Analysis of Quasi-circular Polarization in Near Field of Smart Shelf RFID Antenna Radiation

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Abstract— This paper presents the EM simulation and accurate analysis of quasi-circular polarization (CP) of the so-called smart shelf antenna designed for the UHF RFID retail and item-tagging applications. The design of the proposed antenna is based on the EM coupling between the open-ended or shorted-to-the ground meander microstrip (MS) line utilizing the standing wave current-voltage distribution and periodic metal strips printed on the top surface of a dielectric substrate. It has been confirmed by the series of full-wave EM simulations that the proposed antenna creates strong near field within the entire volume where multiple RFID tags are placed. The required quasi-CP near field has been numerically optimized by utilizing the three-section layout of the periodic metal strips and changing the angles of strip sections so that it results in both Ex- and Ey-components being produced. The prototypes with different layouts of the proposed antenna have been produced and their performance in the UHF RFID system has been verified.

1. INTRODUCTION

The radio frequency identification(RFID) technology continues to find numerous applications in a variety of industrial designs and solutions. Among the four different frequency bands used for RFID communications, UHF (865–960 MHz) band has attracted strong popularity and support of RF community because of its ability to provide varying read range and also high read and data rates. Recently, the concept of so-called smart shelf UHF RFID system has attracted much interest in retail industry and supply chain management [1–4]. In contrast to the conventional high gain read/write(R/W) antennas designed for maximizing the read range, the smart shelf antenna system utilizes the near field communication within a range close to a wavelength between the planar R/W antenna and several tagged items being placed on the shelf. To provide reliable detection of the multiple tags which can generally be distributed within a wide interrogation volume over the shelf surface, uniform and strong near E-field radiated over the smart shelf antenna is required. This paper presents the antenna design with an improved field distribution and analyzes the near field of such an antenna characterizedby quasi-CP radiation. Quasi here means that the E-field is also having z-component (normal to antenna surface). However, the most important property of smart-shelf antenna is its ability to produce the E-field having a well-balanced x- and y-components at the different distances from antenna surface and within an entire interrogation volume.

2. NEAR FIELD CALCULATION AND OPTIMIZATION

Typical scenario of the analysis of E field radiated by a planar smart-shelf RFID antenna is shown in Fig. 1. A 50-Ohm open-ended or shorted-to-the ground MS line on FR4 substrate is covered by the 1 mm-thick FR4 layer and on its top surface a few periodic 4 mm-wide metal strips are printed so that they are EM coupled to the MS feed line. Because of an open-ended or shorted termination, a voltage-current standing wave is produced. The strongest currents on the EM coupled strips are induced when they cross over the MS line at the points of zero current and maximum voltage. By utilizing the meander MS line and by making the electric length of meander sections between the neighboring strips equal to one wavelength, in-phase excitation of periodic elements is produced which substantially improves the uniformity of E-field distribution in the near-field zone and increases the amplitude of E-field radiated by the antenna. It has also been shown by CST MS simulation that the optimum length of periodic strips is approximately one wavelength so that they operate like a full-wavelength dipoles.

At a point P over the antenna surface the total E field can be calculated as

$$\vec{E}_T(x,y,z)=\sum_{n=1}^{N}\left[\vec{E}_d(x,y,z)\right]_n+\sum_{n=1}^{N-1}\left[\vec{E}_m(x,y,z)\right]_n \quad (1)$$

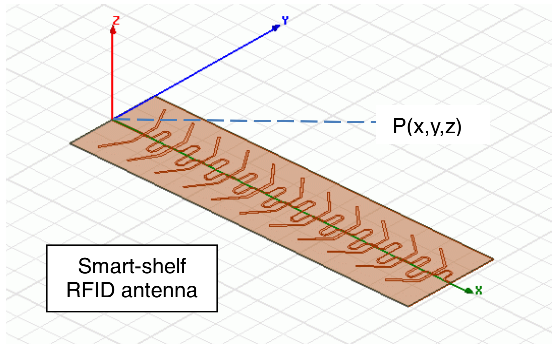

Figure 1: The geometry of a smart-shelf antenna and corresponding coordinate system.

where N is total number of EM coupled strips, E_d is an electric field radiated by each strip element while E_m is that radiated by a meander MS segment between the neighboring EM coupled strips. In a near-field zone, the total E field radiated by an antenna has Ez-component in addition to the Ex- and Ey-components being parallel to the antenna surface. Since the radiating strip elements and meander MS line are in XY-plane, it has been confirmed by EM simulation that

$$\left|\vec{E}_z(x,y,x)\right| \ll \left|\vec{E}_x\left(x,y,x\right)\right| + \left|\vec{E}_y(x,y,x)\right| \tag{2}$$

In the apparel tagging applications where tagged items are arbitrary oriented in the plane parallel to the antenna surface, the most important requirement is the antenna's ability to radiate the E-field with a well-balanced in amplitude and quarter-period in phase x- and y-components at the different distances from the surface and within an entire interrogation volume. In such a case, the antenna would produce a quasi-CP radiation in the near-field zone.

