Broadband Circularly Polarized Loop Antenna Based on High-pass and Low-pass Filters for Handheld RFID Reader Applications

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Abstract— Recent researches on portable circularly polarized (CP) Radio Frequency Identification (RFID) reader antennas have 3-dB axial ratio bandwidth (ARBW) lower than 80 MHz. In order to cover all the Ultrahigh Frequency (UHF) RFID bands simultaneously, this paper present a novel broadband handheld RFID CP reader antenna. The proposed antenna consists of a square-loop radiating element with 2 feed ports and a broadband feeding network in the same plane, measuring $95\,\mathrm{mm} \times 95\,\mathrm{mm} \times 1.6\,\mathrm{mm}$. The feeding network, which realizes broadband ARBW, is composed of a Wilkinson power divider, a high-pass filter (HPF) and a low-pass filter (LPF), connected to the radiating element, producing broadband right-hand circular polarization (RHCP) in z direction and left-hand circular polarization (LHCP) in $-z$ direction. The measured broad impedance bandwidth ($S_{11} < -10\,\mathrm{dB}$) is from 710 MHz to 1150 MHz. The measured 3-dB ARBW of the proposed antenna is from 800 MHz to 940 MHz. The peak gain in the maximum radiation direction is 1.3 dBic at 910 MHz.

1. INTRODUCTION

UHF RFID systems have been widely deployed in various areas including cold-chain, logistics, Electrical Toll Collection (ETC) and security systems. RFID systems are typically composed of two parts: tags and readers. RFID tags carrying information can be read or writtenby RFID readers through backscattering modulation in UHF band. Several UHF RFID band standards have been adopted, such as the band standards of U.S. (902–928 MHz), Europe (866–869 MHz) and China (840–844.5 MHz and 920.5–924.5 MHz).

Most tags in commercial applications are designed as dipole or patch antennas [1–4] with linear polarization (LP) because of low manufacturing cost and compact size. Therefore, reader antennas with circular polarization (CP) are preferred in order to avoid polarization mismatch between reader antennas and tag antennas. A lot of work has been done on handheld RFID CP reader antennas [5–8]. [5] proposed a single-layer, dual-fed CP square-ring via a Wilkinson power divider with 80 MHz ARBW. [6] proposed a compact X-shaped slotted square-patch antenna for CP application with 18 MHz ARBW. [7] presented a fractal-based coplanar waveguide CP antenna with 26 MHz ARBW. [8] proposed a dual-band CP antenna based on 4 dipoles with 90-degree difference, whose ARBW is about 20 MHz in UHF band. However, few works focused on broadening the ARBW of RFID CP reader antennas, for the purpose of covering all the mainstream band standards including the band standards of U.S., Europe and China (840–928 MHz).

In this paper, a UHF RFID reader antenna based on a feeding network, which consist of a HPF, LPF, and a Wilkinson power divider, is well designed and fabricated for handheld RFID reader applications. The proposed feeding network, based on [9], contributes to a broadband ARBW. The 3-dB ARBW of the proposed antenna is 140 MHz covering UHF RFID bands including the band standards of U.S., Europe and China.

The design of the proposed antenna is presented, followed by the simulated and measured results, discussions and conclusions.

2. ANTENNA CONFIGURATION AND DESIGN

For convenience, the geometry of the proposed antenna, which is depicted in Fig. 1, is similar to the one in [8]. It can be seen that in Fig. 1(a) the antenna consists of a $95\,\mathrm{mm} \times 95\,\mathrm{mm}$ square-ring loop, which works as a radiating element, and a feeding network based on a Wilkinson power divider. The left output of the Wilkinson power divider is connected to a pi-topology HPF, and the right output is connected to a T-topology LPF. The feed port of the power divider is connected to a $50\,\Omega$ SMA port. Lumped resistance $R = 100\,\Omega$ is used for isolation in Wilkinson Power divider. Impedance match can be acquired by selecting $W_1 = 3\,\mathrm{mm}$ and $W_2 = 1.6\,\mathrm{mm}$. By selecting appropriate values of lumped inductors and capacitors, and adjusting the resonant frequency of two filters to 910 MHz, the HPF and the LPF working together as a broadband 90-degree phase shifter as [9, 10]:

