PROXIMITY EFFECTS IN EMF MEASUREMENTS AND STANDARDS

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INTRODUCTION

Electromagnetic Field (EMF) measurements for labour safety and environment protection purposes are in the majority cases performed in the Near Field, in close proximity to primary or/and secondary radiation sources. The proximity causes mutual interaction of a measuring probe and the source that affects the sensitivity of the probe and, as a result, accuracy of the measurement. The probes are usually calibrated with the use of guided wave standards, e.g.: a TEM cell. The probe's calibration factor in the procedure depends upon sizes of the set and that of the probe. Similar devices (secondary standards, exposure systems) and phenomena exist while a guided wave system is used for EM susceptibility measurements in bioelectromagnetics and EMC. The three issues are discussed in the paper.

EMF MEASUREMENTS IN THE NEAR FIELD

Hazard, created by an exposure to EMF, requires the field measurements in the neighbourhood of primary and secondary sources as well as fields disturbed due to presence of material media; it focuses an involvement to the Near Field. High curvature of the field and mutual interaction of the probe and primary or/and secondary source (-s) remarcably reduces accuracy of the EMF measurements in the Near Field if compare to the far Field conditions.
While an antenna of the measuring probe is placed near a conducting object it's input impedance changes from that in the free space in a mutual impedance of the antenna and it's mirror image. The mutual impedance Z_{21} of 2h-long dipole made of a conductor of the diameter 2a, located parallel at distance b/2 to a flat, infinitely large and perfectly conducting plane, and its mirror reflection is given by (1) [1]:

$$Z_{21} = 30\Big[\left(2+e^{-j2kh}\right)\left(Ci\,kx - j\,Si\,kx\right)\Big|_{\sqrt{h^2+b^2}-h}^{b} + \left(2+e^{j2kh}\right)\left(Ci\,kx - j\,Si\,kx\right)\Big|_{\sqrt{h^2+b^2}+h}^{b} + e^{j2kh}\left(Ci\,kx - j\,Si\,kx\right)\Big|_{\sqrt{h^2+b^2}+h}^{\sqrt{4h^2+b^2}+2h} + e^{-j2kh}\left(Ci\,kx - j\,Si\,kx\right)\Big|_{\sqrt{h^2+b^2}-h}^{\sqrt{4h^2+b^2}-2h}\Big]. \tag{1}$$

Taking into account that the sizes of the problem are much less as compare to the wavelength of the considered field, i.e. for: a, b, h << λ, one may neglect the real part of the impedance it reduces free space input impedance Z_{11} and Z_{21} to X_{11} and X_{21} respectively. After taking the limit of the impedance given by formula (1) for $\lambda \to 0$ and omitting its real part we will have mutual reactance of two dipoles placed at distance b one to the other. The demanded input reactance X_i of the dipole is a difference of the two reactances, that is:

$$X_i = X_{11} - X_{21} \tag{2}$$

The probe should be calibrated in the conditions where $X_{21} \approx 0$ then, while the measurements are performed in a neighbourhood of a conducting medium (represented, in the estimations by the infinitely large and perfectly conducting plane) will appear an error of the measurement, as a result of the probe's antenna input impedance change caused by the presence of the medium. The error may be defined it in the form:

$$\delta = \frac{\Delta X_i}{X_i}, \tag{3}$$

where:

X_i – the input reactance of short dipole in the free space,
ΔX_i – input reactance change due to a mutual coupling.

The input impedance of the antenna as well as the mutual impedance of the antenna and its mirror reflection is a function of its slenderness ratio [4]. The slenderness represents the ratio of the antenna length to the diameter of the conductor which its made of, i.e.: h/a. Thus, it makes as necessary to introduce here the slenderness as a parameter in presented considerations. Estimations of the error δ versus b/2h for h/a = 30, 300 and 1000 are plotted in Fig.1.

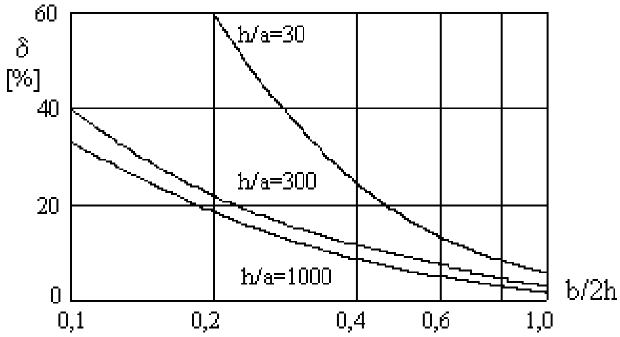

Fig. 1. Error δ versus b/2h.

