Phased array probehead for magnetic resonance

Oliver G. Gruschke[1], Elmar Fischer[2], Maxim Zaitsev[2], Jürgen Hennig[2], and Jan G. Korvink[1,3]
[1]*Lab. of Simulation, University of Freiburg - IMTEK, Freiburg, Germany,* [2]*Dept. of Radiology Medical Physics, University Medical Center, Freiburg, Germany,*
[3]*Freiburg Institute for Advanced Studies – FRIAS, University of Freiburg, Freiburg, Germany*

Abstract: We present a magnetic resonance (MR) probehead for investigation of micro samples. A Helmholtz coil (Tx), for homogeneous excitation of transverse magnetization, is optimized for a previously reported [1] MEMS-based receive-only phased array of microcoils (Rx). The setup is a compact and easily handable probehead allowing to acquire MR images with an resolution of 39x39x200µm^3. For example an SNR of 80 can be found for a sample of ionized water (1 g/l $CuSO_4$) in a total experiment time of only 1:42min.

Introduction: Signal-to-noise ratio (SNR) and available resolution are factors that have been under investigation since the early days of magnetic resonance imaging. Thus, for an investigation of very small samples, microcoils have been developed that increase resolution e.g. to the size of single cells in biological samples. The phased array of microcoils (PAM), presented in [1] extends the limited but high sensitivity of a single microcoil in the lateral dimension, thus extending the total FOV to 18.3mm^2, with the much higher SNR provided by microcoils. If used as transmit/receive coil, the PAM, as most other planar coils, suffers from the decreasing magnetic field strength when moving further away from the coil's surface. Combined with the non-uniform field excitation pattern, an inhomogeneous distribution of flip angles throughout the sample is observed and thus a decrease of image quality occurs. [2] Therefore, it is often advantageous to use a separate volume coil for transmission. A customized volume coil, optimized for the PAM FOV is presented and characterized, here. An image of the setup is displayed in Fig.1. The previously used circularly polarized ^{1}H excitation coil delivered good results, however, the arrangement of the PAM in that resonator due to the tight space constraints and the time-consuming geometric re-alignment of Tx and Rx coils was difficult when replacing the sample. The presented probehead improves the setup, combining features of the old setup with increased usability and an option of future use in MR scanners with smaller bore diameter.

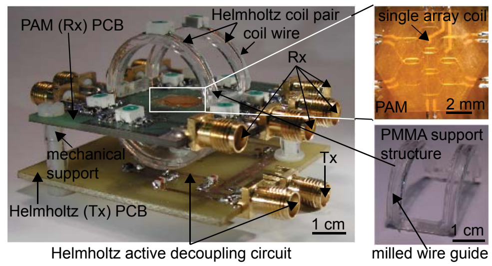

Fig. 1: Assembled MR Probehead including Rx phased array of microcoils (PAM) and Tx Helmholtz coils and zoom in on PAM and PMMA coil support structure. The wire guides are milled along the outer rim of the support structure.

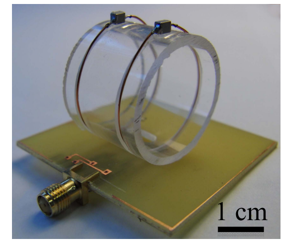

Fig. 2: Helmholtz coil setup without the phased array of microcoils inserted, for measuring the coils B_1 field uniformity.

Materials/Methods: Different setups were simulated with COMSOL (COMSOL, Inc., Burlington), in order to find the optimum Tx coil configuration taking the PAM's space restrictions into account. The well-known Helmholtz coil setup, consisting of two parallel-aligned loop wires with a defined coil distance to coil radius ratio [3], showed good results across the PAM FOV, with easy access to the region on top of the PAM for an exchange of the sample. In a first approach for construction, electric circuits for tuning and matching, together with the active decoupling of Tx and Rx coils were placed on a printed-circuit-board (PCB), which is mechanically connected to the PAM (see Fig. 1). The two PCBs will be merged in a future design. In an attempt to avoid coupling between Tx and Rx coil, which leads to image artefacts and possible damage to the attached low noise amplifiers, Tx and Rx coil are arranged under at a 90° angle to each other, as a can be seen in Fig.1. A frame in the shape of the loop wires was laser cut out of a 30mm diameter PMMA tube, wire-guide milled into it and attached to the PCBs. A 300µm diameter copper wire was attached to the PMMA frame and soldered to the circuit.

