Distance Determination of Active Tag Location in the Near Field of Two Coils on NFC Standard Frequency

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***Abstract*— This paper describes a method for determining the location of an active tag operating at 13.5 MHz, in the form of a flat spiral antenna (tag), placed between two receiver coils, with the possible presence of obstacles. Signal amplitude values are used as input parameters. The ability to determine the position is based on the preservation of the transfer (target) function of the "active tag-receiver coils" system, despite variations in the physical parameters of obstacles. Numerical calculations of the coil field distribution are performed, and the coefficients of the target function polynomials approximating the real dependencies are calculated. An estimation of potential location determination errors in the absence and presence of obstacles between coils is provided. The coil system and the data processing technique allow for one-dimensional spatial localization of the signal source, which can be applied in practical RFID-based applications.**

Keywords—localization; wireless power transfer; near-field interaction; RFID

I. Introduction

In the context of various laboratory research, medical and technical applications, the localization of objects in the near field has recently been given an important role. Measuring distance, calculating coordinates in a given direction is one of the special cases of this general problem. Various parameters such as signal strength (power), phase or arrival time are used to determine the position of an object. In received signal strength indicator (RSSI) method, the distance to the object is determined by the signal strength. While in the time-of-arrival (TOA) and time difference of arrival (TDOA) methods the time of signal arrival (time difference) is measured, the distance is determined by calculating the attenuation of the radiated signal or multiplying the radio signal velocity and transmission time [1]. For localization of RFID tags and their arrays apply a combination of methods RSSI and phase of the received signal, which is presented in [2]–[4].

However, for near-field communication (NFC) systems it is necessary to take into account some specific features, such as short reading range (up to 10 cm) and operating frequency 13.56 MHz (wavelength 22m) [5]. These factors complicate the use of methods based on signal phase or RSSI without significant modification of receiving antennas. For example, in [6] and [7] a traveling wave antenna for reading NFC tags is demonstrated. One-dimensional localization is performed using the TOA method. The maximum tag detection range is 10cm at 1W power, with antenna length from 5 to 48m. However, this method requires designing an antenna with low group velocity, which increases propagation losses. The problem of short-range detection of NFC tags can be solved by combining NFC and RFID tags as presented in [8]. The NFC tag handles the localization at short distances, while at greater distances, the RFID RSSI method is used. NFC tags can serve as auxiliary elements in indoor localization. For example, in [9] NFC in the phone is utilized to improve the localization accuracy. Additionally, NFC tags are linked to the indoor map [10].

However, none of the considered systems assumes the presence of obstacles between the receiver and the localization object. In this paper we simulate the presence of a shadow obstacle with a metal sheet and analyze its effort on the desired characteristic – the difference in amplitude of the received signals on two flat coils. These coils are located in parallel planes at some distance from each other, with the source, in the form of a small spiral coil operating at a frequency of 13.5 MHz, moving between them. As studies show, the dependence of the difference signal on the receiving coils at the displacement of the source is easily approximated with high accuracy. Moreover, this approximation approach for determining the target function works well even in the presence of obstacles, whose parameters only weakly affect the nature of this function.

II. Design of the coils

All the results presented below were obtained by using the finite element modeling software for electrodynamic processes CST Microwave Studio 2024. Calculations were performed using the Frequency Domain Solver module, with intermediate results combined in the Schematic module.

The localization system consists of two identical receiving square printed coils and an active tag. The active tag is a transmitting coil simulating the object to be localized, it is also a printed coil. The sizes of the active coil are chosen close to the sizes of typical coils used in standard devices operating in the range of NFC standard. Geometrical characteristics of receiving

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(large) and transmitting (small) coils are presented in Fig. 1. The dielectric material of the printed circuit board substrate is FR-4, with parameters ε = 4.3 and δ = 0.025. The thickness of the copper layer is 0.035 mm. The board thickness for the large coils is 2 mm, while for the small coils, it is 1 mm. The matching of all coils with 50 Ohm transmission lines and their simultaneous tuning to resonance was performed at 13.5 MHz by L-type circuits with two capacitors. Components of all matching circuits are placed on the printed parts of the coils. The metallisztion topology of the receiving coils was previously optimized to maximize the level of magnetic field generated at distances from its plane exceeding 10 cm.

