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QDSPSL-Fed Straight Dipoles Antenna Array for UHF RFID Near-Field Applications

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Abstract—A broadband ultra-high frequency reader antenna based on magnetic coupling is proposed for radio frequency identification (RFID) near-field application. The design utilizes four quarter-wave impedance transformer double-side parallel stripline (QDSPSL)-fed dipoles to form a square region to achieve broadband impedance matching and strong and uniform magnetic field distribution. The phases of currents on each dipole are kept same, thus, strong distribution of magnetic can be generated by the antenna. A $200 \times 200 \times 1.6\,\text{mm}^3$ antenna has been fabricated on an FR-4 substrate to fit RFID near-field application. The measured 10-dB impedance bandwidth is 107 MHz (860–967 MHz), which covers the entire UHF RFID frequency band (860–960 MHz). Measured tests on the antenna read range are carried out by observing the feedback received signal strength indication (RSSI) values, exhibiting a large reading region of $140 \times 140\,\text{mm}^2$ and 100% reading rate within 100 mm for near-field tags.

1. INTRODUCTION

Ultra-high frequency (UHF) radio frequency identification (RFID) technology based on magnetic coupling has received much attention due to its stable performance and high reading rate in the near-field item-tracking applications such as bottles of water, retail goods, luxury goods, and pharmaceuticals. As an internal part of RFID systems, near-field (NF) antenna needs to generate strong and uniform distribution of magnetic field. Besides, licensed UHF bands are allocated within the 860 MHz to 960 MHz, so broadband of the antenna meeting different standards from disparate districts is necessary. Many efforts have been adopted in the design of antennas [1–6]. In [1], a four-way power divider is designed to keep the current in phase, while the bandwidth is narrow (840–845 MHz). Meander line is adopted in [2] to achieve opposite direction currents (ODC), while the reading distance for near-field tags is just up to 20 mm, and bandwidth is 914–929 MHz. Reference [3] proposes a Zero-Phase-Shift-Line (ZPSL) antenna, which can achieve broadband, but the read distance is within 13.5 mm. In addition, [4] achieves broadband with a taper structure. The antenna is designed as a circular one, at the center of which the magnetic field is lower than other places for the interval distance. This will cause failed identification at the center of antenna first at a fixed height. Besides, planar antennas for opposite directed currents [5, 6] are also adopted for NF application.

In this letter, a broadband UHF near-field reader antenna is proposed and analyzed. Four straight dipoles form a square region where strong and uniform magnetic field can be achieved. Measured tests are carried out by observing the feedback received signal strength indication (RSSI) values in terms of antenna read range. Large reading region of $140 \times 140\,\text{mm}^2$ and 100% reading rate within 100 mm for near-field tags are exhibited. Measured performance in terms of reflection coefficient and tag detection is presented as follows.

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2. ANTENNA LAYOUT AND PERFORMANCE

The proposed array antenna is composed of 4 straight dipoles fed by QDSPSL structure, printed on a 1.6 mm-thick FR-4 substrate with a dielectric constant of 4.4 and loss tangent of 0.02 (Fig. 1). Coaxial probe is adopted at the center of the antenna to feed four straight dipoles. Length of each dipole is less than $\lambda/2$ ($L1$ is set as 101 mm in the design), on surface of which currents are kept in phase. Besides, parameter $L1$ influences the resonant frequency. This is because large dipole arm length has a lower resonant frequency. Double-side parallel stripline (QDSPSL) based on impedance transformers is introduced to match the input impedance ($= 50\,\Omega$) and also avoid radiation influence caused by itself for magnetic field on upper and lower surfaces counteracting. Phases of currents on each array element are kept same, obtaining strong magnetic field close to the antenna. Four straight dipoles form a square region, where uniformity of field can be achieved along the central axis. Feed arm lengths include two different parameters, one of which is set as $\lambda/4$ wavelength ($G2 = 48$ mm), and the other parameter $G1$ is set to achieve better impedance matching and obtain large reading region for near-field tags. Antenna configuration and parameters are as follows (Fig. 1). Main geometrical parameters are: $L = W = 200$ mm, $L1 = 101$ mm, $G1 = 27$ mm, $G2 = 48$ mm, $W1 = 5$ mm, $W2 = 3.5$ mm and $R = 10$ mm.

