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A Compact Antenna Design for UHF RFID Applications

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Abstract—This paper presents a new compact end-fire antenna for ultra-high frequency (UHF) radio frequency identification (RFID) applications. The antenna has two meandered dipole drivers. A folded reflector and a rectangular reflector are demonstrated. 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 end-fire antenna is fabricated on a FR4 printed circuit board (PCB), the dimension of the antenna is $81 \times 58\,\text{mm}^2$. The measured bandwidth is around 25 MHz (905–930 MHz) under the condition of VSWR less than 2. The maximum gain of the end-fire antenna is 3.5 dBi, it is suitable for fabrication on low-cost, low dielectric constant materials. The antenna configuration, design, simulated and measured results have been well discussed. A good agreement is obtained between the simulated and experimental results. This new compact end-fire antenna is desirable for RFID reader applications.

1. INTRODUCTION

Radio frequency identification (RFID) is an automatic identification technology that uses radio wave to transfer data between a reader and tag attached to an object for objective of identification and tracking [1–3]. Currently, radio frequency identification has become a widespread technology in our daily life. RFID system in ultra-high-frequency (UHF) band has received considerable attention for various commercial applications, such as automatic retail item management, warehouse management, access control system, electronic toll collection, etc. This is because the UHF band can provide high data transfer rate and broad readable range [4–7]. An RFID system generally consists of a reader, a tag, and a data processing system. The RFID reader antenna is one of the important components in RFID system and its capability will determine the performance of whole RFID system [8, 9].

The explosive growth of the wireless communication industry has led to an increasing demand for low cost, low profile antenna that can be printed on a substrate. Printed antenna enjoys many advantages over standard antenna, such as low manufacturing cost, low profile, ease of integration with monolithic microwave integrated circuits (MMICs) and integrated passives, the ability to be mounted on planar, non-planar, and rigid exteriors [10–12]. For the applications involving item-level management, a RFID handheld reader plays an important role owing to its advantages of compactness, flexibility, and maneuverability. The growing demand for small compact wireless device has increased the need for small antenna that can be integrated while providing acceptable overall performance [13–15]. Most of antennas do not have directional radiation. Some antennas have bidirectional radiation, but its size is big for handheld reader. In addition, usability of the reader unit in terms of reading direction and orientation of tags have to be taken into account [16–19]. One of the feature 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 [20–22]. It is noted that, however, the antenna design in a RFID handheld reader should

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fulfill several unique requirements. 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 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 6 dBi in order to prevent the reader from violating the maximum allowed EIRP, i.e., moreover, regarding the public exposure to electromagnetic field and the associated health issue, it would be beneficial if one could design a RFID handheld reader antenna with high front-to-back ratio, that will reduce the electromagnetic energy absorbed by the users [23–26].

The end-fire antenna owns many excellent characteristics compared to the traditional antenna [27], such as good directional radiation simple structure, easy to fabricate, low cost, and low aerodynamic profile [28, 29]. This article presents a compact end-fire antenna for the UHF band radio frequency identification reader, it has good end-fire radiation pattern and can reduced the electromagnetic energy absorbed by users. The end-fire antenna is composed of meandered printed dipoles, a folded reflector element, and a rectangular reflector element. The proposed antenna has good directional radiation. The RFID handheld reader owned this antenna can work in a specific direction. The organization of the paper is as follows: the antenna structure and design methodology are discussed in Section 2. Section 3 shows the simulated and experimental results. The conclusion is given in Section 4.

2. ANTENNA STRUCTURE AND DESIGN

The configuration of the proposed antenna is shown in Figure 1. The final antenna parameters are optimized using the commercial three-dimensional electromagnetic simulator HFSS v12 [30]. The length of the antenna is 81 millimeter and the other parameters are given in the Table 1. The antenna is designed for UHF RFID applications in the frequency range of 905–930 MHz. The length of the driven dipole and the reflector elements are optimized for simultaneously achieving excellent input impedance matching, 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 improve the antenna impedance matching over a wide frequency range. Meander elements affect the resonant frequency of the antenna. The antenna elements are bent into meander shape, 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 band. Both top and bottom 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.

