Design of Quadrifilar Spiral Antenna with Integrated Module for UHF RFID Reader

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***Abstract*— In this paper, a quadrifilar spiral antenna (QSA) with an integrated module for UHF radio frequency identification (RFID) reader is presented. The proposed QSA consists of four spiral antennas with short stubs and a microstrip feed network. Also, the shielded module is integrated on the center of the ground inside the proposed QSA. In order to match the proposed QSA with the integrated module, we adopt a short stub connected from each spiral antenna to ground. Experimental result shows that the QSA of size 80 × 80 × 11.2 mm^3 with the integrated module (40 × 40 × 3 mm^3) has a peak gain of 3.5 dBic, an axial ratio under 2.5 dB and a 3-dB beamwidth of about 130°.**

***Index Terms*— Quadrifilar spiral antenna, module integrated antenna, RFID reader antenna, circular polarization.**

I. Introduction

RFID (Radio Frequency Identification) has become a mainstream and its various applications can be found in many industries ranging from defense to healthcare, from customer to enterprise, and from supply chain to value chain [1]. In RFID system, a reader communicates with a tag. For UHF RFID, the role of reader is especially emphasized due to the use of passive tag [2].

In order for a reader to communicate with a tag efficiently, the transceiver performance in the reader and the front-end isolation are important as well as the performance of reader antenna is emphasized. The stable and portable reader antennas for reliable RFID operation should be characterized by high quality circular polarization characteristics, high gain, wide beamwidth and high front-back ratio. 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].

In this paper, we propose a quadrifilar spiral antenna (QSA) with an integrated module for UHF RFID reader. For the proposed QSA, the module is integrated on the empty space between the ground and four spiral antennas, thus, the antenna and the module can be combined. Since the QSA with integrated module is matched by the short stubs connected from each spiral antenna to the ground, the proposed antenna resonates well in the UHF RFID band and has a good radiation performance.

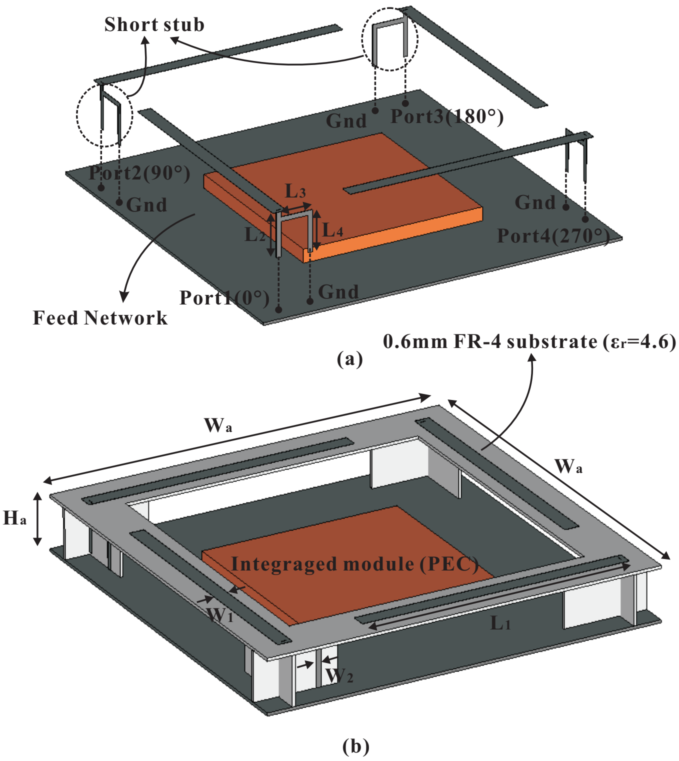

Fig. 1. The geometry of the proposed QSA with integrated module in (a) and the prototype in (b) with W_a = 80 mm, H_a = 11.2 mm, L_1 = 55 mm, L_2 = 10 mm, L_3 = 7 mm, L_4 = 9 mm, W_1 = 2 mm, W_2 = 1 mm.

