Multi-coil MR imaging with a receive array of eight microcoils

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Introduction

Three-dimensional microcoils are used in medical technology for high-resolution magnetic resonance analysis at the micro level. The coil sensitivity, and therefore the desired signal, is maximized when the size of the coil matches that of the sample [1]. Micro solenoids show exceptional performance compared to planar coils and due to their 3-D shape, the B_1 field is stronger and more uniform [2]. Difficult 3-D processes [3] or hand-made coils [4] prevented the production of suitable, reproducible, and economical coils. As devices are often single use, low-cost solutions are required.

Receive coil arrays have been introduced in MRI to take advantage of improved local SNR in their reduced active volume. Parallel techniques lead to a reduction of phase gradient steps for imaging which eventually accelerates imaging acquisition [5]. In an arrangement of coils close to each other, mutual inductance leads to coupling between the coils. Therefore, coil decoupling needs to be done carefully. In case of microcoils, the corresponding sensitive volume is small, only extending around one to two coil diameters outside the coil volume. Consequently, arranging microcoils not too close to each other, mutual coil inductance can be neglected.

We present an array of eight microcoils, which was produced using MEMS technology being therefore very cost-effective. It is a suitable environment for testing parallel excitation and simultaneous detection schemes suitable for high-throughput and disposable MR analysis.

Methods

Eight microcoils together with their corresponding tune/match capacitors and diodes for decoupling from transmitter power were placed on a PCB substrate to fabricate identical resonance circuits for MR experiments at 9.4 T, see figure 1(a). The microcoil diameter was 1 mm, whereas the distance between coils were chosen to be 10 mm, safely avoiding any possible coil coupling of these microcoils. Thus, each microcoil works as a localized sensor for sample material at that position. The coil manufacturing principle was introduced in [6]: a fully mass production compatible process with 550 um high SU-8 posts on a glass substrate in combination with the capabilities of an automatic wire bonder led to coils as pictured in figure 1(b). Wire bonder coils are being fabricated with extremely high speed (< 200 ms), very precisely, and fully batch-process compatible in a simple single step process. Therefore, the eight-coil array manufacturing process takes less than 2 seconds. The post serves as mechanical support as well as sample chamber. Throughout the experiments it was filled with PDMS (*Dow Corning Toray SE 1740 A*). The resistance and inductance of the coils is measured to be 2.25 Ω and 41 nH at 400 MHz, respectively. This leads to a coil quality factor of 46. All coils of the array have a variance of the electrical data of less than 10%. The coils show an S_{xx} of at least -28 dB and an S_{xy} of at least -30 dB, i.e. a sufficient coil-to-coil decoupling.

MR experiments

Experiments were performed using a *Bruker Biospin MRI Spectrometer* at a magnetic field strength of 9.4 T corresponding to a ^{1}H resonance frequency of 400 MHz. A volume resonator with inner diameter of 72 mm produced transversal magnetization over the whole array of microcoils, while reception was performed in the so-called array mode for eight microcoils simultaneously. Images were recorded with a FLASH pulse sequence, a resolution of 256 x 256 points for 8 x 8 cm, TR = 100 ms, TE = 6 ms, and a flip angle = 30° for a slice thickness of 2 mm. Image reconstruction was performed either calculating the sum of squares of all channels (figure 2) or subdivided into selective images for each channel (figure 3), reflecting the sensitivity profile for each microcoil (figure 4). With an FOV of 8 cm in both *x*- and *y*-direction, a resolution was chosen in which the microcoil existence could be concluded from strong image intensity coming from just a few pixels of the image.

Discussion/Conclusion

Using an array of eight microcoils arranged on a PCB substrate in a straight line, conceptual questions of parallel imaging with multiple coils were addressed. A volume resonator was used for creating transverse magnetization over the whole array, while reception was done with the eight microcoils in parallel. Obtained images show that microcoils nearly coincide with their signal intensity on the array, i.e., they indeed work as local MR detectors that can be used for future applications. With the large distance of 10 mm between the microcoils along a straight line, any possible inductive coupling could be prevented. Therefore, further decoupling by low-impedance preamplifiers was not necessary and experiments could be performed with the simple setup shown.

We are able to produce a microcoil array in an easy, reproducible process even suitable for one-time usage. The eight-coil array is capable for simultaneous detection of signal from samples at predefined spatial positions. Future work will include smaller coil-to-coil distances.

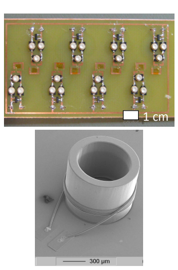

Figure 1: Microcoil array (a) and close-up view (b).

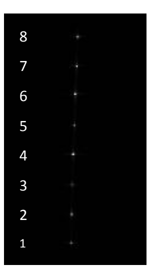

Figure 2: Sum of squares RECO.

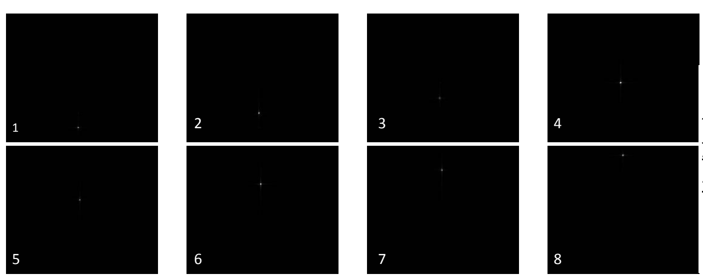

Figure 3: Selective images reconstructed for each channel, sagittal view.

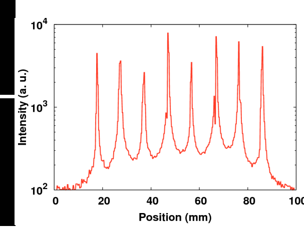

Figure 4: Sensitivity profile along line of microcoils.

References

[1] A.G. Webb: *Radiofrequency microcoils in magnetic resonance*. PROG NUCL MAG RES SP, 31:1–42, 1997. [2] Ehrmann et al.: *Microfabricated solenoids and Helmholtz coils for NMR spectroscopy of mammalian cells*, LAB CHIP, 7:373–380, 2007. [3] J.A. Rogers, R.J. Jackman, G.M. Whitesides: *Using microcontact printing to fabricate microcoils on capillaries for high resolution proton NMR on nanoliter volumes*. APPL PHYS LETT, 70(18):2464–2466, 1997. [4] T.L. Peck, R.L. Magin, and P.C. Lauterbur: *Design and analysis of microcoils for NMR microscopy*. J MAGN RESON, 108:114–124, 1995. [5] M.A. Ohliger and D.K. Sodickson: *An introduction to coil array design for parallel MRI*. NMR BIOMED, 19(3):300-315, 2006. [6] K. Kratt, V. Badilita, T. Burger, J.G. Korvink, U. Wallrabe: *Micro Helmholtz coil pair towards cellular applications*. ISMRM, ID: 2962, 2008

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