Design Methods for Magnetic Resonance Based Field Monitoring Devices

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TARGET AUDIENCE – Physicists, engineers, researchers requiring field sensing and monitoring devices.

PURPOSE – Magnetic resonance field probes have been demonstrated to be useful in a multitude of ways, including post-processing correction of MRI data[1], real-time shimming[2], and correction of subject motion[3]. At the same time, measuring the magnetic field provides a means of examining[4] and optimizing pulse sequences. We aim to improve the design of the field probe head using magnetic susceptibility simulations originally used in MR to predict the susceptibility-induced field in the human head.

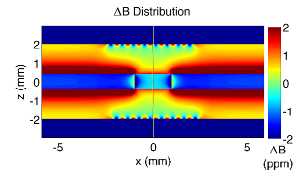

Fig. 1: Simulated field distribution in vicinity of a field probe.

METHODS – A field probe consists of a micro-coil, wound around a capillary containing a droplet of sample fluid. A Fourier-based simulation[5] was used to investigate B0 field distortions in a droplet inside a field probe caused by susceptibility mismatch of the field probe components and surrounding material. We use 3D models of the different components: droplet, buffer plugs, capillary and solenoid and derive from these a mesh of 256x256x256 voxels over a range of 12x12x6 cm^3. We deduce from this the susceptibility distribution of the local magnetic field perturbations within this area by assuming boundary conditions in which the capillary extends into infinity and is surrounded by an infinite volume of either air or epoxy (figure 1). The local field distributions within the NMR-active sample droplet were then analysed.

For verification of the model, measurements were made with a field probe system used in a 9.4T scanner. We compare field probes made from of 1 mm (thin) and 4 mm (thick) outer diameters, 0.8 mm inner diameter, filled with manganese chloride sodium chloride solution. These field probes were positioned at a fixed location within the scanner bore and exposed to a ramped linear gradient.

RESULTS – We simulated the two probe configurations and the impact of plugs as well as enclosing the probe using epoxy vs. air (figure 2). The susceptibility of the plugs was adapted to the susceptibility of the droplet and the susceptibility of the epoxy was adapted to that of the copper wire. In general it is necessary for the field distribution within the droplet to be as homogeneous as possible. With a gradient applied this distribution should broaden. These conditions are very difficult to meet. Any deviation, e.g. off centre peaks, can cause a decrease in signal fidelity. Both plugs and epoxy can cause a more favourable configuration for field probe measurements, but it is also apparent that encasing the probe in epoxy is more important in case of a thin capillary and coil, whereas it loses significance as the capillary walls create a sufficiently large buffer zone. Buffering using a matched plug is beneficial in both cases.

Methods to characterize field probes for their performance and field sensing capabilities are demonstrated. Gradient perturbed FIDs are prone to exhibit a splitting of the NMR peak (figure 3), due to local field distortions within the sample droplet caused by the field probe itself. From the measurements with different capillary diameters we observe that field probes using thin capillaries suffer significantly more from this effect. In the case shown here a peak splitting occurs at 20 mT/m gradient. A field probe using a thick capillary does not show a significant splitting even at gradient strengths of 25 mT/m.

