ИЗМЕРИТЕЛЬНАЯ ТЕХНИКА

УДК 621.317.1

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INTERFERENCE OF ELECTROMAGNETIC FIELD SENSORS

This paper deals with determining of interference of orthogonal sensors (dipoles) of electromagnetic field, which measure a magnitude of electric vector of the field. The interference is primarily expressed by a change of mutual impedance between the sensors. The mutual impedance is varying with spatial arrangement of the sensors and also with a frequency. This phenomenon affects induced voltage at terminals of sensors and directional pattern of sensor arrangement as well as an accuracy of the measurement.

Keywords: electromagnetic field measurement, electromagnetic compatibility, mutual impedance of dipoles, probes of electric field, moment method, numerical methods

1. Introduction

In area of electromagnetic compatibility (EMC), rf techniques and telecommunication especially, there is a necessity to measure one of components of the electromagnetic field. Since electric – E and magnetic – H components of the field are vector quantities and their directions are generally unknown, it is necessary to make measurement of three orthogonal components of these fields.

Then the measurement of electric field means measurement of components |Ex|, |Ey|, |Ez| as it may be seen in Fig. 1.

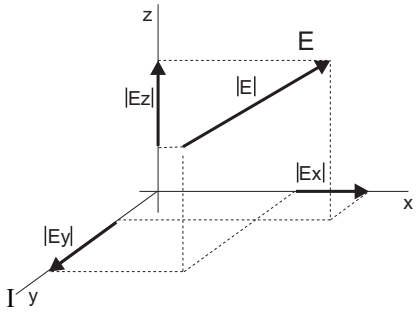

Fig. 1. Vector of electromagnetic field and its components

If dipole antennas are used to field measurement, they have to be arranged to be identical with the axis x, y, z. Hence, magnitude of the electric field can be obtained as:

$$|E| = \sqrt{E_x^2 + E_y^2 + E_z^2} \ . \tag{1}$$

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It means, that every antenna (dipole) measures the component of electric field, which is tangential to itself. An example of such dipole arrangements is in Fig. 2. The dipoles (sensors) are creates orthogonal system, where equation (1) is fulfilled.

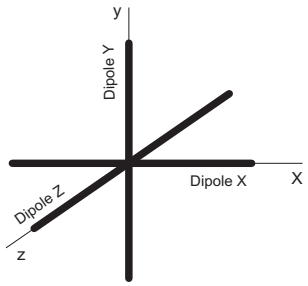

Fig. 2. Arrangement of three sensors in space

As it is evident from the Fig. 2, such implementation of the dipoles is not possible. It is necessary to consider real dimensions of dipoles – their thickness and the point of feeding connection. It means that it is not possible in practice to place three dipoles so that they will have one common point, as it may be seen in Fig. 2.

In case of measuring instruments of electromagnetic field we may meet probes with shifted sensors in direction of axis of the rectangular coordinate system (probe ETS), or with spatial shifts and rotation according Fig. 3 (probe Holladay). Such arrangement of sensors eliminates the problem with practical realization of feeding. On the other side mutual couplings among sensors occur. They are expressed as variation of input impedance of the dipoles (sensors), as variation the current distribution and also as variation of radiation (directional) pattern. The geometrical arrangement of sensors affects isotropic (omni-directional) properties of the probe (also a validity of equation (1)), and therefore an accuracy of the measurement of electromagnetic field too.

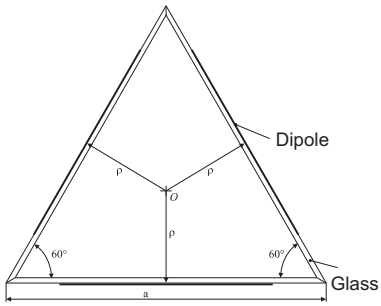

Fig. 3. Arrangement of three sensors in Holladay probe

2. Theory of the Mutual Impedance

In the case of two conductive elements, which are affected by electromagnetic field and which are situated in proximity of each other, their properties are affected reciprocally. The same situation is in case of two (or more) the field sensors [1]. This effect may be desired, as it is in case of Yagi-Uda antennas, or parasitic. The mutual impedance, which is represented by variation of input impedance occurs between these two elements.