The proposed antenna is designed based on basic Yagi-Uda antenna principle, consists of two radiating elements (driver and reflector). Both elements are shaped to fit into the available dimension while maintaining their resonant frequencies in the desired band. Key parameters in the design are

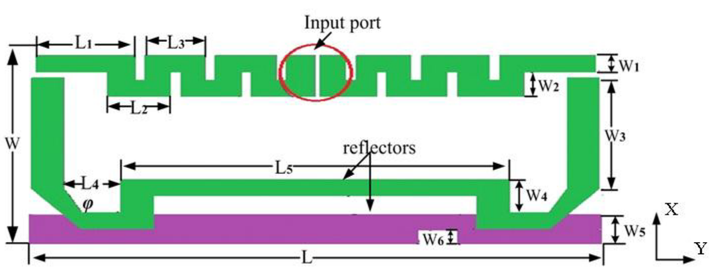

Figure 1. Configuration of the proposed antenna.

L_1	L_2	L_3	L_4	L_5
14.7	9.2	9.2	8	54
L	φ	W_1	W_2	W_3
81	120	4	6.6	30.6
W_4	W_5	W_6	W	
9	8	4	58	

Table 1. The parameters of the antenna (unit: mm).

length, shape 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. The proposed antenna was designed on a 1.6 mm FR4 substrate, the dielectric constant is 4.4 and the loss tangent is 0.02. The size of the antenna is $81 \times 58\,\text{mm}^2$.

3. SIMULATED AND MEASURED RESULTS

To verify the analysis that has been presented for this antenna structure, the antenna was simulated. This antenna was fabricated and measured in an anechoic chamber using microwave test instruments. A photograph of the fabricated antenna is shown in Figure 2. An Agilent N5230A series vector network analyzer was used to take the reflection coefficient. All simulations were performed by high-frequency structure simulation (HFSS v12) based on the finite-element method (FEM).

The simulated and measured return loss versus frequency is presented in Figure 3, which shows the comparatively good agreement. It is observed from Figure 3 that the measured reflection coefficient is less than −12 dB over the frequency range of 905–930 MHz, the agreement between the results is fairly good over the frequency band of interest. The simulated and measured center frequencies are given by 918 MHz and 916 MHz, respectively. The slight frequency shift between the results can be mostly attributed to the fabrication tolerance. The measured XY-plane and XZ-plane normalized radiation patterns and 3D radiation at 905 MHz, 915 MHz, and 930 MHz are illustrated in Figure 4, respectively. The normalized radiation patterns are measured in 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. It is observed from Figure 3 that the simulated and measured reflection coefficient is less than −12 dB over the frequency range of 905–930 MHz. 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 −12 dB covers the allocated spectrum for UHF RFID applications.

For ease of practical applications, the studies of important parameters of the driver meander dipoles are also performed by simulation. One parameter is changed, while the other parameters are kept as in Table 1. Figure 5 shows that the center frequency is increasing while the length of L_1 varies in a range when is changed from 14.6 mm to 15 mm.

The Gain of the antenna was measured using the gain comparison method [31], where the received power of the antenna under test is compared with known gain of a standard antenna. The simulated and measured gain are shown in Figure 6, variation between the simulated and measured gain is within 0.5 dB, and this may be due to higher dielectric losses of the substrate, or additional loss in the surface roughness of the microstrip patch.

Referring to the Figure 3, measured results can be observed over the frequency band of interest.

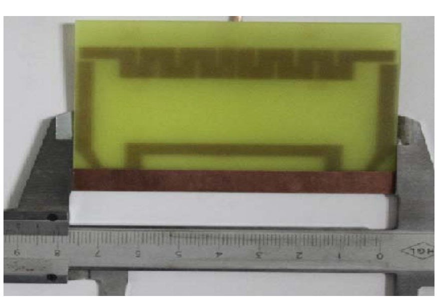

Figure 2. Photograph of the antenna.

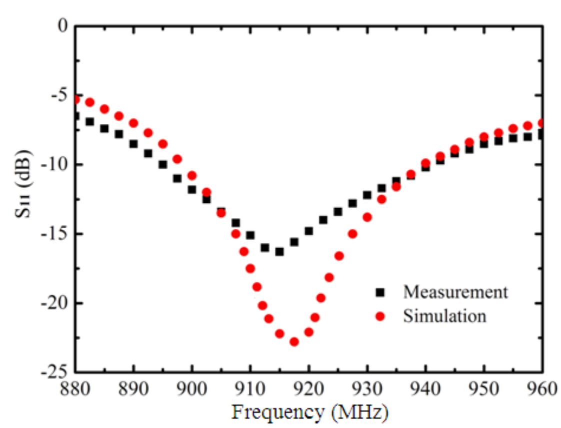

Figure 3. Simulation and measured S_{11}.

