CALIBRATION OF E-FIELD PROBE FOR SAR MEASUREMENT IN LOSSY LIQUID.

Richard Dlouhy and Zbynek Skvor

Czech Technical University in Prague, dpt. Electromagnetic Field, Technicka 2,
166 27 Praha 6, Czech Republic
Internet: skvor@fel.cvut.cz, voice: (+420-2) 2435 2276

Abstract
A new technique for probe calibration has been developed. It enables for accurate characterisation of the probe, and therefore gives the opportunity for precise measurements of SAR distribution. The technique has been used for measurement of SAR caused by mobile phones in a model of human head.

Introduction
Fast expansion of mobile radioelectronic equipment, especially mobile phones, and concerns about health issues have developed a strong demand for measurement techniques aimed at direct field mapping. So far, direct field mapping in a human head is not possible, and one has to use models. Such a model often consists of a ball filled by liquid possessing properties similar to human brain.
Special probes are used to map electromagnetic fields. The probe disturbs the field under measurement. Proper calibration techniques are necessary to account for probe imperfections as well as to remove probe effect from measured data.
This paper describes a new calibration procedure. It was used for a special E-Field probe in order to measure absolute value of the SAR (Specific Absorption Rate) caused by mobile phone in a phantom (physical model of the human head). The basic requirement for the calibration is that output signals of three orthogonally positioned sensors are transformed so that the reading corresponds to the SAR in the case of the absence of the probe. For the calibration, one needs a well defined measurement volume with a known electrical field.

Previous solutions
In the literature some different principles of the calibration were found. All these calibration techniques require comparison with another kind of probe or complex numerical computation [1], [2], [3]. The determination of calibration coefficients is possible only in an indirect way in previously reported techniques (for example: calibration in the air and then numerical recalculation for the lossy dielectric). Another disadvantage was that dielectric parameters of phantom liquid had to be determined applying different measuring methods, prior to probe calibration itself.

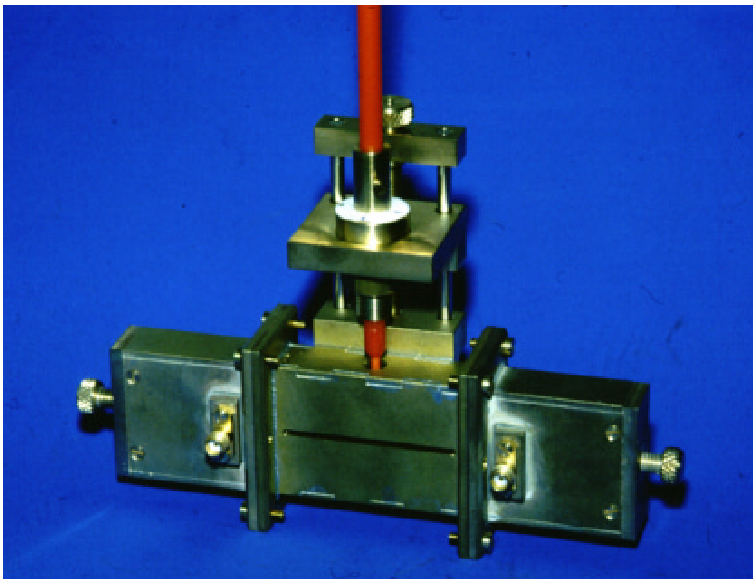

Fig. 1. Calibration setup.

New solution
In order to overcome above-mentioned limitations, a new calibration method has been proposed and experimentally verified. The main idea of the method reported in this paper is in

1. measurement – calibration directly in the phantom liquid
2. creating well-defined field distribution using a waveguide set filled by liquid

3. simultaneous determination of liquid properties during calibration (the calibration set suffices for determination of all electric parameters of the liquid.

The new calibration set (specially constructed waveguide filled with lossy liquid) allows in this technique not only the calibration by direct way but also measurement of dielectric parameters of the liquid simulating the brain, which is very important for the accuracy of whole calibration procedure.

Calibration setup

Calibration setup should provide a well-defined field distribution. This distribution should depend on but a few parameters that can be measured directly and accurately.
A waveguide with rectangular cross-section (*36 x 12 mm*) has been chosen, see Fig. 1. The probe is inserted into the middle of the waveguide through a hole and its position can be adjusted using a holder. The holder allows rotation and vertical motion of the probe. The waveguide is fed through two special junctions with standard SMA connectors.
The set is placed into a tank filled by lossy liquid simulating human brain dielectric parameters. This setup is completed by two waveguide lines of different length (not pictured at Fig. 1.). These lines are used for liquid parameter determination.
In order to force one mode operation over all frequency bands currently used for GSM communication, eg. 900 – 1900 MHz, the waveguide set has slots serving as mode filters.
Authors have no information on a similar calibration setup.
Special care had to be paid to coupling circuits. Delivering energy from coaxial cable into the waveguide with lossy media was uneasy. A number of experiments and numerical analyses have been carried out, resulting in a teflon housing for coupling rods inside the junctions (diameter of 8 mm). This has reduced losses by 30 dB, and enabled meaningful measurement. Transmission between SMA connectors was –30 dB, close enough to numerical calculations (-28 dB).