Fig. 4. Two-port network

To simplify our analysis, we consider only two elements, which may be regarded as two-port network according [1]. The influence of one element on other may be expressed by impedance equations (matrix) of the two-port network:

$$\begin{aligned} U_1 &= Z_{11}I_1 + Z_{12}I_2 \\ U_2 &= Z_{21}I_1 + Z_{22}I_2 \end{aligned} \tag{2}$$

where

$$Z_{11} = \left.\frac{U_1}{I_1}\right|_{I_2=0} \tag{3}$$

is the input impedance at port “1” with port “2” open circuited,

$$Z_{12} = \left.\frac{U_1}{I_2}\right|_{I_1=0} \tag{4}$$

is the mutual impedance at port “1”due to current at port “2” (where port “1” is open circuited),

$$Z_{21} = \left.\frac{U_2}{I_1}\right|_{I_2=0} \tag{5}$$

is the mutual impedance at port “2”due to current at port “1” (where port “2” is open circuited),

$$Z_{21} = \left.\frac{U_2}{I_1}\right|_{I_2=0} \tag{6}$$

is the input impedance at port “2” with port “1” open circuited.

Impedances Z_{11} and Z_{22} are input impedances of two analyzed sensors – dipoles. Because reciprocity theorem are valid in case of antenna also Z_{12}=Z_{21}.

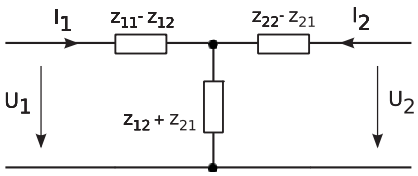

Fig. 5. T equivalent of the two-port network

The impedance Z_{12} is higher (and also Z_{21}), the greater is interference between elements (antennas). That means that influence of one antenna on properties of other one is then more evident. By modification of the equations (2), we can calculate input impedance at input terminal of elements:

$$Z_{1d} = Z_{11} + Z_{12}\frac{I_2}{I_1}$$
$$Z_{2d} = Z_{22} + Z_{21}\frac{I_1}{I_2} \quad (7)$$

As it is given by (7) input impedance of antennas “1” and “2” depends on their mutual impedances, current ratio I_1/I_2 and self impedance of the antenna.

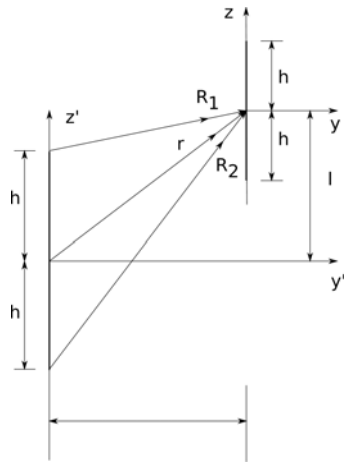

Fig. 6. Dipole positioning for evaluation mutual coupling

Based on Fig. 6 we can determine induced voltage on unloaded terminals of antenna “2”, which occurs due to electromagnetic field effect of antenna “1”:

$$U_{21} = \int_{-h}^{h} E_{z21}(z')I_2(z')dz' \quad (8)$$

where E_{z21} is component of electric field, which is radiated by antenna “1” and was incident on antenna “2” tangentially, and $I_2(z')$ is the current distribution along antenna “2”. By substituting (8) into (7) we get:

$$Z_{21} = \frac{U_{21}}{I_{10}} = \frac{1}{I_{10}I_{20}}\int_{-h}^{h} E_{z21}(z')I_2(z')dz' \quad (9)$$

3. Numerical solution

As it was mentioned before, the probe of electric field consists of three sensors – dipoles, which are placed in a space in such way that they create orthogonal system. The sensors affect mutually and this effect is expressed as mutual impedance.

To simplify such situation we considered two sensors, which are perpendicular to each other. One sensor is identified with axis y and other with x. Now we calculate the mutual impedance of these dipoles if the second dipole is shifted in direction of axis y. Such situation is presented in Fig. 7.

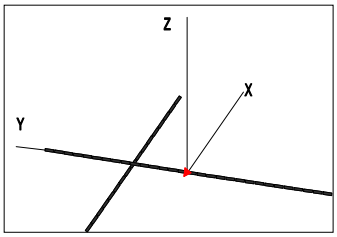

Fig. 7. Model of two dipoles in the environment FEKO

The antenna numerical simulator FEKO [5] was used to calculate parameters of such wire structure. It is a commercial software based on the moment method. The dipole parallel with axis y is fed in its center by the sinusoidal voltage with amplitude 1V. The other dipole, which is parallel with axis x, is loaded by impedance 50 Ohm at its terminal. We decided to divide dipoles to obtain constant current distribution in all the segments for simulation purposes.

It means that segment dimensions (mainly length) have to be much smaller than a wavelength. Also the diameter of the segment has to be smaller than its length.

Real and imaginary part of input impedance of dipole as a function of frequency is shown in Fig. 8 and 9 respectively. The pattern of this impedance is similar in cases of single dipole as well as of two dipoles, which are crossed at their center. It means that influence of one dipole on other is vanishing, if they create rectangular system (dipoles are identical with axis y and x) and their centers are in the center of coordinate system.

