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Direct optical measurement of the RF electrical field for MRI

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Purpose

In magnetic resonance imaging (MRI), the real time measurement of electrical field E associated with the radiofrequency (RF) magnetic field B_1 is important to quantify the energy absorbed by the tissues and to assess possible safety hazards due to local heating phenomenon. E -field could effectively increase the temperature in the tissues nearby by inducing RF currents in any implant or metallic cables used for signal transmission and placed inside the transmit body-coil^{1,2}. For the measurement of the intensities and the distribution of E -field, the adequate probe should be non-magnetic and non-perturbative regarding the E -field and must have a large working frequency range depending on B_0 . The commonly used probes have either a metallic structure or a large dimension which limits their bandwidth^{3,4} and may disturb the electromagnetic field with bias measurements. Others optical probes do not measure directly the E -field⁵. In the following, the E -field measurement experiment using a sub-cm electro-optical (EO) probe in a preclinical 4.7-T MR system is presented.

Methods

The EO probe is basically formed from a monocentrosymmetric crystal (ZnTe, BSO...) that changes its refractive indexes proportionally to the applied electrical field (Pockels' effect). In fact, this index variation leads to a modification of the polarization state of the distributed feedback (DFB) laser (wavelength $\lambda=1.55 \mu\text{m}$), according to the electrical field. This DFB laser is emitted toward the crystal through a 15 m optical fiber. Then, this optical polarization is transmitted, using the same optical fiber, to be analyzed in real time and to be converted to an analogue electrical signal due to optoelectronic components. This small size probe (sub-cm) is non-invasive and insensitive to the variation of the temperature or the magnetic field (static or dynamic)⁶ which is suitable for MRI environment. It can operate in a frequency range from 30 Hz to 18 GHz and the electrical field is directly proportional to the measured output signal. The experiment was performed using a 4.7-T preclinical MRI using a 60 cm inner diameter transceiver birdcage linear coil (figure 1). A moving EO probe was inserted into the transceiver coil to localize E -field concentrations. The optical detected signal was transmitted via an optical fiber to the signal processing unit in order to be visualized by an oscilloscope. The trigger signal was provided by MR system. For this experiment, a RARE sequence with hermite shape RF pulse was used. The imaging parameters are: $TR/TE=6020.6\text{ms}/14\text{ms}$, flip angle= 90° and turbo factor=8.

Results

First of all, in order to demonstrate that the probe is completely dielectric and non-perturbative; the EO probe was placed on the NiSO₄ phantom. The presence of the probe had no impact on the image quality (absence of artefacts and similar signal to noise ratio). Second, the probe was moving (axial and radial movement) inside the RF coil to detect the presence of E -field. Three hot spots of the E -field were detected clearly at proximal and distal sides of the transceiver coil corresponding to three different probe's locations (figure 2). Their magnitudes vary between 10000 V/m and 20000 V/m. Figure 3 shows the shape of the detected EO signal and related electric field during the emission of RF signals. The E -field is linearly proportional to the EO signal with a factor of linearity around 38000 and with a dynamic range exceeding 120 dB. Using the Fast Fourier Transform (FFT), the frequency of the detected signal is 200 MHz that corresponds exactly to the proton resonant frequency at 4.7-T (figure 4).

Discussion

The EO probe can detect directly the E -field in real time at Larmor frequency with a transverse spatial resolution lower than 5 mm. The analysis of hot spots' magnitudes shows that the \vec{E} field is not uniform and it depends on both the position of the EO probe inside the transceiver and the orientation of the probe itself. Further experiments will be performed to study this correlation. The results exhibit the effectiveness of measuring directly the E -field in a preclinical 4.7-T MRI using an optical probe without alteration of environment. Due to availability, the experiments were performed at 4.7-T but will be further addressed in a clinical 3-T MRI system.

Conclusion

The objective of this study was to validate the use of a specific EO probe to determine the local magnitude of the E -field associated to the RF magnetic field. During the RF emission, a non-perturbative EO probe can be used to give a real time measurement of the electrical field in order to protect the patient from any safety risk. Such probe could be used to provide localized E_I -field map.

