UHF RFID reader antenna with switchable far-field and near-field working state

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Abstract

An ultra-low profile and high-performance UHF RFID reader antenna is proposed in this letter, which can be switched between far-field (FF) and near-field (NF) operative mode. This antenna is composed of four dipoles and a reconfigurable feed network. The four dipoles form a square, and the feed network is located in the center. The feed network is a four-way power divider, and the phase of the output signal can be controlled by switching diodes. As a balanced structure, double-sided parallel-strip lines (DSPSLs) are used to feed four dipoles. Compared to the balun structure, the application of DSPSLs can reduce the area of the feed network, thereby reducing the influence of the feed network on the central magnetic field. Experimental results show that the proposed antenna can provide a NF reading area of 180×180 mm2, and the identification rate can reach 100% within 30-60 mm height. The FF gain of the antenna is 4.7 dBic, and the overlapping range of 3 dB AR bandwidth and -10 dB impedance bandwidth is 800-960 MHz. The good FF and NF performance of this antenna is conducive to its application in RFID systems.

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Introduction: In traditional RFD systems, the principle of magnetic field couple is used for NF identification in LF and HF bands, which can achieve better reading performance for tags attached to objects with high dielectric constant. UHF bands transmit energy and information through electric fields for FF recognition. UHF bands have faster reading speeds than LF and HF bands. Due to different operating frequency bands, the NF antenna and FF antenna need to perform their functions separately.

In recent years, some scholars have proposed UHF NF reader antennas. Because of the short wavelength of UHF bands, the inverted current will appear on the antenna, which will weaken the magnetic field. How to solve this problem becomes a matter of concern. In [1-4], the segmented ring structure is adopted. The capacitive coupling between the segmented rings changes the current phase to achieve the same current direction on the whole circle, thus generating a strong and uniform magnetic field distribution. In [5-7], the currents in opposite directions are excited on two adjacent microstrip lines. The two currents generate mutually superimposed magnetic fields between the microstrip lines. With the appearance of UHF RFID NF reader antennas, researchers began to consider designing UHF RFID reader antennas with NF and FF identification functions. Integrating the NF reader antenna and FF reader antenna allows system volume and cost to be effectively reduced. A multiple-port antenna is designed in [8]. The antenna has various operating modes, including NF operating mode and two different linear polarized FF operating modes. Reference [9] proposed a reconfigurable NF and FF reader antenna controlled by switching diodes. The NF identification area of the antenna is only 72.3×72.3 mm^2. In the far field, the antenna is also linearly polarized. Reference [10] proposed an antenna with a switchable NF and FF working state. However, due to the use of seven Wilkinson power dividers, the size of the antenna is large, and the antenna is a multi-layer structure with a high profile.

This letter proposes a reader antenna with switchable FF and NF working states. The antenna consists of four dipoles and a reconfigurable feed network. By controlling the excitation phase of the dipoles, the FF and NF operating states of the antenna can be switched. The antenna works in the NF state when the four dipoles are fed with the same amplitude and phase. The magnetic field generated by the current is overlapped in the square ring, so a strong and uniform magnetic field distribution in the ring has been achieved. When the four dipoles are fed with equal amplitude and 90° phase difference, the antenna works in the FF state and radiates circularly polarized waves. The proposed antenna has the advantages of a simple structure and ultra-low profile, and has good application prospects.

Antenna design and operating principle: Fig. 1 shows the geometry of the proposed antenna. It is printed on a single-layer dielectric substrate made of R4003C material with a relative dielectric constant of 3.55 and a thickness of 0.813 mm. As can be seen, the arms of the four dipoles are printed on the upper and lower surfaces of the dielectric substrate in turn. The feed network consists of a four-way power divider, phase shifters, DSPSLs, and switching diodes. When switches M are off and switches N are on, the currents of the four dipoles are of equal amplitude and phase, and the antenna works in the NF state. Conversely, when switches M are on and switches N are off, phase-shifting lines are introduced into the circuit, and the antenna works in the FF state. Table1 lists the detailed dimensions of the antenna.

