Compact Square Quadrifilar Spiral Antenna with circular polarization for UHF mobile RFID Reader

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***Abstract*— A compact square quadrifilar spiral antenna (QSA) with right-hand circular polarization for mobile UHF passive radio frequency identification (RFID) reader is presented. The proposed QSA consists of four spiral antennas fed by microstrip feed network. The proposed reader antenna matching is optimized by using the matching condition for a small 4-port antenna. Experimental results show that the QSA of size 60 × 60 × 17 mm^3 has a 3-dB beamwidth of more than 130, the front-to-back ratio of more than 15 dB, the peak gain of 2.5 dBic and the axial ratio under 2 dB.**

***Index Terms*— Quadrifilar spiral antenna, UHF mobile RFID reader antenna, circular polarization.**

I. Introduction

RFID has become a mainstream and its various applications can be found in many industries ranging from defence to healthcare, from customer to enterprise, and from supply chain to value chain [1]. RFID can be classified into LF, HF, UHF, Microwave RFID systems according to its use in different frequency bands. Especially, RFID in UHF band can be classified into active UHF RFID and passive UHF RFID according to the need of power supply. Since passive UHF RFID self-generates operation power from the CW signal received from reader, it has a limited read-range comparing to active UHF RFID. Therefore, there have been many studies on improvements of transmit/receive characteristic of reader, Tx/Rx isolation characteristic and tag sensitivity in order to increase the read-range between tag and reader. However, the read-range is fundamentally affected by the strength of the signal delivered from reader to tag and thus, the performance of reader antenna is also an important factor for the read-range.

Generally, the antennas for the passive UHF RFID reader should be characterized by high quality circular polarization characteristics, high gain, wide beamwidth and high front-back ratio. For mobile environment, the above characteristics should still be satisfied although the antenna size gets significantly smaller. Thus, many researchers are currently studying ceramic and microstrip patch antenna, spiral antennas, dipole antennas and inverted-F antennas for UHF RFID reader [3]-[7].

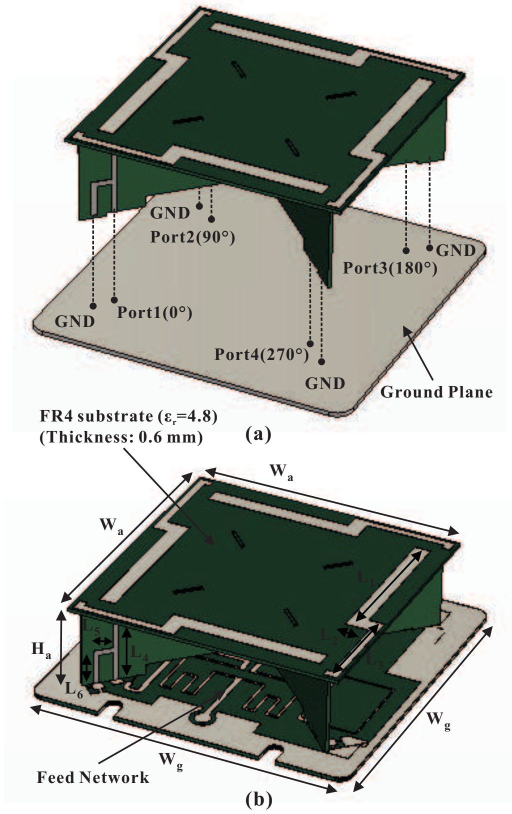

Fig. 1. The geometry of the proposed QSA with circular polarization in (a) and the prototype in (b).

In this paper, we propose a compact square quadrifilar spiral antenna (QSA) for UHF RFID reader. For wide range of RHCP, four spiral antennas are located on each corner of a square ($\leq 0.2\ \lambda \times 0.2\ \lambda$) with equal amplitude and quadrature phases (0^o, 90^o, 180^o, 270^o) fed by a feed network.