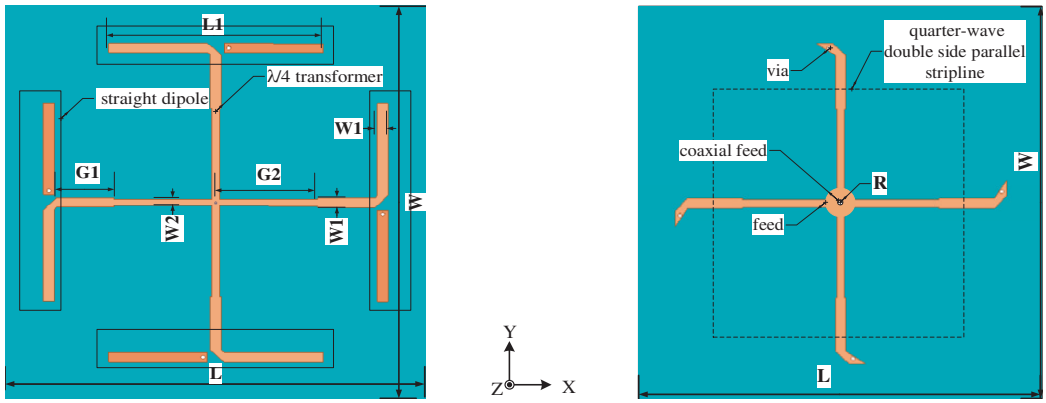

Figure 1. Antenna prototype (a) top view, (b) bottom view.

Figure 2 shows the simulated current distribution of the proposed antenna at 900 MHz. As can be seen, the current along the loop is kept in phase. Such a current distribution generates strong and uniform magnetic field over the interrogation zone.

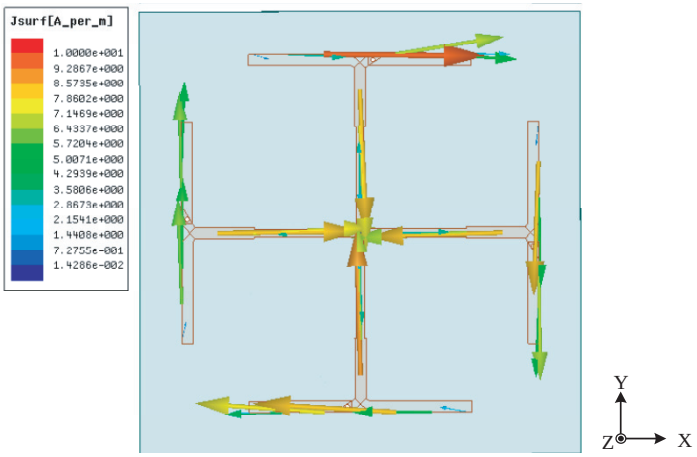

Figure 2. Antenna currents distribution at 900 MHz.

Quarter-wave impedance matching structure is adopted in the antenna. The quarter-wave impedance transformer and the equivalent circuit are shown in the Fig. 3.

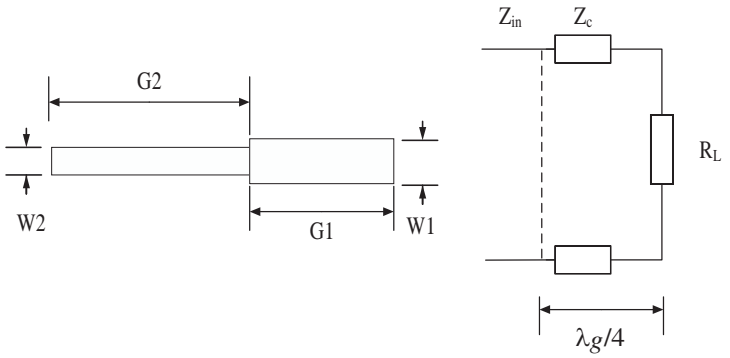

Figure 3. Quarter-wave transformer and the equivalent circuit.

The formula for the quarter-wave transformer is known as:

$$Z_c = \sqrt{Z_{in}}\sqrt{R_L} \tag{1}$$

Z_c = transformer characteristic impedance; Z_{in} = input impedance; R_L = terminal load.