$$L_1 = \frac{Z_0}{2\pi f \sin(\phi_1)} \quad (1)$$

$$L_2 = \frac{Z_0 \sin(-\phi_2)}{2\pi f} \quad (2)$$

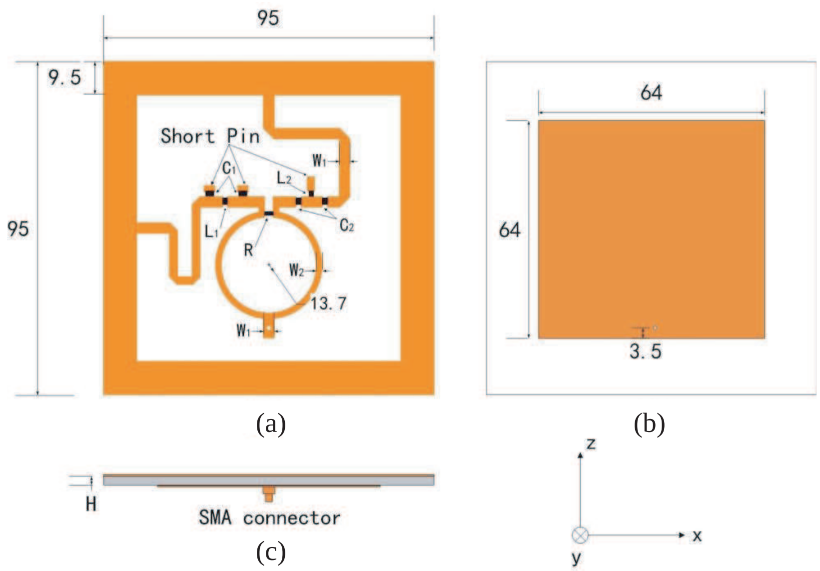

Figure 1: Geometry of the proposed RFID antenna. (a) Top view. (b) Bottom view. (c) Side view.

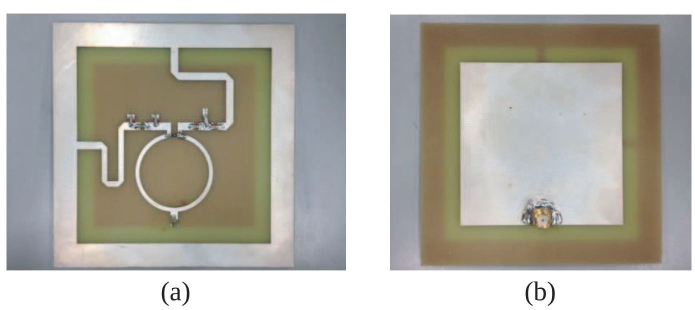

Figure 2: Fabricated antenna. (a) Top view. (b) Bottom view.

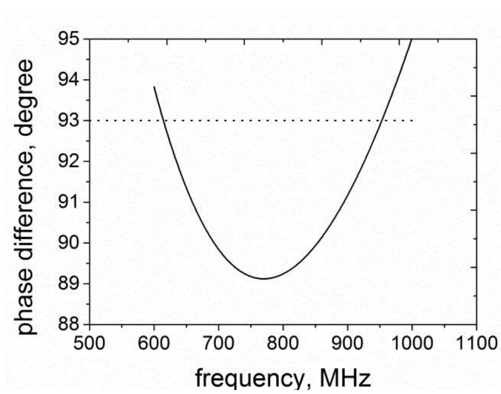

Figure 3: Simulated phase difference between two outputs corresponding to HPF and LPF.

$$C_1 = \frac{1}{2\pi f Z_0 \tan(\phi_1/2)} \tag{3}$$

$$C_2 = \frac{\tan(-\phi_2/2)}{2\pi f Z_0} \tag{4}$$

In this work, $f = 910\,\text{MHz}$, $\phi_1 = 45°$, $\phi_2 = -45°$, $Z_0 = 50\,\Omega$, thus, $L_1 = 6.2\,\text{nH}$, $L_2 = 12\,\text{nH}$, $C_1 = 1.4\,\text{pF}$, and $C_2 = 8.5\,\text{pF}$. The phase difference is $\Delta\phi = \phi_1 - \phi_2 = 90°$. The length of the two microstrip lines connected to the Wilkinson power divider is equal, thus the microstrip lines contribute nothing to the phase shift. The HFSS simulated phase difference between the two outputs corresponding to the HPF and the LPF is $90° \pm 3°$ from 615 MHz to 952 MHz, as shown in Fig. 3.

The bottom view of the proposed antenna is shown in Fig. 1(b). By adjusting the size of ground plane, a good impedance match is achieved since the loop is inductive and the ground plane provide capacitive coupling. The proposed antenna is manufactured on a FR4 substrate with thickness $H = 1.6\,\text{mm}$ and relative permittivity $\varepsilon_r = 4.4$. Fig. 2 shows the fabricated antenna.