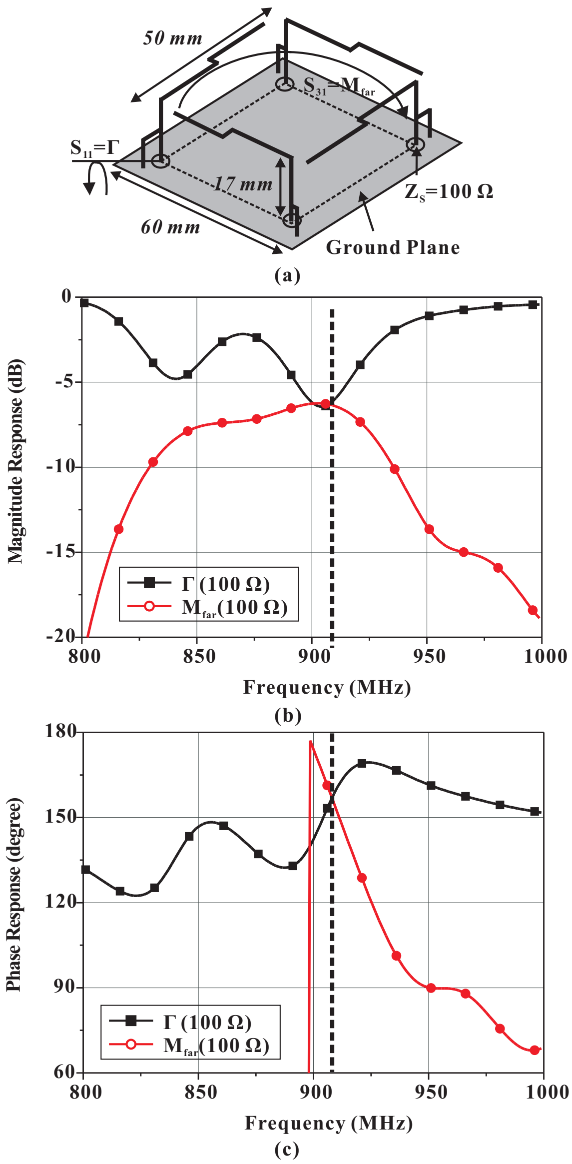

Fig. 2. (a)Test setup for measurement of Γ and M_{far} and simulated (b)magnitude and (c)phase response of Γ and M_{far} of the proposed QSA when a port impedance is 100 Ω (L_1 = 28.5 mm, L_2 = 4.4 mm, L_3 = 19 mm, L_4 = 15 mm, L_5 = 3.5 mm, L_6 = 6.5 mm).

II. Design of Compact Square QSA

When the ports of 4-port antenna like QSA are compactly placed each other ($\leq$ 0.2 λ), mutual coupling among the ports strongly occurs and thus the conventional Γ-matching technique used for 1-port antenna can no longer be used. That is, a compact 4-port antenna matching must consider both reflection coefficient and mutual coupling among each port. In general, a compact 4-port antenna matching condition can be expressed as follows [8]

$$\Gamma = M_{far} \tag{1}$$

where Γ and M_{far} denote the reflection coefficient at each port and mutual coupling between diagonally located ports,

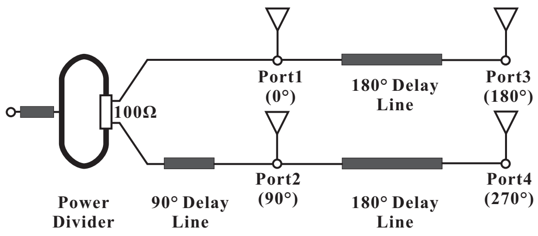

Fig. 3. The equivalent circuit model of a microstrip feed network for a wide range of RHCP radiation.

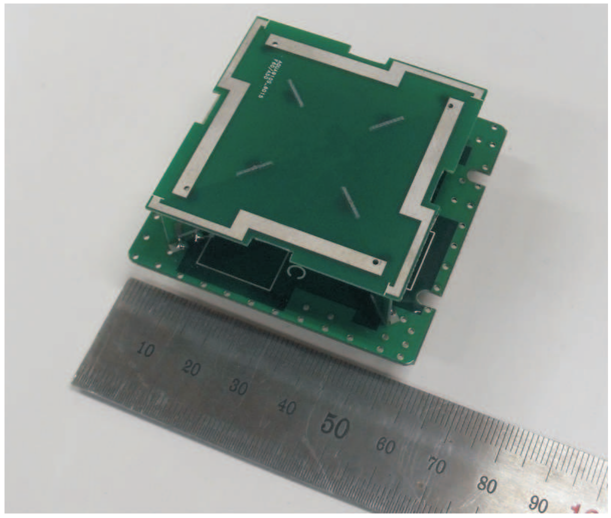

Fig. 4. The implemented compact square QSA optimized with L_1 = 28.5 mm, L_2 = 4.4 mm, L_3 = 19 mm, L_4 = 15 mm, L_5 = 3.5 mm, L_6 = 6.5 mm.