II. Design of the QSA with Integrated Module

Since a 4-port antenna such as QSA experiences a mutual coupling among the ports, its matching cannot be done by just adjusting a reflection coefficient of each port like an 1-port antenna. Instead, both the reflection coefficient of each port

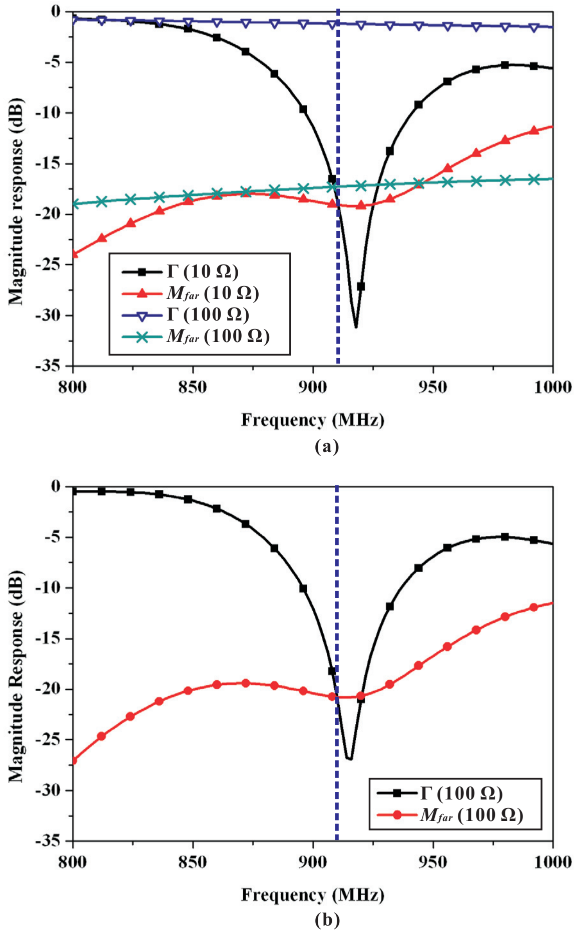

Fig. 2. Simulated magnitude response of Γ and M_{far} when (a) a port impedance is 100 Ω and 10 Ω without short stub and (b) a port impedance is 100 Ω with short stub.

and the mutual coupling among the ports should be considered. The matching condition is expressed as follows [8],

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

where Γ and M_{far} denote a reflection coefficient at each port and a mutual coupling coefficient between the ports in opposite side, respectively.

Using simulation, we observe the relation between Γ and M_{far} of the proposed QSA without a short stub when the port impedance is 100 Ω and 10 Ω. As shown in fig. 2(a), the relation between Γ and M_{far} does not follow (1) at all and the radiation efficiency is too low (about 30 %) when the port impedance is 100 Ω. On the other hand, when the port impedance is 10 Ω, the relation between Γ and M_{far} satisfies (1) and the radiation efficiency is also improved to about 87 %. However, for 10 Ω port impedance, a feed network cannot be designed due to the limited antenna size. Thus, we adopt a short stub to satisfy the matching condition (1) while the port impedance also increases as high as about 100 Ω. In fig. 2(b), the relation between Γ and M_{far} well satisfies (1).