3. RESULTES AND DISCUSSIONS

The antenna is designed to operate at the frequency of 910 MHz. The simulated and measured return loss is plotted in Fig. 4. It is shown that the proposed CP antenna has broad impedance bandwidth. The measured 10-dB return loss ranging from 710 MHz to 1150 MHz, agrees well with HFSS simulated results ranging from 645 MHz to 1050 MHz. The measured AR in the boresight direction is plotted in Fig. 5. The measured 3-dB ARBW is 800–940 MHz, covering UHF RFID bands including bands of U.S., Europe and China. Although the measured AR is 3.04 dB and 3.07 dB at 840 MHz and 850 MHz, respectively, we believe by adjusting the values of lumped inductors and capacitors, the AR at these frequencies can also be lower than 3 dB. Despite the flaws

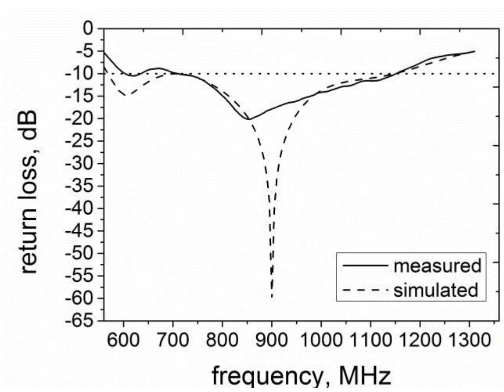

Figure 4: Simulated and measured return loss of the proposed antenna.

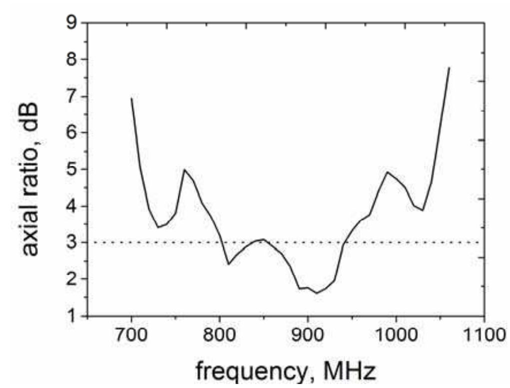

Figure 5: Measured axial ratio of the proposed antenna.

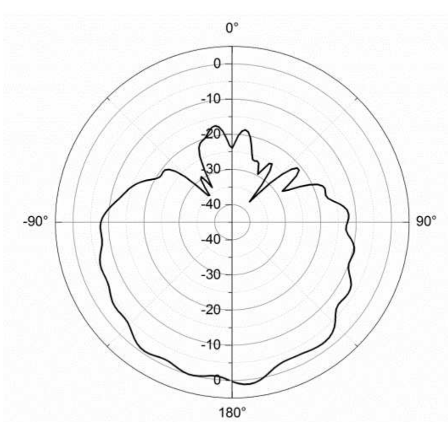

Figure 6: Measured LHCP radiation patterns at 910 MHz in x-z plane.

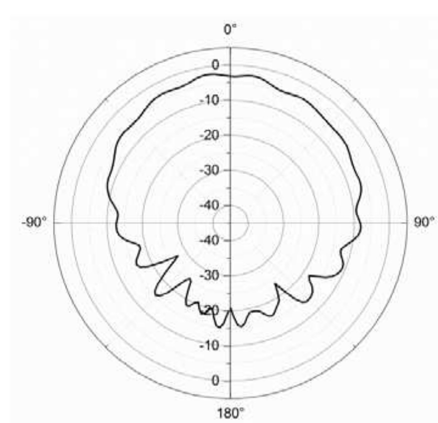

Figure 7: Measured RHCP radiation patterns at 910 MHz in x-z plane.

around 840 MHz, the measured 3-dB ARBW is much wider than [5–8]. Fig. 6 presents the measured left-hand circular polarization (LHCP) radiation patterns at 910 MHz. The measured 3-dB LHCP beamwidth is about 55° in x-z plane. The obtained peak gain is 1.3 dBic in $-z$ direction. Fig. 7 presents the measured right-hand circular polarization (RHCP) radiation patterns at 910 MHz. The measured 3-dB RHCP beamwidth is about 82°. The obtained peak gain is -2.21 dBic. Compared LHCP patterns with RHCP patterns, Fig. 6 and Fig. 7 show that the proposed antenna has better CP gain in $-z$ direction since the feeding network on the top severely affects the RHCP patterns.

4. CONCLUSIONS

In this paper, a RFID reader CP antenna has been proposed using a feeding network based on a Wilkinson power divider, a HPF, and a LPF The proposed antenna can obtain 140 MHz ARBW with 1.3 dBic peak LHCP gain Compared to other reader CP antennas [5–8] in similar size, it has a broader ARBW, which makes it a good choice for handheld RFID applications.

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