Compact Quasi-Yagi Antenna for Handheld UHF RFID Reader

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Abstract **─** This paper describes a compact printed Quasi-Yagi antenna for ultra high frequency (UHF) radio frequency identification (RFID) reader that can be used in both Europe and US regions. The proposed antenna is a Yagi type structure with a microstrip-to-coplanar stripline transition, a meander dipole, a folded finite-size ground plane and a rectangle ground plane. The proposed antenna has compact size (0.18λ×0.24λ). The proposed antenna has an endfire radiation pattern within operation bandwidth, with peak gain values of more than 3 dBi and return loss is less than -10 dB in approximately 100 MHz band that can cover European and US RFID bands (860 MHz - 960 MHz). We described the antenna structure and presented the comparison of simulation results with experimental data. Good return loss and radiation pattern characteristic are obtained, measured results are presented to validate the usefulness of the proposed antenna structure for RFID reader.

Index Terms **─** Endfire radiation pattern, gain, Quasi-Yagi antenna, RFID reader.

I. INTRODUCTION

In recent years, radio frequency identification (RFID) in the UHF band (860-960 MHz) has become popular in many applications. These applications include supply chain management, automatic retail item management, warehouse management, access control system, electronic toll collection and etc. [1]. Many typical RFID tags have been studied [2-4]. For applications, the RFID handheld reader plays an important role owing to its advantages of compactness, flexibility and maneuverability. The antenna design in a RFID handheld reader should fulfil several unique requirements [5]. One of the important considerations is the size, weight and shape. The broadband antenna designs to cover total frequency span of the UHF band for RFID applications. Several RFID antennas have been reported [6,7]. The size of the broadband antennas are bulky and not suitable for handheld or portable reader applications. Antenna development for RFID applications has focused on the size reduction and wideband performance to cover multiple service at the same time [8]. Also, wideband antennas for RFID system has been reported [9,10]. But these antennas are too large and not suitable for the RFID handheld antenna. The majority of devices have become small and compact. Therefore, the compact antenna is more important and practical. The antenna [11] has endfire pattern and compact dimension for RFID handheld reader, but the antenna can only cover narrow bandwidth.

In this paper, the proposed antenna is compact and still efficient to provide desired performance. The antenna consists of a meander dipole, a microstrip-to-coplanar stripline transition and a folded finite-size ground plane which is optimized for the operation of 860 MHz - 960 MHz. The proposed antenna is compact and can be easily fabricated. The performance of the designed antenna is simulated using the simulation tool HFSS v13. According to the measured results of the proposed antenna, the antenna has well-defined endfire radiation patterns and the gain of the presented antenna is more than 3 dBi around Europe and US RFID bands (860 MHz - 960 MHz).

II. ANTENNA CONFIGURATION AND DESIGN

The configuration of the proposed Quasi-Yagi antenna is shown in Fig. 1. The final antenna parameters are optimized using the commercial electromagnetic (EM) solver HFSS 13.0, and are given in the Table 1. The proposed antenna is designed for UHF RFID applications in North America and Europe. Simple microstrip patch antenna is considered in proposed design due to their numerous advantages such as low profile, low cost easy to manufacture and easy to integrate with other electronics. The length of the driven dipole and reflector elements are optimized for

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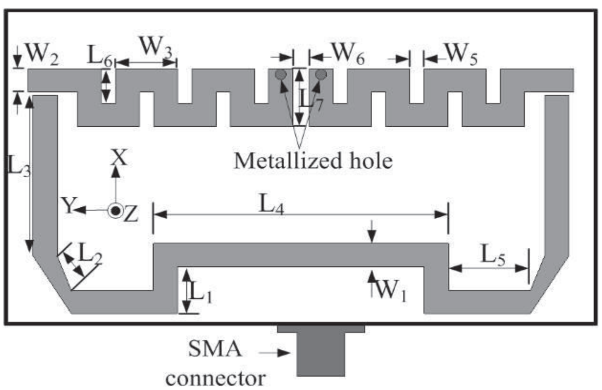
simultaneously achieving excellent input impedance matching, and dipole arms are meandered to reduce the occupied dimension. Unlike conventional Quasi-Yagi antennas, here a reflector element is in close proximity to the driven element, and is also meandered in accordance with the outline of the dipole 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 affect the resonant frequency of the antenna. The antenna elements are bent into meander shape, suitable for the handheld RFID reader. The antenna has a high directional gain which results in the operating range around the RFID bands (860 MHz - 960 MHz). 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 endfire radiation.



