A Compact Printed End-Fire Antenna for Radio Frequency Identification (RFID) Handheld Reader

Yuanhua Sun [1], **Guangjun Wen** [1], **Ping Wang** [1, 2], **Yongjun Huang** [1], **and Zhibo Du** [3]

[1] Centre for RFIC and System Technology, School of Communication and Information Engineering
University of Electronic Science and Technology of China, Chengdu, 611731, China
sunyuanhua17@gmail.com

[2] College of Electronic and Information Engineering
Chongqing Three Gorges University, Chongqing, 404000, China
wangpingcqz@163.com

[3] Chengdu University of Information Technology, Chengdu, 610225, China
du139123456789@163.com

Abstract **─** A new compact end-fire linear polarized printed antenna for a handheld radio frequency identification (RFID) reader is proposed for ultra high frequency (UHF) radio frequency identification (RFID) system in North America. The proposed planar end-fire antenna using two meandered dipole drivers, a folded reflector and a rectangular reflector are presented. The new antenna uses low-cost fabrication. The advantage of the end-fire antenna with meander dipole drivers compared to the conventional quasi-Yagi antenna is a reduction in the length of the driver, which allows closer space for RFID reader. the dimension of the antenna is 80×59 mm^2. The antenna has maximum gain of 3.6 dB and VSWR better than 2 around the US RFID bands (902-928MHz). We describe the antenna structure and present the comparison of simulation results with experimental data. The proposed antenna is fabricated, and measured reflection coefficient, radiation patterns and gain are presented.

Index Terms **─** RFID Reader, end-fire antenna, Radiation pattern, Gain.

I. INTRODUCTION

In recent years, radio frequency identification (RFID) technology has been rapidly developed and applied to many service industries, manufacturing companies, distribution logistics, goods flow systems and moving vehicle identification[1-3]. Many typical RFID tags have been studied[4-7]. For the applications involving item-level management[8][9], a RFID handheld reader plays an important role owing to its advantages of compactness, flexibility and maneuverability. By incorporating with a personal data assistant (PDA), a RFID handheld reader has the ability to provide a total solution for retail or library automation management. The growing demand for small compact wireless devices has increased the need for small antennas that can be integrated while providing acceptable overall performance[10][11]. Most of antennas do not have directional radiation. Some antennas have bidirectional radiation, but the its size is big for handheld reader [12]. In addition, usability of the reader unit in terms of reading directions and orientations of tags has to be taken into account. One of the features affecting the size, weight and ergonomist of handheld RFID reader is the reader antenna size and its positioning when affixed to the handheld reader unit. It is noted that, however, the antenna design in a RFID handheld reader should fulfill several unique requirements[13]. First of all, the reader antenna in a passive RFID system should demonstrate a somewhat lower reflection coefficient level than that in a usual communication system. It is because in such a

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system the backscattered signal from the tag is relatively weak, and prone to be interfered by the strong reflected signal from the reader antenna terminal. Second, in accordance with the emission regulation, the peak gain of a linear-polarized reader antenna must not exceed 6dBi in order to prevent the reader from violating the maximum allowed EIRP, i.e., 4W in North America. Moreover, regarding the public exposure to electromagnetic fields and the associated health issue, it would be beneficial if one could design a RFID handheld reader antenna with high front-to-back ratio so that the absorbed electromagnetic energy by the users can be substantially reduced. We proposed the antenna having good end-fire radiation pattern and can reduced the electromagnetic energy absorbed by users.

In this paper, we describe the design of compact end-fire antenna for the UHF band RFID handheld readers in North America. The antenna is composed of meandered printed dipoles, a folded reflector element and a rectangular reflector element. The proposed antenna has good directional radiation than others RFID antennas[11][12] and size of the proposed antenna is smaller than other handheld RFID antenna[10][12]. The antenna configuration and design methodology will be discussed in detail in Section II. The simulated and experimental results will be illustrated in Section III. This paper is concluded with a brief summary in Section IV.