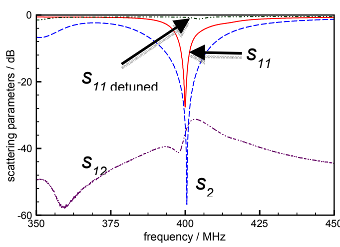

Fig. 3: Measured values of the input port voltage reflection coefficient (s_{11} & $s_{11\ \text{detuned}}$) of Tx Helmholtz coils and one representative array Rx coil (s_{22}). The curves show that the coils are tuned to 50Ω at 400MHz. Additionally the coupling, when unloaded, between the Tx (Helmholtz) coil and one array coils (s_{12}) is shown, demonstrating a weak mutual coupling.

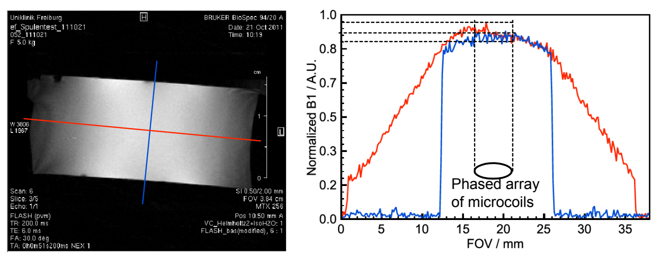

Fig. 4: Coronal image acquired with the setup shown in Fig. 2, with flash sequence, TR = 200ms, TE = 6ms, resolution 150x150x2000 µm^3 in 51s. As sample a ionized water (1 g/l $CuSO_4$) water phantom is used, allowing to determine the homogeneity of the Helmholtz coil's B1 field, The measured homogeneity profile shows a deviation of 4.25% along the vertical and 9.6% along the horizontal cut, the area where the phased array of microcoils is located.

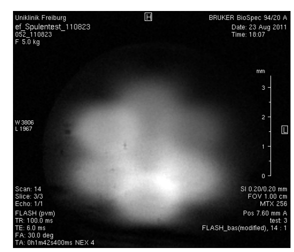

Fig. 5: The coronal MRI image of ionized water (1 g/l $CuSO_4$) has an in-plane resolution of 39x39um^2 for a slice thickness 200 µm. It was acquired in 1:42min with 4 averages and has an SNR of 80.

Results and Discussion: After determination of the Tx coil's inductance (approx. 79nH), scattering parameters of the Tx coil were measured using a network analyser (Agilent E5071B). Results shown in Fig. 3 demonstrate that the coils are tuned and matched to 50Ω at 400MHz, the ^{1}H Larmor frequency in a 9.4T scanner.

The s_{12} parameter graph shows, the good decoupling between the Tx and Rx coil. The manufactured Helmholtz coil (see Fig. 2) was inserted into a Bruker 9.4T scanner and images of a water-filled tube were acquired, allowing to determine the homogeneity of the Helmholtz coil. This is shown in Fig.4. A container filled with ionized water ($CuSO_4$) is placed on the PAM system (see Fig. 1) and high-resolution images are acquired. Results are shown in Fig. 5.

Conclusion: The transmission Helmholtz coil integrated with the PAM setup completes the standalone probehead and represents a good start towards commercial utilization. B_1 field uniformity will be further improved in the next design step. The capabilities of the compact and easily usable probehead concept were demonstrated, allowing high resolution imaging over a larger FOV with a strong SNR than with a single microcoil.

Acknowledgment:
The authors gratefully acknowledge the funding through the INUMAC project supported by the German Federal Ministry of Education and Research, grant #13N9208 and by the EC through the NEST Project 028533.

References:
[1] O. G. Gruschke, L. Clad, N. Baxan, K. Kratt, M. Mohmmadzadeh, D. von Elverfeldt, A. Peter, J. Hennig, V. Badilita, U. Wallrabe, and J. G. Korvink, *Proc. Transducers 2010,* pp. 962 - 965.
[2] J. B. Kneeland, J. S. Hyde, High-resolution MR imaging with local coils. *Radiology 1989; 171:1-7*
[3] J. Mispelter, M. Lupu and A Briguet, *NMR Probeheads for Biophysical and Biome: Theoretical Principles and Practical Guidelines*, (World Scientific Pub Co), pp. 307-308