EM Analysis of Smart Shelf RFID Antenna with Reconfigurable Interrogation Zone

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***Abstract*—This paper presents the design and EM analysis of a near-field RFID antenna for the smart shelf applications where spatially-reconfigurable interrogation zone is required. Antenna operation is based on the EM coupling between the open-ended or shorted microstrip (MS) feed line and parallel planar metal strips printed on top of a dielectric layer. The novelty of the proposed design corresponds to utilizing the RF switches altering the length of meander MS line and thus changing the phase distribution of the radiating antenna elements. Near-field distributions calculated in the planes parallel and normal to the antenna surface illustrate the mechanism of extending an area of strong E-field necessary to activate multiple RFID tags.**

I. Introduction

During the last a few years, the so-called smart shelf UHF RFID system applications have become popular solutions in the supply chain management, office item-tracking and retail industry [1-3]. Specifically designed near-field antenna is a major element of any smart shelf RFID system. Novel design of a planar smart shelf antenna based on EM coupling between meander MS line and periodic metal strips has been introduced in [4]. In this work, an approach for extending the interrogation area of a planar UHF RFID near-field antenna by utilizing the reconfigurable MS layout is presented. E-field distributions calculated in the planes parallel and normal to the antenna surface show the detailed mechanism of time-domain change of the interrogation zone by activating the RF switches integrated into antenna layout.

II. Antenna Design and EM Analysis

The layout of the proposed antenna is shown in Fig. 1 and the design details are presented in [4]. Parallel metal strips are printed on the top surface of a FR4 substrate sized 73x20cm. They are EM coupled to the 50-Ohm MS feed line open-ended or shorted-to-the ground to produce a voltage-current standing wave and placed inside the substrate. Meander MS line segments having the electric length equal to one wavelength produce the in-phase current excitation of EM coupled strips. The strip length is approximately one wavelength (l=178mm) to optimize the input impedance performance at 902 to 928MHz UHF RFID band with 50-Ohm input port.

The in-phase excitation being realized when h=66mm produces the predominantly Y-polarized E-field with the amplitude strong enough to activate multiple RFID tags placed as far as 60cm in front of the antenna surface. Next, 3-port RF switches are integrated directly into the meander MS line to alter the meander electric length and thus to change the phase-condition excitation of the EM coupled strip elements.

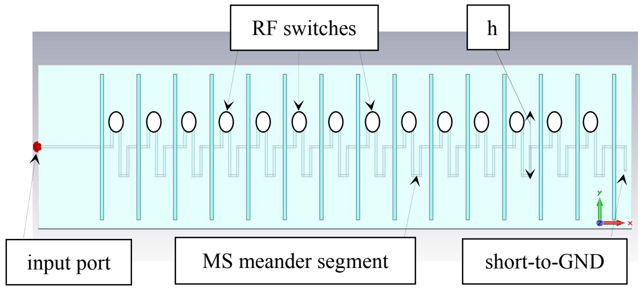

Fig. 1. The top-view layout of the proposed antenna showing the locations of RF switches integrated into MS meander line.

Fig. 2 depicts the E-field distribution in the xy-plane 20cm above the antenna surface calculated in the time domain (0 and 180 degrees phase) for h=73mm.

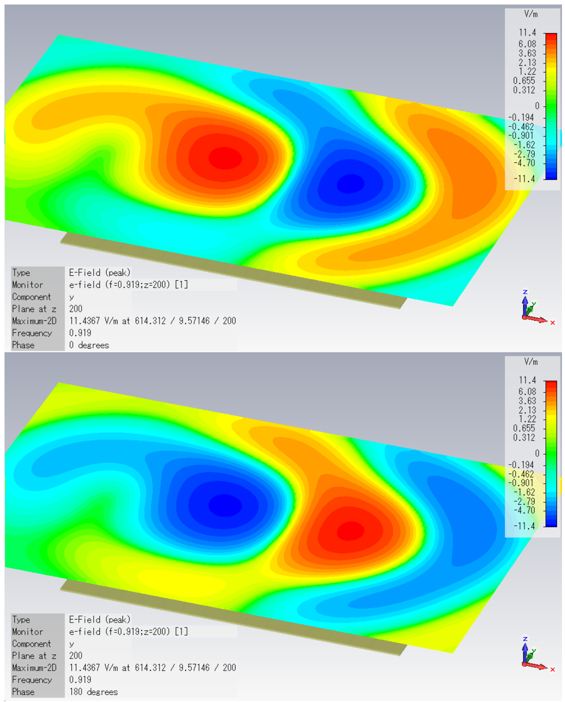

Fig. 2. E-field distribution at 919MHz in time domain at z=20cm plane.