In this proposed antenna, the input impedance $Z_{in} = 50\,\Omega$, $R_L = 36\,\Omega$, the calculated transformer characteristic impedance value is:

$$Z_c = \sqrt{50 \times 36} = 42.4\,\Omega \tag{2}$$

Calculated and optimized parameters of the feedline are: $W1 = 5$ mm, $W2 = 3.5$ mm, $G2 = 48$ mm.

The measured antenna reflection coefficient is shown in Fig. 4. It is below -10 dB between 860 MHz–967 MHz covering the whole UHF band, and that below -15 dB in 880 MHz–930 MHz covering the Chinese UHF band (920–925 MHz) and FCC band (902–928 MHz). In [6], the -15 dB impedance bandwidth is just 850–880 MHz. Fig. 5 plots the vertical magnetic field strength distribution |Hz| (dBA/m) along X-axis and Y-axis at the height of 10 mm above the antenna when frequency is at 860 MHz, 900 MHz and 960 MHz. The strength of magnetic field is about -5 dBA/m in the interrogation zone (30 mm $\leq X \leq$ 170 mm, 30 mm $\leq Y \leq$ 170 mm). Simulated results indicate that strong and uniform distribution of magnetic field is generated in the square area formed by dipoles, and the antenna also achieves broadband between 860 MHz–960 MHz.

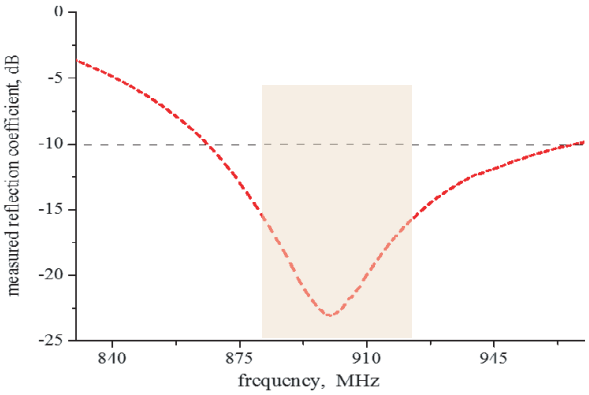

Figure 4. Measured reflection coefficient of proposed antenna.

Parameters of the proposed coaxial probe-fed broadband antenna are also analyzed. Fig. 6 shows that the simulated reflection coefficients are affected by the length of the dipoles. It can be seen that the impedance bandwidth shifts downward as the $L1$ increases from 99 mm to 103 mm. This is because

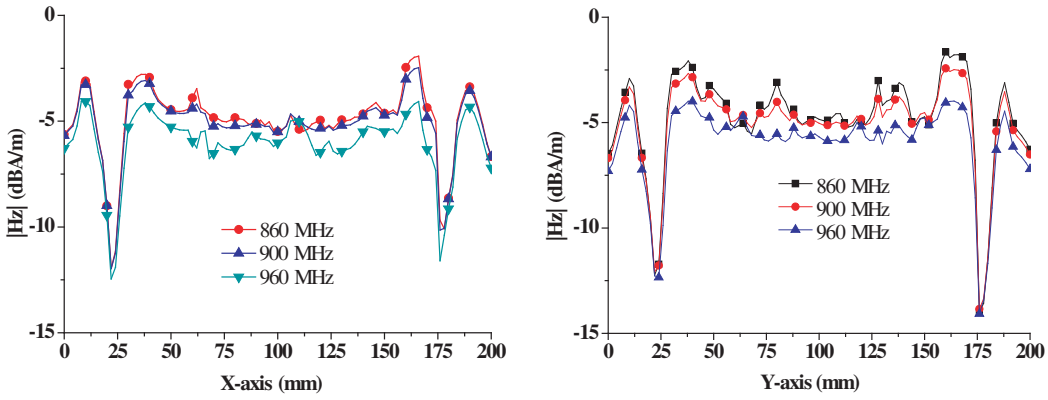

Figure 5. Simulated |Hz| (dBA/m) along X and Y-axis of the proposed antenna when $Z = 10\,\text{mm}$.

