Optimized Near-Field Antenna for UHF RFID Smart Shelf Applications

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***Abstract*—This paper presents the design of UHF RFID read/write (R/W) antenna for the variety of smart shelf retail applications. Antenna operation is based on the EM coupling between the open-ended or shorted MS feed line and periodic planar metal strips of certain layout. The proposed antenna can be easily customized for the required volume of smart shelf RFID interrogation. Several antenna prototypes have been designed, produced and measured. The antenna performance has been evaluated in UHF RFID system for the simultaneous detection of arbitrary oriented tagged apparel items placed on the antenna surface. The proposed antenna demonstrates excellent ability to provide strong and uniform E-field distribution at the distances up to 50 cm form the antenna surface.**

I. INTRODUCTION

In the last couple of decades, the 70-years old RFID technology has found the tremendous popularity in a variety of real-life applications. Among the four different frequency bands used for RFID communications, UHF (865-960 MHz) band has gained strong support and investment 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 for communication between tagged items and planar R/W antenna taking place within the confined volume over the shelf has attracted much interest in retail industry and supply chain management. In contrast to the conventional high gain R/W antennas designed for maximizing the read range, the smart shelf RFID system operates in antenna's near-field zone. Specific requirements for the embedded into the shelf R/W antennas are the ability to cover the custom-sized, and often varying, tag interrogation volumes as well as planar and low-cost design layout. The solutions reported in the literature are straight and meandered microstrip (MS) loaded line [1], an asymmetrical meandered coplanar waveguide line [2], and MS structure with slotted ground plane [3]. All these smart shelf antennas produce the read range limited to 10 cm or less from the antenna surface and are able to detect the UHF tags oriented in a certain direction.

A combination of near-field antenna activating the near-field tags by the magnetic field and the conventional far-field patch antenna communicating with the electric field-type tags has been presented in [4]. However, to reduce the RFID system total costs utilizing the same type of tags in all possible interrogation zones is always preferable. It should also be noted that in apparel retail applications tagged items must often be detected within the extended volume above the R/W antenna, typically up to 50 cm. In addition, it is necessary to read the tags arbitrary oriented in the plane parallel to the shelf, an important condition not addressed in the previous works. An original idea for the design of planar smart shelf antenna has been introduced in [5]. In this paper, novel design of smart shelf near-field antenna with the improved E-field performance which satisfies the above mentioned requirements is presented. Modified layout of the proposed antenna has resulted in optimized near-field distribution and made it possible to communicate with multiple electric field-type UHF RFID tags within the extended volume of the smart-shelf interrogation.

II. NEAR-FIELD ANTENNA DESIGN

The layout of the proposed 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 1mm-thick FR4 layer and on its top surface a few periodic 4mm-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. For the shorted MS end, as shown in Fig. 1, the first strip should be placed quarter-wavelength away from the MS shorted point.

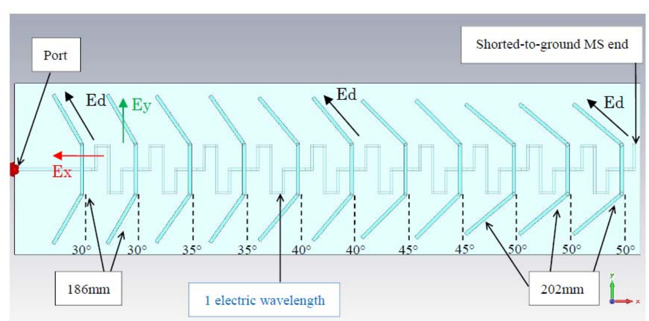

Fig. 1. Layout of the near-field antenna sized 20x75cm.

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 as has been confirmed by the calculated current distribution. In-phase excitation greatly improves uniformity of E-field distribution in the near-field zone and increases the amplitude of E-field radiated by the antenna. The distance from the MS line to the EM coupled strips (1mm in this design) has been optimized in terms of the induced strip current densities and antenna's impedance matching. 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.

III. ANTENNA PERFORMANCE

Fig. 1 shows that each of the EM coupled strips consists of 3 sections. The reason of such a layout is to produce evenly-balanced Ex and Ey-components in the near-field. The angle forming the strips has been optimized so that the total E-field Ed formed in the near-field zone as a superposition of fields radiated by all the strip elements and meander MS line can be characterized as a "quasi-circularly" polarized in XY-plane (quasi means Ez-component is also produced). Such a polarization of near-field is required for communicating with the RFID tags arbitrary oriented in the XY-plane at the different distances from the antenna surface. 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 illustrated in Fig. 1. In addition to this, the length of strip elements has also been increased to widen the impedance bandwidth. Such an effect is illustrated in Fig. 2 by comparing the calculated S-11 parameter of the structure shown in Fig. 1 with that of antenna where all the strip elements are 186mm-long. The design frequency band has been 916.8 to 920.4 MHz but the obtained impedance bandwidth is more than 60 MHz.

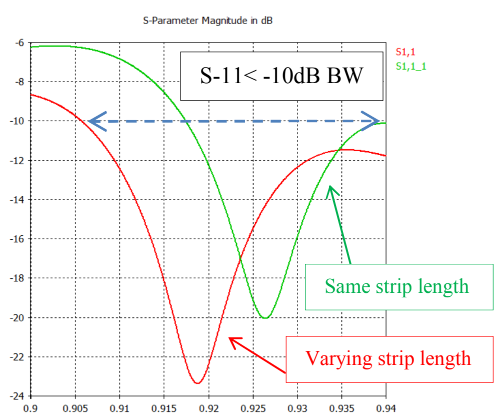

Fig. 2. Calculated S-11 for different lengths of strip elements.

Typical E-field distribution of the proposed antenna is shown in Fig. 3 where the field amplitude is much higher than 2V/m needed to activate the commercial UHF RFID tags in stacked apparel. E-field vectors are rotating in time domain as a "quasi-RHCP" radiation. Similar field distribution is observed at different planes parallel to the antenna surface. Several antenna prototypes have been produced and measured. One example of 2.6mm-thick smart-shelf antenna is presented in Fig. 4. The proposed antenna performs with 100% read rate for the multiple (20 to 30) tags being placed on various apparel occupying 20x70x50cm interrogation volume.

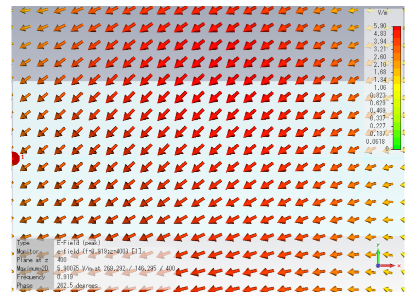

Fig. 3. Time-instant vector E-field distribution at 919 MHz in the XY-plane 40cm above the antenna shown in Fig. 1.

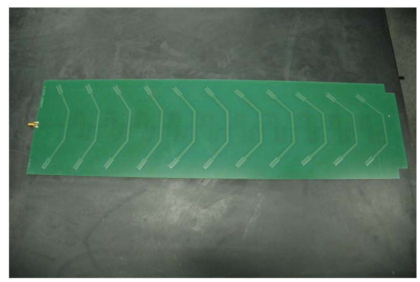

Fig. 4. Prototype of the proposed smart-shelf antenna.

IV. CONCLUSIONS

The design of novel near-field antenna for smart-shelf UHF RFID applications has been presented. The proposed design allows producing near-field antennas of various dimensions according to the custom requirements of smart-shelf UHF RFID systems. The designed antenna prototype demonstrates world-leading performance in terms of read range and uniformity of electric field distribution.

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