II. ANTENNA CONFIGURATION

Similar to the quasi-Yagi antenna in[14]. Figure 1 shows the geometry of proposed antenna. The final antenna parameters are optimized using the commercial electromagnetic (EM) solver HFSS 13.0, and are given in the table I. The antenna is designed for UHF RFID applications in North America, i.e., in the frequency range of 902-928MHz. The length of the driven dipole and the reflector elements are optimized for simultaneously achieving excellent input impedance matching and the dipole arms are meandered to reduce the occupied dimension. Unlike a conventional quasi-Yagi antenna, here a reflector element is in close proximity to the driven element, and is also meandered in accordance with the outline of the dipole element. Accordingly, in addition to the surface wave excited in the substrate, in the proposed design the strong near-field coupling between the driven dipole and the reflector elements also helps improve the antenna impedance matching over a wide frequency range. Meander elements affects the resonant frequency of the antenna. The antenna elements are bent into meander shapes, suitable for fitting manufacturing form factors for a handheld RFID reader. The antenna has a high directional gain which results in the operating range around the US RFID bands (902-928MHz). Both top and bottom ground planes, which serve as reflectors in the design, keep the surface wave from propagating towards the backward direction. With such an arrangement, the backward-propagated surface wave can be substantially bounced back and further facilitates the end-fire radiation.

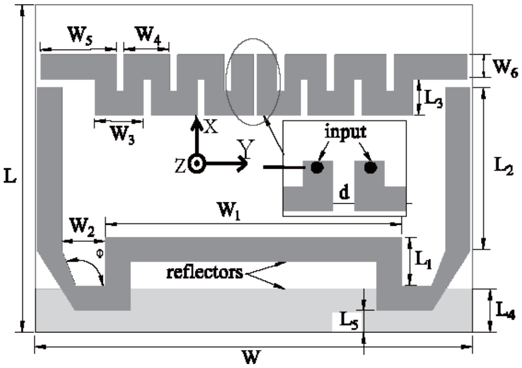


Fig. 1. The proposed antenna.

The finally chosen dimensions of the proposed antenna are illustrated in Table I.

Table I: The dimensions of the antenna (in mm)

L	W	W_1	W_2	W_3	W_4
51	80	54	8.1	9.3	9.3
W_5	L_1	L_2	L_3	L_4	φ
14.4	9	30.8	6.6	8	121°

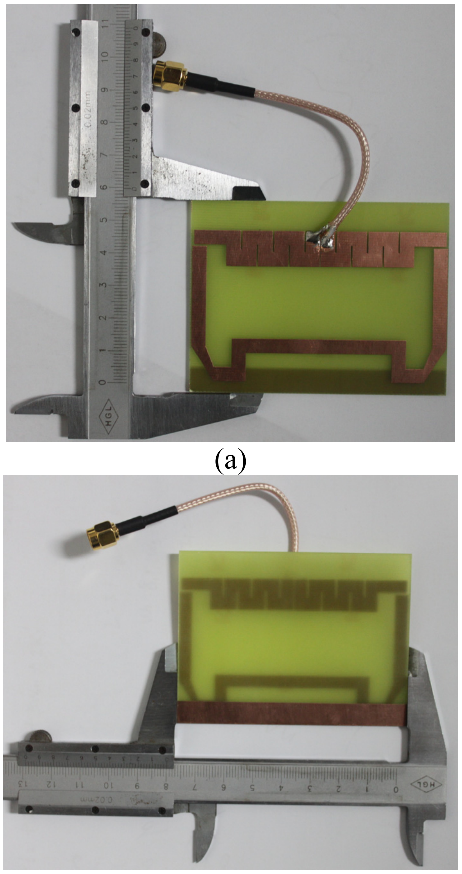
The proposed anenna is designed based on basic Yagi-Uda antenna principle, consists of two radiating elements (driver and reflector). Both elements were shaped to fit into the available dimension while maintaining their resonant frequencies in the desired band. Key parameters in the design are lengths and shapes of antenna elements and their mutual spacing. The antenna was tuned to achieve 50 ohm (RFID Reader) impedance without using any external matching circuit that will occupy additional space.

