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A CP Antenna of Wide Half-Power Beamwidth for UHF RFID Near- and Far-Field Applications

Jingming Zheng, Yang Yang, Xiaoxiang He*, and Chenyang Mao

Abstract—A wide half-power beamwidth antenna based on magnetic coupling in near-field (NF) regions and circular polarization (CP) in far-field (FF) is proposed for RFID multiservice applications in UHF band. The prototype consists of a cross-strip and an L-shaped strip on the top layer, fed by an F-shaped network on the bottom layer. CP electromagnetic wave is radiated by the cross-strip, and the antenna also simultaneously brings opposite directed currents (ODC) to generate strong magnetic field in near-field region. Half-power beamwidth is 100° in xoz-plane and 102° in yoz-plane, which can be used to scan for large regions. An $88 \times 88 \times 1.6\,\text{mm}^3$ antenna has been fabricated on an FR-4 substrate to fit RFID applications. Measured tests on read range by observing feedback received signal strength indication (RSSI) values are carried out, exhibiting 100% read rate for near-field tags within 25 mm and exciting read distance for far-field tags up to 1 m for large reading region of $170 \times 170\,\text{mm}^2$.

1. INTRODUCTION

Radio frequency identification (RFID) technology has been widely adopted due to high reading rate in the item-tracking applications. Over the years, UHF RFID systems have expanded from identification of bulky objects to smaller ones. This development makes great demands on reader antennas of high radiation efficiency and wide beamwidths, which obtain scanning for large reading areas. Besides, circular polarized antenna is preferred in real scenarios because it ensures far-field tags detection irrespective of their orientations. In many applications such as logistics and pharmaceuticals, both far-field (for solid goods) and near-field tags (liquid drugs) are needed at the same time. So multiservice antennas working both at near- and far-field regions are also necessary. In near-field region of the antenna, the radius R is usually below $2D^2/\lambda$ (D is the maximum size of antenna, and λ is the wavelength). When the distance increases, far field of the antenna forms. In [1], coplanar waveguide (CPW)-fed antenna just for far-field regions is used. The efficiency is 86%, and beamwidth is only 76°. A slits loaded CP antenna is designed in [2]. Although the efficiency is improved to 92%, the 3-dB beamwidth is 73°. Besides, this antenna cannot be applied to near-field regions. [3] proposes a multiband antenna used for RFID applications, and the far field is linearly polarized as well as in [4, 5]. Orientations of far-field tags have impacts on the reading distance. Compact antenna with asymmetrical slot perturbation and a long L-shaped feedline is proposed [6]. The slot edge is adopted to achieve CP, and extra structure is designed to enhance the magnetic field. This causes the low radiation efficiency just 80%–85% and high directivity. The beamwidth is narrow as the gain is enhanced and in low efficiency. Apart from this, large length of feedline can produce nonuniform field distributions.

In this Letter, a multiservice antenna based on magnetic coupling and CP is proposed for RFID

