LETTER

Broadband cross dipole antenna for UHF near-field RFID applications
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Abstract A broadband cross dipole antenna for ultra-high frequency (UHF) near-field radio frequency identification (RFID) applications is proposed in this paper. The proposed antenna with two perpendicular coplanar dipoles can identify the tags that placed random perpendicularly to the antenna’s surface. A prototype is fabricated and tested for verification. By adjusting the length of one dipole, the broadband characteristic is obtained. Measured results show that the operating bandwidth (S¹ < -10 dB) is about 210 MHz from 852 to 1062 MHz. Meanwhile, a strong and uniform magnetic-field distribution surrounding the antenna is achieved with an interrogation zone of 142 mm × 142 mm.

key words: ultra-high frequency (UHF), near field, radio frequency identification (RFID), broadband cross dipole, antenna

Classification: Microwave and millimeter-wave devices, circuits, and modules

1. Introduction

With the explosive development of Internet of Things (IoT), radio frequency identification (RFID), as one of the key technologies, has received more and more attention [1, 2, 3, 4, 5]. Based on the operating principle, the RFID system can be classified into near-field and far-field system. The near-filed system usually works by the inductive coupling at low frequency (LF) or high frequency (HF). While, the far-filed system realizes the high read rate and long identification distance through the propagation mechanism at ultra-high frequency (UHF) or micro-wave (MW) band, which means that the tags cannot be directly attached to the metal surface. To obtain the advantages of the near-field and far-field system simultaneously, the UHF near-filed RFID system has become the research focus [6, 7, 8, 9, 10, 11].

As the most common type of the near-field RFID reader antenna, loop antenna is the first choice to be used at UHF band [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31]. However, due to the inverse current, the conventional loop antenna could generate the blind area. Therefore, many researchers have been studied to modify the electrically-large loop antenna, such as segmented loop antenna with lumped capacitors [12], zero-phase-shift line (ZPSL) [13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24], several dipoles to form the loop antenna [25, 26, 27, 28, 29] and other modified loop antenna [30, 31]. The other popular type of UHF near-field reader antenna is based on the oppositely directed currents (ODCs) [32, 33, 34, 35, 36, 37, 38]. These researches mainly focused on how to generate an uniform magnetic-field distribution at a large interrogation zone. Meanwhile, it can be found that all of them are based on a basic premise that the tag surface is parallel to the reader antenna surface. So far, only a few studies have been considered the tag placement [39, 40, 41]. For instance, H.-W. Liu et al. utilize curved strips and coupled stubs to identify the tags placed perpendicularly to the antenna surface [40]. Nevertheless, the tags are still placed in the fixed direction.

For more flexible tag placement, a broadband cross dipole antenna is proposed for UHF near-field RFID applications. Through theoretical analysis and formula derivation, the dipole placed along x-axis generates such magnetic-field to read the tags placed perpendicularly to the y-axis. Similarly, the dipole placed along y-axis generates such magnetic-field to read the tags placed perpendicularly to the x-axis. Thus, the proposed antenna consisting of two perpendicular dipoles can identify the tags placed random perpendicularly to its surface. By optimum design, our proposed antenna covers the global UHF RFID frequency band, and has the interrogation zone of 142 mm × 142 mm.

2. Antenna configuration

Fig. 1 demonstrates the top view of the proposed antenna. It is composed of two dipoles placed along x-axis and y-axis, respectively. The proposed antenna is supported by a square FR4 substrate with thickness 1.6 mm and
relative dielectric constant of 4.4. The physical dimensions denoted in Fig. 1 are as follows: \( L = 160 \text{ mm}, \) \( l_1 = 62 \text{ mm}, \) \( l_2 = 54 \text{ mm}, \) \( w_1 = 3 \text{ mm}, \) \( w_2 = 1 \text{ mm}, \) \( d = 2.2 \text{ mm}, \) and \( fed = 1 \text{ mm}.\)

Fig. 1 Top view of the proposed antenna

3. Analysis of the proposed antenna

3.1 Near-field distribution of the half-wave dipole

Assuming that the half-wave dipole is placed along \( x \)-axis, its current distribution can be displayed as follow.

\[
I(x') = \begin{cases} \frac{I_0 e^{j\varphi}}{4\pi} \sin[k(\lambda/4 - x')], & 0 \leq x' \leq \lambda/4 \\ \frac{I_0 e^{j\varphi}}{4\pi} \sin[k(\lambda/4 + x')], & -\lambda/4 \leq x' \leq 0 \end{cases}
\]

(1)

Where, \( I_0 \) and \( \varphi \) are the maximum current and the initial phase respectively, as well as \( k \) equals to \( 2\pi/\lambda \). According to the Ampere’s Law, the magnetic-field surrounding the dipole is generated as shown in Fig. 2. The dipole only generates the \( y \) and \( z \) components of magnetic-field \( (H_y, H_z) \) under the Cartesian coordinate. Meanwhile, it is noted that there are nearly no \( H_x \) right above the dipole, which means it will has the identify blind area if the tags are placed parallel to the antenna surface as usual. However, there always exists the \( y \) component above the dipole.

