Proposal of Novel Sensor Applicable to Contactless Displacement Measurement

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Abstract. *The paper deals with sensor design, which is applicable for contactless displacement measurement. Sensing principle is based on change of electromagnetic field properties. They are changed during resonance of electrical part of the sensor. In this paper there is in detail described the sensor construction. The sensor consists of the mechanical part – load cell and electrical part – parallel resonance circuit, which is implemented on load cell body. Structure of the load cell is proposed so that the value of resonance frequency is dependent on size of sensing displacement. The change of electromagnetic field properties is in turn visible in behaviour of easily measurable input parameters of the electromagnetic field radiator.*

Keywords: Electromagnetic Field, Mutual Impedance, Parallel Resonance Circuit, Load Cell

1. Introduction

Nowadays it is more popular the design of sensors applicable to micro and nano-technologies, where the mechanical parts of structures are in micrometer or nanometer dimensions. These structures are usually named MEMS. For realization of ultra-high precision systems in deep sub-micron or nano-scales one of important sensors is displacement sensor. Different methods for realization of high precision displacement sensor have been used. In this area, optical methods, ultrasound methods, methods using piezoelectric materials and new opto-mechatronics method opens new insight to sensor design.

In this paper we introduce new sensor applicable for contactless displacement sensing. The working principle of this sensor is based on measuring method making use of electromagnetic energy. This method is applicable for signal transmission and for the measurement of displacement. The advantages of this method are high sensitivity and usability in harsh environment such as ultra-high vacuum systems [1].

2. Mutual impedance between wire structure

Let us consider an electromagnetic field, which is generated by a wire structure, specifically by half-wave dipole 1. Put another dipole 2 into the vicinity of the dipole 1, as it is shown in Fig. 1. We must take into account the mutual effects between dipole 1 and dipole 2. This interaction causes the mutual impedance creation between dipole 1 and dipole 2:

$$Z_{21i} = -\frac{1}{I_{1i}I_{2i}}\int_{-h'}^{h'} E_{z21}(z')I_2(z')dz' \tag{1}$$

where

I_{1i}, I_{2i} – input current of dipole 1 and dipole 2, respectively
$E_{z21}(z')$ – component of E-field radiated by dipole 1, which is parallel to dipole 2
$I_2(z')$ – current distribution along dipole 2

Equation (1) describes the electromagnetic (EM) field $E_{z21}(z')$, which is the field radiated by dipole 1 at any point on dipole 2. This kind of EM radiation causes the change of input impedance of dipole 1 due to generation of the mutual impedance Z_{21i}. One may say that the change of this input impedance indicates a presence of the dipole 2. As it is evident from equation (1) the mutual impedance is changing together with current distribution $I_2(z')$ of the dipole 2, too. Current distribution of dipole 2 is mainly changed with its dimension (arm length – h'). It means that the input impedance change of dipole 1 contains not only information about presence of some conducting object, but also information about its basic physical dimensions [1].

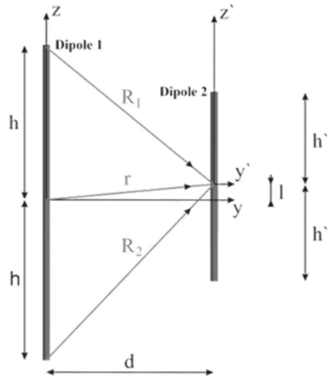


Fig.1. Dipole positioning for mutual coupling

According to [1], when dipole 2 is in the EM field, it acts as resonance circuit at some frequency. Based on this, there is possible to replace dipole 2 with a LC resonance circuit (Fig. 2 b)), whereby a relation in equation (1) is still valid [2]. The distance of the capacitor plates is in this case represented by a distance between two planar parts of load cell. The dipole 1 is need replaced by EM generator with constant amplitude-frequency characteristic at the operating frequency band. The stripline is used as convenient EM field generator [3].