For demonstration purpose in the laboratory, the proposed antenna was designed on a 1.6 mm

FR4 substrate with a dielectric constant $\varepsilon = 4.4$ and loss tangent $\tan\delta = 0.02$. The overall dimension of the antenna is 80×59 mm, or equivalently roughly $0.24\lambda_g \times 0.18\lambda_g$.

III.SIMULATION AND MEASUREMENT

To verify the proposed antenna design, a prototype is fabricated as shown in Fig. 2, and the results are presented here. All the measured results are carried out in anechoic chamber using a vector network analyzer (VNA) and other microwave test instruments.



(a)

(b)

Fig. 2. Fabricated prototype of the proposed antenna. (a) top layer; (b) bottom layer.

All simulations were performed by Ansoft high-frequency structure simulation (HFSS) based on the finite-element method (FEM) [7][15]

The antenna simulated and measured magnitude of S_{11} are shown in Fig. 3. The simulation was performed by HFSS 13.0 and the measurement was taken by an Agilent performance network analyzer.

As shown in the Fig. 3, the agreement between the results in fairly good over the frequency band of interest. The simulated and measured center frequencies are given by 915 and 920 MHz, respectively. The slight frequency shift between the results can be mostly attributed to the fabrication tolerance. The measured XY-plane and XZ- plane radiation pattern and 3D radiation at 902, 915 and 928MHz are illustrated in Figs. 4, respectively. The radiation patterns are measured in a $7\times3\times3$ m^3 anechoic chamber and the measurement is performed by an Agilent network analyzer along with far-field measurement software. In the measurement the connecting cables along the Bakelite support ware carefully shielded by absorbers to reduce the multi-reflection interference. Meanwhile, the simulated -10 dB reflection coefficient bandwidths are from 890 to 940 MHz and the corresponding measurement data are given by 900-940MHz. and the current distribution at 915MHz are shown in Fig. 5. The experimental results demonstrate that the proposed design completely complies with the stringent requirement of impedance matching imposed on a handheld reader antenna, and the operating bandwidth with reflection coefficient better than -10dB covers the whole allocated spectrum for UHF RFID applications in North America.

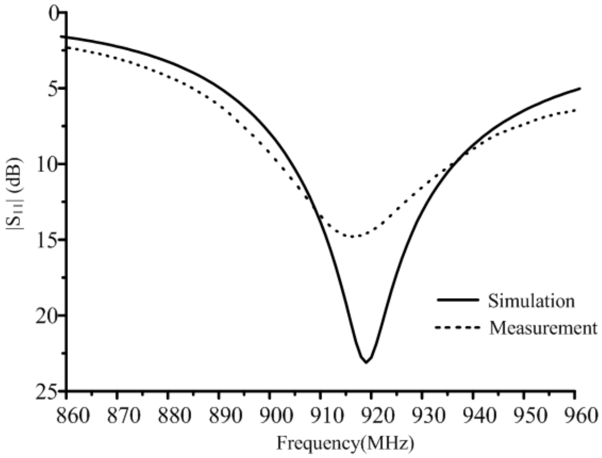
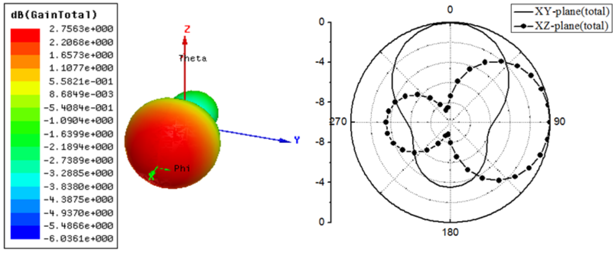


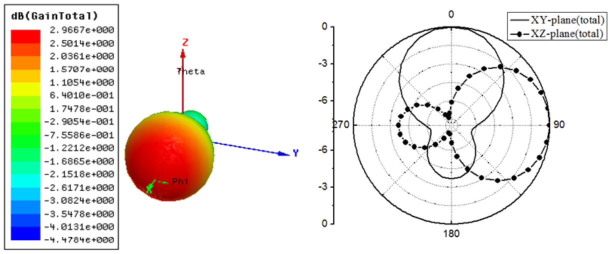
Fig. 3. Simulation and measured $|S_{11}|$.