Fig. 2 Magnetic-field of the dipole placed along \( x \)-axis

On the other hand, according to the derivation of Eq. (2), it is used to quantify the magnetic-field that is consistent with the theoretical analysis.

\[
I = e_z I_z \Rightarrow A = e_z A_z
\]

\[
\Rightarrow H = \frac{1}{\mu} \times A = \frac{1}{\mu} \begin{bmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{bmatrix}
\]

(2)

Combined with Eq. (1) and Eq. (2), the detail magnetic-field distribution can be expressed by the following function.

\[
H_z = 0
\]

\[
H_y = \frac{1}{\mu} \frac{\partial A_z}{\partial z} = \frac{I_0 e^{j\varphi}}{4\pi} \int_{-\lambda/4}^{0} c \times \sin[k(\lambda/4 + x')] dx' + \int_{\lambda/4}^{0} c \times \sin[k(\lambda/4 - x')] dx'
\]

(3)

Where,

\[
H_y = \frac{1}{\mu} \frac{\partial A_z}{\partial z} = \frac{I_0 e^{j\varphi}}{4\pi} \int_{-\lambda/4}^{0} d \times \sin[k(\lambda/4 + x')] dx' + \int_{\lambda/4}^{0} d \times \sin[k(\lambda/4 - x')] dx'
\]

(4)

With the aid of MATLAB software, the magnetic-field distribution of the half-wave dipole at 920 MHz can be obtained by Eq. (3) and Eq. (4). For comparison, the high frequency structure simulator (HFSS) is used to model the half-wave dipole. Fig. 3 shows the normalized \( |H_y| \) distribution along \( x \)-axis at \( z=50 \text{ mm} \). It is observed that the calculated results are well coincided with the simulated ones.

Fig. 3 \( |H_y| \) distribution along \( x \)-axis at \( z=50 \text{ mm} \)

In order to understand the near-field magnetic-field characteristics of the half-wave dipole more intuitively, \( |H_y| \) and \( |H_z| \) distributions at \( z=50 \text{ mm} \) are shown in Fig. 4a and Fig. 4b respectively. The \( |H_y| \) along \( x \)-axis are nearly zero that results in the blind area. The \( |H_z| \) are weakening from center to sides, which is similar to the \( |H_y| \) of the conventional loop antenna. So, the half-wave
dipole placed along $x$-axis could read the tags that are set perpendicularly to the $y$-axis.

3.2 Characteristics of the crossed half-wave dipoles
In a similar way, the half-wave dipole along $y$-axis can identify the tags that are perpendicular to the $x$-axis. Inspired by this, the near-field reader antenna consisting of two crossed dipoles is proposed to identify the tags placed perpendicularly to the $xoy$ plane. To verify the idea, suppose two ideal half-wave dipoles are perpendicular to each other and they have the same maximum current and initial phase, Fig. 5 displays its magnetic-field distributions of the $x$, $y$ and $z$ components respectively under $z=50$ mm.

Due to the superposition effects, the strength of $|H_x|$ along $y=x$ are weaker than that required to identify the tags. However, $|H_x|$ and $|H_y|$ have almost the same distribution that they have a relatively uniform and strong region right above the crossed dipoles surface. Hence, by theoretical analysis, the crossed dipoles can identify the tags that placed parallel to $z$-axis. Meanwhile, due to the simple structure, there are reasons to believe that the proposed antenna can be adapted well to the practical near-field RFID applications.

At the same time, from Fig. 5(c), it can be found that the $|H_z|$ distribution of the proposed crossed half-wave dipoles looks like one dipole’s distribution that placed along $y=x$. Thus, the crossed dipoles with the same source have the linear polarization. To verify this point, the simulated axis-rat (AR) is shown in Fig. 6. It can be found that from 0.5 to 1.5 GHz, the AR is larger than 10 dB. Usually, the antenna with AR less than 3 dB is considered as circularly polarized antenna.
3.3 Optimization of structural parameter

In order to achieve better performance, the proposed antenna is optimized by HFSS. In view of the complexity of design and fabrication, the feed network needs to be simple. Therefore, the maximum current and initial phase of the two crossed dipoles are kept the same. At the same time, since other parameters such as the widths of the dipole and feed have little impact on the near-field performance, only the length of the dipole should be optimized.