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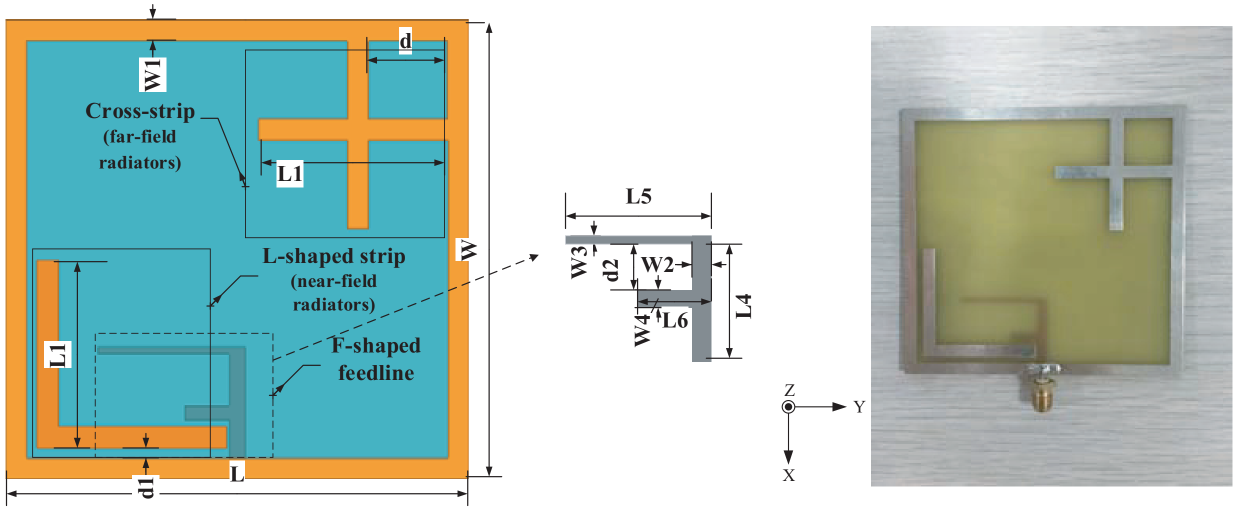
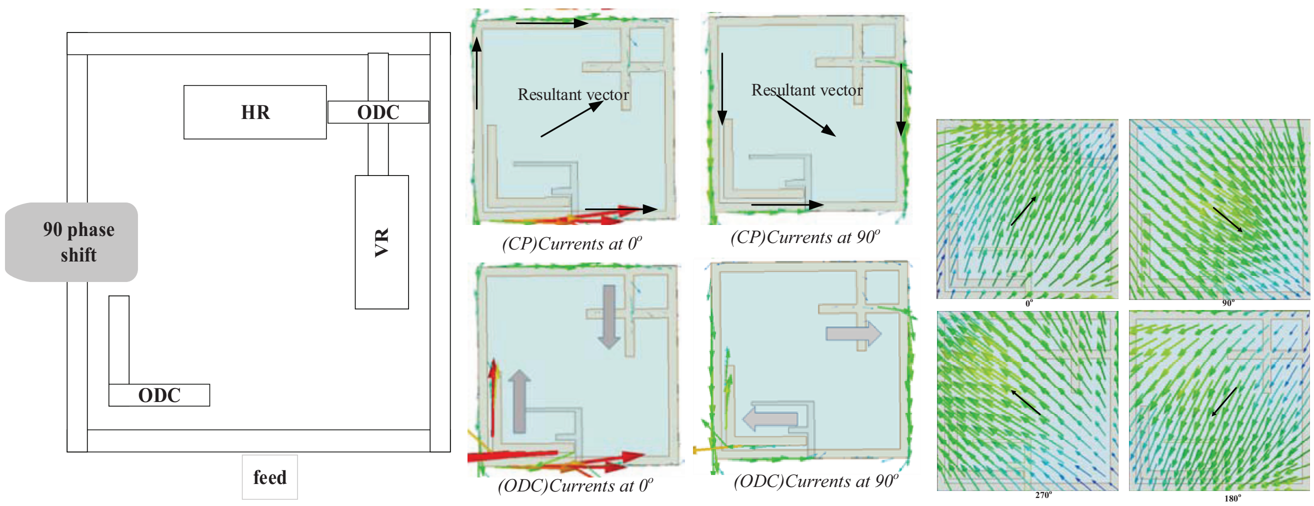
* Corresponding author: Xiaoxiang He (eexxhe@nuaa.edu.cn).
The authors are with the College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics (NUAA), Nanjing 210016, China.



(a) (b) (c)

Figure 1. Antenna prototype. Main geometrical parameters are: $L = W = 88\,\text{mm}$, $L1 = 36\,\text{mm}$, $W1 = 4\,\text{mm}$, $d = 15\,\text{mm}$, $d1 = 2\,\text{mm}$, $L4 = 24\,\text{mm}$, $L5 = 28\,\text{mm}$, $L6 = 11.5\,\text{mm}$, $W2 = 3\,\text{mm}$, $W3 = 1.5\,\text{mm}$, $W4 = 2.7\,\text{mm}$ and $d2 = 10\,\text{mm}$. (a) Top view. (b) Bottom view. (c) Physical antenna.