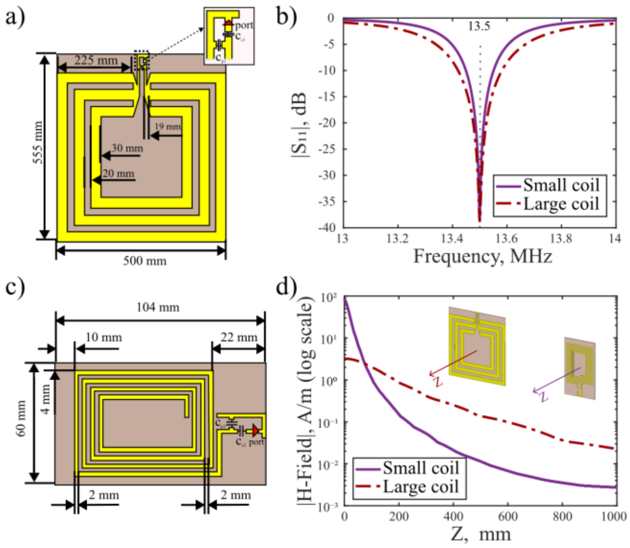

Fig. 1. Geometrical and electrical characteristics of the coils of the system: (a) characteristics of the large coil: Cs1=33 pF, Cp1=106.5 pF; (c) characteristics of the small coil: Cs2=18.3 pF, Cp2=106.5 pF; (b) reflection coefficients S11 of the coils; (d) magnetic field of the coils along the Z axis in logarithmic scale

III. Modeling of the Localization System

Illustration of the model of the whole system and its main electrical characteristics are shown in Fig. 2. The large receiving coils (1) and (2) are separated relative to each other at a distance of 1 m, while the small transmitting coil (3) moves between them (Fig. 2 *a*,*c*). The coil placement condition is as follows: all coils are placed on a single axis passing through their centers of symmetry and parallel to each other. The elements of the system are tuned by S-parameters (reflection coefficients) in resonance when the small coil is at the same distance (50 cm) from the large coils. The corresponding plots are shown in Fig. 2*b*. Fig. 2*d* shows the received signals at the large coils; it can be observed that the small coil interacts initially with the coil (1), and from a distance of d=50 cm it interacts predominantly with the coil (2). The resulting characteristic – the difference between the amplitudes of the received signals on the first and second coils – was also obtained. As it is possible to notice, this dependence is almost linear on a site from 350 mm to 650 mm that allows to define uniquely the position of an active coil on axis Z. The steepness of the obtained characteristic is 0.0015. Thus, it is possible to determine the change in the position of the mark on the OZ axis by 1 mm, with a minimum detectable change in the signal by 1.5 mV, the highlighted area is shown in Fig. 3*a*.

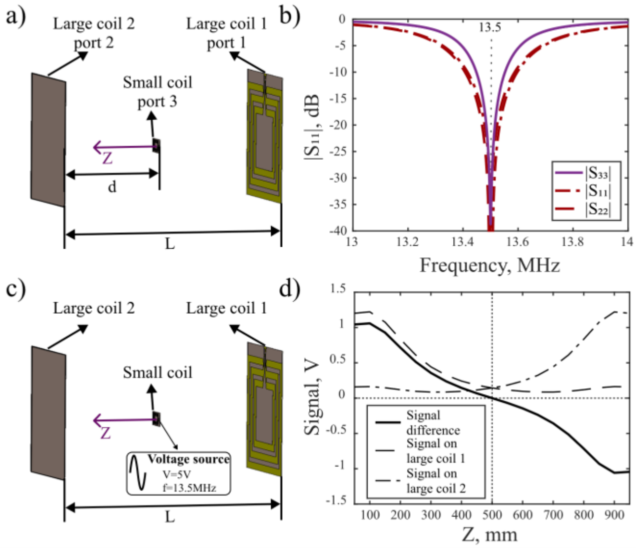

Fig. 2. Coil system and some electrical characteristics: (a) initial position at tuning: Cs1=35.6 pF, Cp1=236.5 pF, Cs2=18.3 pF, Cp2=106.5 pF, distance between coils L=1000 mm; (b) frequency dependences of reflection coefficients of the system coils at d=500 mm: S11(S22), S33 - for receiving and transmitting coils; (c) motion of the transmitting coil between the receiving coils: Cs1=35.6 pF, Cp1=236.5, Cs2=18.3 pF, Cp2=106.5 pF; (d) amplitudes of harmonic signals received by coils 1 and 2

IV. Localization Accuracy, Approximation of the Target Function

Nevertheless, the range of the linear section between 350 mm and 650 mm appears to be insufficient in relation to the total pickup coil spacing. Therefore, a more accurate approximation by means of a nonlinear function was considered. The graph of the target function (without obstacle) and variants of its approximation are shown in Fig. 3. The initial dependence permits the unambiguous determination of the position of the small coil along the Z-axis.