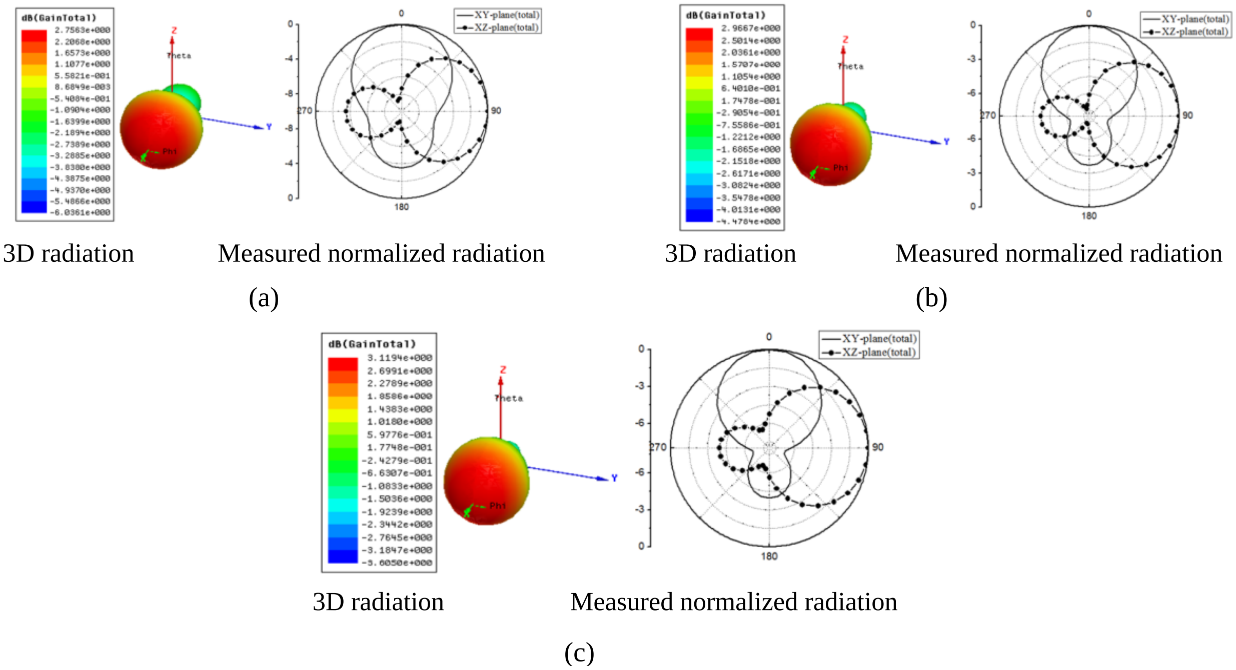

Figure 4. 3D radiation and Measured normalized radiation. (a) 905 MHz. (b) 915 MHz. (c) 930 MHz.

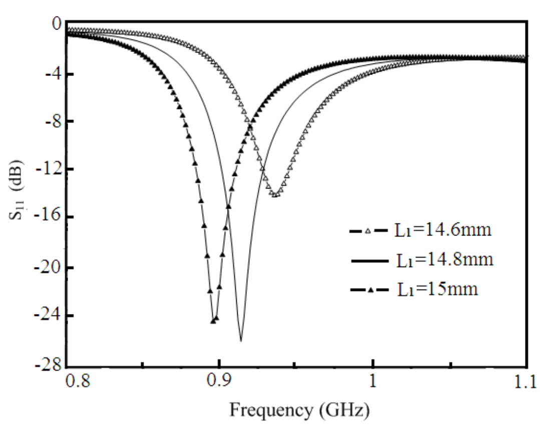

Figure 5. Simulated S_{11} with different values of L_1.

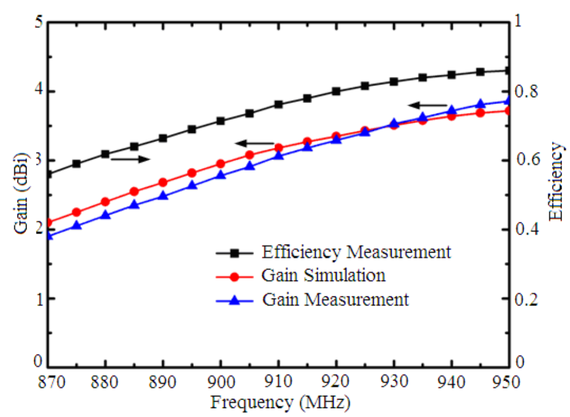

Figure 6. Simulated gain, measured gain, and measured efficiency of the antenna.