respectively. The relation between Γ and M_{far} of the proposed QSA is analyzed with the simulation model as shown in Fig. 2(a). With short stub, we can observe that the relation between Γ and M_{far} satisfies (1) in magnitude and phase response at the center frequency of 910 MHz as shown in Fig. 2(b), (c). In magnitude response, two parabola shaped graphes of Γ and M_{far} are adjacent to each other at the frequency of 910 MHz with response of about -7 dB. Also, in phase response, two graphes meet at the frequency of 910 MHz with response of about 158 degrees. Fig. 1 shows the prototype of the proposed QSA in a well-matched condition. Both horizontal and vertical parts of four spiral antennas are printed on a FR4 substrate (thickness of 0.6 mm) and the length of each spiral antenna is about 70 mm to resonate at the center frequency of 910 MHz. Also, the input impedance and resonance frequency of the QSA can be controlled by adjusting the length of each spiral antenna and shorted stub ($L_1 \sim L_6$ of Fig. 1(b)). These four spiral antennas are fed by equal amplitude but with relative quadrature phase differences of 0^o, 90^o, 180^o and 270^o obtained by a microstrip feed network for a wide range of RHCP with good gain performance. As shown in Fig. 3, the feed network is composed by the Wilkinson power divider, 90^o delay line and 180^o delay lines. Also, the feed network is implemented on the same type of FR4 substrate (60 $\times$ 60

TABLE I
PARAMETERS OF THE PROPOSED QSA FOR UHF RFID READER

Parameter	W_a	H_a	W_g	L_1	L_2	L_3	L_4	L_5	L_6
Value (mm)	50	17	60	28.5	4.4	19	15	3.5	6.5

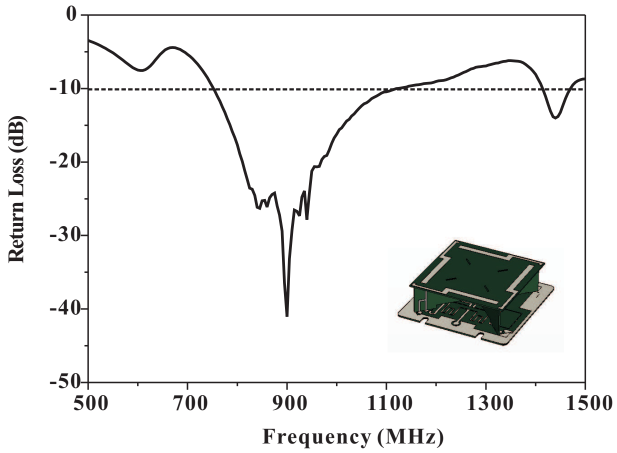

Fig. 5. Measured return loss of the proposed QSA.

mm^2) used a ground plane. The parameters of the proposed QSA are presented in Table I.

III. EXPERIMENTAL RESULT

Fig. 4 shows the implemented compact QSA for UHF RFID reader which has been optimized. Fig. 5 shows the measured return loss of the proposed compact QSA. The QSA has the resonance at the center frequency of 910 MHz and has the reflection characteristic of less than -10 dB in the bandwidth of about 250 MHz. This wide-band characteristic of the measured return loss is caused by the wide-band characteristic of the Wilkinson power divider in the feed network. The peak gain and axial ratio of the proposed compact QSA for UHF RFID reader are also measured from 900 MHz to 930 MHz in an authorized anechoic chamber as shown in Fig. 6, 7. The QSA has the peak gain about 2.5 dBic at the center frequency of 910 MHz and 3-dB gain bandwidth about 50 MHz as shown in Fig. 6. The axial ratio is less than about 2 dB in the measured frequency range as shown in Fig. 7. But the bandwidth of the peak gain and axial ratio is narrower than the bandwidth of the return loss. Although the bandwidth of the peak gain and axial ratio is narrower, it can sufficiently be used in the UHF RFID band. The radiation pattern is also measured at the center frequency of 910 MHz in X-Z and Y-Z direction as shown in Fig. 8. The difference between RHCP and LHCP radiation pattern in range of 130^o zenith direction is more than about 15 dB, so the proposed QSA has the good circular polarization performance in radiation direction. Also, the proposed QSA has the directivity in zenith direction and the 3-dB beamwidth about 130^o. So, the proposed antenna is suitable for a RFID reader antenna and can be used instead of a ceramic patch antenna.