The strong E-field is shifted to the right relative to the antenna area as a result of a negative phase shift between the neighboring strip elements. On-off activation modes of a 3-port RF switch makes it possible to alternate the length of the MS meander line so as to produce two modes of not-in-phase antenna excitation. In such a case, the proposed antenna operates similar to a fixed mode scanning phase array system.

This effect in illustrated in Fig. 3 showing the E-field distribution in the xy-plane 20cm above the antenna surface calculated in time domain for h=61mm. In Figs. 2 and 3, the antenna dimension is also shown. Compared to the results presented in Fig. 2, the area of strong E-field in Fig. 3 is clearly shifted to the left (along the negative x-axis). It can be seen that the antenna interrogation area has been expanded to make it wider along the x-axis. Therefore, the proposed antenna operates with a reconfigurable capability to spatially change the interrogation area as required in a variety of office item-tracking and retail RFID applications. The near-field scanning of this antenna has also been verified by analyzing the E-field distributions in the planes normal to the antenna surface, i.e. in the xz- and yz-planes.

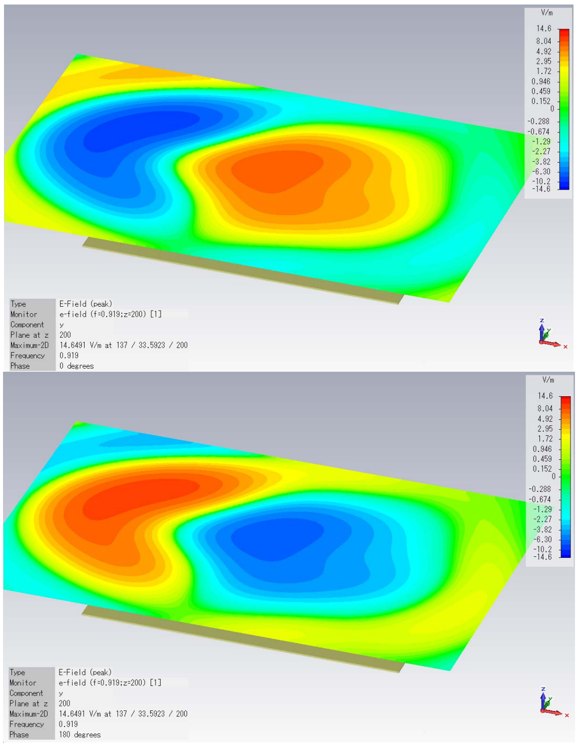

Fig. 3. E-field distribution at 919MHz in time domain at z=20cm plane for the case of h=61mm.

RF switch elements integrated into each meander segment of the MS line operate as the 3-port switches. Simple implementation of this design is the RF switch consisting of 2 pin-diodes placed at the specific points above the MS line and connected to it by via-holes. Fig. 4 shows the layout of a single MS meander segment with 2 pin-diodes forming the 3-port switch. Alternate activation of the pin-diodes shown by red and green arrows produces two antenna modes, namely with negative and positive phase shift between neighboring strip elements corresponding to different values of parameter h.

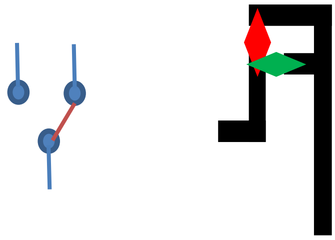

Fig. 4. 3-port switch (left) and its realization by 2 pin-diodes integrated into the meander segment of the MS line (right).

As an additional illustration of the antenna performance, Fig. 4 presents the far-field gain patterns at 919 MHz calculated for the varying length of the MS meander segments. For the in-phase excitation (h=66mm), antenna radiates mostly normal to its surface while the positive and negative phase shifts between the periodic elements result in the main beam being tilted to the left and to the right from z-axis, respectively.