The error δ is a function of the distance probe-source. If take into account that the estimations were carried out for an antenna located parallel to infinitely large conducting medium while in the real conditions the antenna may be placed arbitrarily close to an object of limited sizes and the dominant role is usually played by the radial E-field component and the measuring antenna should be spatially oriented with an accordance to the component; thus, the estimations presented give results majorizing any error of this kind that could appear in the metrological practice. Apart from the error analysis it makes it possible an optimization of a probe sizes while a measurement at limited distance and with deprived accuracy is planned.

PROBES' CALIBRATION

One of the most known EMF standard is a TEM cell, proposed by Crawford [2]. In the case of calibration the antenna is placed between two paralell plates (as shown in Fig.2) or between four plates, in the case of a cell with side walls. It requires to take into account infinitely large number of mirror reflections and, as a result, mutual impedances (Fig.2) while accuracy of the procedure is estimated.

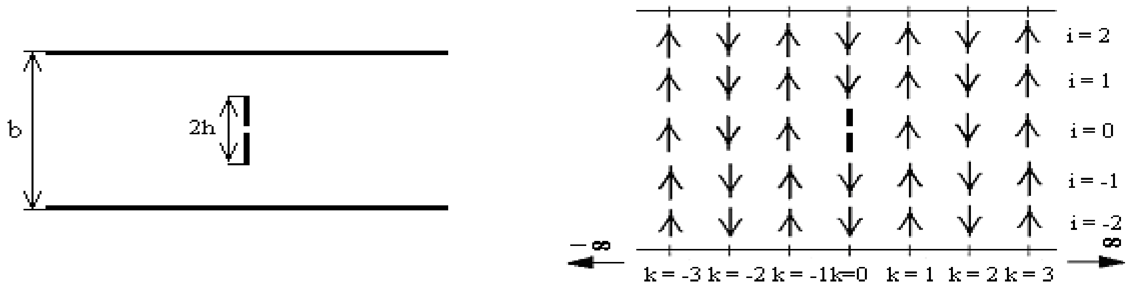

Fig. 2. Dipole placed between infinitely large and perfectly conducting planes and it's mirror reflections.

Taking the above said into account an analysis of calibration error calculated along with (3) was performed in analytical and numerical way. An example of calculations performed for a probe immersed in "open-side" type line (as shown in Fig.2) and for h/a = 30 are shown in Fig.3.

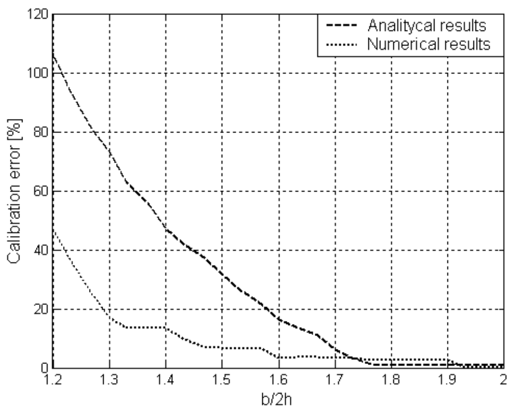

Fig. 3. Calibration error $\delta_{\perp}$ for antenna placed in TEM cell.

The run of the error is very similar in the two cases. It may be noticed, however, that the theoretical estimations dominate numerical ones and it may be assumed as majorizing any possible case. The latter was verified in experimental way. The analysis shows the limitations of the calibration method and leads to introduction of appropriate correction factors that may allow correct use of the probe while measurements are performed in free space. The procedure was experimentally verified and is in permanent use in the Lab.

SUSCEPTIBILITY STUDIES

Similar procedure is applied in variety of biomedical investigations and EMC studies. Contrary to antenna the objects investigated in the studies are spatial and sometimes semiconducting ones. A possibility of a free space interpretation of investigated phenomena requires similar analyses as in the case of antennas' calibration.
As it was shown in Fig.1 a decrease of the slenderness ratio causes increasing mutual interaction between the cell ant tested object. A question arrises: what will happen if tested object will be a biological object, for example a mouse? (Fig. 4a) [3]. Such a mouse, in the first approximation can be simulated as a cube (Fig. 4b).

a) b)

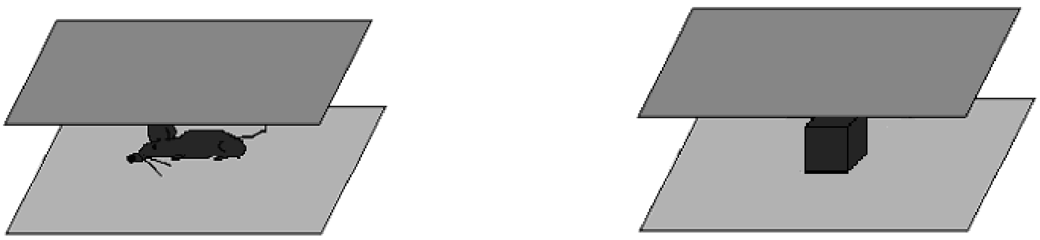

Fig. 4. Exposure system assumed for the analyses:
a) real object, b) equivalent model [2].