Clearly, Figure 4 shows the radiation patterns similar to conventional Yagi radiation characteristics. By adding director elements can increase the front-to-back ratio, but these will increase the dimension of the antenna. Radiated efficiency is a measure of the power radiated through the antenna as an electromagnetic wave to the power fed to the antenna terminals. If an antenna could be made to be a totally ideal electrical component, it would transform all the power fed to its terminals to a radiating electromagnetic energy that propagates into the surrounding space. This is possible only in theory, and thus in real life some of the power fed to the antenna terminals is always lost. The measured radiated efficiency of antenna is illustrated in Figure 6. We test the efficiency of the proposed antenna in the anechoic chamber by feeding some power to the antenna feed pads and measuring the strength of the radiated electromagnetic field in the surrounding space. Referring to Figure 6, the antenna radiated efficiency rises steadily from 66% at 890 MHz to 83% at 940 MHz.

4. CONCLUSIONS

A design of a new compact antenna for UHF RFID handheld reader has been described. The new antenna is based on the conventional printed quasi-Yagi antenna, where a half-wavelength dipole driver element is replaced with two meander dipoles of different lengths. The new end-fire antenna is suitable for fabrication on low-cost, low dielectric constant materials such as FR-4. 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 antenna configuration, design, simulated and measured results have been well discussed. The proposed antenna can be a good candidate for UHF RFID applications.

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REFERENCES

1. Nititin, P. V. and K. V. S. Rao, "Theory and measurement of backscattering from RFID tags," *IEEE Antennas and Propagation Magazine*, Vol. 48, No. 6, 212–218, Dec. 2006.
2. Kim, D.-Y., J.-G. Yook, H.-G Yoon, and B.-J. Jang, "Interference analysis of UHF RFID systems," *Progress In Electromagnetics Research B*, Vol. 4, 115–126, 2008.
3. Fan, Z., S. Qiao, J. T. Huang-Fu, and L.-X. Ran, "Signal descriptions and formulations for long range UHF RFID readers," *Progress In Electromagnetics Research*, Vol. 71, 109–127, 2007.
4. Zhang, M., Y. Chen, Y. Jiao, and F. Zhang, "Dual circularly polarized antenna of compact structure for RFID application," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 14, 1895–1902, 2006.
5. Xu, Z. and X. Li, "Aperture coupling two-layered dual-band RFID reader antenna design," *IEEE International Conference on Microwave and Millimeter Wave Technology*, Apr. 2008.
6. Zhang, L. and Z. Wang, "Integration of RFID into wireless sensor networks: Architectures, opportunities and challenging problems," *IEEE Proceeding of the Fifth International Conference on Grid and Cooperative Computing Workshops (GCCW)*, 463–469, 2006.
7. Chen, Z. N., X. Qing, and H. L. Chung, "A universal UHF RFID reader antenna," *IEEE Trans. Microw. Theory Tech.*, Vol. 57, No. 5, 1275–1282, May 2009.
8. Nasimuddin, Z. N. Chen, and X. Qing, "Asymmetric-circular shaped slotted microstrip antennas for circular polarization and RFID applications," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 12, 3821–3828, Dec. 2010.
9. Huang, J. and M. Bialkowski, "Investigations of an aperture coupled microstrip Yagi antenna using PBG structure," *IEEE Transactions on Antennas and Propagation*, Vol. 39, No. 7, 1024–1030, Jul. 1991.
10. Gray, D., J. Lu, and D. Thiel, "Electronically steerable Yagi-Uda microstrip antenna array," *IEEE Transactions on Antennas and Propagation*, Vol. 46, No. 5, 605–608, May 1998.
11. Chen, X., G. Fu, S.-X. Gong, J. Chen, and X. Li, "A novel double-layer microstrip antenna array for UHF and RFID," *Journal of Electromagnetic Waves and Applications*, Vol. 23, Nos. 11–12, 1479–1487, 2009.
12. Kwa, H. W., X. Qing, and Z. N. Chen, "Broadband single-fed single-patch circularly polarized antenna for UHF RFID applications," *Proc. IEEE AP-S Int. Symp.*, 1–4, San Diego, CA, 2008.
13. Ng, W. W. Y., 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," *Machine Learning and Cybernetics (ICMLC)*, Vol. 2, 465–470, 2011.