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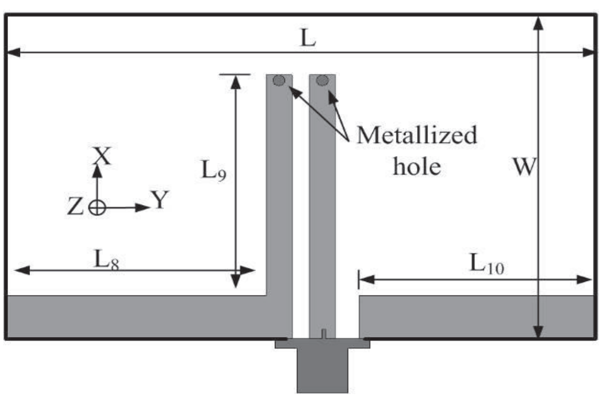


(b)

Fig. 1. The construction of the proposed antenna: (a) the top layer, and (b) the bottom layer.

Table 1: The dimensions of the antenna (in mm)

L	L_1	L_2	L_3	L_4
100	9	7.09	30.8	54
L_5	L_6	L_7	L_8	L_9
7	6.6	11	44.1	40.7
L_{10}	W	W_1	W_2	W_3
40	50	4.4	4.4	10.4
W_4	W_5	W_6	W_7	W_8
10.4	1.6	3	8	4.4
W_9	W_{10}	W_{11}	-	-
3	8	4.4	-	-

All these elements are shaped to fit into the available footprint while maintaining their resonant frequencies in the desired band. The lengths and shapes of antenna elements and their mutual spacing are key parameters in the design. The length of every meander part of antenna is less than the wavelength of the central frequency. So the transmission module of antenna is equal to the dipole antenna with inductance. The meander part of the proposed antenna balance the negative imaginary part of the dipole antenna, and the current distribution changed.

According to the transmission theory [14], the input resistance of every meander part is:

$$Z_{in} = jZ_0 \tan\left(KL_m\right), \tag{1}$$

$K = K_O\sqrt{\varepsilon_{re}}$, K_O is the wave numbers in free space. ε_{re} is effective dielectric constant. L_m is the length of the meander part.

The characteristic impedance of the meander part is:

$$Z_O = \frac{\eta}{\pi} \cosh^{-1}\left(\frac{\alpha}{\beta}\right), \tag{2}$$

α is the distance among the every meander part. β is the width of the meander part. $\eta = \sqrt{\mu\varepsilon}$ is the characteristic impedance. According to above equations, the distance among meander lines, width of lines, length of the meander lines can change the impedance of antenna. So we can change these parameters to design the proposed antenna. Antenna design is tuned to achieve 50 ohm (RFID reader) impedance without using any external matching circuit that will occupy additional footprint.

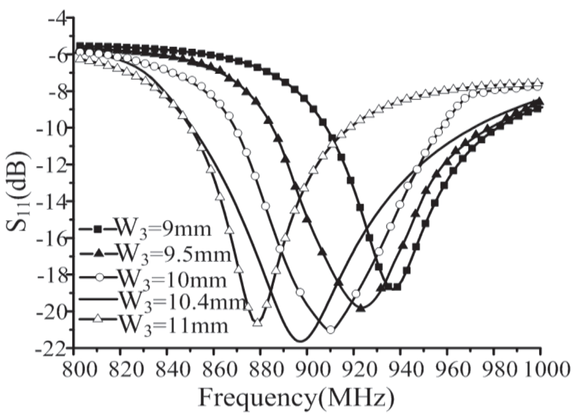
For demonstration purpose in the laboratory, the proposed antenna is designed on a 1.6 mm FR4 substrate with a dielectric constant ε=4.4 and loss tangent tanδ=0.02. The overall dimension of the antenna is 50 mm × 100 mm, or equivalently roughly 0.18λ×0.24λ. The finally chosen dimensions of the proposed antenna are in Table 1.

