Two-dimensional Near-field Localization of Active Tag in the NFC Frequency Range

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***Abstract*—This paper describes a method for determining the position of an active tag in the form of a flat spiral coil within a fixed plane. The position is analyzed using a five-channel planar receiver system composed of three resonant coils. Signal amplitude values are used as the initial information parameters. The ability to identify the position arises from the unique mode structure of the field generated by the coils. Numerical calculations of the field distribution of the coils are performed, and the system's sensitivity to tag movement is evaluated. The examined coil system and the data processing technique enable two-dimensional spatial localization of the signal source, which can be applied in practical applications based on RFID technology.**

Keywords—Localization; Wireless Power Transfer; Near-Field interaction; RFID

I. INTRODUCTION

The problem of localization in both the near and far fields (at short distances) has received significant attention in recent years, as evidenced by the large volume of publications [1]. A review of the most-commonly used methods, including received signal strength indicator (RSSI), time-of-arrival (TOA), time difference of arrival (TDOA) is provided in [1]. For localization of RFID tags and their arrays, a combination of RSSI and received signal phase measurement methods is utilized as presented in [2]–[4].

There exists a substantial group of methods based on the connected homogeneous arrays of receiving elements [5]–[7]. These algorithms are based on the use of the so-called subspace method, which requires that the number of sources must be less than the number of sensors for a signal to noise subspace to exist. A Mixed Localization algorithm using the Exact model (MILE) source-sensor approach, which is based on large-scale multiple-input multiple-output (MIMO) technology, is introduced in [8].

Here we propose a technique for multichannel amplitude measurements that provides high sensitivity to the signal, a high slope of the system transfer characteristic and a wide range for determining the signal source offsets. This technique is based on the use of a compact system of three coils with a high degree of isolation achieved through polarization isolation and differences in the structure of the modes formed in the near-field space. The focus is on localizing a single source with a fixed orientation relative to its center of mass. It is assumed that the source is powered by a continuous harmonic signal at a frequency of 13.5 MHz, with a power level approximately corresponds to the maximum power output of a typical laboratory generator. By analyzing the relationships between the voltage amplitudes taken from five points of the receiving coils, it is possible to construct quasi-linear characteristics associated with the signal source's location over a wide range of its displacements. A key advantage of the computational methods employed is that they do not require any preliminary calibration of the system.

II. COIL SYSTEM DESIGN AND SIMULATION RESULTS

The flat spiral coil (tag) localization system consists of three coils: two printed rectangular (dumbbell-shaped) coils and one wire circular coil, all operating at 13.5 MHz. The numerical simulation of the system is analyzed using the finite element electrodynamic analysis software CST Microwave Studio. Figure 1(a) shows the general layout of the localization system, while more detailed coil parameters are presented in Fig. 1(b),(c). Large rectangular coils were made from a 2 mm FR4 substrate with 35 μm metallization. The active tag was made from a 1 mm substrate with similar material and metallization parameters. The size of the active coil roughly corresponds to the dimensions of a typical antenna embedded in plastic magnetic cards. Each coil of the system has an isolated connection to the ports.

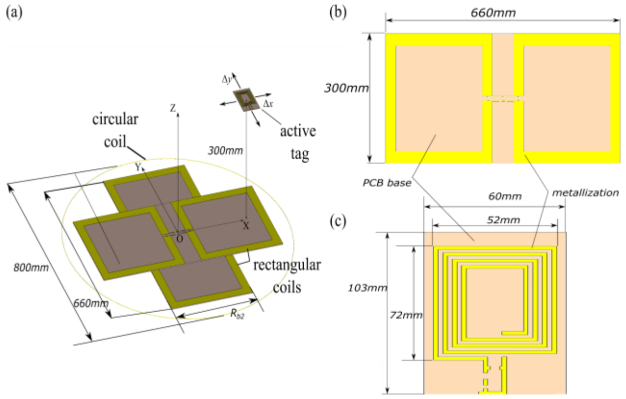

Fig. 1. Main geometrical parameters of the system of receiving coils (a),(b) and transmitting tag (c)

An important factor in maximizing sensitivity is the optimal resonance tuning of the large passive coils. It can be done by using capacitors C1=212 pF and C2=8.8 pF, connected to

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the coils as it shown in Fig. 2. In the operating mode, measurement of received signals is made by connecting high-impedance transmission lines to ports P1x and P2x. Tuning the circular coil to resonance is done in a similar way – the transmission line is matched to the input port by adjusting two capacitors C1circ=16.2 pF and C2circ=18.8 pF, connected in an L-type circuit.

