TEM cell for calibration of an electro-optic E-field sensor in a clinical scanner

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Introduction and Motivation

Controlling SAR is crucial for patient safety in ultra-high field MR. EMF simulations of RF coils and coil arrays are basic tools for predicting SAR in the human body. In addition to $B_1^{(+)}$ measurements, complementary E-field measurements using MR compatible E-field sensors are inevitable for an experimental validation of such simulations inside the MR scanner [1]. However, the significance of such measurements is limited by the quality of the sensor calibration. Here we present a MR compatible transverse electromagnetic cell (TEM cell) used as calibrating unit for a time-domain electro-optic E-field sensor (OEFS) via $B_1^{(+)}$ measurements. Since the E-Field in a TEM cell is exactly related to the $B_1^{(+)}$ field by $E = 376.73\ \text{Ohm}{*}2{*}B_1^{(+)}/\mu_0$ the calibration procedure is based on MR techniques only. Using the receiver system of the MR scanner for recording the sensor's RF output signal no additional hardware is necessary.

Materials and Methods

For the TEM cell an open double strip-line design was used, supplemented with 2 tapered feeding sections. The distance between the septum and the outer conductors is 3 cm allowing to accommodate the sensor head in a homogeneous region of the cell (Fig.1). The width of the cell was adjusted to obtain a 50 Ohm impedance of the transmission line which was terminated by a 50 Ohm dummy load to obtain a traveling wave operation mode. All conductors were made from FR4 circuit board material with 18 µm copper layer to minimize eddy current artifacts. At the edges of the cell two small copper sheets (1cmx1cm) are used to stabilize the taper. Both ends of the cell are terminated by a semi rigid cable and a nonmagnetic SMA connector. Due to the open design of the cell there are two symmetric measurement cavities. In the upper one a water filled capillary made of Perspex (i.d.=3mm, o.d.=5mm) was inserted to perform measurements of the cells $B_1^{(+)}$ field. In the lower cavity the sensor head of the time-domain electro-optic field sensor system (Seikoh Giken OEFS-S1B), consisting of a 3-axis sensor head (o.d.=12 mm) and a controller unit, is mounted on an adjustable gantry (Fig. 2). The sensor head consists of three orthogonal Mach-Zehnder-type electro-optic E-field sensor chips coupled to the controller by 10 m of optical fiber but for the present study only one sensor channel was used. By rotating the sensor in steps 120° all three complex E-field components can be measured. The controller unit was placed outside the RF shield in order to avoid EM interferences. The RF output of the sensor was connected to a receiver channel of the 3 T whole-body MR scanner (Verio, Siemens Healthcare, Erlangen, Germany). For E-field measurements rectangular RF pulses (5.12 ms) with five different transmitter voltages (U_{eff}= 10, 20, 40, 80, 100 V) were applied for all three angular positions. High accuracy $B_1^{(+)}$-maps were acquired for a transversal slab (5 cm) using a preparation pulse sequence [2].

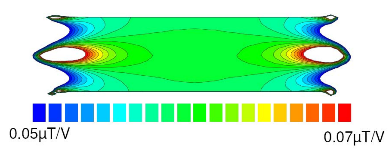

Fig.1: $B_1^{(+)}/U_{in}$ distribution in the sensor's plane (from FDTD)

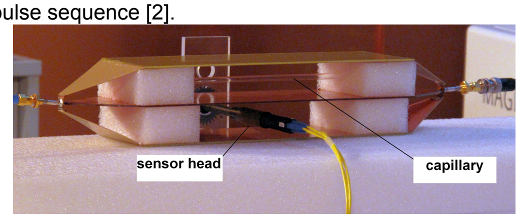

Fig.2: TEM cell with water capillary and OEFS

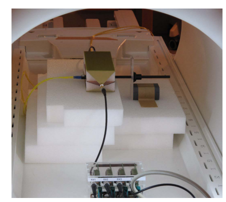

Fig.3: TEM cell and OEFS in magnet bore

Results

Gradient echo images of the water filled tube demonstrate the high RF field homogeneity along the TEM cell's principal axis (Fig.4). Reliable $B_1^{(+)}$ measurements can thus be expected. For a transmitter voltage of $100V_{eff}$ we obtained a value of $|B_1^{(+)}|$ of (5.94 ± 0.3) µT. The corresponding E-field is 3.56 kV/m and the magnitude of the sensor's vector output is 0.00393 (in scanner specific units). In Fig.5 the time course of sensor output is shown for angular position 1. A linearity plot is shown in Fig.6.

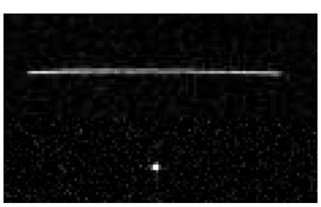

Fig.4: MR images of capillary taken with TEM cell as MR coil: sagittal (top), transversal (bottom)

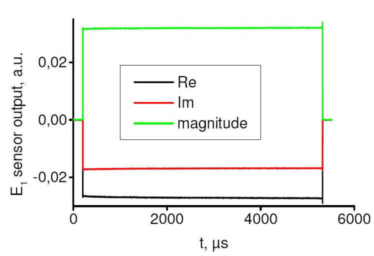

Fig.5: Sensor signal for a 5.12ms, $100V_{eff}$ rectangular Tx pulse (sum of 10 scans)

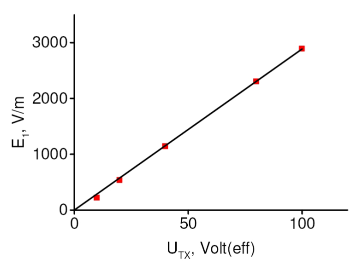

Fig.6: Linearity of calibrated sensor output

Conclusions

Using an MR compatible TEM cell we calibrated an electro-optic E-field sensor inside a clinical scanner by MR techniques only. No further correction of the calibration regarding feeding lines etc. is needed. The uncertainty of the calibration is about 5% or 0.2 dB. Due to the broadband nature of the TEM cell the technique is also applicable at 7 Tesla or higher.

References

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[2] F. Seifert, G. Wuebbeler, S. Junge, B. Ittermann, and H. Rinneberg, JMRI 26 (2007) 1315-1321