(a) (b)

Figure 2. Antenna currents distribution. (a) Design thought. (b) CP and ODC currents distribution at 0° and 90° when frequency is at 900 MHz.

applications in UHF band. Cross-strips are designed to excite vertical and horizontal components of electric fields. Side length is set to ensure 90° phase difference (Fig. 2(a)). Meanwhile, the currents on cross-strips are adjusted to satisfy ODC with L-shaped strip to generate magnetic field in NF region (Fig. 2(b)). High radiation efficiency (up to 98%–99%) and wide beamwidth (100° in xoz and 102° in yoz planes) achieved by F-shape feedline can also meet requirements of scanning for large regions. Measured tests are carried out by observing the RSSI values in terms of antenna read range. Measured performance in terms of reflection coefficient and tag detection is presented as follows.

2. ANTENNA LAYOUT AND PERFORMANCE

Antenna layout: The proposed multiservice antenna is composed of an L-shaped strip and a cross-strip on the top layer, 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(a)). The side length of the antenna is set as 88 mm comparable to quarter wavelength, which can produce 90° phase shift between horizontal and vertical currents on the cross-strip. An F-shaped feedline is also adopted on bottom layer of the substrate.

Performance: The CP electromagnetic wave is radiated by the cross-strip exciting vertical and horizontal components of electric fields. At the frequency of 900 MHz, the currents rotate in a clockwise direction as the phase is increased from 0° to 90° (Fig. 2(b)).

Therefore, the antenna excites left-hand CP (LCHP) radiation. In NF regions, the currents on cross strip are in opposite directions to that on L-shaped strip (Fig. 2(b)). The length of L-shaped strips is the same as that of cross strip (L1 is 36 mm). This can generate uniform magnetic field for NF tags. The design makes full use of currents on NF and FF radiators, and no extra structure is adopted, which also enhances the efficiency. An F-shaped feedline is also adopted on the bottom layer to broaden the impedance bandwidth, which includes the axial ratio bandwidth (ARBW) (Fig. 1(b)). The feedline can be viewed as two overlapping L-shaped lines with different lengths (separately L5 and L6). The horizontal strip (L5) can provide capacitive effects, and the other (L6) can be viewed as a tuning stub. Vertical strip can be adjusted to match the input impedance. By this method, the antenna can achieve good impedance matching. This can enhance the efficiency up to 98%–99% (Fig. 3) and broaden the beamwidth obviously because the gain is the product of directivity and radiation efficiency. Besides, parameters of the feedline are set small as soon as possible to have little impacts on magnetic uniformity for NF tags simultaneously. Antenna configuration and parameters are as follows (Fig. 1(c)).

Current distributions including CP and ODC respectively and designing thought are shown. In Fig. 2, the currents rotate in a clockwise direction, and the antenna excites LCHP radiation. Opposite directed currents form on L-shaped strip and cross strip on the top layer, which generate strong magnetic field in NF region. The measured antenna reflection coefficient is shown in Fig. 3. It is below −10 dB between 840 MHz and 950 MHz. As seen, the radiation efficiency is up to 98%–99%. Meanwhile, the feedline broadens the impedance bandwidth obviously.