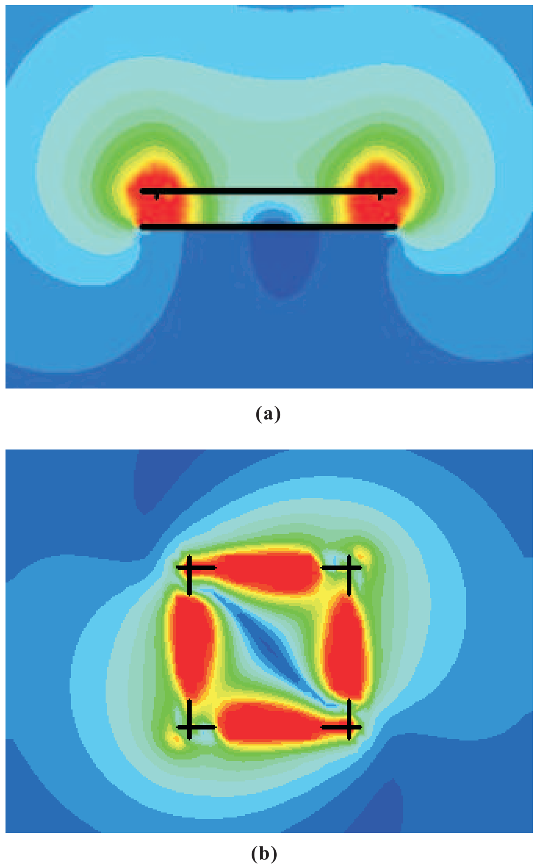

Fig. 3. Simulated electric field distribution inside the QSA without integrated module (a) side view (b) top view.

Moreover, we observe an electric field distribution inside the proposed QSA without a shielded module. As shown in fig. 3, the electric field in the center of the QSA is weak enough to have the shielded module integrated without degrading the antenna performance. In more detail, when the shielded module is integrated inside the QSA, the performance of the QSA rarely varies as the radiation efficiency changes very little from 87 % to 86 %.

Fig. 1 shows the prototype of the proposed QSA with integrated module. Four spiral antennas are printed on a FR-4 substrate (thickness 0.6 mm, relative permittivity 4.6) and the resonant frequency of the QSA can be controlled by adjusting the length of antennas (L_1, L_2). Also, the four spiral antennas are fed by equal amplitudes but with relative quadrature phase differences of 0^o, 90^o, 180^o, and 270^o. obtained by a microstrip feed network consisting of Wilkinson power divider, 90^o delay line and two 180^o delay lines. The designed feed network provides a good RHCP gain for the QSA with a wider beamwidth in the upper hemisphere. The feed network is also implemented on the same type of FR-4 substrate (80×80 mm^2) along its edges since the shielded module needs to be integrated on the center of FR4 substrate. A short stub is connected to the ground from each spiral antenna to increase the port impedance adjusted by its length

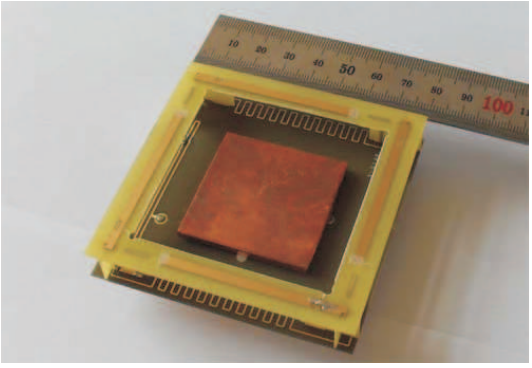

Fig. 4. The implemented QSA with integrated module.

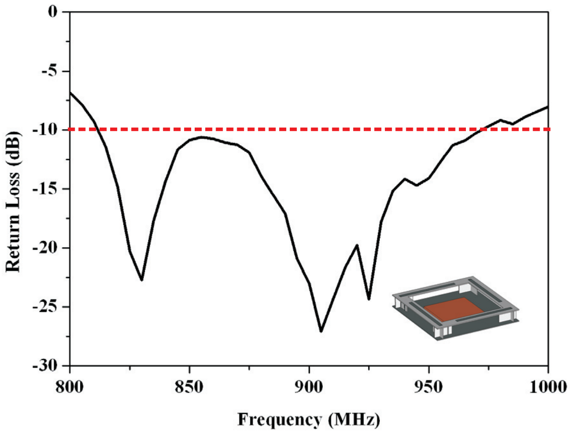

Fig. 5. Measured return loss of the proposed QSA with integrated module.

(L_3, L_4).