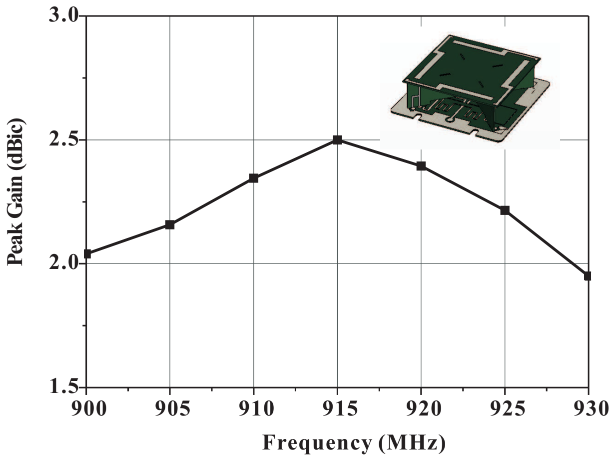

Fig. 6. Measured peak gain of the proposed QSA optimized in frequency range from 900 MHz to 930 MHz.

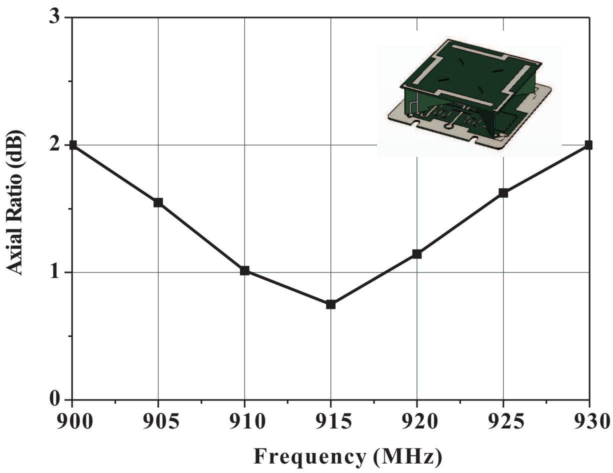

Fig. 7. Measured axial ratio of the proposed QSA optimized in frequency range from 900 MHz to 930 MHz.

IV. CONCLUSION

A compact square QSA for UHF RFID reader has been presented. Based on the matching condition of compact 4-port antenna, the compact QSA has been optimized to have high performance. Excellent matching and optimal performance of the fabricated QSA have been verified by experiment as well. The optimized QSA has a peak gain of 2.5 dBic, an axial ratio of less than 2 dB, and a 3-dB beam width of more than 130^o.

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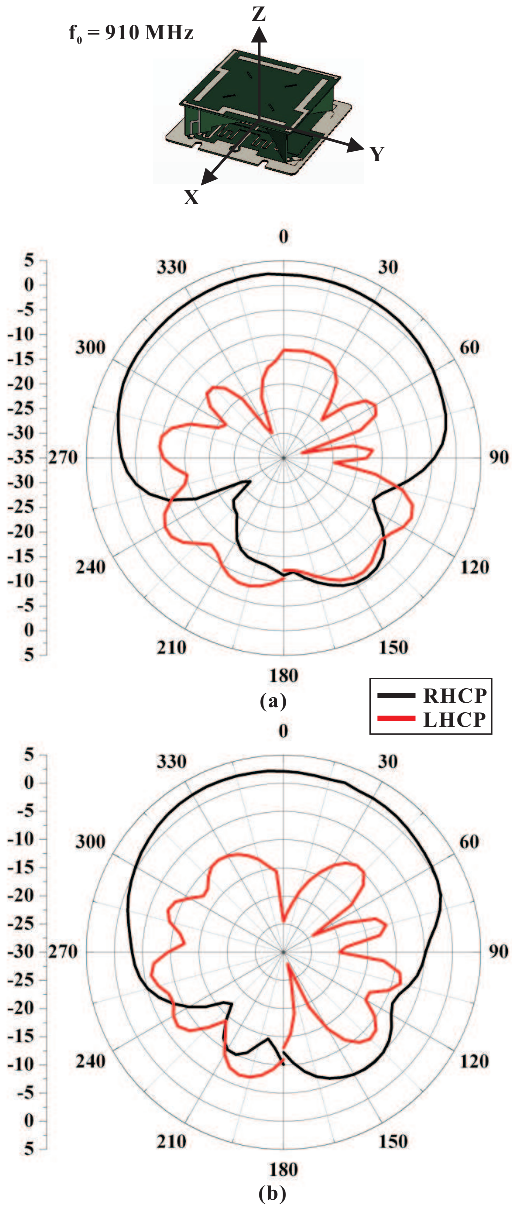

Fig. 8. Measured radiation pattern in X-Z and Y-Z direction of the proposed QSA optimized at center frequency 910 MHz.

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