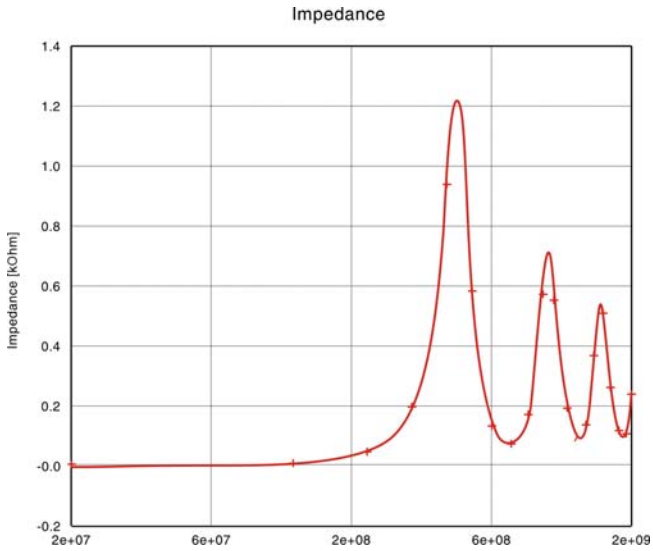

Fig. 8. Real part of the dipole input impedance

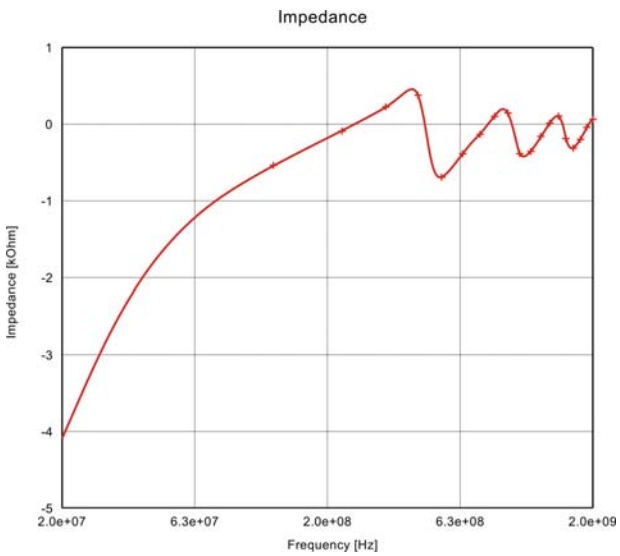

Fig. 9. Imaginary part of the dipole input impedance

Next, we calculated resonant frequency of the dipoles, at which mutual impedance was determined. Based on dipole dimensions 2h=548 mm and assumption, that resonance of dipole is achieved at 0.47 multiple of wavelength [2], we obtain:

$$fr = \frac{c}{\lambda} = \frac{2{,}998 \cdot 10^8}{548/0{,}47} = 257{,}13 \ \ [MHz] \tag{10}$$

This fact is confirmed also by frequency dependence of voltage stand wave ratio (VSWR), which is shown in Fig. 10.

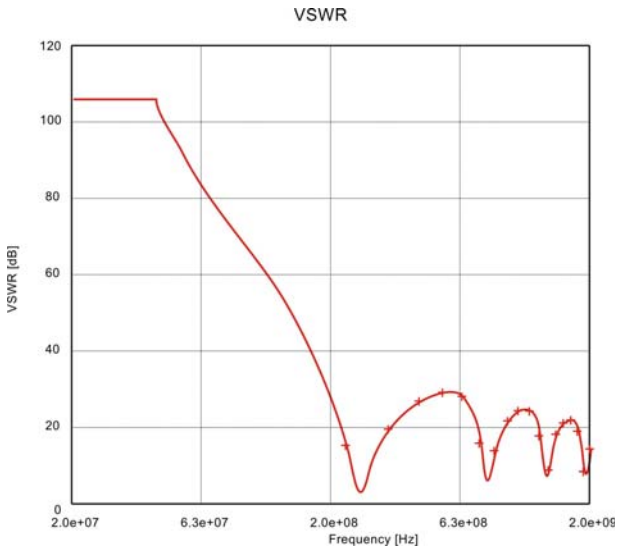

Fig. 10. VSWR of the dipole antenna

To calculate mutual impedance, it is necessary to obtain input impedance of single dipole, which is parallel with axis y. This impedance is marked as Z_{11}. Then, we added into simulation model other dipole and moved it in direction of axis y with step 0,01 □. Input impedance $Z_i(y)$ of first dipole is recorded for every shift of other dipole. The mutual impedance (7) between these two dipoles is then:

$$Z_{1d} = Z_{11} - Z_{12} \tag{11}$$

From (11):

$$Z_{12} = Z_{11} - Z_{1d} \tag{12}$$

Based on (12) the graphic chart of dependance of real and imaginary part of mutual impedance of dipoles, which are situated perpendicularly (orthogonally) to each other, on shift in direction of axis y was created (see Fig. 11 and 12).