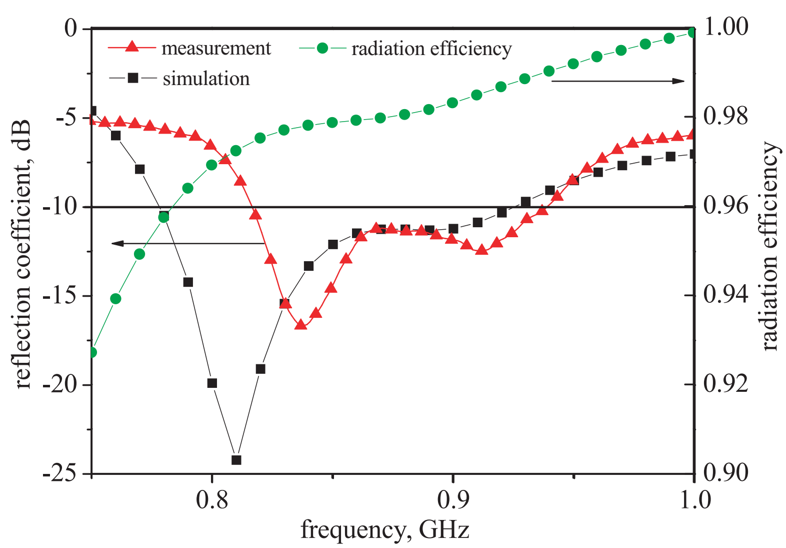


Figure 3. Measured reflection coefficient and radiation efficiency of proposed antenna.

Figure 4 exhibits the measured gain and axial ratio bandwidth compared to simulation. The measured gain is about 3.3 dBic, and ARBW of 20 MHz (885–905 MHz) is shown. Two horn antennas are adopted in the comparison measurement because of the limit experiment condition. Diffraction of electromagnetic wave occurs easily in microwave chamber. Apart from this, due to fabrication and

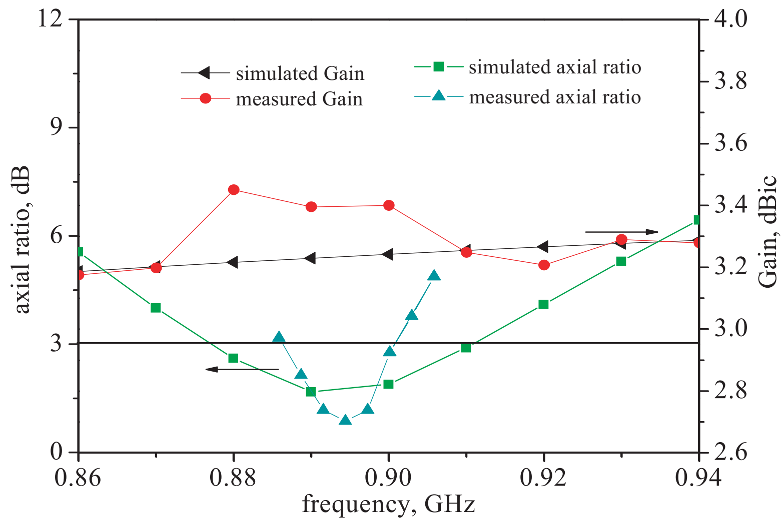


Figure 4. Measured ARBW and Gain.

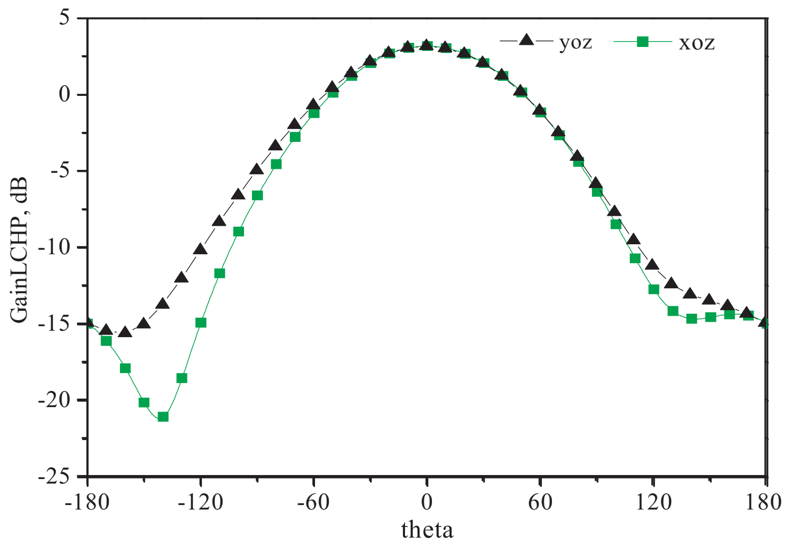


Figure 5. Measured Gain LCHP in *xoz* and *yoz* planes at 900 MHz.

