Isotropic Electromagnetic Sensor Measurement Error

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Abstract. *This article deals with classifying and quantifying of electromagnetic field measurement errors when an isotropic sensor is used as a field probe. The focus is mainly given to the error of the measurement method resulting from the mutual interaction of the field probe sensors associated with the origin of the so-called mutual impedance.*

Keywords: Electromagnetic Field, Sensors, Measurement Error

Introduction

In many areas of electrical engineering it is required to measure the amplitude of electromagnetic field with sufficient accuracy (e.g. during electromagnetic compatibility testing of electrical devices). The measurement is in many cases performed in a far field. Then it is sufficient to measure only one component of the electromagnetic field while the other can be easily estimated. Despite this simplification, the measured component of the electromagnetic field is a vector. This means that we need to know all the vector components (x, y, z) which determine its final amplitude. To determine the mentioned components of the vector, an omnidirectional probe of the electromagnetic field must be used. In general, such a probe is made of three orthogonal sensors and the output voltage of the sensors is determined as follows:

$$U_E = \sqrt{U_x^{\ 2} + U_y^{\ 2} + U_z^{\ 2}} \tag{1}$$

In order to ensure sufficient accuracy, the sensors have to meet a series of conditions: frequency independence [1]; sufficient output voltage [1]; sensitivity to only one component of the electric field vector [1], [2]; linearity [2], [3]; no (or negligible) interaction with surrounding objects. In the scientific literature, attention is given to the first four conditions; however the *fifth condition is not solved*. Therefore this article deals with the mutual interaction of sensors, and their effects on the error of the electromagnetic field measurement.

Mutual Impedance

If a conductive object is situated in an electromagnetic (EM) field, there is an interaction between the field and the object. This interaction is reflected by changed distribution of the EM field’s geometry and origin of electric current or electromotive voltage in the conductive object. If there are other objects in the EM field, also other interactions are created; not only the interaction between the field and the object but also an interaction between the objects. This interaction is known as mutual impedance in the antenna theory, and is reflected by a change of the voltage and the current conditions in the field of the objects, similar to the theory of linear circuits. The mutual impedance may be calculated by several methods. All the methods are based on the interaction between the incident and the radiated EM fields of the studied objects (for example: two wires with lengths 2h). According to Balanis [3] the mutual impedance may be expressed as:

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

where $I_2(z)$ is the current distribution in wire 2, Ez_{21} is E-field component radiated by wire 1, which is parallel to wire 2; I_{1i}, I_{2i} are wire input currents. As mentioned above, the mutual impedance affects the induced voltage at the inputs of wire 1 and wire 2 as follows:

$$U_1 = U_{11} + Z_{21} I_2 \qquad (3)$$

where U_1 is the driving point voltage of wire 1 when wire 2 is present. U_{11} is the driving point voltage of wire 1 without wire 2.

Let's return to the EM field probe which consists of three sensors. If one of the sensors captures only x-axis component of the field, its output voltage will be:

$$U_x = k_x E_x \qquad (4)$$

If the two sensors for *x*-axis and *y*-axis component of the field are situated close to each other, then their output voltage will be:

$$\begin{aligned} U_{x1} &= U_x + Z_{xy} I_y \\ U_{y1} &= U_y + Z_{yx} I_x \end{aligned} \qquad (5)$$

One can see that the sensors interact mutually which results in a change of the output voltage. This influence brings a systematic error to the measurement of the EM field which can be expressed [2], e.g. for x-axis sensor, in the presence of the other sensor as a percentage:

$$\delta_{U_x} = \frac{Z_{xy} I_y}{U_x} .100\% \qquad (6)$$

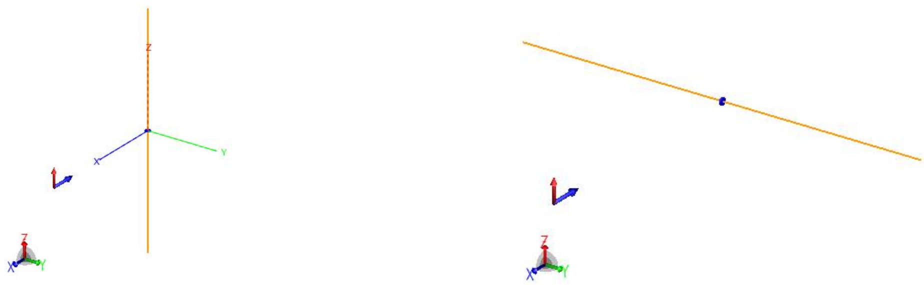
and in the presence of the two other sensors:

$$\delta_{U_x} = \frac{Z_{xy} I_y + Z_{xz} I_z}{U_x} .100\% \qquad (7)$$

Numerical calculation

Mutual impedance of the electromagnetic field sensors and its impact on the induced voltage at the sensors' terminals may be calculated analytically or numerically. However, analytical calculation is very complex and it exceeds the scope of this work. Therefore, we will rather pay attention to the numerical calculation which may be used to calculate the mutual impedance between the sensors as well as the induced voltage at their terminals.

