Design of RFID Near-Field Focusing Circular Patch Array Antenna at 2.4GHz with Applications

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Abstract—In this paper, a planar circular patch array antenna that features electric fields focused in the near-field zone for 2.4 GHz radio frequency identification (RFID) applications is presented. This array antenna is implemented by using six circular patch elements and a microstrip feeding network with a proper input phase for each element. The array antenna is capable of enhancing electric field distributions in the near zone to charge and interrogate dipole-like passive tags near the array antenna by capacitive coupling. Readable range is measured for up to 12 tags lined up closely with 1 cm spacing. Applications using the proposed array antenna with an RFID reader by Sunlit are discussed.

Keywords—RFID, circular patch array antenna, near-field UHF reader antenna, near-field focusing, mutual coupling.

I. INTRODUCTION

Radio frequency identification (RFID) technologies [1], [2] have recently earned a lot of attentions in various applications, such as tracking goods, supply chain managements and retail store applications. Compared to the barcode system, the RFID system with automatic wireless data access can reduce the resource, cost and manpower for those applications. To tackle various requirements with better identification performance, many kinds of RFID systems rapidly arise. Low frequency (LF, 125-134 KHz) and high frequency (HF, 13.56 MHz) RFID systems are for short-range applications with inductive coupling between the reader and the tag antennas through the magnetic field. However, a number of UHF RFID near-field communication (NFC) systems for reading multi-tags have become a promising solution to item level tagging, such as point of sale (POS) and intelligent shelf [3]. Nevertheless, conventional reader antennas used for far-field reading may not perform well in the near-field region. Besides, for tags closely stacked or lined up together, the performance of the tags will be degraded significantly due to severe mutual coupling among them [4] [5].

Different from the inductive coupling using the magnetic fields [6]-[8], the capacitive coupling between the reader and tag antennas requires stronger electric fields to obtain better near-field reading. A 4×4 array configuration was studied to focus the radiating beam to a small spot in the near-field zone [9]-[11]. However, lower focusing performance for those array designs is expected due to higher dielectric and conductor losses. This is because complicated feeding network and array elements are utilized in the array structure. Also, those designs are too large to have strong electric fields in the near zone. A potential solution to those problems is to develop an array antenna system which utilizes a simpler feeding network with fewer array elements. Thus, the loss can be reduced and the electric field intensity in the near zone may be enhanced with such array design.

In this paper, we propose a novel circular patch array antenna operating at 2.4 GHz for enhancing the electric field distribution in the near-field zone. The proposed design is simply implemented by utilizing six array elements and a microstrip feeding network. Analogous to dielectric lens, with suitable input phases and feeding locations for the elements, this array can have good near-field focusing property for increasing the electric field intensity near and above the array to read several closely-aligned dipole-like tags with the capacitive coupling.

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II. ANTENNA GEOMETRY AND DESIGN CONCEPT

The geometry of the proposed circular patch array antenna with detailed design parameters is depicted in Fig. 1, which occupies a volume of 218(L)×166(W)×3.5(H) mm³. This array antenna possesses a double-layer structure that includes 2×3 circular patches on the top layer and a microstrip feeding network on the bottom layer. In our design, those circular patches to resonate at 2.4 GHz were fabricated on a 120 mil thick Arlon 870 substrate with a dielectric constant $\varepsilon_r$ and a loss tangent $\tan\delta$ respectively equal to 2.33 and 0.0013 to reduce substrate loss. The diameter of each patch is about equal to a half guided-wavelength at 2.4 GHz. Also, different from the conventional array design, the two rows of the elements have been fed inside back-to-back as shown in Fig. 1(a) to further enhance the electric field intensity in the near-field zone of the array antenna.

Furthermore, the feeding network of the array antenna is designed with suitable input phases for the array elements so that the electric field intensity and distribution are improved the most for locations at 10 cm right above the array for this near-field reading application. A 20 mil thick Arlon 870 substrate has been employed to construct the feeding network, where each element is fed by a 50 $\Omega$ microstrip line with a 0.4 mm via hole. As depicted in Fig. 1(b), the ground planes of the top and bottom layers are attached to each other and then become a single ground plane. To focus the electric field in the near-field zone, the central two elements have a phase delay relative to that of the adjacent four elements. With this array structure, the proposed array antenna is capable of concentrating the electric field for reading tags close to the reader antenna by the capacitive coupling. An electromagnetic software package, HFSS has been employed to simulate and analyze the electrical properties and near-field distributions for the proposed array antenna. The design parameters optimized for the array have been listed in Table 1.

III. RESULTS AND DISCUSSIONS

A. Near-Field Focusing

A prototype of the proposed near-field focusing patch array antenna has been fabricated and tested. The measured results were performed by using a vector network analyzer (Agilent PNA 8362B). Figure 2 exhibits the simulated and measured return losses versus frequency for the array antenna, where some discrepancies between them may be mainly attributed to the effects of the connector and feeding cable in the measurements. The impedance bandwidth with 12 dB return loss of the proposed array antenna is about 2.35-2.55 GHz, corresponding to 8.16 %, which well covers the 2.4 GHz RFID operation band. For such design structure, the total radiation efficiency is about 83 %, which is better than those of prior works shown in [9]-[11].

