Optical Dipole Probes for Quantitative Electric Field Measurements up to 7T

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Introduction

To estimate local specific absorption rates (SAR) an accurate measurement method for both electric and magnetic fields is necessary [1]. To estimate elevated SAR regions relative *E*-field measurements have been performed up to 3 Tesla, however, no quantitative E-field values have been specified [2, 3]. In this work an optical electric field probe is presented to quantify E-fields of transmit coils up to 7 Tesla.

Materials and Methods

It has been shown that resistive dipole probes up to 120 MHz provide accurate E-field measurements [4]. Here, this concept is applied to an optical measurement system. It consists of two parts, the optical dipole probe and a controlling system.

The probe is built of a dipole with an overall length between 4 and 7 cm (Fig. 1). Two circuits are integrated into the probe: (1) The RF-part which is tuned to the target frequency, consists of a vertical-cavity surface-emitting laser diode (VCSEL, XM67-R5P0U, Laser Components GmbH, Olching, Germany), an inductor, and a tunable capacitor (optional; for frequencies up to 65 MHz). (2) The DC-circuit consists of a photodiode array (PA1001, RLS d.o.o., Ljubljana-Dobrunje, Slovenia) and a PIN diode (BAP 51-02, NXP Semiconductors, Eindhoven, The Netherlands), which loads the dipole when the photodiode array is irradiated by light (Fig.2). Two capacitors are integrated to block the DC current to the VCSEL, and two RF-chokes are installed between PIN diode and photodiode to block the RF current. Three different probes were built, which detect E-fields at 63.69 MHz, 123.20 MHz, and 297.15 MHz. The calibration of the dipoles was performed in a custom-built Crawford TEM cell [5]. At field strengths up to 550 V/m it is possible to measure the light output power of the VCSEL directly.

The controller is needed to extend the measurement range of the dipole probe for electric field strengths higher than 550V/m. It consists of a photo amplifier, a peak detector and a controlling element with a tunable reference voltage. The dipole probe and the controlling unit are connected via two optical fibers that are long enough to reach the iso-center of the specific MR-system (Fig.2). The peak detector detects and holds the photo amplifier's output voltage for about 2 seconds. The controlling element compares the voltage from the peak detector with the reference voltage and drives an output laser diode to keep the light output of the VCSEL constant. Thus, the controller system measures the E-field via the light output of a laser diode.

E-field measurements were performed at 7 T (Magnetom, Siemens, Erlangen, Germany) on a 1-channel Rx/Tx head coil (Invivo Corp., Orlando, Florida, USA). An FID sequence (TR: 51.5 ms, Pulse length: 50 ms, Duty Cycle 97 %, Voltage: 23.9 V; Average Power 10.7 W, SAR: 97 %) was used to generate the RF field. The E- field in z-direction was measured in air on one side of the coil (Fig. 3). In total 141 data points were acquired (109 points in a $2.0 \times 2.0\ cm^2$ pattern and 32 points around the inner wall of the coil in an angular distance of 11.25 °). The position with the highest field strength (cf. Fig. 4, Coord.: 12 cm / 5 cm) was measured with the dipole-controller system. To further test the controlling system the voltage of the FID sequence was increased up to 27.9V.

Results and Discussion

Figure 4 shows the distribution of the z-component of the electric field in the xy-plane. The minimum measurable electric field strength was 65 V/m, the maximum 550 V/m. The electric field could be measured with an overall accuracy of 7.5% (sensor calibration in TEM-cell and accuracy of the Voltage meter). With the controlling system the measurement range of the dipole probe could be extended to 643.5 V/m at a duty cycle of 73.1%.

The new probe design provides a simple and reliable tool for electric field measurements in MRI transmit coils. Due to the peak detector and the controlling system every standard pulse sequence with constant RF peak amplitude can be used for the E-field measurement. The next step would be to measure the E-field within phantom material to determine SAR values and compare them with a measured temperature increase. Further developments include decreasing the size of the dipole to improve the spatial resolution of the E-field map.

References

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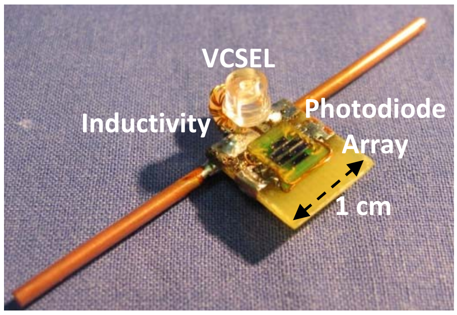

Fig.1: Dipole probe with a total length of 7 cm. The toroidal inductivity and the capacity of the VCSEL form a resonating circuit for 297.15MHz. The PIN diode is placed on the back of the circuit board.

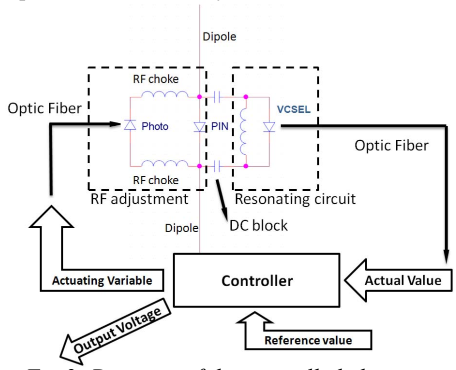

Fig.2: Diagram of the controlled electric field probe.

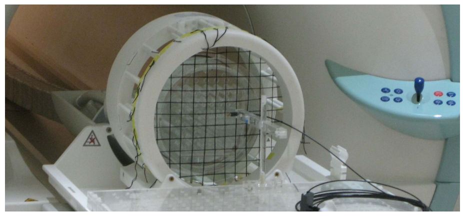

Fig.3: Setup at the 7T system. Each point of the pattern has been measured.

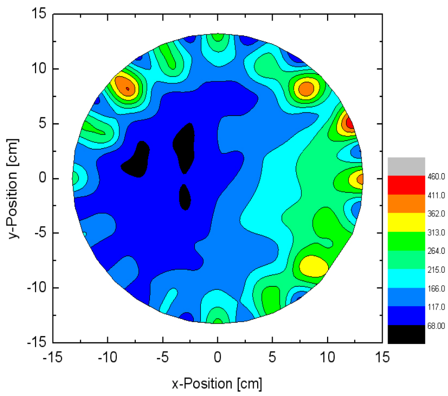

Fig.4: Electric field distribution of the z-component in the x-y plane of the Rx/Tx coil. Legend shows E-field in [V/m].