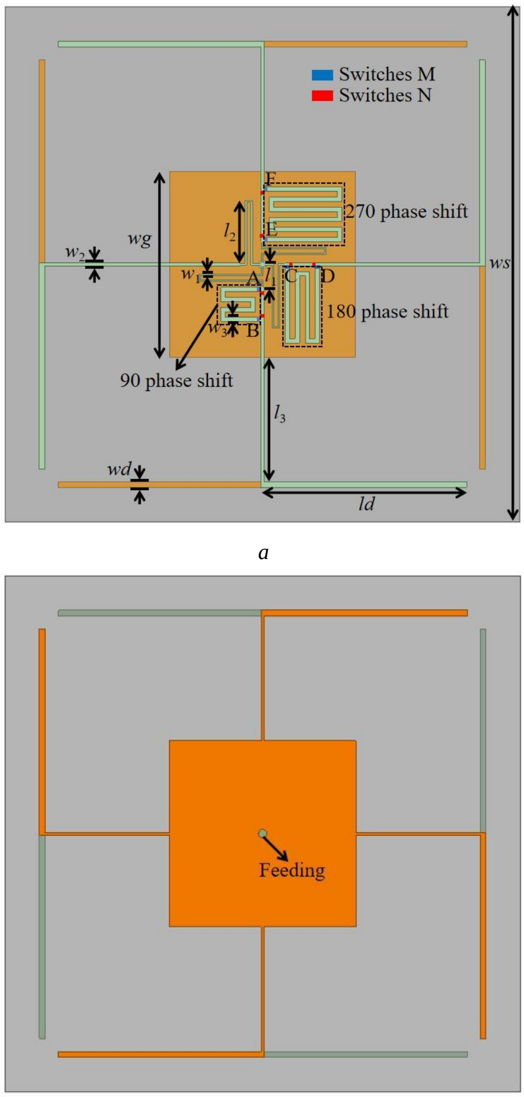
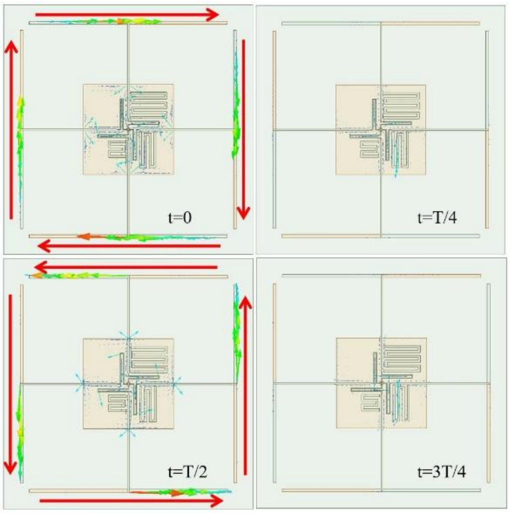


Fig. 1 *Structure of the proposed antenna.*
a Top view of the substrate
b Bottom view of the substrate

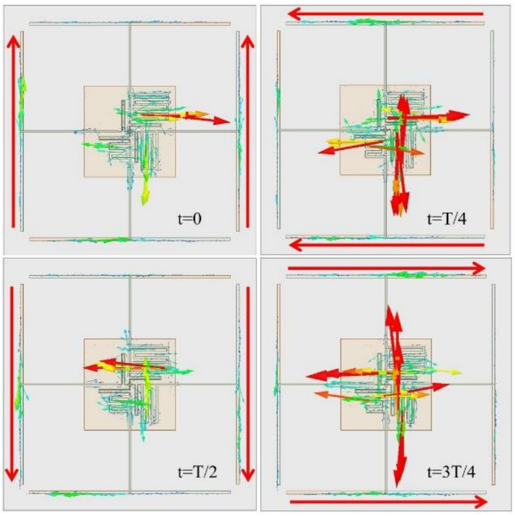
Table 1: *Dimensions of the antenna (UNIT: mm).*

ws	180	*wd*	2	AB	48
wg	65	l_1	8	CD	110
w_1	0.5	l_2	22	EF	165.8
w_2	1	l_3	43.5		
w_3	1.5	*ld*	71		

Fig. 2 shows the current distribution of the antenna in the NF and FF operative mode at 915 MHz. When the antenna works in the NF state, at t=0, the current on the four dipoles remains in phase. The current on the square ring is clockwise. At t=T/4 and t=3T/4, the current is minimum. At t=T/2, the current on the square ring is anticlockwise. The magnetic fields generated by the four dipoles are always superposed inside the ring, which is conducive to achieving strong and uniform magnetic field distribution. When the antenna works in the FF state, due to the effect of the phase shift line, the four dipoles are fed with equal amplitude and a phase difference of 90°. The electromagnetic waves generated by the four dipoles are superposed to achieve circularly polarized radiation.