Acknowledgment

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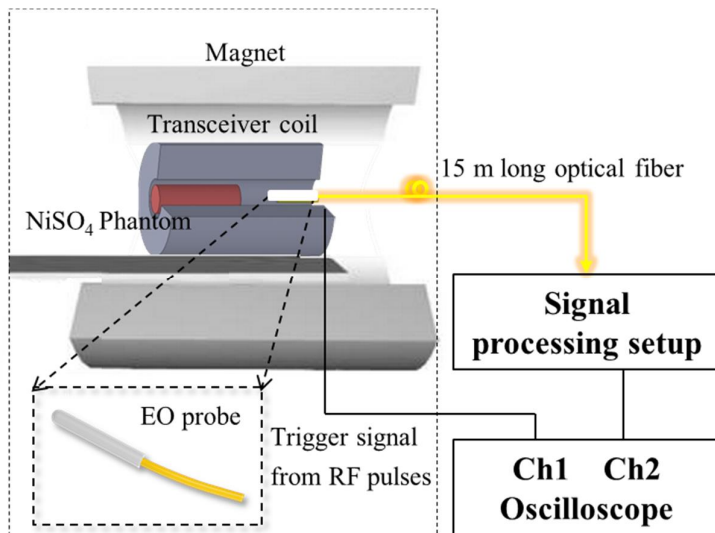


Figure 1. Schematic set-up of electrical field measurement experiment.

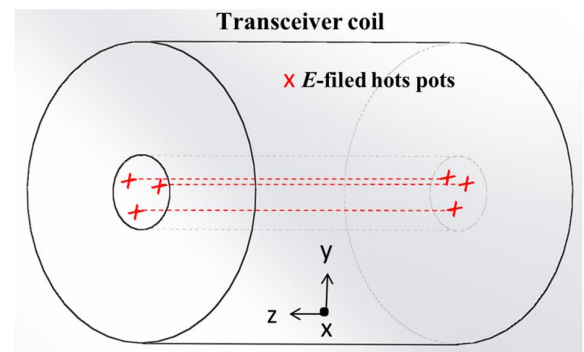


Figure 2. Locations of the detected hot spots at proximal and distal sides of the transceiver coil.

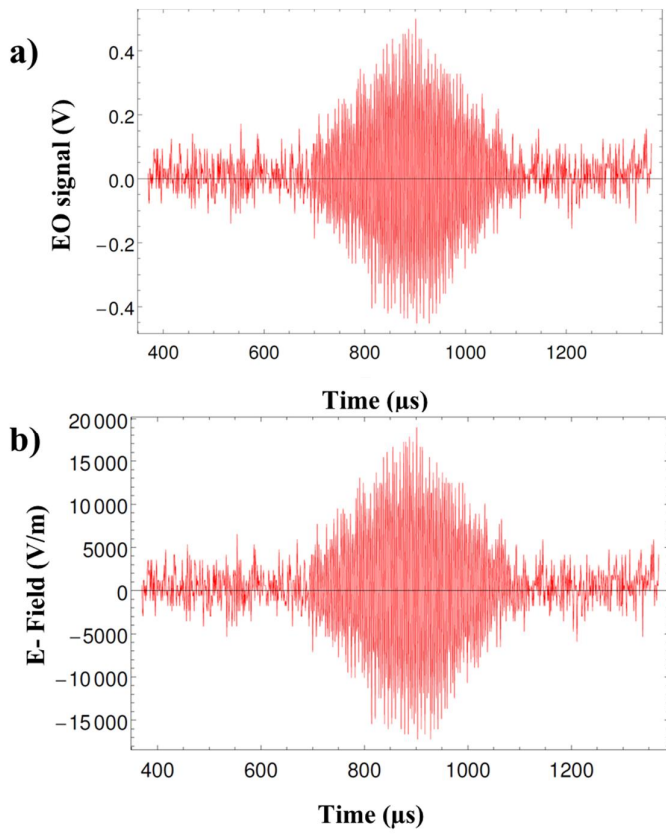


Figure 3. a) The detected EO signal during RF transmission period. b) The direct conversion of EO signals into an electrical field.

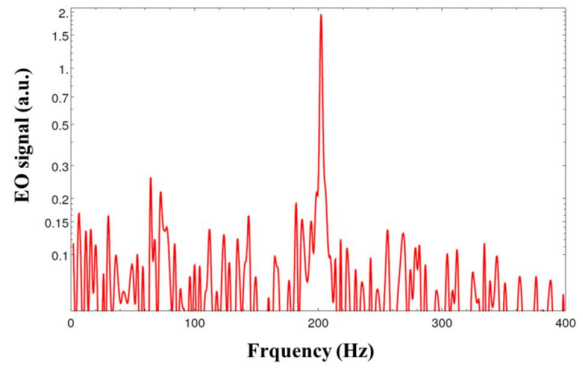


Figure 4. The spectrum of the EO signal was obtained using the fast Fourier transform. The frequency corresponds to the proton resonant frequency at 4.7 T MRI