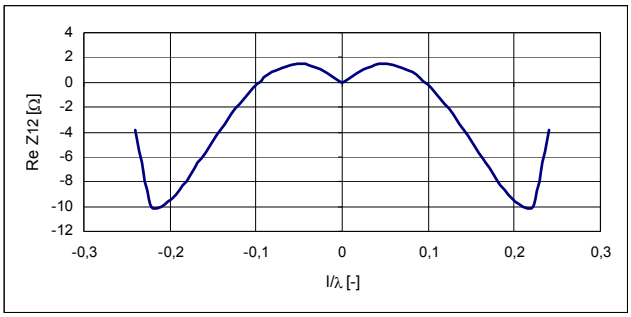

Fig. 11. Real part of the mutual impedance

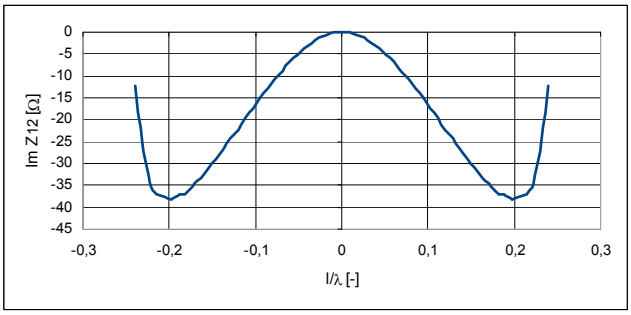

Fig. 12. Imaginary part of the mutual impedance

As it may be seen from Fig.11 and 12, the minimal influence between two dipoles occurs in case of their crossing in centers or their closeness. This influence (and also mutual impedance) increases with raising distance between centers of dipoles. As soon as shift of the second dipole is greater than length of the first dipole, mutual impedance will rapidly fall.

4. Measurement

The measurement of mutual impedance was implemented in anechoic chamber according scheme in Fig. 13. The measurement was executed by network analyzer (NA) E5071C-285 of Agilent Technologies. The influence of feeder cables was included in

a calibration of network analyzer and the instrument was situated to affect the measurement results minimally. To eliminate disturbing current flows through the cables shielding common mode ferrite chokes FA were used.

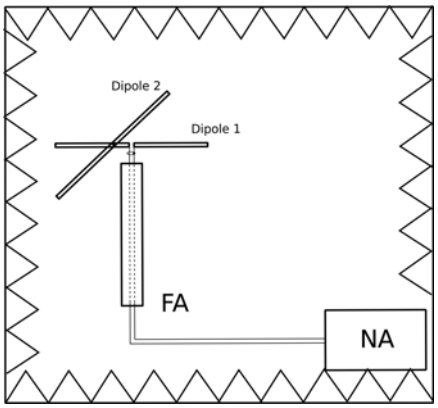

Fig. 13. Measuring of the mutual impedance

The measurement of input impedance of “Dipole 1”, in frequency range from 1MHz to 450 MHz, for various position of “Dipole 2” was executed by means of network analyzer. The position, when “Dipole 2” crossed “Dipole 1” exactly in its center, was marked as zero. The value of shift was raising with movement from this point.