The required near-field optimization has been achieved by the specific strip layout as illustrated in Fig. 2 showing that each of the EM coupled strips consists of 3 sections. The angle forming the strips has been optimized so that the total E-field (1) formed in the near-field zone is a quasi-CP polarized in XY-plane. To further improve the uniformity of E-field distribution over the entire antenna aperture along X-axis, the angle of 3-section strip has been gradually changed from 30-deg close to input port to 50-deg for the elements at the antenna end as shown in Fig. 2. In addition to this, the length of strip elements has also been increased to widen the impedance bandwidth. The design frequency band has been 916.8 to 920.4 MHz but the obtained impedance bandwidth is more than 60 MHz. One example of the E-field distribution calculated in XY-plane at the distance $z = 40$ cm from the 50 cm-long smart-shelf antenna is shown in Fig. 3. Over the entire antenna aperture the E field amplitude exceeds the 1.5 V/m level required to activate an IC chip in UHF RFID tag. In time domain, the field vectors rotate as a RHCP.

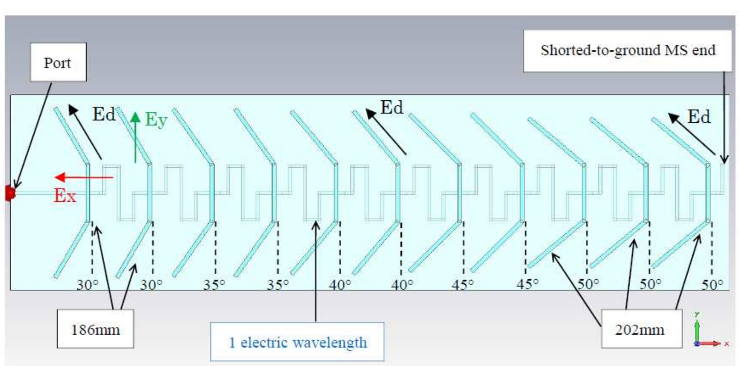

Figure 2: The detailed layout of the proposed smart-shelf antenna.

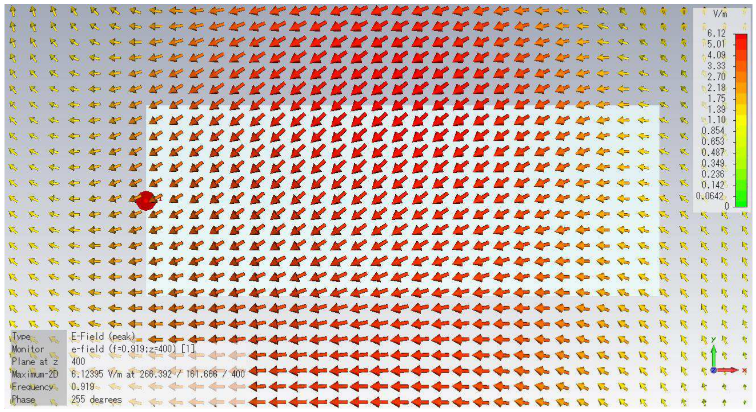

Figure 3: Time instant E field vector distribution at 919 MHz in XY-plane 40 cm over antenna.

3. MEANDER LINE EFFECT ON NEAR FIELD DISTRIBUTION

The MS line meander layout is very important for producing the required uniform E field over the antenna. As an illustration, consider the Ey-component distribution in the XY-plane at $z = 20$ cm radiated by an antenna with the straight MS line as shown in Fig. 4. Because of the symmetry in antenna elements layout with respect to x-axis, 0-field zone is produced along the x-axis in XZ-plane so that Y-oriented (and polarized) RFID tags cannot be activated there. In contrast to this, MS meander geometry produces strong Ey-component over the antenna's central part and removes such a "dead-zone" for tag interrogation as illustrated in Fig. 5.

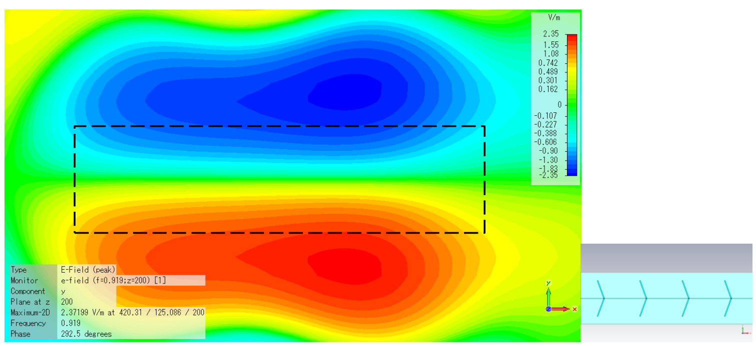

Figure 4: Ey-component distribution in the XY-plane at $z = 20$ cm, the case of straight MS line.