a



b

Fig. 2 *The simulated 915MHz current distribution.*
a NF current distribution
b FF current distribution

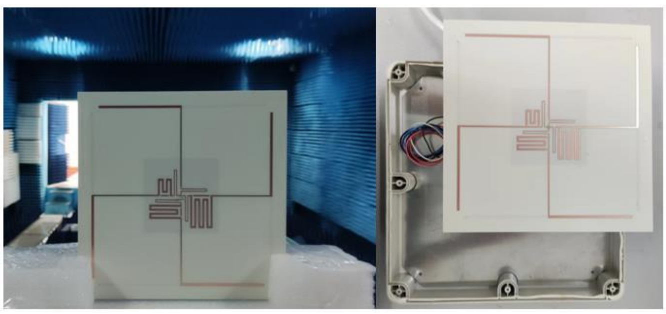


Fig. 3 *The measurement setup of the antenna.*

Simulation and Experimental Results: In this section, the antenna we designed has been fabricated and tested, and the switches are replaced by copper bars for verification. The photographs of the fabricated antenna and measurement setup are shown in Fig. 3.

Fig. 4 shows the S parameters of the simulation and measurement when the antenna works in the NF state. It can be seen from the figure that the curve trends of antenna simulation and measurement are basically consistent. The bandwidth of test results has been broadened, which may be caused by welding loss. The impedance bandwidth of the antenna test is 9.0% (857-940 MHz), covering 902-928 MHz commonly used in the UHF band of RFID systems. Fig. 5 shows the variation of the magnetic field strength along the X-axis at different heights from the antenna surface. It can be seen that when the distance from the antenna surface is within 30mm, the magnetic field at the center of the antenna is weak due to the influence of the metal ground. With the increase of distance, the influence of metal ground is weakened. When the distance from the antenna surface is more than 40mm, the magnetic field of the antenna is evenly distributed. The intensity is gradually weakened with the increase of distance. Fig. 6 shows the label identification rate at different heights from the antenna surface. Within 30mm from the antenna surface, due to the weak magnetic field in the central area, the tag reading rate is less than 100%. Between 30mm and 60mm, the magnetic field intensity is evenly distributed, and the tag reading rate can reach 100%. With the increase of distance, the magnetic field intensity decreases, and the tag reading rate also decreases.

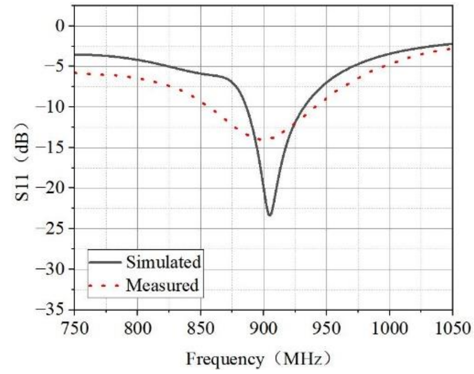


Fig. 4 *Simulated and measured S11 for the NF state.*

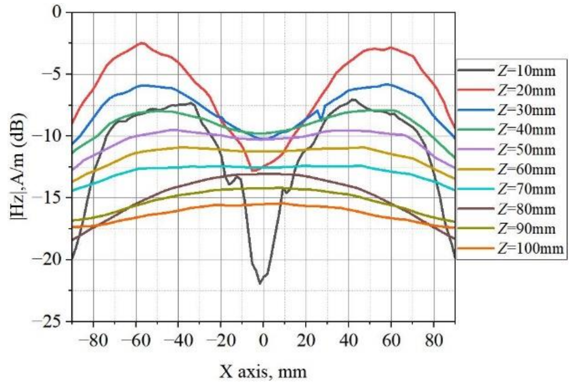


Fig. 5 *The variation of the magnetic field strength along the X-axis at different heights.*

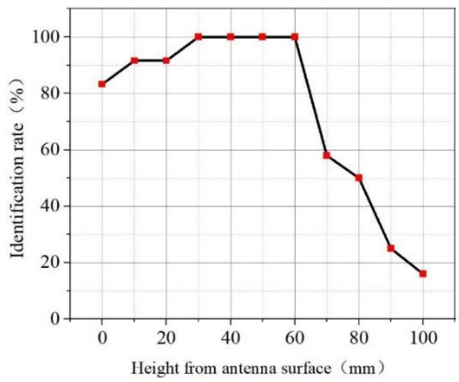


Fig. 6 *The label identification rate at different heights from the antenna surface.*