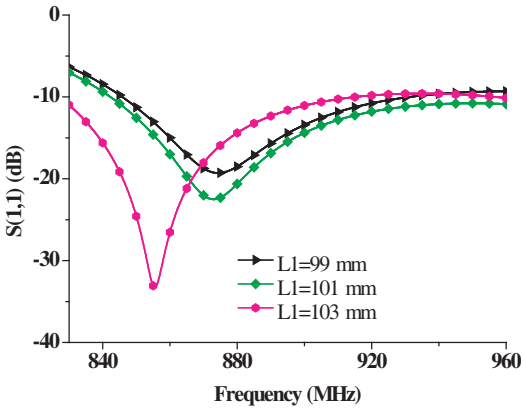

Figure 6. Simulated $S(1,1)$ for different values of $L1$.

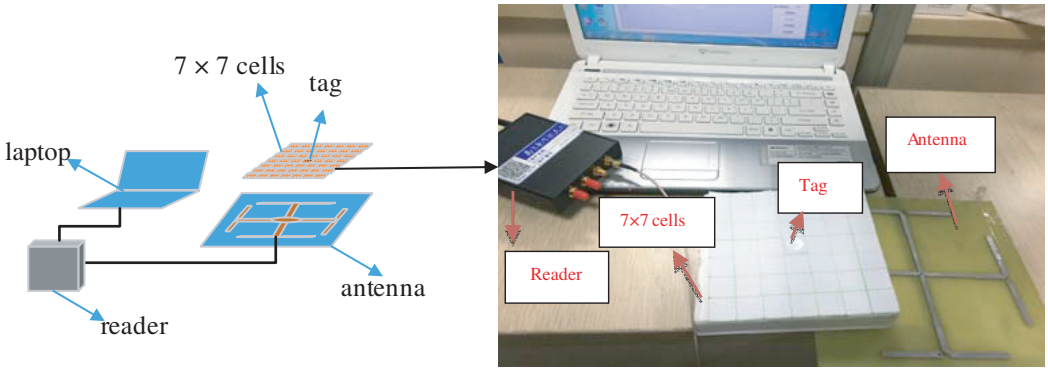

Figure 7. Measurement on read range.

large dipole arm length should have a lower resonant frequency. To achieve good impedance matching, $L1$ is set as 101 mm.

The antenna has been integrated into a commercial desktop reader, and read range tests have been carried out. Measured system is set up in Fig. 7. In this test, the near-field tag (Impinj J41, field strength at least $-24\,\text{dBA/m}$,) and Imping Speedway Revolution reader R220 are chosen. The J41 tag is a commercial Monza 4 microchip tag using a 6-mm-radius (out radius) loop antenna. The read sensitivity of the chip is 17.4 dBm. Identifying the tag J41 requires the component of the magnetic field (normal to the surface of the antenna) at least $-24\,\text{dBA/m}$. The antenna surface ($140 \times 140\,\text{mm}^2$) is