Electric field intensities in the near-field zone are evaluated to determine the reading area. With a 15×15 cm² observed

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**TABLE I. GEOMETRIC PARAMETERS OF THE PROPOSED ARRAY ANTENNA**

<table>
<thead>
<tr>
<th>L1</th>
<th>L7</th>
<th>W2</th>
<th>W8</th>
</tr>
</thead>
<tbody>
<tr>
<td>218 mm</td>
<td>10 mm</td>
<td>26 mm</td>
<td>18.1 mm</td>
</tr>
<tr>
<td>27 mm</td>
<td>25 mm</td>
<td>6.8 mm</td>
<td>16.5 mm</td>
</tr>
<tr>
<td>44 mm</td>
<td>25 mm</td>
<td>26 mm</td>
<td>33.9 mm</td>
</tr>
<tr>
<td>16 mm</td>
<td>10 mm</td>
<td>166 mm</td>
<td>26.2 mm</td>
</tr>
<tr>
<td>218 mm</td>
<td>23.5 mm</td>
<td>14.1 mm</td>
<td>15.9 mm</td>
</tr>
<tr>
<td>23.5 mm</td>
<td>166 mm</td>
<td>13.7 mm</td>
<td>38.3 mm</td>
</tr>
</tbody>
</table>
plane at a distance of 10 cm above the array antenna, the 
electric field intensities of the array antenna with a phase 
delay $65^\circ$ have been simulated, as shown in Fig. 3. This near-
field focusing circular patch array reader antenna can have a 
$13(L) \times 14(W)$ cm$^2$ reading area for 12 tags lined up closely 
with 1cm spacing at 10 cm above the reader antenna using a 
reader with 25 dBm output power from Sunlit.

Besides, the feeding network of the array antenna has been 
replaced by an FR4 stripline structure to reduce the cost and 
avoid the effects from the objects near and behind the antenna.
Also, the substrate of the patch array antenna has been 
changed to Rogers 5870. Figure 4 simulates the return losses 
for such design, where good performance across the 2.4 GHz 
RFID band is obtained. Compared with the previous design 
using Arlon feeding network and antenna substrate, the total 
efficiency of this design is 68 %, which is 15 % lower due to 
higher loss from the FR4 substrate. Figure 5 also depicts the 
simulated electric field distribution at 10 cm right above the 
proposed array antenna using the FR4 feeding network. The 
field strength is lower than that shown in Fig. 3. However, a 
$13(L) \times 14(W)$ cm$^2$ reading area can still be achieved with the 
design using the FR4 stripline feeding network.

**B. Applications**

An RFID reader consisting of the proposed near-field 
focusing array antenna with the Sunlit RFID reader module 
has been developed, as depicted in Fig. 6. This RFID reader 
using a microprocessor control unit (MCU) has been designed 
with a maximum output power of 25 dBm in the 2.4 GHz band.
Also, frequency hopping is utilized to have better reading 
performance for such design. Consequently, this RFID reader 
with an anti-collision function features a high performance in 
detecting multiple $\mu$-chip tags to reach real-time management,
such as tracking goods, supply chain managements and retail store applications. When multiple tags mounted on the objects are lined up closely, the problem due to mutual coupling among the tags and the reader antenna can be solved with the proposed near-field focusing array antenna design. Thus, near-range multi-tag identifications can be performed better for those applications.

For example, the resource and manpower in a library can be significantly reduced by using the RFID reader in the book management system of the library. As shown in Fig. 7, an operator holds the RFID reader for reading books on a shelf. In this application, the proposed near-field focusing array antenna has been mounted on a rod for scanning books. Besides, this RFID reader is also suitable for the POS system to replace the barcode scanner.

Fig. 6. An RFID reader using the proposed array antenna with the Sunlit RFID reader module. (a) Top view. (b) Bottom view. (c) Cross-sectional view.

IV. CONCLUSIONS

A 2.4GHz reader antenna based on the capacitive couplings for near-field RFID applications has been presented in this paper, where a 2×3 circular patch array antenna with the focusing property suitable for near-field RFID applications at 2.4 GHz has been discussed. Unlike the ordinary array design, this array antenna employs six circular patches fed back-to-back to enhance the electric field distribution in the near-field zone. Also, with a proper input phase for each array element, the near-field focusing characteristic of the array antenna has been utilized to improve reading multiple μ-chip tags by capacitive coupling. The electric fields in the near zone are enhanced so that the dipole-like tags lined up closely can be detected near the reader antenna. A reading area of 13(L)×14(W) cm² has been obtained at a height of 10 cm above the array. This focusing circular patch array antenna is a good design for the reader antenna of the UHF near-field RFID system to be applied for item-level reading such as in libraries and stores.

REFERENCES