The numerical calculation was carried out using FEKO EM field solver. First, we placed one sensor into an EM field generated by a planar wave. Our sensor is a dipole oriented to be parallel to the electric field vector – E. Next, we changed the dipole's orientation to be perpendicular to the vector E, as shown in Fig. 1. The intensity of E-field was 1 V/m.



a) b)

Fig. 1. Impact of EM wave on a) tangentially oriented sensor b) normally oriented sensor.

In both cases the dipoles were loaded by impedance of 75 Ω. In the case a) current of 1.35mA flows via the mentioned impedance and in the case b) the current has zero value. The absolute value of the input impedance of the dipole a) was 70.438 Ω. In the next, the model will consist of two sensors located very close to each other, as shown in Fig. 2.

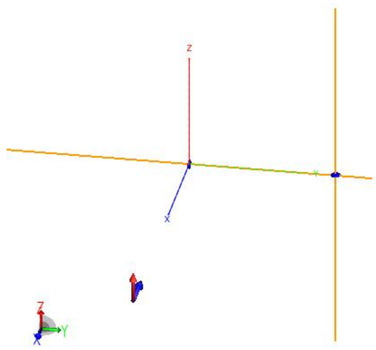
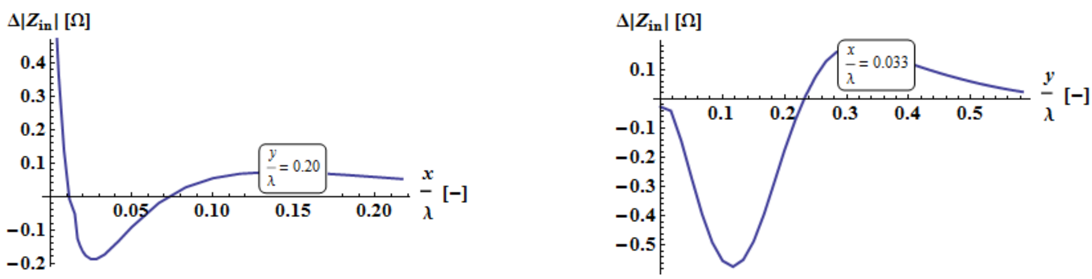


Fig. 2. Arrangement of two sensors in EM field.

It is obvious from Fig. 2 that one sensor (dipole) is located tangentially and the other normally to the electric vector component of the incident electromagnetic field.

Results

Based on the simulation models (Fig. 1 and Fig. 2.) we performed the calculation of input



a) b)

Fig. 3. Dependence of input impedance variation of z-sensor on relative position of the sensors a) shift in x-direction b) shift in y-direction.

impedance of the sensor positioned on the *z*-axis which depends on the position of the sensor situated on the *y*-axis. Fig. 3 shows only the change of the input impedance of the *z*-dipole.

One can see that the input impedance variation of the examined dipole will be zero if the second dipole is placed at a considerable distance from the examined dipole. Similar effect may be reached by locating the second dipole near the center or at the end of the examined dipole. The design of the EM field probe has to be based on Fig. 3 to minimize the interactions between the dipoles (sensors).

Next, we focused on the calculation of the induced current in the y-dipole which is oriented normally to the vector of the incident electric field (see Fig. 4). Unlike the previous case, the induced current takes a zero value only if the examined dipoles are sufficiently far apart.

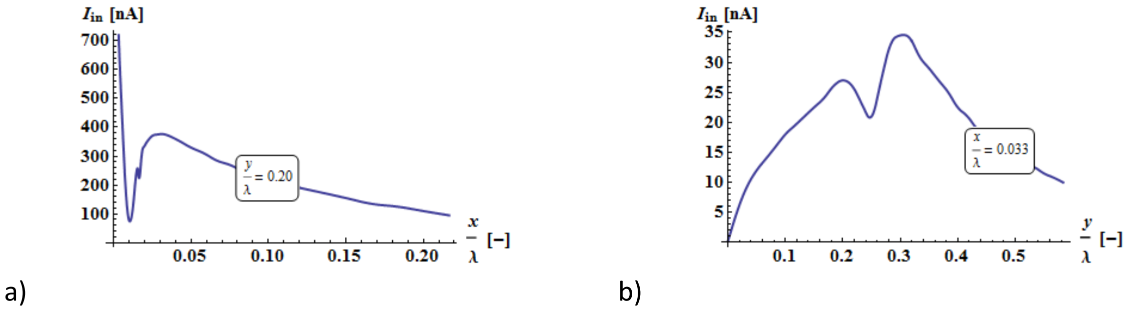


Fig. 4. Induced current of y-sensor depending on relative position of the sensors a) shift in x-direction b) shift in y-direction.

To quantify the effect of mutual impedance on the accuracy of the EM field measurement, we have to rely on Fig. 3 and Fig. 4, and the modified equation (1). Dependence of the relative error (caused by the existence of the mutual impedance) on variation at x and y axes has the same shape as is shown in Fig. 3. In this case the y-axis value will reach values in the range from -0.2% to 0.6% in a) and from -0.8% to 0.2% in b).

Conclusions

In the case of EM field measurement with multiple sensors which are situated close to each other, there is mutual impedance between the sensors which may affect the measured results by up to 1% error, depending on relative positions of the sensors.

Acknowledgements

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