For ease of practical applications, the studies of an important parameters of the driver meander dipoles and is also performed by simulations. One parameter is changed, while the other parameters are kept as in Table I. Figure 6 shows that the center frequency is increasing while the length of the meander dipoles varies in a range when is changed from 4.5 to 4.9mm.



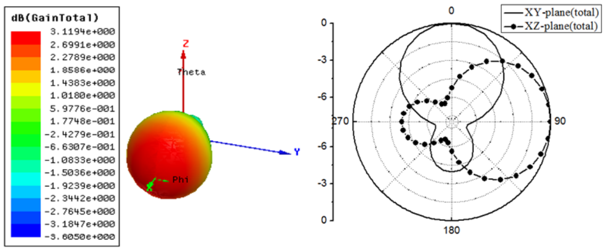
3D radiation Measured radiation

(a)



3D radiation Measured radiation

(b)



3D radiation Measured radiation

(c)

Fig. 4. 3D radiation and Measured radiation in the XY-plane and XZ-plane. (a) 902 MHz. (b) 915 MHz. (c) 928 MHz.

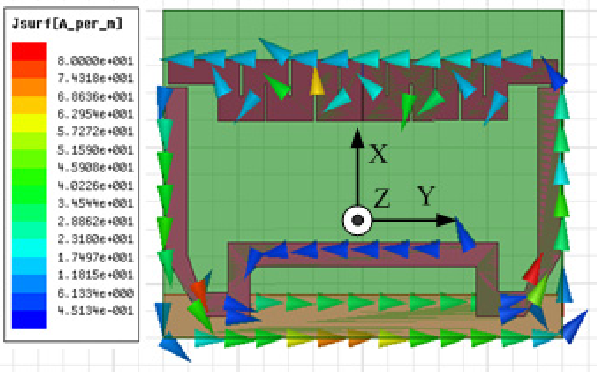


Fig. 5. The current distribution at 915MHz.

The Gain of the antenna was measured using the gain comparison method [16] , where the received power of the antenna under test is compared with known gain of a standard horn antenna. The simulated and measured gain and effectively are shown in Fig. 7, variation between the simulated and measured gain is within 0.5 dB , and this may be due to higher dielectric losses of the substrate, additional loss in the surface roughness of the microstrip patch.

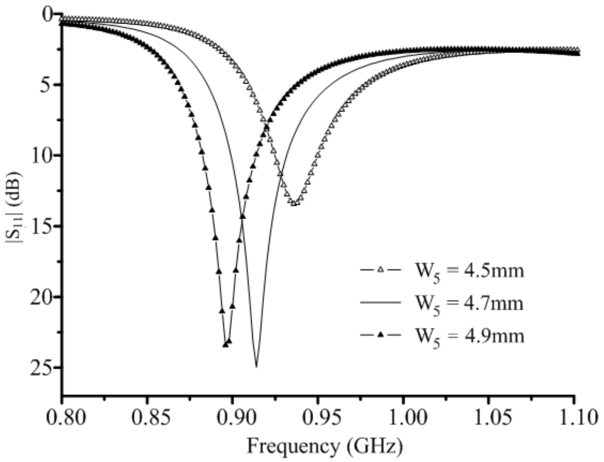


Fig. 6. Effects of varying driver mender length W_5.

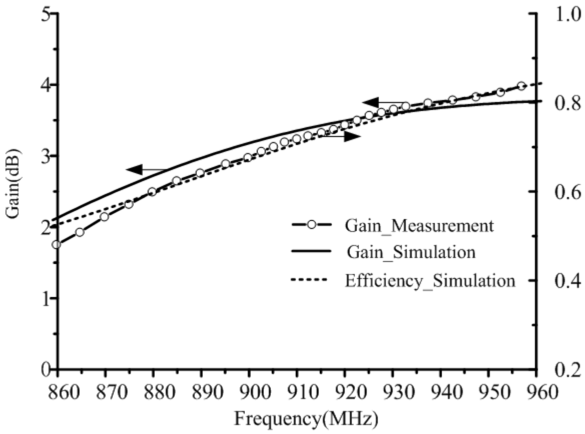


Fig. 7. Simulated gain and Measured gain in the +X direction, and Simulated efficiency of the antenna.