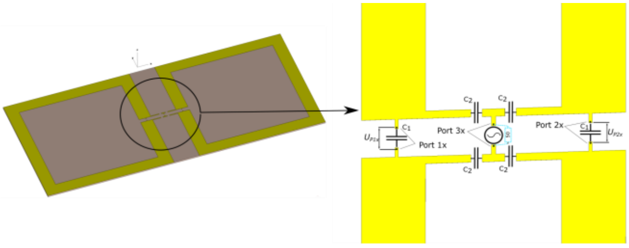


Fig. 2. The matching circuit and the port connection scheme for the large coil

Fig. 3 shows the distribution of the normal component of the magnetic field amplitude Hz in each of the orthogonal sections ZOY, ZOX of the three-coil system operating in the transmission mode. The power of the source connected to all coils in this work is the same and is equal to 16 dBm (maximum power of the available laboratory generator).

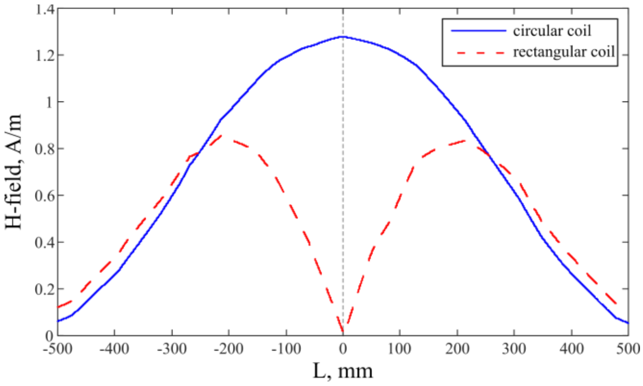


Fig. 3. Distributions of magnetic field amplitude of coils in the central sections of the system.

Due to the anti-phase of the half-waves of the field from the circular coils, one of them is always in phase and the other is always out of phase with the field of the circular coil. Therefore, while the active tag is above one of the amplitude maximum regions, it simultaneously excites currents in the corresponding turn of the rectangular coil and the circular coil. On the opposite side of the receiving coil, the field of the circular coil is out of phase with the field of the corresponding turn of the rectangular coil. This leads to a decrease in the amplitude of the currents flowing in it, as a result of which we register a difference in the signal level at the output ports. Thus, the spatial determination of the active tag position is reduced to analyzing the amplitude ratio at the output ports of the specified structure. As the initial data, Fig. 4 shows the frequency distribution of signals UP1x and UP2x (Fig. 3) at the corresponding ports at the position of the source on the following coordinates: x = 200 mm, y = 0 mm, and z=300 mm. The difference in signals indicates the possible identification of the active tag. In the given example it is located in the area of spatial maximum of field amplitude (Fig. 3).

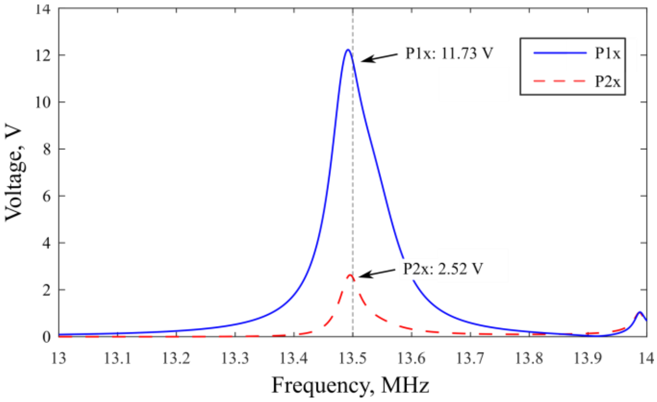


Fig. 4. Amplitude of signals at the output ports of the coils

Fig. 5 shows a series of plots of signal amplitude values at ports P1x, P2x and their difference, as well as the change in signal amplitude in the circular coil, using the example of tag displacement along the OX axis. Similar dependencies presented for ports P1y and P2y of the second orthogonal coil.

In Fig. 5, the range values are counted from the vertical axis passing through the geometric center of the receiving system. Analyzing these graphs it is possible to notice the unambiguous determination of the position of the external signal source relative to the coordinate center. This unambiguity is related to the sign of the received difference, otherwise – the phase of the difference signal.

Considering the ratio of signals at the ports P1x (P2x) or P1y (P2y) and the signal from the circular coil as:

$$Ux = \frac{U_{P1x(P2x)}}{U_{Pz}},$$

$$Uy = \frac{U_{P1y(P2y)}}{U_{Pz}},$$

then taking into account the mirror symmetry of signals in channels P1x and P2x (P1y and P2y) we can obtain the following graphs, specifically the distance' ratio, as it shown in Fig. 6(a). From the analysis of these figures it is possible to conclude the present ambiguity of distance definition. All of them can have identical values at different positions of a source along the distance axis. However, comparing the left and right branches relative to the origin of coordinates, s we can observe that on one of side they behave relatively monotonically. To preserve the monotonicity and, as a consequence, eliminate ambiguity, it is necessary to reduce the range of distance estimation. Fig. 6(b) is obtained based of this principle: using the branches of the graphs and the range of distances where they maintain their monotonic growth. This leads to the fact that at displacements of the source with respect to the main axes, can significantly reduce the range of reliable horizontal distance estimation. For instance, when the active tag is displaced along the OY axis by 500 mm, its coordinate along the OX axis can be measured within the range from -100 mm to 100 mm.

