Analysis of Possible Short Length Measurement Using Energy Sucking of Electromagnetic Field

L. Marsalka, R. Hartansky

Dept. of Measurement, Slovak University of Technology, Ilkovicova 3, 812 19
Bratislava, Slovakia
Email: lukas.marsalka@stuba.sk

Abstract. *The paper deals with taking advantage of electromagnetic field energy sucking to measure very short distances, for example in microstructures. A mechanism of two wire structures, which are situated in the vicinity, effect, a variation of their mutual and input impedances and the influence of one segment's length to frequency dependence of other are described.*

Keywords: Short Distance Measurement, Electromagnetic Field Energy, Mutual Impedance

1. Introduction

Nowadays multi-discipline project using state of art technologies from various fields gain ground, whereby synergic effect is achieved in many cases. One of such a field is theoretical design and experimental realization of micro-electromechanical components, or elements, which may work as autonomous unit performing simply function. In our case, it is a measurement of extremely short distances necessary for control of micro-objects [1]. A process of gripping shall be integrated with a process of actuator control and a process of measurement of distance between the gripper's arms. Some limitations exist in the gripper's dimensions and micro-movement of the arms. An use of tensometers or utilization of magnetostriction or electrostriction properties are limited at such dimensions [2].

Another complication occurs in information transmission between the gripper and external control unit. Based on these considerations, an idea to use one of physical characteristic of the microstructure to ensure rf electromagnetic energy for signal transmission and for the measurement of arms distance. If the position of arms affects an incident electromagnetic field that some of field parameter (magnitude, phase or frequency) contains information about the distance between the arms, it would be an ideal case of measurement. At first it is necessary to focus on the antenna theory and to create an equivalent rf model of the structure, which is situated in electromagnetic field, to verify such a hypothesis.

2. Coupling between wire structures in electromagnetic field

Consider an electromagnetic field, which is generated by a wire structure – half-wave dipole 1. The dipole's length is 2h, so it has a resonance at frequency *f* given by:

$$f = \frac{c}{4h} \tag{1}$$

where *c* is speed of light. The input current of the dipole depends on its input impedance, which value is changing according to [3]:

$$Z_m = -\frac{1}{I_m^2} \int_{-h}^{h} I_z(\rho = a, z = z') E_z(\rho = a, z = z')\, dz' \tag{2}$$

As it can be seen from (2), the input impedance varies with the change of a current distribution I_z *(ρ=a, z=z')* and a *z* component of electric field E_z *(ρ=a, z=z'),* or more simply with frequency. So, input current also varies with the frequency of a signal. Put another dipole, with same dimensions as dipole 1 has, into the vicinity of the dipole 1, as it can be seen in Fig. 1.

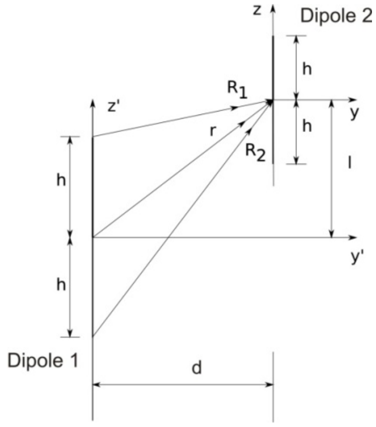

Fig. 1. Mutual impedance between two dipoles

The dipoles start to interact. This interaction causes an origin of mutual impedance between dipole 1 and dipole 2:

$$Z_{21i} = -\frac{1}{I_{1i} I_{2i}} \int_{-h}^{h} I_2(z') E_{z21}(z')\, dz' \tag{3}$$

where $E_{z21}(z)$ is the field created by dipole 1, which affects the dipole 2. Also the input impedance of dipole 1 and input current of this dipole are changing due to mutual impedance Z_{21i} origin. One may say that the change of current of the incidence dipole indicates presence of the dipole 2. As it can be seen from (3) the mutual impedance is changing with current distribution of the dipole 2 and the current distribution is changing with dimensions of the dipole 2 [3]. It means that the input current flowing into the dipole 1 contains not only information about a vicinity of some conducting object but also about its dimensions.

3. Numerical modeling of wire structures

It is necessary to solve equations (2) and (3) to verify the mentioned consideration. Formulation of current *Iz(z)* of dipole 1 or dipole 2 represents the most problematic part of the solution. This formulation is linked to solution of Maxwell's equations, or wave equation in form of integral Pocklington's equation. A general solution of Pocklington's equation does not exist [3]. Therefore numerical solution was chosen. The best method to solve hereof the problem is method of moments (MoM), which solves such kind of equations with sufficient

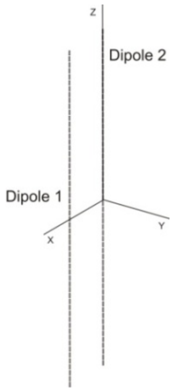

Fig. 2. Model of two dipoles in FEKO simulator.

accuracy. There exist also many commercial software products which have implemented the MoM. The simulation model of two wire structures in simulator FEKO are shown in Fig. 2.

The dipole 1 is situated in z-axis and it is supplied by rf voltage in frequency range from 700MHz to 1.2 GHz. Level of a input power P_{12} of the dipole 1 is changing with the frequency of input signal. The input power is maximal at resonant frequency. If the dipole 2 is approached the dipole 1, the variation of input power P_{12} may be observed (see Fig. 3).