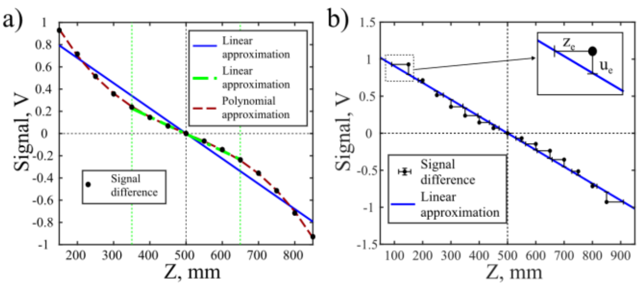

Fig. 3. The selection of the degree of the approximation polynomial of the target function and calculation of the error: (a) approximation variants of the obtained dependence; (b) approximation error for linear dependence at z from 150 mm to 850 mm

Expressions for approximating dependencies are given below. For linear: $U_a = a_0 z^0 + a_1 z^1$; for linear polynomial approximation:$U_a = a_0 z^0 + a_1 z^1 + a_2 z^2 + a_3 z^3$. The approximation error of the difference function U_e is found as the difference between the function obtained from the simulation and the one that approximates it: $U_e = U - U_a$. To find the longitudinal displacement error z_e, we first need to calculate the function inverse to the approximating function ${U_a}^{-1}$, then find the difference: $z_e = z - {U_a}^{-1}(U)$.

Table 1 summarizes the relevant coefficients and the resulting errors.

TABLE I. EVALUATION THE PARAMETERS OF APPROXIMATION FUNCTIONS AND THEIR ERRORS

	Approximation coefficients			
	a_0	a_1	a_2	a_3
Linear	1.1336	-0.0023	0	0
Polynomial	2.0170	-0.0093	1.6×10^{-5}	-1.06×10^{-8}
	Approximation error z_e			
	min, mm	***max, mm***	***mean, mm***	
Linear	16×10^{-4}	59.75	32.28	
Polynomial	0.05	3.56	1.91	
	Approximation error u_e			
	min, V	***max, V***	***mean, V***	
Linear	3.6×10^{-6}	0.136	0.07	
Polynomial	7.42×10^{-5}	0.015	0.006	

Table 1 indicates that the polynomial approximation should be employed in subsequent analyses, as it gives the lowest errors (z_e and U_e).

V. EFFECT OF SHADOW OBSTACLE ON LOCALIZATION

In practical applications where object localization is required, the environment is often subject to dynamic changes. This means that extraneous interfering objects may sometimes appear between the tag and the receiving systems. Such obstacles can introduce errors in the estimation of the coordinates of the object location. However, the analysis of the results from electrodynamic modeling shows that the system under study is resistant to obstacles that may occur near one of the receiving coils. These obstacles included aluminum sheets of two sizes – 65x65 cm2 and 30x30 cm2. [1] Fig. 4*a*,*c* shows the counseling systems and Fig. 4*b*,*d* shows the signal differences obtained from the receiving coils.

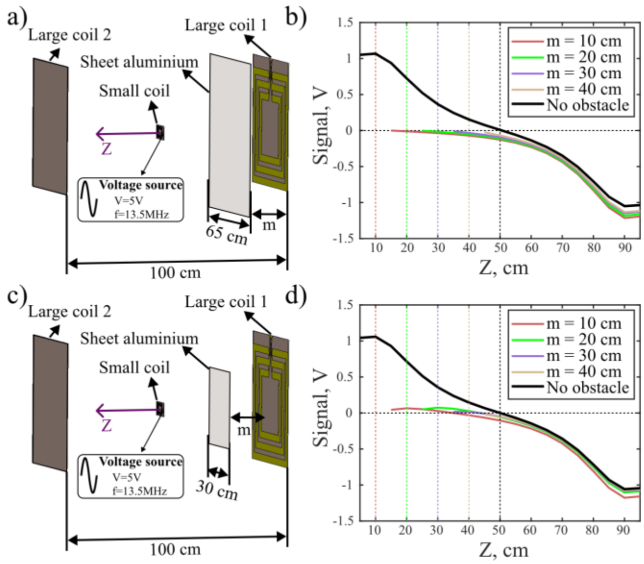

Fig. 4. The coil system and its electrical characteristics: (a) the large sheet; (b) the difference signal from the receiving coils in the presence of the large sheet; (c) the small sheet; (d) the difference signal from the receiving coils in the presence of the small sheet

The figures clearly show that when the active tag is located close to the central region, the accuracy of its position detection depends slightly on the displacement of the obstacle and its size. It is even more important to note the fact that the presence of a shadow object does not change the character of the difference signal when the marker is displaced. This observation allows us to derive the average values of approximation coefficients and further evaluate the resulting errors.