3. Modelling of the sensor for numerical calculation

It is necessary to create the numerical model of designed sensor to verify the theory described above. The precise solution of the model may be obtained by numerical Method of Moments (MoM). MoM is mainly focused on solve current distribution on conducting surface. In order to calculate dielectric parts of sensor MoM is combined with Finite Element Method (FEM). This kind of solution which combines several methods is known as hybrid framework. In the computational code FEKO, several numerical techniques are used combining the MoM with high frequency asymptotic techniques, and also with mentioned FEM.

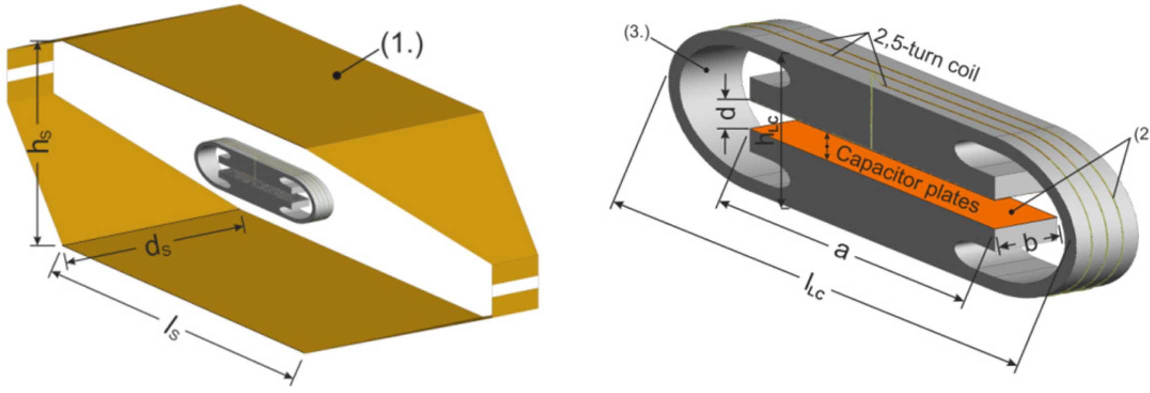
Created model of the sensor is shown in Fig. 2. The sensor structure consists of EM field generator – stripline (1.) and electrical part – parallel resonance circuit (2.). The resonance circuit with load cell [4] (3.) create coupled unit as it is shown in Fig. 2 b). Specific equivalent materials and dimensions of modelled sensor structure are stated in Table 1.

Table 1. Parameters of modelled sensor:

Used materials:	Structure parts:	Important dimensions:
Brass (σ=2,5647 S.m^{-1})	Stripline	l_S= 100 mm, h_S= 50 mm, d_s= 50 mm
Silver (σ=6,1737 S.m^{-1})	LC resonator	a= 30 mm, b= 5 mm, d=0-2 mm, n=2.5
Teflon (ε_r=2,08 F.m^{-1})	Load cell	l_{LC}= 50 mm, h_{LC}= 100 mm

n – count of inductor winding

As it was previously mentioned the sensing principle is based on resonance frequency change of sensor's electrical part, which is dependent on distance between capacitor's plates [2]. Considering this fact the shape of load cell was designed. During the sensing process specific parts of load cell (where plates of capacitor are implemented) are changed. As it was mentioned before, the behaviour of the wire structure at the resonant frequency is similar to those of resonant circuits. Therefore, it is necessary to analyse influences of such a resonant circuit on the stripline's input characteristics. We consider the scattering parameter s_{11}.