The Referring to the Fig. 3, measured results can be observed over the frequency band of interest. Clearly, Fig. 4 shows the radiation patterns similar to conventional Yagi radiation characteristics. The measured front-to-back ratio is at least 3 dB at 902 MHz and reaches 3.6 dB at

928MHz and remains better than 3 dB over the whole UHF RFID band from 902 to 928MHz. By adding directors elements can increase the front-to-back ratio, but these will increase the dimension of the antenna.

The measured bore sight gain is illustrated in Fig. 7. Referring to Fig. 7, the antenna gain rises steadily from 2.7dBi at 890MHz to 3.8dBi at 940MHz. The efficiency of the proposed antenna rises steadily from 62% to 80%.

IV. CONCLUSIONS

In this paper, we proposed a new printed end-fire antenna for UHF RFID handheld reader applications. The new end-fire antenna is suitable for fabrication on low-cost, low dielectric constant materials such as FR-4. The new antenna is based on the conventional printed quasi-Yagi antenna, where half-wavelength dipole driver element is replaced with two meander dipoles. The input impendence of the folded dipole quasi-Yagi antenna and its resonance frequency can be tuned by properly adjusting the parameters of the mender dipoles giving freedom for optimization. The advantages of the new antenna element are that it is more compact than the conventional design and is suitable for fabrication on low-cost, low dielectric constant materials. The antenna configuration, design, simulated and measured results have been well discussed. The experimental results reveal that the proposed antenna features a compact size of $0.24\lambda_g \times 0.18\lambda_g$, -10 dB reflection coefficient bandwidth of 50MHz and moderate gain around 2.7 to 3.8 dB. The antenna is well designed and may find applications in a variety of circumstances and the antenna is involved in item-level automation management with UHF RFID techniques.

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REFERENCES

[1] A. Toccafondi, C. D. Giovampaola, P. Braconi, A. Cucini, “UHF-HF RFID Integrated Transponder for Moving Vehicle Identification,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 6, pp. 543-551, Jun. 2010.

[2] W. W. Y. Ng, Y.-S. Qiao, L. Lin, H.-L. Ding, P. P. K. Chan, and D. S. Yeung, “Intelligent Book Positioning for Library Using RFID and Book Spine Matching,” in *Machine Learning and Cybernetics (ICMLC), International Conference on*, vol. 2, pp. 465-470, 2011.

[3] C. Feng, “Research for Application of RFID in Library,” in *Computer and Communication Technologies in Agriculture Engineering (CCTAE), 2010 International Conference On*, vol. 1, pp. 262 -264, 2010.

[4] D. D. Arumugam, D. W. Engels, M. H. Mickle, “The Effect of Curvature on the Performance and Readability of Passive UHF RFID Tags,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 3, pp. 206-217, Mar. 2010.

[5] H. Rajagopalan, Y. Rahmat-Samii, “Platform Tolerant and Conformal RFID Tag Antenna: Design, Construction and Measurements,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 6, pp. 406-497, Jun. 2010.

[6] B. D. Braaten, R. P. Scheeler, M. Reich, R. M. Nelson, C. Bauer-Reich, J. Glower, G. J. Owen, “Compact Metamaterial-Based UHF RFID Antennas: Deformed Omega and Split-Ring Resonator Structures,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 6, pp. 530-542, Jun. 2010.

[7] K. ElMahgoub, T. Elsherbeni, F. Yang, A. Z. Elsherbeni, L. Sydänheimo, L. Ukkonen, “Logo-Antenna Based RFID Tags for Advertising Application,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 3, pp. 174-181, Mar. 2010.

[8] C. Goebel and O. Gu&#x0308 andnther, “The Information Value of Item-Level RFID in Retail Supply Chain Operations,” in *System Sciences (HICSS), 2011 44th Hawaii International Conference on*, pp. 1-10, 2011.