Adjusting the length $l_2$ showing in Fig. 1, the reflection coefficient ($S_{11}$) of the proposed antenna is demonstrated in Fig. 7. With the length $l_2$ decreasing, the bandwidth broaden. When $l_2$ equals to 50 mm, the bandwidth of $S_{11} < -10$ dB is about 260 MHz from 830 to 1090 MHz. From this perspective, $l_2$ seems to be smaller to obtain the better performance.

![Fig. 7 Reflection coefficient curves under different length $l_2$](image)

While, for the near-field reader antenna, its magnetic-field distribution is more important, which determines the recognition performance. $|H_x|$ and $|H_y|$ distributions along y-axis are shown in Fig. 8 under different length $l_2$. $|H_x|$ distributions are mainly affected by the dipole along y-axis, which the length does not change. Fig. 8(a) shows that with $l_2$ decreasing, the strength of $|H_x|$ becomes larger, which means the other dipole’s effect is reduced. Through Fig. 8(b), it can be seen that the strength of $|H_y|$ at $l_2=50$ mm is the smallest, while under other conditions they are almost the same.

![Fig. 8 Magnetic-field distributions along y-axis under different length $l_2$: (a) $|H_x|$; (b) $|H_y|$](image)

Considering the reflection coefficient and the magnetic-field distribution, the length $l_2$ is optimized to be 54 mm. At this point, the bandwidth is about 170 MHz from 850 to 1020 MHz that covers nearly all the UHF RFID frequency band of the world. Meanwhile, the $|H_x|$ and $|H_y|$ strength are both larger than -20 dBa/m (the threshold strength to identify the tags) from -70 mm to 70 mm, which means the largest interrogation zone. Moreover, it can be found that the SMA connector can be directly connected the proposed antenna to achieve the impedance matching. In conclusion, the optimized antenna is simple in processing and has good performance.

4. Experimental verification

The proposed antenna was fabricated with the same dimensions as the simulated one (160 mm × 160 mm × 1.6 mm in section 2), as shown in Fig. 9. The crossed dipoles are printed on the top of the substrate, and the SMA connector is directly connected at back.

![Fig. 9 Photograph of the fabricated antenna](image)

With the help of a vector network analyzer, Fig. 10 gives the measured reflection coefficient of the proposed antenna. For comparison, the simulation results are added to the Fig. 10. It shows that the measured results are nearly consistent with the simulated ones. The measured -10 dB bandwidth is about 210 MHz (from 852 to 1062 MHz) and the corresponding relative
bandwidth is about 21.9%, which is larger than the conventional dipole and loop antenna.

![Measured and simulated results of the reflection coefficient](image)

Fig. 10 Measured and simulated results of the reflection coefficient

To measure the interrogation zone, the experiment device is shown in Fig. 11. One hundred tags are uniformly attached to a piece of foam board with the dimension of 160 mm × 160 mm, which means that each tag takes up 16 mm × 16 mm space. In the test process, by shifting the labeled foam board along the x-axis and y-axis respectively, the reading performance of the proposed antenna can be obtained.

Fig. 11 Experiment device

Fig. 12 gives the measured interrogation zones at different heights. In Fig. 12, each square represents a tag. The green square means that the tag in this location can be identified by the proposed antenna. While, the white one expresses that the proposed antenna cannot read the tag. As can be seen, with the tags away from the antenna surface, more tags cannot be identified. Through Fig. 12, about 9 × 9 tags are identified from the surface of the proposed antenna to 70 mm height, whether the labeled foam board is perpendicular to the x-axis or y-axis. Considering the occupied space of each tag, the interrogation zone of 100% tag detection is about 142 mm × 142 mm under 70 mm. Therefore, the experimental results also validate the reading performance of the proposed antenna.

![Measured interrogation zones at different heights](image)

Fig. 12 Measured interrogation zones at different heights: (a) Labeled foam perpendicular to x-axis; (b) Labeled foam perpendicular to y-axis.

5. Conclusion

A broadband cross dipole antenna has been proposed for the UHF near-field RFID applications. The proposed antenna is simple, and demonstrates high performance. The measured bandwidth about 210 MHz (852–1062 MHz) covers the global UHF RFID frequency band. Meanwhile, the proposed antenna can identify the tags placed random perpendicular to its surface with the interrogation zone of 142 mm × 142 mm. Such a design is more suitable for the special UHF near-field RFID applications.

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