manufacture tolerance, the allowable error exists in measurement. Fig. 5 gives the gain in *xoz* and *yoz* planes at 900 MHz. As seen, the half-power beamwidth is approximately 100° in *xoz* and 102° in *yoz* planes for high radiation efficiency and suitable gain.

The simulated magnetic field strength (|Hz|, dBA/m) along X-axis is shown at the center of the antenna when $Z = 5$ mm in Fig. 6. As seen, the strength is above -10 dBA/m, and uniform distribution of magnetic field can be obtained. More uniform and stronger magnetic field at a higher height can be obtained than [6]. Fig. 7 gives the magnetic field distribution of interrogation zone ($170 \times 170\,\mathrm{mm}^2$) at $Z = 10$ mm, 20 mm, 30 mm when the input power is set at 1 W. By increasing the height of zone from antenna surface, the strength of magnetic field is lowered. When the height is at 10 mm and 20 mm, the magnetic field is strong to identify all tags in the region. Even when the height is at 30 mm, the magnetic field strength is below -24 dBA/m just in a small part of the region.

To evaluate the performance in a real scenario, the proposed antenna has been integrated into a commercial desktop reader, and read range tests have been carried out. In this test, the near-field

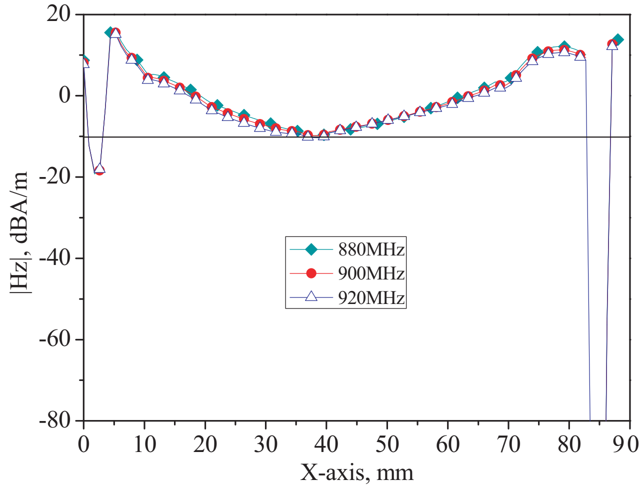


Figure 6. Simulated |Hz| along X-axis at $Z = 5\,\text{m}$.

