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Calibrated Induced E-field Measurement System for Frequencies from 20 Hz to 100 kHz

Ninad Chitnis*(1), Oliver Munz(1), Sven Kühn(1), and Niels Kuster(1,2)
(1) Foundation for Research on Information Technologies in Society (IT'IS), Zurich, Switzerland; e-mail: chitnis@itis.swiss; omunz@speag.swiss; kuehn@itis.swiss; kuster@itis.swiss
(2) Department of Information Technology and Electrical Engineering, Swiss Federal Institute of Technology (ETH) Zurich, Zurich, Switzerland

Measurement of the electric (E-)field induced inside tissue-simulating media remains an unsolved challenge at low frequencies. Currently available commercial E-field probes only permit measuring induced E-fields above 4 MHz. Typical applications for dosimetric probe systems below 4 MHz include testing compliance with safety guidelines (e.g., ICNIRP 2010 [1]) of devices operating at low frequencies (e.g., wireless power transfer systems, induction heaters) or optimization of neurostimulators (e.g., electrodes, electroceuticals).

This work aims to devise a solution for measuring induced E-fields in the frequency range of 20 Hz to 100 kHz. A four-electrode probe and associated data acquisition electronics were developed. Magnitudes and phases of the signals at each electrode were obtained from the probe electronics. The electrodes were spatially placed such that fields in the X, Y, and Z directions could be obtained by linearly combining the complex number representation of the electrode voltages.

A schematic of the calibration system is shown in Figure 1. A cuboidal phantom filled with a tissue-simulating liquid (TSL) was used to generate a uniform field. The fields in the X and Y direction are calibrated by rotating the probe 360 degrees around its axis. The probe is rotated around the X-axis to calibrate the Z-direction field. In all cases, the expected E-field varies sinusoidally with the rotation angle. The relation between the field magnitude along the X-axis and the probe voltage magnitudes and phases is represented by Equation 1. The coefficients a_i are calculated using a non-linear least squares method. The measured field is obtained by multiplying the computed coefficients with the complex electrode voltages.

$$|E_X| = \sqrt{\sum_{i=1}^{4} a_i^2 V_i^2 + \sum_{i \neq j} a_i a_j V_i V_j \cos(\phi_i - \phi_j)}. \quad (1)$$

A numerically characterized source was used to validate the calibrated system. The field pattern observed from the validation experiments was as expected. An application of this system was demonstrated by using it to validate the new Temporal Interference Brain Stimulator for Research (TIBS-R; TI Solutions AG, Switzerland). A modulation pattern distinctive of temporally interfering fields was observed. A system for measuring induced E-fields in the 20 Hz to 100 kHz range was thus successfully calibrated, validated, and applied to validate the TIBS-R. Detailed results, along with a comprehensive uncertainty budget, will be presented.

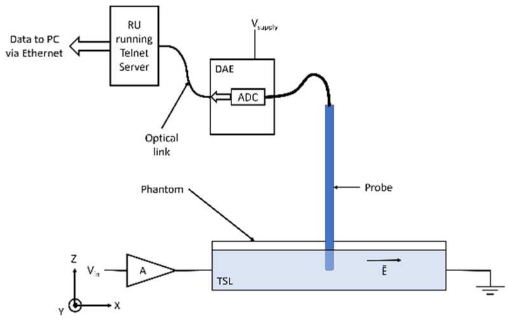

Figure 1. Schematic of the calibration system.

References

[1] International Commission on Non-Ionizing Radiation Protection, "Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz)," *Health Physics*, vol. 99, no. 6, pp. 818–836, 2010.