VI. LOCALIZATION ACCURACY IN THE PRESENCE OF THE OBSTACLE

Fig. 5 shows the plots of the target function for different obstacles, as well as the average approximating curves. The approximating dependencies and their corresponding errors are obtained in the same way as before.

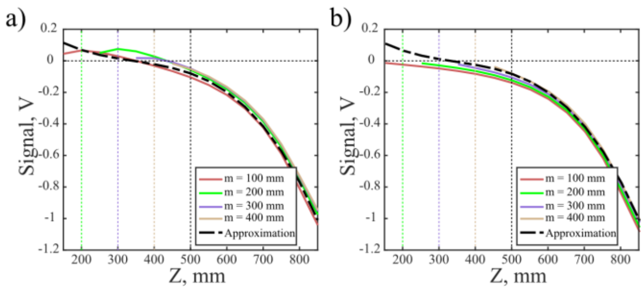

Fig. 5. Graphs of dependencies of the difference signal and its approximation on the tag position in the presence of obstacles: (a) with aluminum sheet 30x30 cm2; (b) with aluminum sheet 65x65 cm2

Table 2 presents the data on the approximation coefficients, and Table 3 presents the resulting errors when using the averaged curves when locating the source of the signal.

TABLE II. EVALUATED FUNCTION APPROXIMATION COEFFICIENTS WITH DIFFERENT OBSTACLES

Obstacle		**Approximation coefficients**			
Size, cm	*m, cm*	a_0	a_1	a_2	a_3
30	10	0.24	-0.0017	4.7×10^{-6}	-5.27×10^{-9}
	20	0.23	-0.0013	3.97×10^{-6}	-4.77×10^{-9}
	30	0.23	-0.0016	4.82×10^{-6}	-5.36×10^{-9}
	40	0.024	-0.0018	5.31×10^{-6}	-5.67×10^{-9}
65	10	0.22	-0.0022	6.3×10^{-6}	-6.45×10^{-9}
	20	0.42	-0.0033	8.14×10^{-6}	-7.44×10^{-9}
	30	0.67	-0.0044	9.86×10^{-6}	-8.26×10^{-9}
	40	0.8	-0.0047	10.1×10^{-6}	-8.26×10^{-9}

TABLE III. DATA ON APPROXIMATION ERRORS

Obstacle		**Error z_e**			**Error U_e**		
Size, cm	*m, cm*	*min, mm*	*max, mm*	*mean, mm*	*min, mm*	*max, mm*	*mean, mm*
30	10	3	87.4	20.16	0.003	0.7	0.2
	20	3.5	138	43.7	0.013	0.06	0.3
	30	7.7	103.4	35.7	0.02	0.6	0.4
	40	9.28	60	24.3	0.03	0.06	0.04
65	10	10.7	216.3	81.02	0.03	0.12	0.06
	20	5.1	121.8	44.53	0.014	0.05	0.035
	30	0.045	42.92	15.8	0.001	0.02	0.013
	40	1.05	25.6	6.2	0.002	0.2	0.01

VII. CONCLUSION

A passive system of planar inductance coils and a technique for one-dimensional localization of the active tag between the coils were proposed. This system, implemented by electrodynamic modeling, allowed to determine the location of the tag with an error of no more than 3.6 mm. At the same time, the tag operates at a frequency of 13.5MHz and radiates a signal. A distinctive feature of this coil system and the method of processing the results is the ability to maintain relatively high accuracy in the presence of obstacles between the active coil and one of the receiving coils. If the presence of a foreign object between the coils can be identified, pre-calculated averaged correction factors can be applied to the approximating dependence. This dependence will be close to the form of the system's overall transfer function. In the presence of obstacles, such as flat metal sheets that may exceed the dimensions of the receiving coils themselves, the maximum position error of the coil will reach 220 mm within a range of z distances from 150 mm to 400 mm. The minimum error is observed in the range of z distances from 500 mm to 850 mm and is 10 mm. Thus, the results obtained are interesting for rangefinder systems that are part of localization systems and operate in the NFC range.

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