Similar curves to those in Fig. 6 will also appear when measuring the signal at ports P1y and P2y, with the signal source shifted parallel to the OY axis.

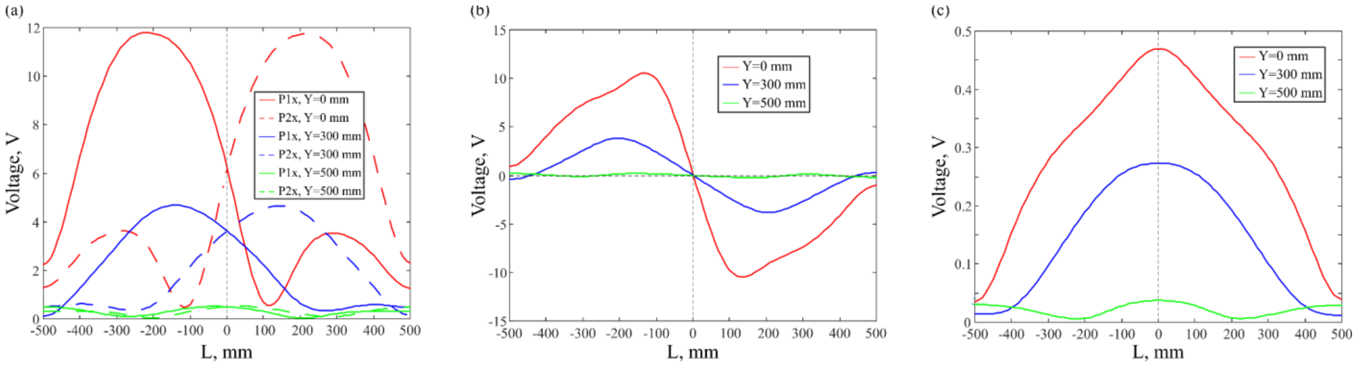
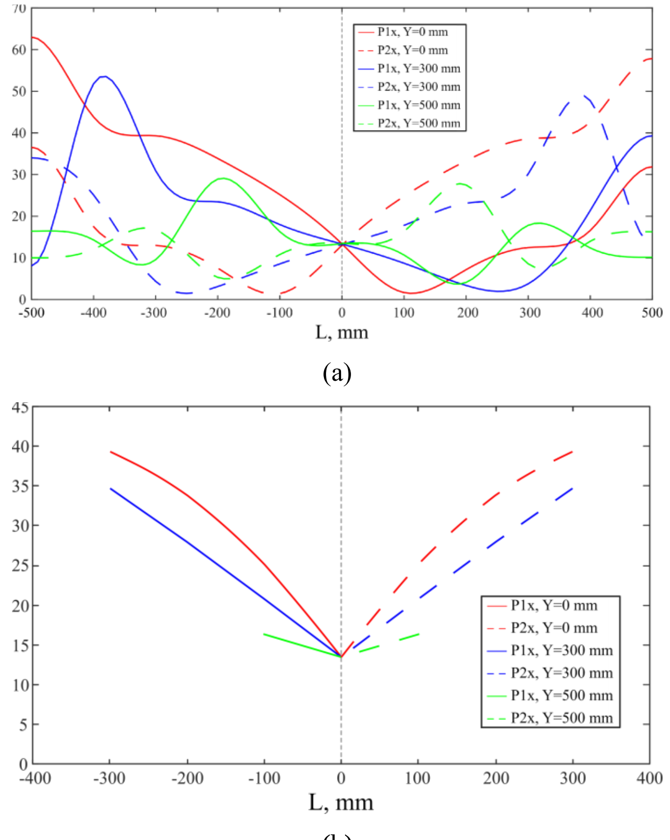


Fig. 5. Signal amplitudes in the ports (a), their difference (P1x – P2x) (b) and signal amplitudes in the circular coil port (c) at different transverse displacements of the active tag



(a)

(b)

Fig. 6. Plots characterizing the horizontal projection of the distance from the center of the receiving system to the signal source (the tag moves along the OX axis): (a) shows all branches of dependencies; (b) shows of only significant branches of dependencies

III. CONCLUSION

Thus, the considered model of the system consisting of two flat printed dumbbell-shaped coils and one circular coil, based on the amplitude ratios of voltages measured at specific connection points, allows the determination of the magnetic field source location with a steepness ranging from 6 dB/cm to 10 dB/cm at the frequency of 13.5 MHz. The field source here is a compact spiral coil, with its plane parallel to the receiving system, and all its movements occurring within this plane. The area of unambiguous determination of the active coil's location at a distance of 30 cm from the plane of the receiving system is 60x60 cm. Furthermore, as shown by additional analysis, increasing the distance to 50 cm expands this area to 80x80 cm. Notably, only five information channels are needed to analyze the location. The combination of these characteristics suggests that further investigation into the three-component inductance coil system is warranted.

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