14. Leong, K. M. K. H., Y. Qian, and T. Itoh, "Surface wave enhanced broadband planar antenna for wireless applications," *IEEE Microwave and Wireless Components Letters*, Vol. 11, No. 2, 62–64, Feb. 2001.
15. Nikitin, P. V., K. V. S. Rao, S. F. Lam, V. Pillai, R. Martinez, and H. Heinrich, "Power reflection coefficient analysis for complex impedances in RFID tag design," *IEEE Trans. Microw. Theory Tech.*, Vol. 53, No. 9, 2721–2725, Sep. 2005.
16. Occhiuzzi, C., S. Cippitelli, and G. Marrocco, "Modeling, design and experimentation of wearable RFID sensor tag," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 8, 2490–2498, Aug. 2010.
17. 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.
18. Wang, Z., S. Fang, S. Fu, and S. Jia, "Single-fed broadband circulary polarized stacked patch antenna with horizontally meandered strip for universal UHF RFID applications," *IEEE Trans. Microw. Theory Tech.*, Vol. 59, No. 4, 1066–1073, May 2011.
19. Panda, J. R. and R. S. Kshetrimayum, "A printed 2.4 GHz/5.8 GHz dual-band monopole antenna with a protruding stub in the ground plane for WLAN and RFID applications," *Progress In Electromagnetics Research*, Vol. 117, 425–434, 2011.
20. Zhao, X., L. Zhao, and K. Huang, "A circularly polarized array composed of linear polarized microstrip patches fed by metamaterial transmission line," *Journal of Electromagnetic Waves and Applications*, Vol. 25, Nos. 11–12, 1545–1553, 2011.
21. Evizal, A. K., T. A. Rahman, S. K. B. A. Rahim, and M. F. B. Jamlos, "A multi band mini printed omni directional antenna with V-shaped for RFID applications," *Progress In Electromagnetics Research B*, Vol. 27, 385–399, 2011.
22. Chung, K. L. and A. S. Mohan, "A systematic design method to obtain broadband characteristics for singly-fed electromagnetically coupled patch antennas for circular polarization," *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 12, 3239–3248, Dec. 2003.
23. Tiang, J.-J., M. T. Islam, N. Misram, and J. S. Mandeep, "Circular microstrip slot antenna for dual-frequency RFID application," *Progress In Electromagnetics Research*, Vol. 120, 499–512, 2011.
24. Grajek, P. R., B. Schoenlinner, and G. M. Rebeiz, "A 24-GHz high-gain Yagi-Uda antenna array," *IEEE Transactions on Antennas and Propagation*, Vol. 52, No. 5, 1257–1261, May 2004.
25. Dejean, G. R. and M. M. Tentzeris, "A new high-gain microstrip Yagi array antenna with a high front-to-back (F/B) ratio for WLAN and millimeter-wave applications," *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 2, 298–304, Feb. 2007.
26. Lin, M. H. and C. W. Chiu, "Human-body effects on the design of card-type UHF RFID tag antennas," *Proc. IEEE Symposium on Antennas and Propagation*, 521–524, 2011.
27. Bashri, M. S. R., M. I. Ibrahimy, and S. M. A. Motakabber, "Design and development of a compact wideband C-shaped patch antenna for UHF RFID tag," *Research Journal of Applied Sciences, Engineering and Technology*, Vol. 12, No. 6, 2118–2126, Jul. 2013.
28. Zhang, J. and K. Huang, "A novel tree-shaped antenna with wideband and end-fire properties designed by competitive algorithm of simulating natural tree growth," *International Journal of RF and Microwave Computer-Aided Engineering*, Vol. 20, No. 3, 342–346, May 2010.
29. Yao, G., Z. Xue, W. Li, et al., "The research of plate end-fire antenna," *Chinese Journal of Radio Science*, Vol. 24, No. 2, 323–326, 2009 (in Chinese).
30. HFSS, ANSYS, "3-D electromagnetic simulation software," ANSYS Corp., Pittsburgh, PA.
31. Balanis, C. A., *Antenna Theory: Analysis and Design,* 2nd Edition, John Wiley & Sons, Inc., New York, 1997.