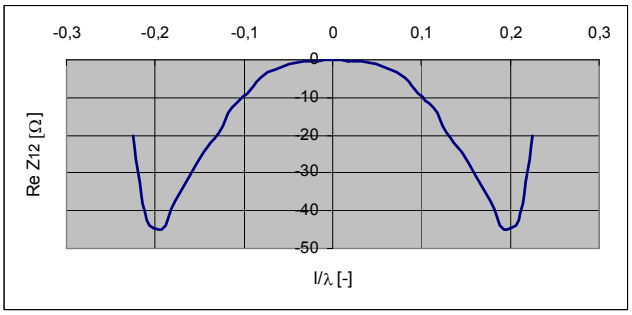

Fig. 14. Real part of the measured mutual impedance

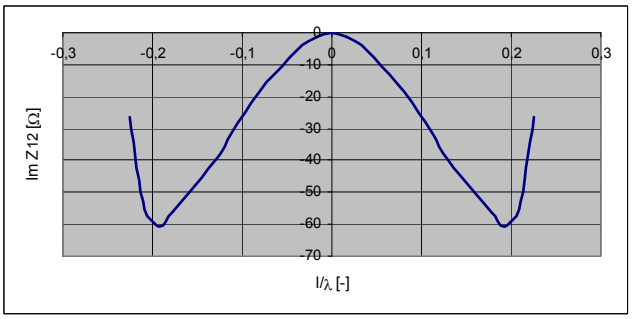

Fig. 15. Imaginary part of the measured mutual impedance

The measured values of real and imaginary part of mutual impedance as a function of position of "Dipole 2" is shown in Fig. 14 and 15. Patterns of obtained curves are similar to those obtained by numerical simulation. The differences in magnitude occurred due to losses in surrounding of measured dipoles (the dipoles were situated on non-conducting dielectric plate with complex permittivity).

5. Conclusion

This paper deals with theoretical analysis and methods of obtaining the mutual impedance of two perpendicular dipoles, which are used as sensors of components of electric field vector. The dependance of mutual impedance as function of relative shift of dipoles was obtained by two different methods: by simulation using numerical simulator FEKO using moment method and measurement in an anechoic shielded chamber. If the dipoles are used as sensors of electric component of electromagnetic field, their interference causes a coupling among sensors. Therefore also result of measurement is affected and error of the measurement increases. To minimize this error, it is necessary to find points with minimal (or zero) mutual impedance on graphs in Fig. 11–15 (for real as well as imaginary component of mutual impedance). No interference between sensors is achieved only if they cross in their centers (in most cases it is not possible due to mechanical construction) or without common projection. Such arrangements of sensors allow us to minimize mutual impedance as well as error of the measurement, which is executed by more dipole sensors.

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

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Оценка взаимного влияния датчиков электромагнитного поля

Определение взаимного влияния ортогональных датчиков (диполей) электромагнитного поля, измеряющих величину его вектора напряженности. Взаимное влияние в первую очередь проявляется в изме-

нении передаточного импеданса между датчиками. Передаточный импеданс изменяется в зависимости от пространственного расположения датчиков, а также частоты. Данное явление оказывает влияние на наводимое напряжение на клеммах датчиков и диаграммы направленности, а следовательно, и на точность измерений.

Ключевые слова: измерение электромагнитного поля, электромагнитная совместимость, передаточный импеданс диполей, зонд электрического поля, метод моментов, численные методы

Получено 12.10.10

УДК 682.2.08: 681.325.5

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МЕТОДОЛОГИЯ ОПРЕДЕЛЕНИЯ ПОГРЕШНОСТЕЙ ИЗМЕРЕНИЯ ВЕРОЯТНОСТНЫХ ХАРАКТЕРИСТИК СЛУЧАЙНЫХ ПРОЦЕССОВ, РЕАЛИЗУЕМЫХ ПРОЦЕССОРНЫМИ ИЗМЕРИТЕЛЬНЫМИ СРЕДСТВАМИ *

Одной из проблем метрологии измерительных процедур, реализуемых процессорными измерительными средствами (ПрИС), является разработка методологии определения погрешностей (характеристик погрешностей) результатов измерения. Предлагается подход, который можно рассматривать как дальнейшее развитие известных подходов к формализованному описанию измерительных процедур при статистических измерениях, в частности, при измерении спектральных функций.

Ключевые слова: процессорные измерительные средства, погрешности измерения, формализованное описание измерительных процедур, статистические измерения, спектральные функции

Основу метрологии измерительных процедур, реализуемых процессорными измерительными средствами (ПрИС), составляет решение двух проблем [1]:

– разработка алгоритмического обеспечения, которое является базой прикладного измерительного обеспечения;

– разработка методологии определения погрешностей (характеристик погрешностей) результатов измерения.

В настоящее время в теории статистических измерений сложилась весьма своеобразная ситуация. Во-первых, в силу целого ряда преимуществ ПрИС перед известными измерительными средствами первые находят самое широкое применение в статистических измерениях. Во-вторых, в основах теории статистических измерений специфика применения ПрИС освещена недостаточно полно [2, 3]. В-третьих, при разработке формализованного описания измерительных процедур, осуществляемых ПрИС, вопрос специфики применения ПрИС в статистических измерениях отражается не в полной мере.

В работе предлагается методология, которую можно рассматривать как дальнейшее развитие известных подходов к формализованному описанию измерительных процедур при статистических измерениях, в частности, при измерении спектральных функций дискретных случайных процессов [3].

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* Работа выполнена в рамках реализации проекта 13.G25.31.0094 между ОАО «Элеконд» и Министерством образования и науки Российской Федерации.