[9] G. M. Gaukler, “Item-Level RFID in a Retail Supply Chain With Stock-Out-Based Substitution,” *Industrial Informatics, IEEE Transactions on*, vol. 7, no. 2, pp. 362-370, May 2011.

[10] A. A. Babar, L. Ukkonen, A. Z. Elsherbeni, L. Sydanheimo, “A Small Dual Purpose UHF RFID Antenna Design,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 12, pp. 1086-1096, Dec. 2010.

[11] A. Ferchichi, N. Sboui, A. Gharsallah, H. Baudrand, “New Antennas Based on Triangular Patch as a Solution for RFID Application,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 3, pp. 199-205, Mar. 2010.

[12] Y. Lin, Y. Kao, S. Pan, H. Chen, "Bidirectional Radiated Circularly Polarized Annular-Ring Slot Antenna for Portable RFID Reader," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 3, pp. 182-189, Mar. 2010.

[13] L. Ukkonen, L. Sydãnheimo, and M. Kivikoski, "Read Range Performance Comparison of Compact Reader Antennas for a Handheld UHF RFID Reader [Supplement, Applications Practice]," *Communications Magazine, IEEE*, vol. 45, no. 4, pp. 24-31, Apr. 2007.

[14] K. M. K. H. Leong, Y. Qian, and T. Itoh, "Surface Wave Enhanced Broadband Planar Antenna for Wireless Applications," *Microwave and Wireless Components Letters, IEEE*, vol. 11, no. 2, pp. 62-64, Feb. 2001.

[15] HFSS: High Frequency Structure Simulator Based on the Finite Element Method. Ansoft.

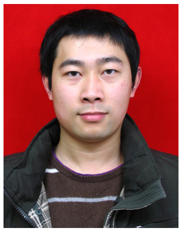
[16] BALANIS C.A, *Antenna theory: analysis and design*. John Wiley & Sons, Inc., New York, 2nd ed., 1997.

Yuanhua Sun received the B.S. degree in communication engineering from the Liaocheng University in 2007, and M.S. degree in signal and information processing from Chengdu University of Information Technology in 2010. He is working toward the Ph.D degree in UESTC. His research interests include analytical and numerical modeling of metamaterials and antenna theory and design and signal processing.

Guangjun Wen was born in Sichuan, China, in 1964. He received his M. S. and Ph. D. degrees in Chongqing University of China in 1995 and UESTC in 1998, respectively. He is currently a professor and doctor supervisor in UESTC.

His research and industrial experience covers a broad spectrum of electromagnetics, including RF, Microwave, Millimeter wave Integrated Circuits and Systems design for Wireless Communication, Navigation, Identification, Mobile TV applications, RFIC/MMIC/MMMIC device modeling, System on Chip (SoC) and System in Package (SiC) Design, RF/Microwave/Millimeter wave Power source Design, "The Internet of things" devices and system, RFID system and networks, antennas, as well as model of electromagnetic metamaterial and its application in microwave engineering area.

Ping Wang received the B.S. degree in Physics from Western Chongqing University of China in 2005 and the M.S degree in Theoretical Physics from Chongqing University, Chongqing, in 2008. Currently, he is working toward the Ph.D. degree in UESTC. His current research interests include patch antennas, wideband antennas, and arrays.



Yongjun Huang received the B.S. degree in Mathematics from Neijiang Normal University of China in 2007, M. S. degree in Communication Engineering from University of Electronic Science and Technology of China (UESTC) in 2010, and is currently working toward a Ph.D. degree in UESTC. His research activities are electromagnetic metamaterial and its application in microwave engineering area, FDTD and CAD analysis for the metamaterial model and characteristics.

Zhibo Du received the B.S. degree in computer science and technology from the Hebei University of Science and Technology in 2007, and M.S. degree in computer application from Chengdu University of Information Technology in 2010. He is working as assistant in Chengdu University of Information Technology. His research interests include application of antenna, and side channel attack on the security chip, for example electromagnetic attack, power attack and so on.