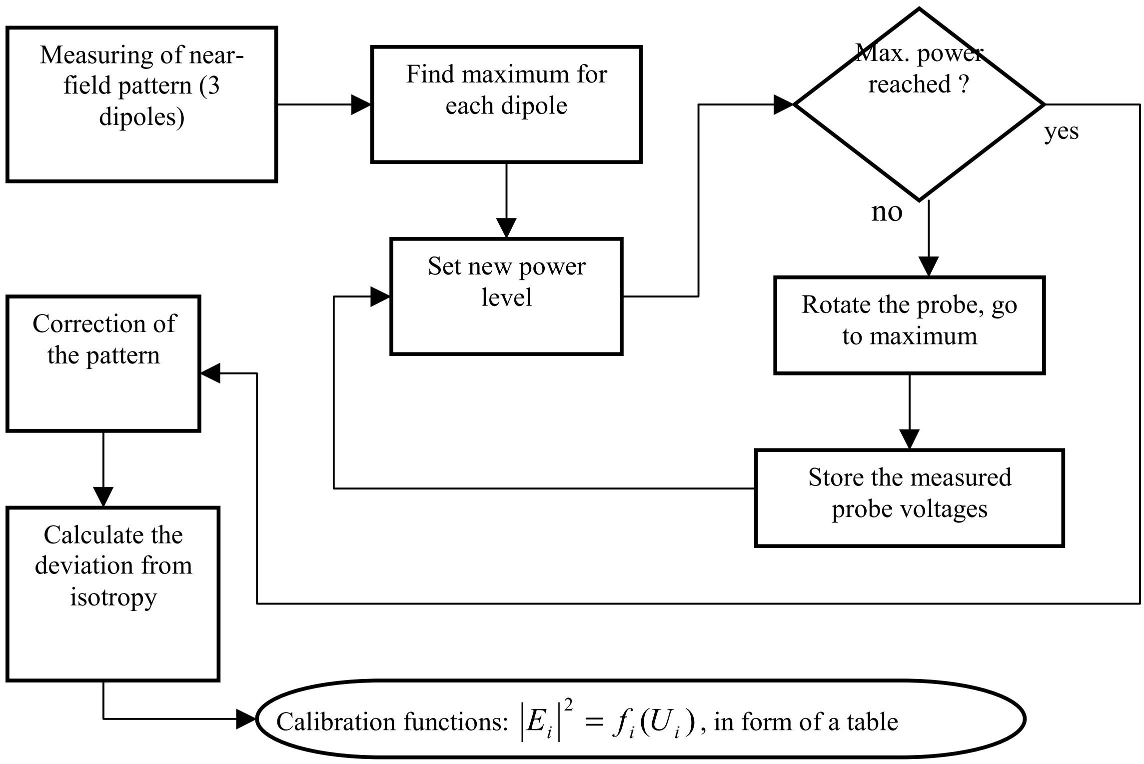

Fig. 2: Calibration algorithm (the index *i* stands for the dipole 1, 2, 3)

2

The setup is connected to a Vector Network Analyser (VNA), either directly or through a power amplifier. VNA operates in CW mode, under different power levels. Calibration procedure is controlled by a computer and automated using stepper motor drives. The calibration is performed under condition that the centres of the probe dipoles are placed exactly in the geometrical middle of the waveguide and the probe axis is positioned normal to E-field component.
Power propagating through the middle of calibration waveguide can be determined as

$$P_{middle}[dBm] = P_{NWA}[dBm] + S_{21setup}[dB] - \frac{S_{21}[dB]}{2} \tag{1}$$

where P_{NWA} is the set power level of the network analyser, $S_{21setup}$ stands for transmission without PA and S_{21} is transmission with PA.

Calibration procedure

The calibration procedure has several steps. The algorithm of the calibration procedure is shown in Fig. 2. First, the near field pattern has to be measured. It is performed by rotation of the probe with step of 3.6 degrees. In each position, the measured voltages are stored in the computer. After deriving the uncorrected pattern, the maximum is found for each of the three dipoles. The stepper motor then rotates the probe to the maximum and the measured voltages are also stored in the memory. This is done for several power levels. The control programme then recomputes the set power levels in the middle of the calibration waveguide. From the measured characteristics, the near field pattern could be corrected. The correction is necessary because the pattern could be measured in the compression area of the used detectors.
From the patterns the deviation from isotropy and correction factors can be obtained. Finally, from the measured characteristics ($U_i = f(P_{middle})$, where U_i stands for output voltage of an i-th dipole in the probe), the inverse functions are determined as $P_{middle} = f^{-1}(U_i) = f_i(U_i)$.