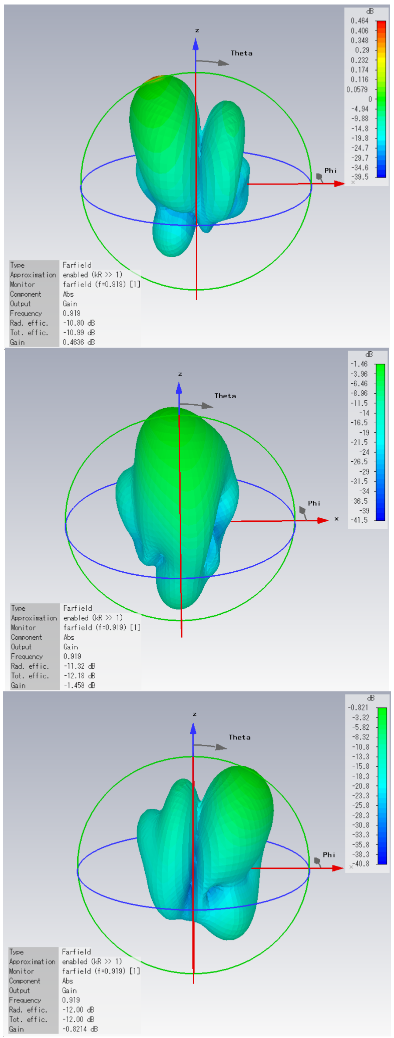

Fig. 5. 3D far-field gain patterns of the proposed antenna for h=61mm (top), h=66mm (middle), and h=73mm (bottom) at 919MHz.

To further illustrate the near-field scanning mechanism of the proposed antenna, E-field distribution calculated in the time domain in the xz-plane, i.e. normal to antenna surface along the x-axis is presented in Fig. 6. The E-field is normalized by 10V/m and the pictures correspond to 0 and 180 degrees phase instants for the case of h=73mm. Fig. 6 shows that the tilt of antenna radiation maximum is clearly observed in the near-field zone. Such a field distribution is a result of negative phase shift along the periodic strip elements. The E-field distributions shown in Fig. 6 correspond to the ones calculated in xz-plane and presented in Fig. 2. For the case of h=61mm, similar E-field distribution but with the tilt to the left from the z-axis is also obtained. An additional data on the EM field characterization of the proposed near-field antenna will be presented in the details at the Symposium.

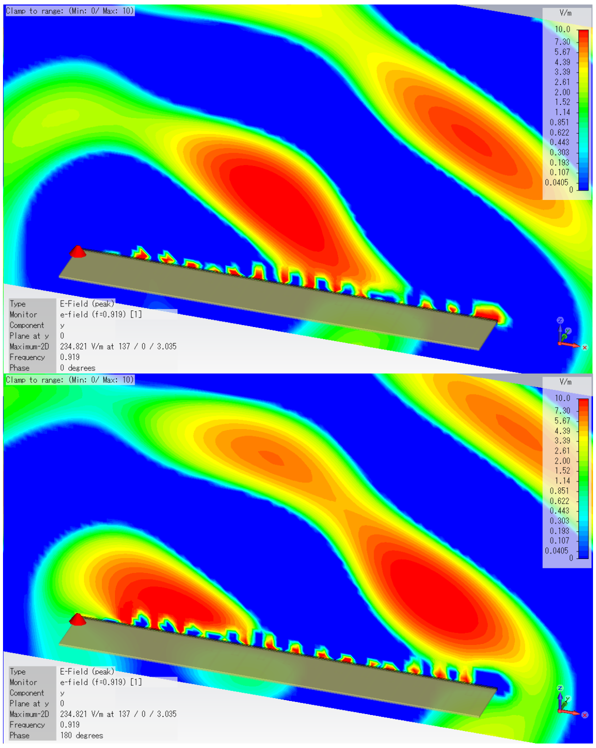

Fig. 6. E-field distribution at 919MHz in time domain at y=0 plane for the case of h=73mm.

The reconfigurable performance of the proposed RF switches integrated smart shelf antenna in the near-field can be illustrated by Fig. 7. It depicts an approximate location of RFID interrogation zones shown in different colors corresponding to the two modes of antenna operation by the appropriate on-off RF switches activation. The interrogation zone of this antenna is expanded to cover the additional volumes off both sides of the smart shelf footprint.

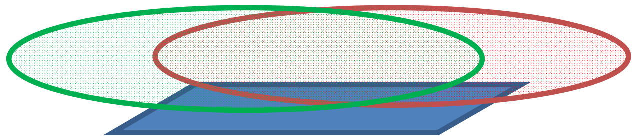

Fig. 7. Reconfigurable interrogation zones in the near-field of the proposed smart shelf antenna.

III. Conclusions

EM near-field analysis of the UHF RFID smart shelf antenna with reconfigurable interrogation zone has been presented. The design is based on integrating the RF switches into the meander MS line feeding the periodic strips printed on top of antenna surface. Two modes of not-in-phase periodic elements excitation result in the spatial shift of the RFID interrogation zone. The proposed smart shelf antenna design will find numerous practical applications in UHD RFID retail, item-tracking and security systems.

References

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