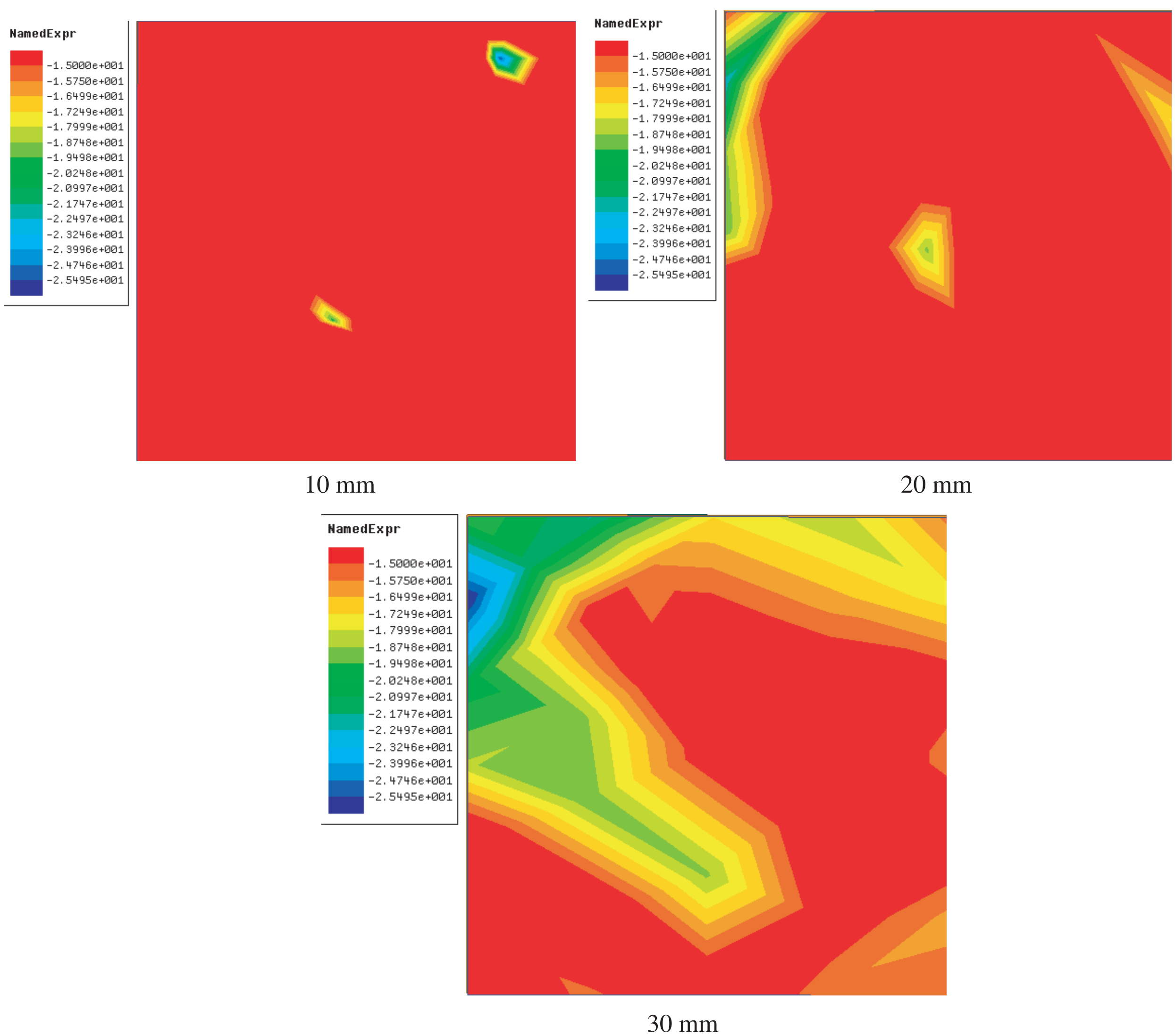


Figure 7. Simulated |Hz| distribution at $Z = 10\,\text{mm}$; $20\,\text{mm}$; $30\,\text{mm}$.

button tag (Impinj J41, |Hz| > −24 dBA/m) and far-field tag (Alien A9662 dipole-like) are separately chosen. Interrogation zone ($100 \times 100\,\mathrm{mm}^2$) is subdivided into 5×5 cells for NF tags, and $170 \times 170\,\mathrm{mm}^2$ of region is tested for far-field tags. Detection tests are repeated in each cell by varying the distance of the tag from antenna surface. In Fig. 8, the RSSI values are shown at different heights. By observing the RSSI values, the 100% read rate is up to 25 mm for the NF tag (Fig. 8(a)). Meanwhile, the far-field tag is tested along X-axis and Y-axis (Fig. 8(b)). The RSSI values of the far-field tag are close, and the measurement confirms that the far field of antenna is well circularly polarized. This can ensure far-field tags detection irrespective of their orientations, and the read distance is up to 1 m. Comparisons of the proposed antenna with other antennas are given in Table 1. As shown, the antenna can be applied in near- and far-field applications and also achieve high efficiency and wide beamwidth for scanning for large regions.