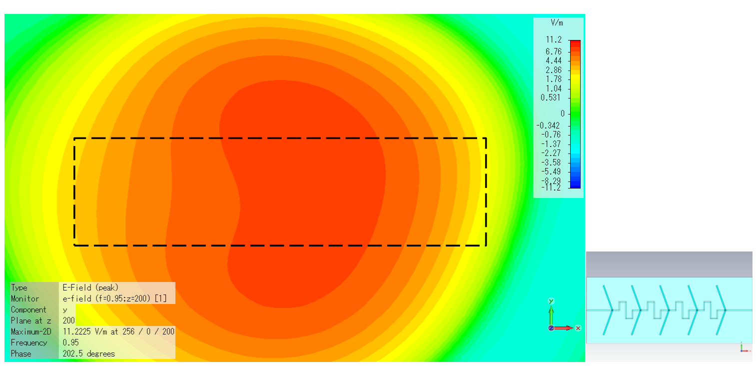

Figure 5: Ey-component distribution in the XY-plane at $z = 20$ cm, the case of meander MS line.

It has also been found out that the shape of MS meander can easily change the quasi-RHCP into quasi-LHCP field characteristics in the near field of the same antenna. Fig. 6 depicts the geometry of 1m-long antenna consisting of two parts with the same strip layout but opposite meander orientation with respect to x-axis.

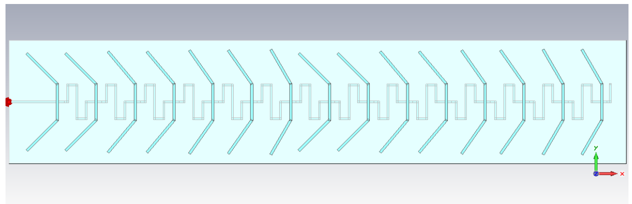

Figure 6: Geometry of 1 m-long antenna consisting of two parts with opposite meander layout.

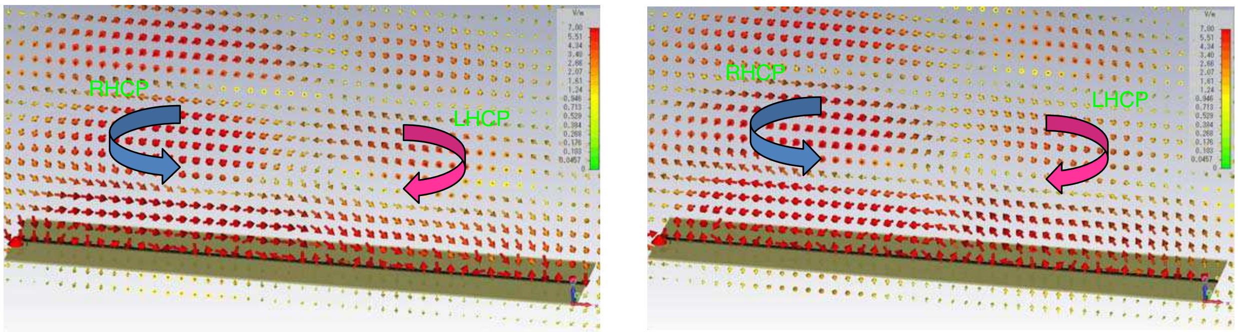

Figure 7: Two time instant vector E field distribution of the antenna shown in Fig. 6 in XZ-plane at $y = 0$.

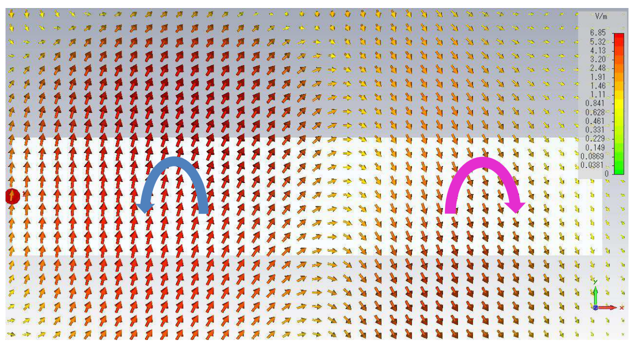

Figure 8: The same as in Fig. 7 but in XY-plane at $z = 40$ cm.

Time-domain analysis of 3D E-field vector distribution has shown that the field vectors over the antenna two segments rotate in opposite directions. Therefore, the antenna now simultaneously produces both quasi-RHCP and LHCP radiation within the different volumes over the antenna surface. The illustration of this effect is presented in Figs. 7 and 8 showing the time instants of vector E-field distribution in vertical XZ-plane at $y = 0$ and in XY-plane at $z = 40$ cm, respectively. The colored arrows here indicate the direction of the E field rotation.

4. CONCLUSION

The analysis of near field distribution of the antenna designed for smart-shelf UHF RFID applications has been presented. The required quasi-CP performance in the near-field zone has been achieved and optimized in the series of EM simulations by utilizing the three-section layout of the periodic metal strips and changing the angles of strip sections resulting in both Ex- and Ey-components being produced. Time-domain calculation of 3D E-field vector distribution has also demonstrated how a simple change of the meander line layout produces both quasi-RHCP and LHCP radiation in the near field of the same antenna. 100% detection rate and the measured read range of 40–50 cm for a large number of tagged items over the produced prototypes in UHF RFID system have confirmed the simulated near field distribution as well as an excellent performance of the proposed smart shelf antenna.

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