Influence of the cell upon the object under test may be defined as a difference of power absorbed by the object inside the cell and that in the free space in (say) identical exposure conditions. Power absorbed by the object is defined in the form:

$$P_{abs} = \frac{1}{2}\sigma\int_V |E|^2 dV , \tag{4}$$

where:

P_{abs} – absorbed power,
σ – absorber conductivity,
E - electric field intensity within the object.

Formula (4) is valid for a homogeneous object. If the condition is not fulfilled the power is represented by a sum of partial powers, absorbed in separate elements of the object, that could be assumed as quasi homogeneous:

$$P_{ab} = \frac{1}{2}\left(\sigma_1 \int_{V_1} |E_1|^2 dV_1 + \sigma_2 \int_{V_2} |E_2|^2 dV_2 + \ldots + \sigma_N \int_{V_N} |E_N|^2 dV_N\right), \tag{5}$$

where:

N – number of elements.

Analysed homogeneous model, in the form of a cube of side 1.5 cm, conductivity σ = 1 S/m and ε_r = 1, was immersed between two parallel, perfectly conducting plates of sizes 20x20 cm. The stimulation was performed with the use of following codes: HFSS from Ansoft [6] based upon FEM and Fidelity from Zeland [7] based upon FDTD.
Results of estimations, as a function of distance between the plates, are plotted in Fig. 5. Contrary to the continuity in the physical phenomena the curves representing both the methods are a bit rough it is, however, intentionally shown in order to illustrate an influence of the calculation accuracy. The use of a filtration method would assume full continously of the curves. With no regard to it the results are very similar and convergent to common asymptote while the distance between plates exceeds 3 cm, that confirms an agreement between the two approaches.

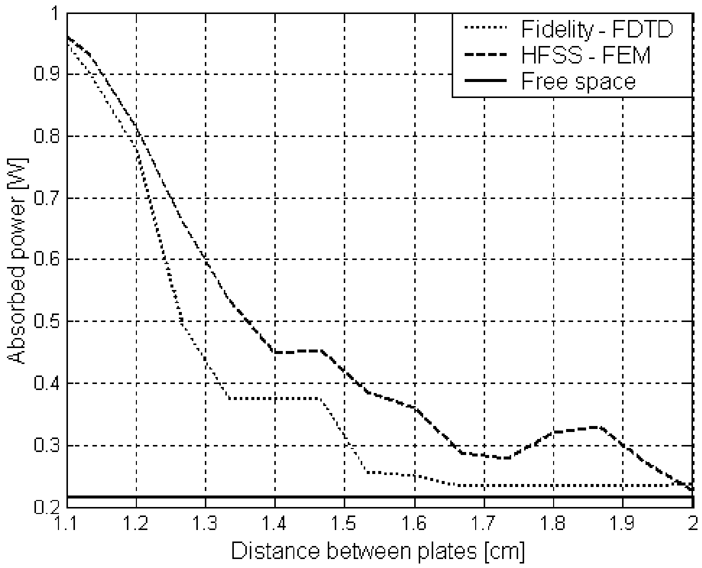

Fig. 5. Comparison of results absorbed power by examined object placed in TEM cell obtained with different numerical methods.

SUMMARY

The three cases of mutual interaction were investigated in the paper. The estimations show that with no regard to the type of the Near Field measurements close to material media or any objects' testing within closed enclosures the interaction exists and it limits accuracy of procedures applied. The phenomenon is especially essential while results of experiments, performed in arbitrary enclosure, should be transferred to the free space conditions. In the case the role of the phenomenon must not be neglected. The issue has satisfactorily been solved for EMF probes calibration where appropriate correction factors are determined in theoretical or/and experimental way.

Although a concept of the "input impedance of a mouse" is unknown we may suppose that such a magnitude exists and is responsible for the power absorption. As a result of the phenomenon discussed the impedance may be affected by presence of conducting walls and, as a result, may change the EM energy absorption. A susceptibility of different devices is usually measured in conditions required by a standard. Thus, the possibility of the results transfer from measuring conditions to real ones is of secondary importance. The role of the phenomenon is of primary importance while biomedical investigations are performed. In the investigations, in order to effective use the volume of the exposure system, often investigated animals are packed in the whole volume of the system. The analysis shows that the equivalence of experiments performed in an enclosure and in the free space may be questionable in the better case. From one side it may explain why similar biomedical investigations performed in different labs give different results, from the other it shows similarity of the phenomena to the antennas' calibration case and suggests similar solutions. Finally it may be helpful in designing biomedical experiments in such a way while the phenomenon is omitable.

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