vol. 114, 481–493, 2011.
3. Tang, T. and G. H. Du, "A thin folded dipole UHF RFID tag antenna with shorting pins for metallic objects," *KSII Transactions on Internet and Information Systems*, Vol. 6, No. 9, Sep. 2012.
4. Cho, H. G., 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, 1232–1239, 2010.
5. Chen, S. L., S. K. Kuo, and C. T. Lin, "A metallic RFID tag design for steel-bar and wire-rod management application in the steel industry," *Progress In Electromagnetics Research*, Vol. 91, 195–212, 2009.
6. Tiang, J. J., M. T. Islam, N. Misran, and J. S. Mandeep, "Circular microstrip slot antenna for dual-frequency RFID application," *Progress In Electromagnetics Research*, Vol. 120, 499–512, 2011.
7. Cho, C., H. Choo, and I. Park, "Design of planar RFID tag antenna for metallic objects," *Electronics Letter*, Vol. 4, 175–177, Jan. 2008.
8. Sharma, A., A. Syed, and A. R. Harish, "Miniature slotted RFID tag antenna for metallic objects," *2011 International Conference on Communications and Signal Processing*, 353–357, Mar. 2011.
9. Mao, L., R. Song, Y. Li, and L. Chen, "UHF RFID tag antenna design and a novel antenna verification development platform," *4th International Conference on Wireless Communications, Networking and Mobile Computing*, 1–3, Oct. 2008.
10. Kuo, S.-K. and L.-G. Liao, "An analytic model for impedance calculation of an RFID metal tag," *IEEE Antennas Wireless Propag. Lett.*, Vol. 9, 603–607, 2010.
11. Bjorninen, T., A. A. Babar, A. Z. Elsherbeni, L. Ukkonen, L. Sydanheimo, and J. Kallioinen, "Compact metal mountable UHF RFID tag on a Barium Titanate based substrate," *Progress In Electromagnetics Research C*, Vol. 26, 43–57, 2012.
12. Yang, P. H., Y. Li, L. Jiang, W. C. Chew, and T. T. Ye, "Compact

metallic RFID tag antennas with a loop-fed method," *IEEE Trans. Antennas Propag.*, Vol. 59, No. 12, 4454–4462, Dec. 2011.

13. Chen, S. L., "A miniature RFID tag antenna design for metallic," *IEEE Antennas Wireless Propag. Lett.*, Vol. 8, No. 1, 1043–1045, Dec. 2009.
14. Koskinen, T. V., H. Rajagopalan, and Y. Rahmat-Samii, "A thin multi-slotted dual patch UHF-band metal-mountable RFID tag antenna," *Microwave and Optical Technology Letters*, Vol. 53, No. 1, Oct. 2011.
15. Koskinen, T. and Y. Rahmat-Samii, "Metal-mountable microstrip RFID tag antenna for high impedance microchip," *3rd European Conference on Antennas and Propagation*, 2791–2795, Mar. 2009.
16. Rajagopalan, H. and Y. Rahmat-Samii, "A novel conformal all-surface mount RFID tag antenna design," *2009 IEEE Antennas and Propagation Society International Symposium*, 1–4, Jun. 2009.
17. Sievenpiper, D., L. Zhang, R. F. J. Broas, N. G. Alexopolous, and E. Yablonovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band," *IEEE Trans. Microwave Theory and Technology*, Vol. 47, 2059–2074, Nov. 1999.
18. Reed, S., "Patch antenna size reduction by means of inductive slots," *Microwave and Optical Technology Letters*, Vol. 29, 79–81, Apr. 2001.
19. http://www.alientechnology.com/tags/index.php.
20. Harish, A. R., A. Gupta, H. Purohit, G. S. Lamba, and N. Grover, "Performance analysis of RFID tag antennas," *International Journal on Wireless and Optical Communications*, Vol. 5, No. I, 60–68, Sep. 2008.
21. http://www.voyantic.com/index.php?trg=browse&id=130.
22. Nikitin, P. V. and K. V. S. Rao, "Lab VIEW-based UHF RFID tag test and measurement system," *IEEE Trans. Ind. Electron.*, Vol. 56, No. 7, 2374–2381, 2009.

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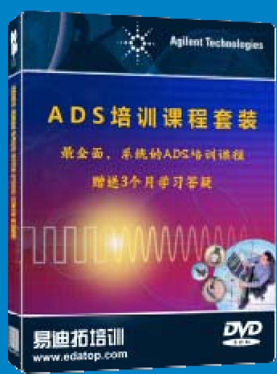

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※ 一直致力并专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求

※ 经验丰富的一线资深工程师讲授，结合实际工程案例，直观、实用、易学

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