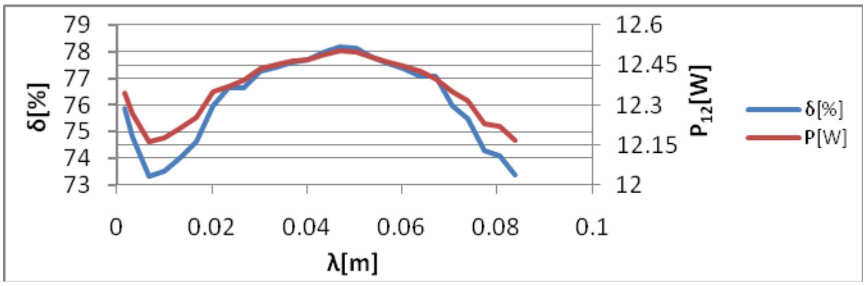

Fig. 3. Dependence of input power on the distance between two dipoles at resonance

The distance between dipoles is expressed as a ratio of the distance to resonant wavelength of the dipole 1 in Fig. 3. The input power of the dipole 1 is equal to P_{11}=7.017W if no other dipole is in its vicinity. If power P_{11} is chosen as a reference value, we may obtain the relative change of input power of dipole 1 regarding to the distance from dipole 2:

$$\delta(\%) = \frac{P_{12} - P_{11}}{P_{11}} \tag{3}$$

A graphical description of the mentioned change is in Fig. 3. It may be seen that the input power changes its value maximally up to 78% over the value P_{11} due to presence of other dipole.

In respect of results shown in Fig. 3, one may say that the input power of the dipole 1 is affected by conducting object in its vicinity. The object – dipole 2 has the same length than the dipole 1th both were in resonance.

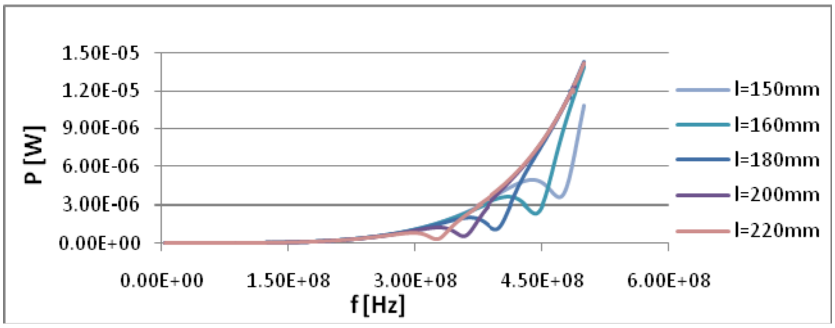

Fig. 4. Frequency dependence of input power on length of conducting object

In next our research was focused on investigation of the influence of dipole 2 of various lengths on a behavior of input power of the dipole 1. It means that it is necessary to observe sensitivity of power P_{12} on length of the dipole 2. The model of simulation is similar to the previous one in Fig. 2. The difference between models is that the dipole 1 is electrically short in respect of a wave. Its length is $2h_1$=146mm. The dipole 2 has length of h_2, which is varied during the simulation process. Distance between the dipoles is constant d=10mm.

As it can be seen in Fig. 4, input power of the electrically small dipole – excited dipole – tends to arise exponentially with increasing frequency. If some conducting object is situated at its vicinity, e.g. influencing dipole, this such tendency of input power is changed, such a characteristic has a local minimum. If length of the dipole's arm is $h_2 = 150$mm such maximum appears at frequency of 465 MHz, if the length is $h_2 = 220$mm maximum is at 319 MHz. Frequency of the characteristic's local minimum depends on dimensions of the influencing dipole, or on its resonant length. Considering a resonance at dipole's physical length:

$$2h = \frac{\lambda}{2} \tag{4}$$

it is a half-wave dipole. Then, the resonance appears at frequency:

$$f = \frac{c}{\lambda} = \frac{c}{4h} \tag{5}$$

Where *4h* is double physical length of influencing dipole. Resonant frequency of influencing dipole with arm's length $h_2 = 150$mm is fr = 499MHz and with $h_2 = 220$mm it is fr = 340MHz. Similar results has been obtained by numerical simulation. The difference between calculated and simulated values are caused by real thickness of the dipole. In such cases the resonance appears at lower frequencies than it is achieved (reciprocal value of half of the wavelength) [3].

Swell of a curve of electrically small dipole's input power appears at frequencies equivalent to half-wave lengths of conducting object - influencing dipole – also to its physical length. Generalizing this consideration, it is possible to measure the object's length by means of an energy generating electromagnetic field in vicinity of the electrical dipole.

4. Conclusion

Analytic model as well as numerical simulation confirmed change of the input power of the excited dipole due to effect of near conducting object. A magnitude of such a change depends on the distance between the dipoles and a frequency of this change depends on the dimensions of the object. This paper shows an interlacing between dimensions (length) of the object and an overshoot of input power of the excited dipole at specific frequency. Such a phenomenon may be utilized as perspective method of distance measurement of conducting object in electromagnetic field. The method transforms directly a length to frequency, which may be easily and accurately measured. Sensitivity of such the method on variation of length of near conducting object (for example arms of the microstructure) depends on the equation (5). Such a change can be till hundreds of MHz if we consider dimensions of the microstructures.

Acknowledgements

This work was supported in part by Ministry of Education of the Slovak Republic under grant 2003SP200280202 and by grant project VEGA 2/0006/10.

References

[1] Binka J, Hricko J. Compliant Mechanisms Exploited as Micro-Grippers in State-of-the-Art in Mechatronics, Volume II. Simulation Research Press, Alphen aan den Rijn, 2010.

[2] Durina P, Stefecka M, Roch T, Noskovic J, Trgala M, Pidik A, Kostic I, Konecnicova A, Matay L, Kus P, Plecenik A. Patterning of Nanometer Structures by Using Direct-Write e-beam Lithography for the Sensor Development in proceeding ASDAM 2010, 2010, 89-92

[3] Balanis C. A. Antenna Theory Analysis and Design. John Wiley & Sons, New York, 1982, 1997.