III. Measured Result

Fig. 4 shows the implemented QSA with an integrated module.

Fig. 5 shows the measured return loss of the proposed QSA with integrated module. The QSA well-resonates at the center frequency and has the reflection characteristic of less than -10 dB in the bandwidth of 150 MHz.

Fig. 6 shows the measured peak gain and axial ratio of the proposed QSA from 900 MHz to 930 MHz. The QSA has the peak gain about 3.5 dBic at the center frequency and axial ratio is less than 2.5 dB in the measured frequency range. But the bandwidth of the peak gain and axial ratio is narrower than the bandwidth of the return loss because of the narrow bandwidth of the 90^o and 180^o lines. Although bandwidth of the peak gain and axial ratio is narrower than the bandwidth of the return loss, it can sufficiently be used in the UHF RFID band of US.

The measured radiation pattern was also measured at center frequency of 915 MHz as shown in fig. 7. The QSA has the directivity in Z-direction and the 3-dB beamwidth about 130 ^{o}.

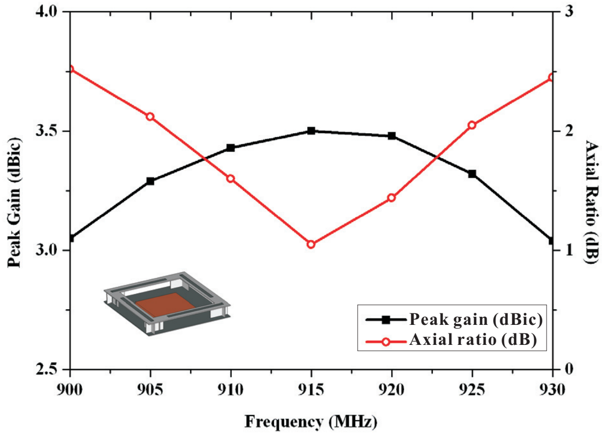

Fig. 6. Measured peak gain and axial ratio of the proposed QSA with integrated module in frequency range from 900 MHz to 930 MHz.

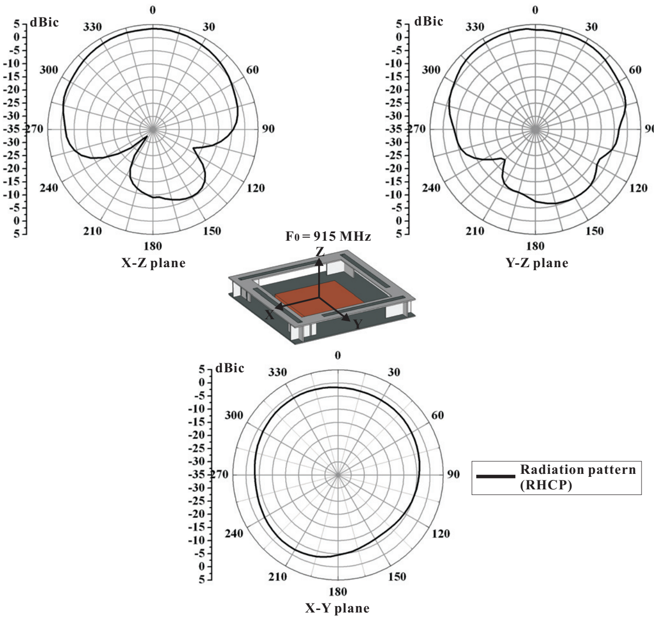

Fig. 7. Measured radiation pattern of the proposed QSA at center frequency of 915 MHz.

IV. Conclusion

A QSA with an integrated module for UHF RFID reader has been presented and measured. A short stub was adopted at each spiral antenna to match the proposed QSA with the port impedance increased as high as about 100 Ω Also, the QSA performance was not degraded when the shielded module was integrated inside the QSA. The optimized QSA had a peak gain of 3.5 dBic, an axial ratio of less than 2.5 dB, and a 3-dB beamwidth of 130^o

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