Fig. 7 shows the simulated and measured S parameters of the antenna under FF operative mode. The antenna shows good impedance matching characteristics. The gain and AR curves of the antenna are shown in Fig. 8. The 3 dB AR bandwidth is 17.4% (800-960 MHz), the maximum gain is 4.7 dBic, and the gain flatness is less than 3dB within this bandwidth. Fig. 9 shows the radiation pattern of the antenna at 915 MHz. The antenna radiates circularly polarized waves. The antenna simulation and measurement results are slightly different, which may be caused by the test environment and processing errors. The test results show that the antenna has good circularly polarized radiation performance.

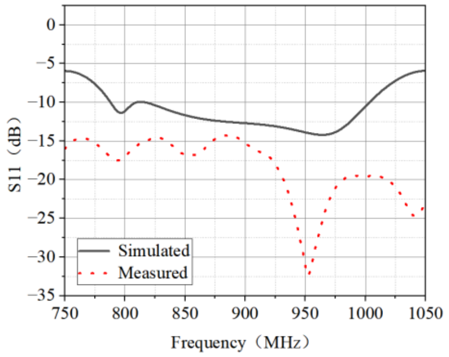


Fig. 7 *Simulated and measured S11 for the FF state.*

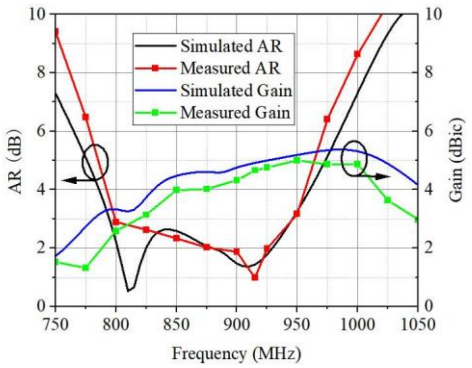


Fig. 8 *The gain and AR curves of the antenna.*

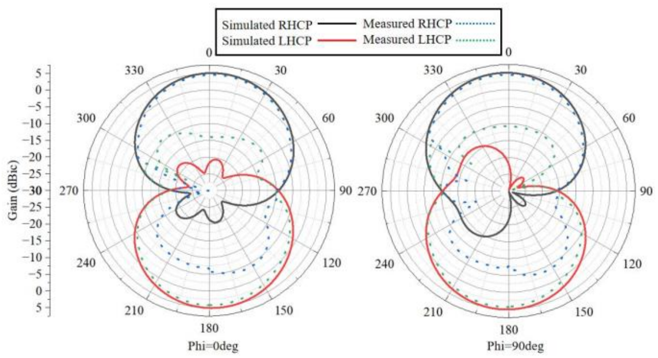


Fig. 9 *The radiation patterns of simulation and measurement at 915 MHz.*

Table 2: *The performance comparison between the designed antenna and other antennas.*

Reference	Size (mm^3)	NF/FF Impedance BW (%)	AR BW (%)	FF Gain
[8]	180×180×1.6	7/>19.6	/	-3.2 dBi
[9]	72.3×72.3×1.5	<5	/	2.6 dBi
[10]	280× 280×30	16.4/>16.4	15.3	7.0 dBic
This work	180×180×0.813	9/>32.7	17.4	4.7 dBic

Table 2 lists the performance comparison between the designed antenna and other antennas. It can be seen that the antenna designed in this paper has good impedance matching characteristics and circularly polarized radiation characteristics while maintaining an ultra-low profile and a large identification area.

Conclusion: In this letter, a reader antenna with switchable FF and NF working state is designed. The antenna uses a combination of a four-way power divider and DSPSLs to feed the dipoles printed on the upper and lower surfaces of the dielectric plate. Compared with the Wilkinson power dividers used in the literature [9], it dramatically reduces the area and complexity of the feed network and realizes an ultra-low profile. At the same time, the antenna also has excellent NF and FF performance. When the height is 30-60 mm from the dielectric substrate, the tag recognition rate can reach 100%. The 3dB AR bandwidth of the antenna is 17.4%, and the maximum gain is 4.7 dBic. The antenna has potential application value in FF and NF RFID systems.

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