III. SIMULATION AND MEASUREMENT

For ease of practical applications, important parameters of the proposed antenna are studied.

One parameter is changed, while the other parameters are kept as in Table 1. Figure 2 (a) shows that the center frequency is decreasing while the length of the meander dipoles, W_3, varies in a range when it is changed from 9 mm to11 mm. Figure 2 (b) shows that the center frequency is increasing while the width of the meander dipoles, L_6, varies in a range when it is changed from 6 mm to 8 mm.

A prototype is fabricated to verify the proposed antenna design as shown in Fig. 3. All the measured results are carried out in anechoic chamber using the NSI300V-30X30 far-field measurement system and Agilent N5230A series vector network analyzer. All simulated results are obtained using HFSS (High Frequency Structure Simulator) based on the finite-element method (FEM) [12,13]. The antenna simulated and measured S11 are shown in Fig. 4. The measurement is taken by an Agilent network analyzer. As shown in Fig. 4, the agreement between the results is fairly good over the frequency band from 860 MHz to 960 MHz.



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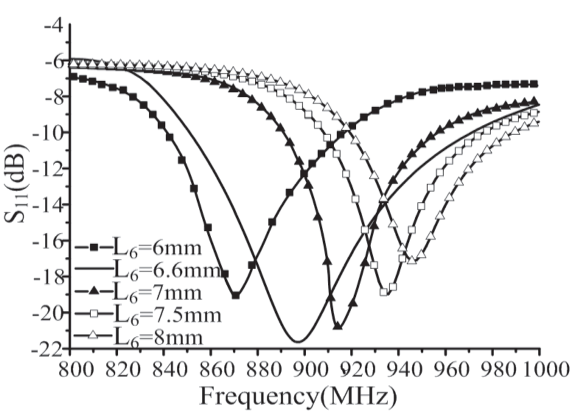

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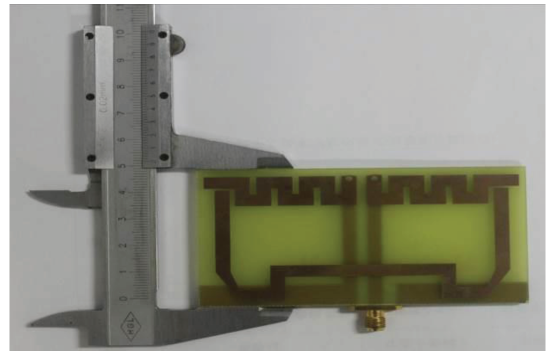
Fig. 2. Effects of varying driver mender dipoles, W_3, L_6.



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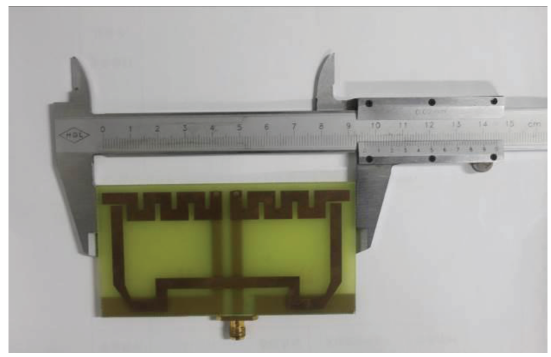

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Fig. 3. Fabricated prototype of the proposed antenna: (a) top layer, and (b) bottom layer.