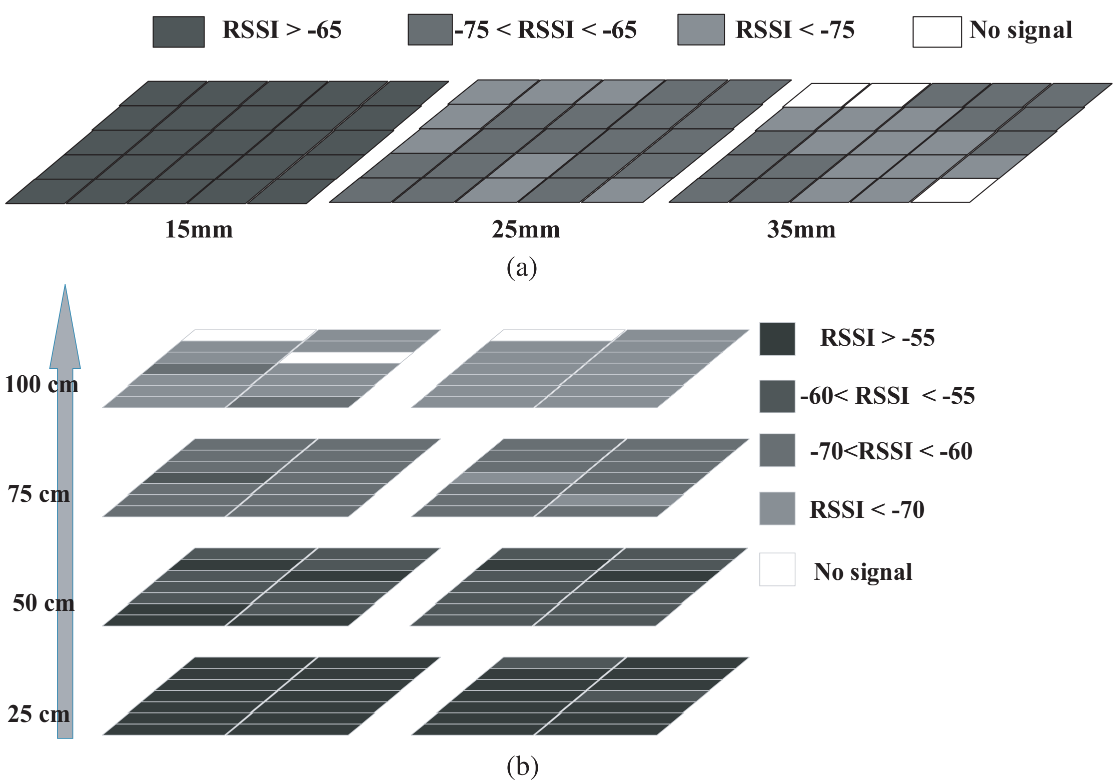


Figure 8. Tag detection test for NF and FF tag, by varying distance, position with respect to antenna surface. Input power has been set to 25 dBm. (a) RSSI values of near-field tags. (b) RSSI values of far-field tags along X-axis and Y-axis.

Table 1. Antenna comparison.

Reference	Far field	Near field Yes/No	radiation efficiency	3-dB beamwidth
[1]	CP	No	86%	76°
[2]	CP	No	92%	73°
[3–5]	LP	Yes	-	-
[6]	CP	Yes	85%	-
Proposed	CP	Yes	98%	102°

3. CONCLUSION

In this Letter, a multiservice antenna based on magnetic coupling in near-field regions and circular polarization (CP) in far-field is proposed for RFID applications in UHF band. The antenna also achieves high radiation efficiency up to 98%–99% and 102° of 3-dB beamwidth for scanning for large regions. 100% read rate of near-field tag is within 25 mm, and read distance for far-field tag is up to 1 m. The multiservice antenna has good prospect in both near-field and far-field applications.

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