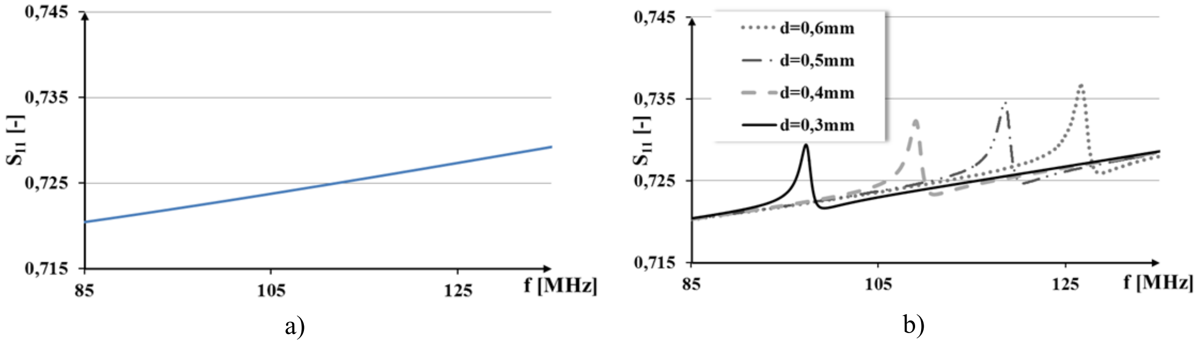


a) b)

Fig. 2 a) Full structure model in CADFEKO environment, (1.) – stripline
b) Electrical part (2.), load cell (3.)

4. Numerical simulation results

The frequency dependence of s_{11} of the stripline without sensor's structure is shown in Fig. 3a). The s_{11} curve of such a structure is not constant. Increase of the s_{11} in operating frequency band is caused by imperfect adaptation of stripline input and output parts. This is not an issue to next simulations.



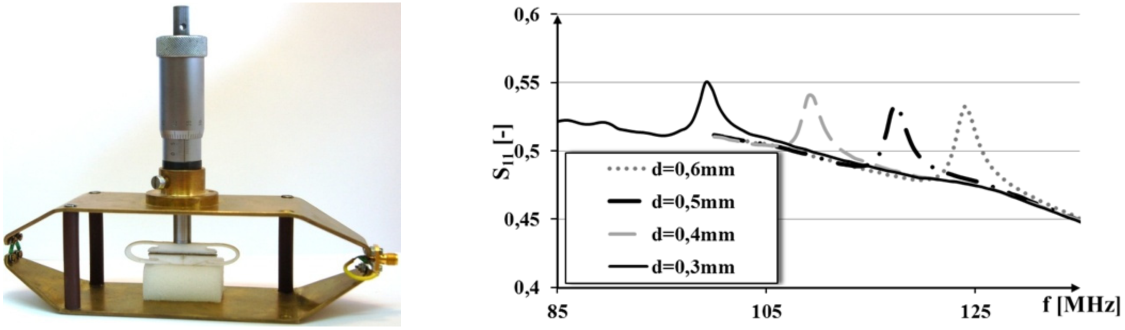
a) b)

Fig. 3 a) The s_{11} curve of stripline
b) The frequency position of s_{11} local maximum as a function of distance capacitor plates

The s_{11} curve of stripline is distorted, if the coupled unit (parallel resonance circuit with load cell) of proposed sensor is placed in the middle of the stripline, as it is shown in Fig. 3b). The deformation or peaks are manifested when the parallel resonance circuit begin to absorb the energy from EM field. Absorbed EM field energy is used for the self-resonance of the resonant circuit. The frequency position of local s_{11} maximum corresponds to resonance frequency of resonance circuit as it is investigated in detail in [1].

5. Real structure measurement

The real model of proposed sensor was created to verify results obtained by numerical calculation. The real structure of sensor we can see in Fig. 4a).The sensing distance of real sensor model was changed by micrometer screw gauge as we can see in Fig. 4a). The s_{11} measurement (Fig. 4b)) by network analyzer confirms functionality of created model of sensor. We can observe difference in amplitude course between calculated (Fig. 3b)) and measured (Fig. 4b)) s_{11} parameter. This kind of difference could be neglected because the sensing distance is represented by frequency position of local s_{11} maximum. The little frequency variations between numerical and measured results are caused by many factors like different inductance of coil, inaccurate of real model dimensions.



a) b)

Fig. 4 a) Real model of proposed sensor
b) The s_{11} curve obtained by measurement on real structure of sensors

6. Conclusions

Results of numerical modelling and measurement on real model confirmed that the proposed sensor is suitable for displacement measurement. The sensing principle uses a method based on change of electromagnetic field parameters. This method is described in detail in [1] and appears to be perspective measurement method applicable in micro or macro area not only for distance or displacement measurement, but also for another physical quantities measurement such as pressure, temperature and so on.

Acknowledgements

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