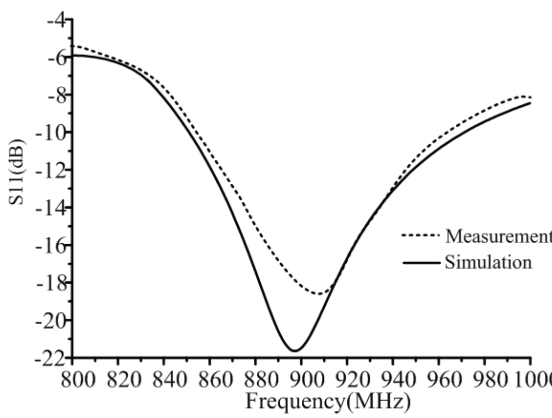
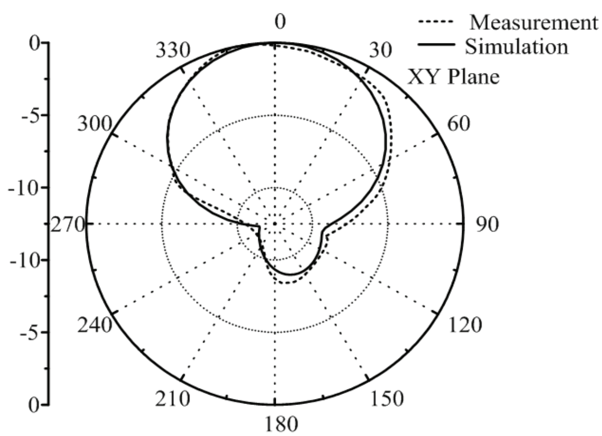


Fig. 4. Simulation and measurement S_{11}.

The simulated and measured center frequencies are given by 896 and 909 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 at 860, 915 MHz are illustrated in Fig. 5, respectively. The radiation patterns are measured in a 7×3×3 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 850 MHz to 970 MHz and the corresponding measurement data are given by 855 MHz - 963 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 -10 dB covers the whole allocated spectrum for UHF RFID applications in North America and Europe.

Figure 5 shows the comparison between the simulated and measured radiation pattern at 860 MHz and 915 MHz in the XY-plane and XZ-plane, respectively, which shows good agreement. It is seen that the proposed antenna has endfire radiation pattern and a symmetrical radiation pattern across the operating bandwidth and its maximum beam is always directed to the +X-axial direction, which have great advantages in practical applications. Radiation pattern can be controlled by placement of radiation elements (director and reflectors).



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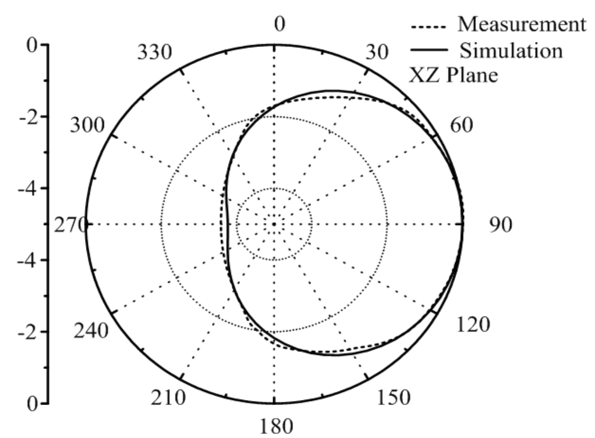

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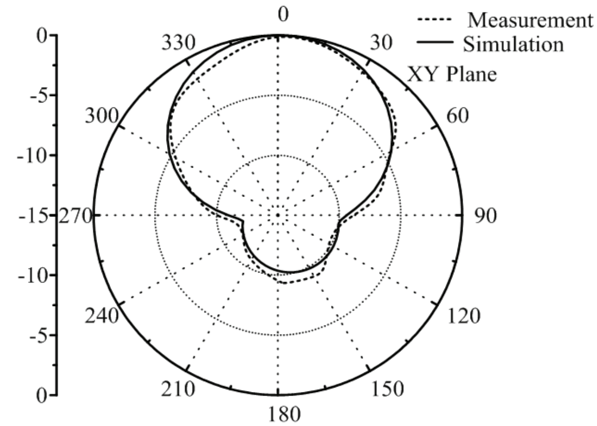