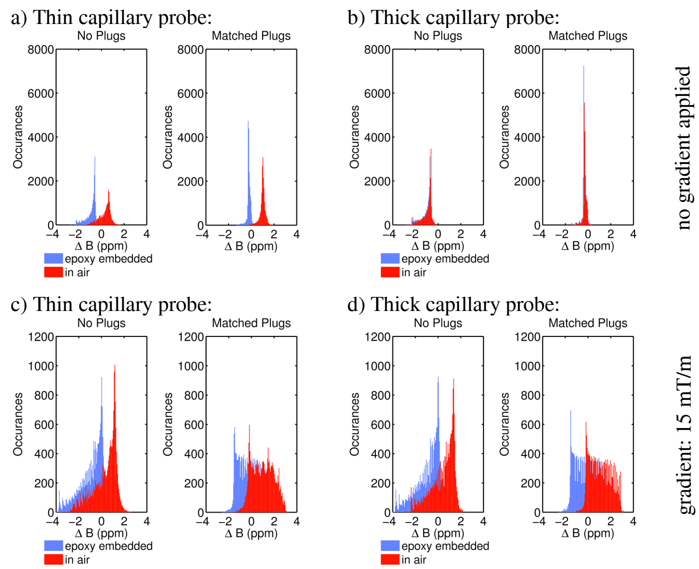

Fig. 2: Comparison of simulated magnetic field distributions inside the droplet of field probes with thin and thick capillaries without gradient (a, b) and with a 15 mT/m gradient applied (c, d). In comparison the effect of susceptibility matched plugs have a significant impact on the symetry of the NMR peak. Embedding the capillary within an epoxy matched to the coil wire (blue bars) shows a more significant effect in case of the thin capillary field probe.

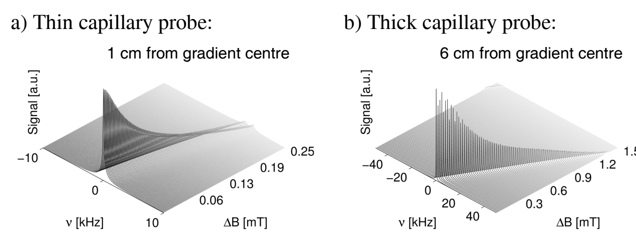

Fig. 3: Applying a constant gradient during a 90-Acquire experiment causes the NMR peak to shift by a frequency **ν** according to the local field **ΔB** at the position of the sample droplet. In case of a thin capillary field probe the NMR peak is suffering a notable splitting for gradients greater than about 20 mT/m (a). This effect is not visible in case of a thick field probe even for stronger applied gradients, e.g. 25 mT/m (b).

DISCUSSION – The simulations enable investigation of the influence of the various components of the probe on field homogeneity within the sample droplet. By comparing the simulation results for both field probe configurations it is apparent how changes in the design influence the local field distribution. Of the two probe models investigated, it is clear that the thin capillary suffers greatly under the effects of field inhomogeneity within its sample droplet, and epoxy should be used to encase the probe. By susceptibility-matching the epoxy surrounding the capillary tube to the micro-coil wire, it is possible to avoid effects from the asymmetries induced by the helical shape of the solenoid and thus circumvent the influence of unmatched susceptibility filling the gaps between the coil and the capillary. Susceptibility matched plugs help avoid inhomogeneity due to unmatched susceptibility in close vicinity to the sample droplet (e.g. air). This agrees well with what is seen in the experiments. Thus, the simulation proves itself applicable and useful for optimization of field probe design parameters

CONCLUSION – The simulation method yields a novel way to assess information about the field distribution within the sample droplet. We now intend to use this information to optimize the geometry of our field probe design.

REFERENCES – 1. Barmet, C. et al., Spatiotemporal magnetic field monitoring for MR. MRM 2008;60:187–197. 2. Van Der Velden, T. A. et al., Real-time correction of field probe observed linear B_0 fluctuations in breast MRI. MAGMA 2013; 26(1):73. 3. Haeberlin, M. et al., Field Decoupling for Real-Time Prospective Motion Correction Using Gradient Tones and Concurrent Field Monitoring. Proc. Intl. Soc. Mag. Reson. Med. 2012;20:595. 4. Dietrich, B. E. et al., An Autonomous System for Continuous Field Monitoring with Interleaved Probe Sets. Proc. Intl. Soc. Mag. Reson. Med. 2011;19:1842. 5. Marques, J. P. and Bowtell, R., Application of a Fourier-Based Method for Rapid Calculation of Field Inhomogeneity Due to Spatial Variation of Magnetic Susceptibility. Concept. Magn. Reson. B. 2005;25B(1):65-78.