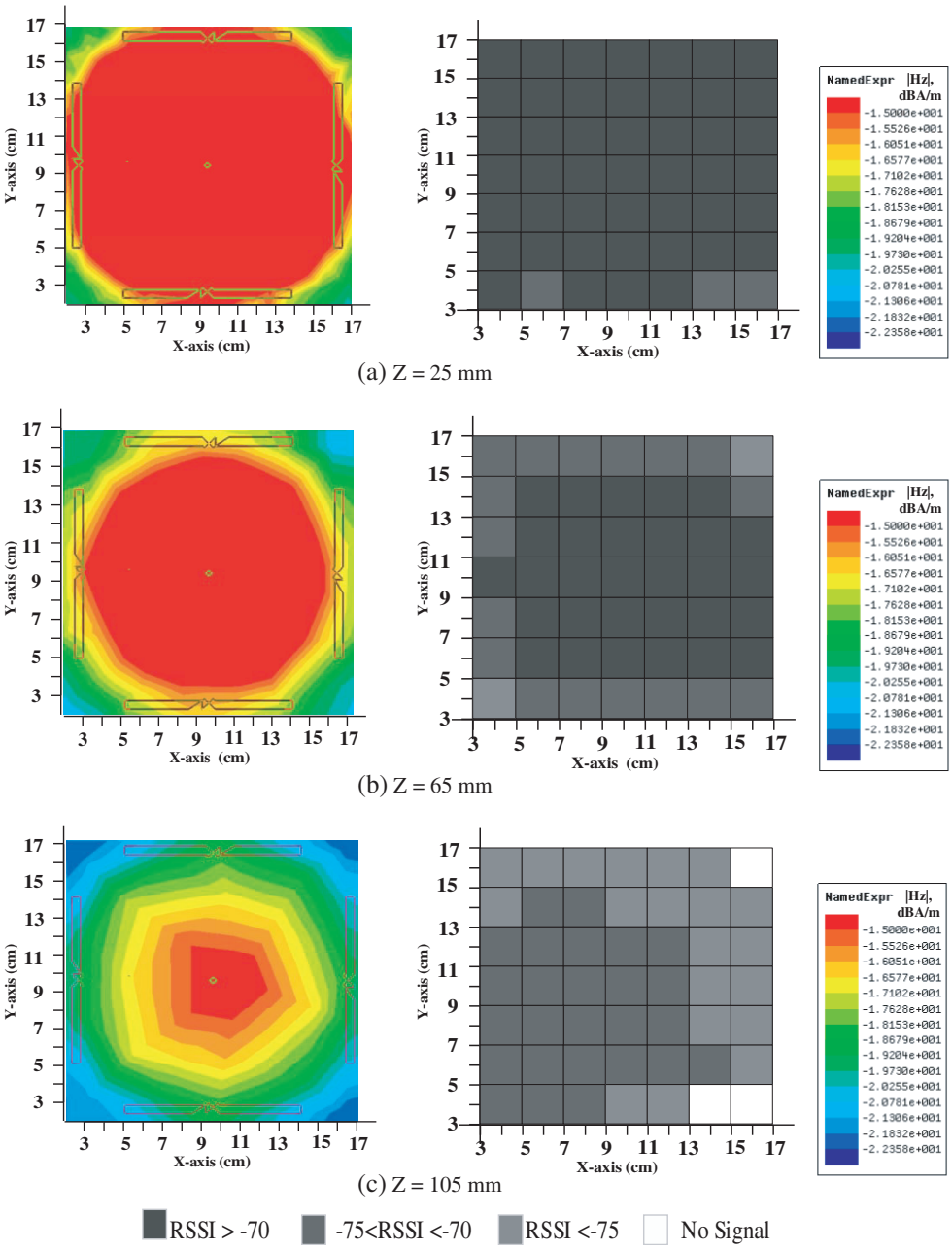

Figure 8. Tag detection test for NF tag, by varying distance, position with respect to antenna surface and simulated |Hz| (dBA/m) distribution. (a) 25 mm, (b) 65 mm, (c) 105 mm.

subdivided into 7×7 square cells. Detection tests are repeated in each cell by varying the distance of the tag from antenna surface, setting an input power to 25 dBm. In Fig. 8, the RSSI values are shown at different heights compared to simulated magnetic distributions (|Hz|, dBA/m). The simulated and measured heights are separately set to 25 mm (Fig. 8(a)), 65 mm (Fig. 8(b)) and 105 mm ((Fig. 8(c)). By observing the RSSI values, the 100% reading rate is up to almost 100 mm, and large reading region is exhibited. Meanwhile, uniformity of field is achieved thanks to straight dipoles forming square region, avoiding fade area at central part.

Comparison of the proposed antenna with other near-field antennas in the literature is shown in Table 1. As shown, the antenna obtains broader band than [2, 5, 6], and 100% reading rate is still up to 100 mm with an input power 25 dBm, which ensures the stability of RFID system in real scenario.

Table 1. Antenna comparison.

Reference	Frequency (MHz)	Bandwidth $S_{11} < -10\,\text{dB}$	Power (dBm)	Read range (mm)
[2]	920	15 MHz (914–929 MHz)	30	20
[3]	915	250 MHz (790–1040 MHz)	30	13.5
[5]	900	43 MHz (907–950 MHz)	30	100
[6]	900	30 MHz (910–940 MHz)	30	100
Proposed	900	107 MHz (860–967 MHz)	25	100

3. CONCLUSION

In this letter, an array of straight dipoles antenna based on quarter-wave double-side parallel stripline (QDSPSL) structure has been proposed for NF-UHF RFID desktop reader applications. Magnetic distribution is maximized in a confined volume close to antenna surface, and field uniformity is obtained in UHF band. Large reading region of $140 \times 140\,\text{mm}^2$ and 100% reading rate up to 100 mm for NF tags are exhibited. The antenna has a good prospect in UHF RFID near-field applications.

ACKNOWLEDGMENT

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