A magnetic field monitoring add-on toolkit based on transmit-receive NMR probes

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Introduction

In MRI precise gradient performance is critical to a number of applications, including fast single and multi-shot data acquisition schemes (EPI, spiral, radial, rosette), and motion encoding sequences based on fast and accurate switching of strong bi-polar gradients (diffusion tensor imaging and phase contrast based flow quantification). Magnetic field imperfections caused by Eddy currents, concomitant fields, group delays etc. can cause detrimental image artifacts. Recently, the concept of Magnetic Field Monitoring (MFM) has been presented to address this challenge (1,2). By placing magnetic field sensors inside the magnetic bore, the goal is to track the gradient and B_0 profiles simultaneous to the execution of the imaging pulse sequences. The acquired data from the sensors is implemented during the reconstruction to correct the effect of the field imperfections. MFM has been previously shown feasible with sensors based on local receive-only NMR probes. However, such probes are relatively cumbersome to use, as the probes have to be aligned with the excitation plane of the imaged object itself.

In this paper, a more practicable MFM setup is described in form of transmit-receive NMR probes. Having a second exciter channel available, the usability of MFM monitoring can be considerably improved based on minor hardware and software modifications only.

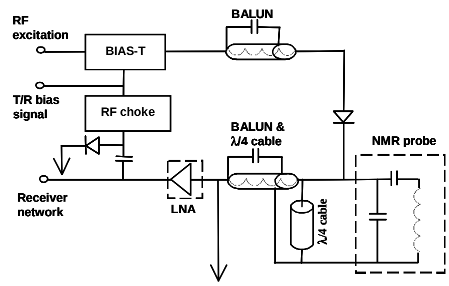

Fig. 1 Electrical schematic of the transmit-receive probe. The probe is switched between the transmit and receive state by turning the pin diodes on and off, respectively.

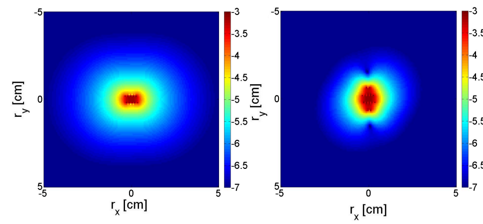

Fig. 2 Simulated B_1 field patterns (on a logarithmic scale) of a 4-turn solenoid coil (left), and a solenoid coil with 4 turns and 2x2 counter-wound turns (right).

Materials and Methods

Several designs of NMR based probes have been previously presented and the functionality of the sensing concept for magnetic field monitoring (MFM) has been proven (1-3). However, the applicability of receive-only probes is drastically limited by the fact that the pulse sequence has to assure excitation for the NMR probes. For 2D imaging, this implies that NMR probes have to be arranged within the desired imaging slice. In the presented work, this limitation is overcome by making the NMR probes transmit receive and supporting them with one single independent exciter. The use of broadband radio frequency (RF) pulse ensures that the NMR probes will get excited despite the governing value of the local B_0 field.

Some changes are required to the probe design itself and to the accompanying electronics. During the transmit phase, one has to verify that no damaging power levels are supplied into the sensitive receiver-network of a MRI system. With our T/R NMR probes, this is done by applying PIN-diode switches and by using low input impedance preamplifiers in combination of quarter wavelength cables (Fig.1). Respectively, the coupling to the imaging coil elements nearby should be minimized in a way that damaging power levels are not exceeded. The B_1 field around the T/R NMR probe coil can locally deteriorate the excitation profile of the imaged object, and lead to unwanted signal received from locations outside the region of interest. To wrap the T/R probes inside a thin conductive sheet has been previously shown to suppress the RF field yet still letting the most of the gradients to penetrate through the shielding (4). However, as the probes are placed in the vicinity of the object, one should avoid having large conductive structures which would couple with the imaging coil elements (ultimately reducing the signal to noise ratio), or which would jeopardize the patient safety through increased SAR (specific absorption rate) values. Such a bulky structure could also deteriorate the spatial B_1 profile, and attenuate the high frequency components of the B_0 fields (up to 50 kHz) penetrating through this conductive sheet, to the sensing NMR samples. Due to these concerns, we have decided to have counter wound solenoid coils to excite and receive the signal from water based NMR probes. Biot Savart field simulations were performed to verify the effectiveness of counter windings (Fig. 2). Thereby, the RF screening was considered to be required around the electronics only.

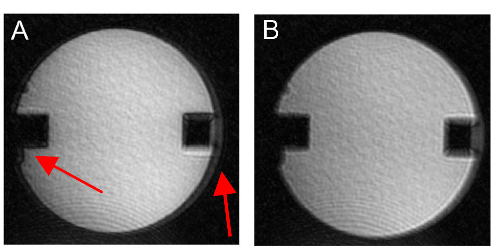

Fig. 3 Image of a resolution phantom without (A) and with (B) magnetic field monitoring. For the acquisition 8-arm spiral with 8192 points and ±125 kHz bandwidth was used.

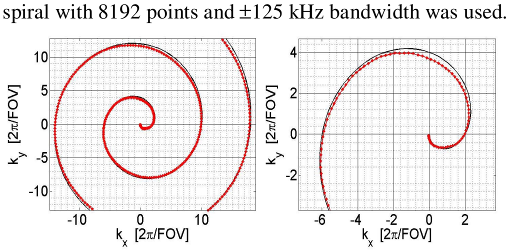

Fig. 4 Zoomed sections of nominal (black line) and measured (dotted red line) spiral k-space trajectories.

Coupling tests between a coil array element and a single T/R probe were conducted. The coil array element was preamplifier decoupled and the probe was placed at a typical distance of ~3cm away from the closest neighboring element. Coupling less than -32 dB was observed. With excitation power of below 10 dBm into the T/R probes, this was well under the limit to cause physical damage to the receiver network connected to the coil array.

A set of four T/R probes was installed to accompany an image acquisition with a standard 8-channel receive-only head coil. The experiments were done with a 3T GE Signa Excite HDx MRI system (GE Healthcare, Milwaukee, WI). An additionally available RF exciter was diverted through a blanking power amplifier and power splitter to provide required excitation profile for the four T/R NMR probes. The probes were connected to the receive channels of the scanner. Gridding image reconstruction was performed based on MFM-measured image encoding information.

Results and conclusions:

Fig. 3A shows common ringing and twisting artifacts caused by the eddy currents in images acquired with spiral pulse sequences. In Fig. 3B the information from the NMR probes is used to correct the field imperfections. The result is improved image quality, verifying the feasibility of our T/R NMR probe design. Fig 4. Shows the difference between the nominal and the measured k-space trajectory. Respectively, the outcome of the measurements agrees with the simulations on the applicability of counter windings in solenoid coil design. The probes are not radiating significantly to the surroundings, and thus not deteriorating the desired excitation profile nor coupling significantly with the head coil. However, the most prominent result of our measurements is that that, only with minor hardware adjustments, a system with additional exciter board can easily be accompanied with a MFM add-on kit.

References (1) G.F. Mason et al., Magn. Reson. Med.,vol.38, p.496-492,1997, (2) K.P. Pruesmann et al., ISMRM 2005:p.681, (3) N. De Zanche et al. ISMRM 2006: p.781, (4) P. Sipilä et al. ISMRM 2007, p.629, (5) N. De Zanche et al. ISMRM 2007: p.626