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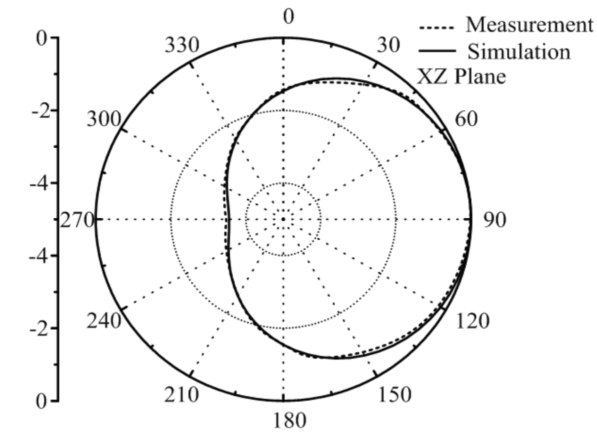

(d)

Fig. 5. Simulated and measured radiation patters of the proposed antenna: (a) XY-plane (860 MHz), (b) XZ-plane (860 MHz), (c) XY-plane (915 MHz), and (d) XZ-plane (915 MHz).

Referring to the Fig. 4, measured result can cover the required frequency band. Figure 5 shows the radiation patterns similar to conventional Yagi radiation characteristics. The gain of proposed endfire antenna reaches 3.6 dBi at 915 MHz and remains better than 3 dBi over the whole UHF RFID band from 860 to 960 MHz. By adding director elements can increase the front-to-back ratio, but these will increase the dimension of the antenna. The gain of the antenna was measured using the gain comparison method [14], 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 efficiency are shown in Fig. 6, variation between the simulated and measured gain is within 0.2 dBi, and this may be due to higher dielectric losses of the substrate, additional loss in the surface roughness of the microstrip patch.

The measured bore sight gain is illustrated in Fig. 6. Referring to Fig. 6, the antenna gain rises steadily from

3 dB at 860 MHz to 3.45 dBi at 960 MHz. The efficiency of the proposed antenna rises steadily from 92% to 94%.

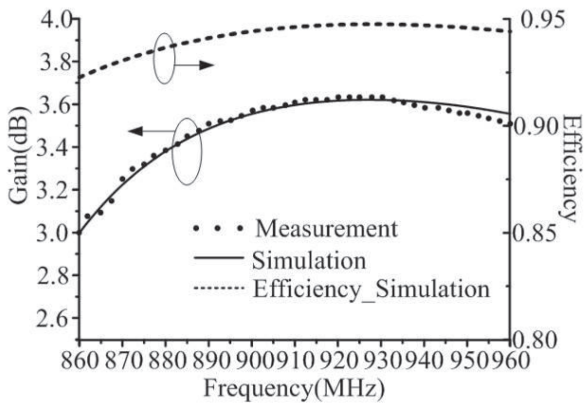

Fig. 6. Simulated and measured gain in the +X direction and efficiency.

IV. CONCLUSION

The compact printed Quasi-Yagi antenna for UHF RFID reader has been presented, constructed and tested. The proposed 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 proposed antenna is suitable for fabrication on low-cost, low dielectric constant materials such as FR4. The size of the antenna is 0.18λ×0.24λ and suitable for UHF RFID handheld reader. The measured results meet the frequency bandwidth and gain requirements for RFID reader applications. The proposed antenna is easy to fabricate and suitable to be an attractive solution for handheld reader in various production, asset management, supply chain including item-level applications.

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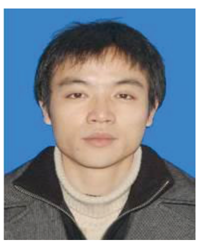

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