The inverse functions were calculated by using several interpolation procedures. In the practical realisation, the relation $|E|^2 \approx P_{middle}$ can be replaced with a constant C_w. For the total electric strength |E|, the following equation can be then written:

$$|E|^2 = K \cdot \sum_{i=1}^{3} |E_i|^2 = K \cdot C_w \cdot \sum_{i=1}^{3} f_i(U_i), \tag{2}$$

where the K is a correction factor calculated from measured patterns. Correction factors are stored in computer memory and used to process probe voltage readings during field distribution measurement. Measured voltages are also stored in the memory. This is done for several power levels. The control programme then recomputes the set power levels in the middle of the calibration waveguide. From the measured characteristics, the near field pattern could be corrected. The correction is necessary because the pattern could be measured in the compression area of the detectors built in the probe.
From the patterns the deviation from isotropy and correction factors can be obtained. Finally, from the measured characteristics ($U_i = f(P_{middle})$, where U_i stands for output voltage of i-th dipole in the probe), the inverse functions are determined as $P_{middle} = f^{-1}(U_i) = f_i(U_i)$.

Results

The Device under test - field probe - consists of three dipoles, positioned with mutual anles of 55 degrees, connected to detection diodes. Detected voltages carry the information on field distribution at probe location.

The calibration procedure should map manufacturing imperfections and device V- A characteristics.

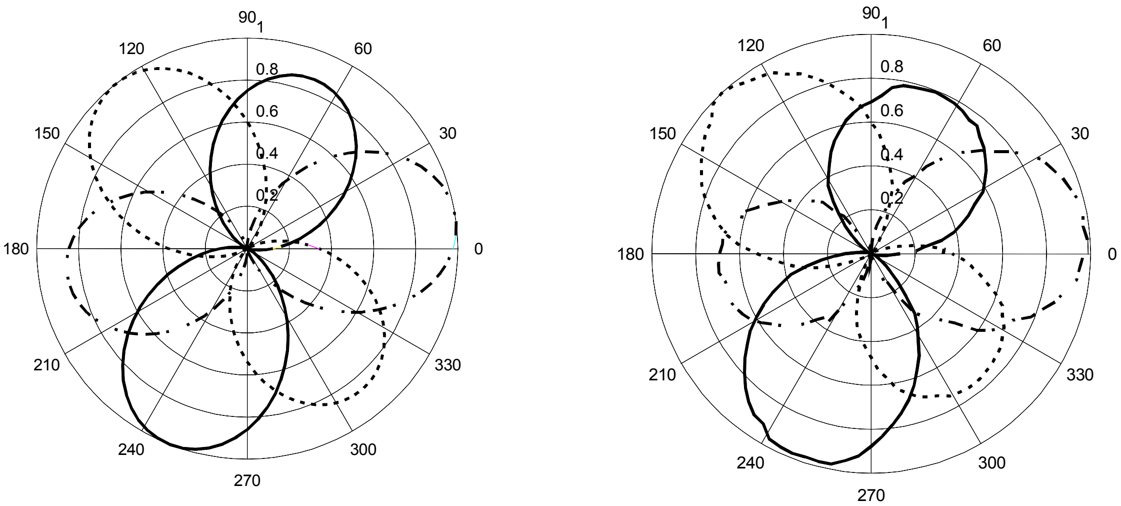

Figure 3: Calculated (left) and measured (right) near field power patterns of E-field probe

A comparison of measured characteristics against calculated one is found at Fig. 3. The calibrated E-field probe is used in measurement of SAR caused by handheld phones (mobiles). A simple phantom (glass sphere filled with lossy liquid) together with a simple dummy-mobile was used for practical experiments and for numerical modelling as well. Good correspondence was found between experiment and numerical simulations. Error analysis has shown that the uncertainty of SAR measurement is 17% when this calibration is used, which is an improvement when compared to previous methods.

Conclusion

A new calibration technique has been presented. The technique enables for precise E-field probe calibration directly in lossy liquid. The main advantage of the method is in reducing calibration errors. The method has been experimentally verified and is currently used in a setup for mobile phone user SAR distribution test bench.

Acknowledgement

Experiments have been performed at the Laboratory for High Frequency Technology, Friedrich-Alexander-University Erlangen-Nuremberg, Germany. The authors thank G. Schaller for discussions and suggestions.

This publication has been supported by research program “Investigation of new methods for measurement of physical quantities and their application in instrumentation” No.: J04/98:210000015 of the Czech Ministry of Education and “New methods for broadband vector network measurements”, No GACR 102/01/0573.

Literature

[1] G.S. Smith, A Comparison of Electric Short Bare and Insulated Probes for Measurement the Local Radio Frequency Electric Field in Biological Systems. IEEE Transaction on Biological Engineering, vol. 22, no. 6, 1975

[2] K. Meier, M. Burkhardt, T. Schmid and N. Kuster. Broadband Calibration of E-Field Probes in Lossy Media. IEEE Transaction on Microwave Theory and Techniques, 44, 1954-1962, October 1996

[3] D.A. Hill. Waveguide Technique for the Calibration of Miniature Implantable Electric-Field Probes for Use in Microwave-Bioeffects Studies. IEEE Trans. On Microwave Theory and Techniques, vol. 30, no. 1, January 1982

[4] R. Dlouhy. Electromagnetic Exposure of Mobile Phone Users, Ph.D. Thesis, CTU Prague, February 2000.

4