Helical microcoil system for high resolution magnetic resonance imaging

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Abstract: We present a magnetic resonance (MR) system for acquiring images of samples in the micrometer range, like cell clusters or single cells. The previously reported [1] wound helical microcoils are spatially closely integrated with a custom-built passive Transmit-Receive (TR) switch and a custom-built low noise amplifier (LNA). The setup has been characterized for MRI application, enabling an **in-plane resolution** of **10x10 µm^2** with a **slice thickness** of **80 µm** of a ionized water (1 g/l $CuSO_4$) phantom at 9.4 T**. The measured signal-to-noise ratio** (**SNR)** of **32** was obtained in a short **acquisition time** of **11:42min**.

Introduction: It is well known that microcoils offer an increased SNR, for micrometer-sized samples and therefore allow high-resolution imaging. However, the signal strength extracted from a sample is proportional to its volume. The acquired signal from the limited samples is degraded during transmitting, by the cables and connectors attenuation in the signal path to the spectrometer, leading to a reduced SNR. To compensate for this loss, one can either perform multiple signal acquisitions or connect a low noise amplifier (LNA) closely to the microcoil, before the signal is transported through the signal path. Since imaging in the micrometer range is prone to mechanical vibration and thermal drift, the averaging may produce blurred images, due to the geometrical sample shift. Additionally, when considering high throughput MR acquisition, averaging increases the scan time, leading to increased costs.

Material and Methods:

System development: The TR system is laid out and simulated in Agilent Advanced Design system (ADS). It consist of a tuning & matching network, a LC-Balun and a TR switch, The assembled printed circuit board (PCB) is shown in Fig. 1. The simulation results of the scattering parameter s_{11}, corresponds to measured ones in Fig. 3. The 50 Ω input and output LNA, shown in Fig. 1 right, is developed using a Matlab routine [2]. The results are verified in Agilent ADS and correspond to each other. The microcoil, which fabrication is based on a hybrid MEMS and automatic wirebonder process, is mounted on to the PCB and electrically connected to the matching network.

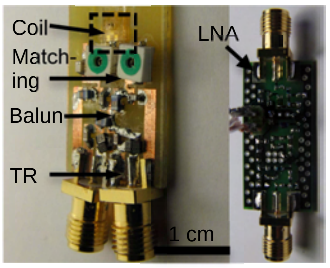

Fig. 1: Image of the custom built TX switch, with mounted helical wirebonded wound coil and the ionized water (1 g/l $CuSO_4$) custom-built LNA (50Ω in- and output). Gain: 31 dB, noise figure (simulated) 0.44 at 400 MHz.

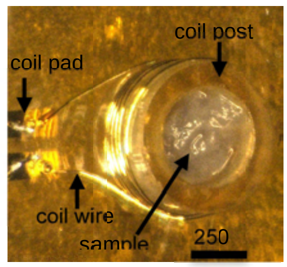

Fig. 2: The helical coil, with an inner diameter of 750 µm, is fabricated based on an automatic wirebonder compatible MEMS process.

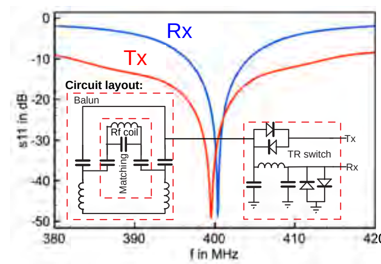

Fig. 3: The scattering parameters s_{11} of the TR switch are shown, for Rx and Tx mode. Both s_{11}, i.e., for Tx and Rx, are smaller than -30 dB. Additionally the circuit layout of the TR system is given.

Results/Discussion:

Experimental results: To verify the systems improvement, the TR MRI system, is tuned and matched to 50 Ω at 400 MHz, the Larmor frequency of ^1H at 9.4T and inserted into a 9.4 T Bruker BioSpec 94/21 system. Gradient-echo images of ionized water (1 g/l $CuSO_4$) (TR = 300 ms, TE = 6.1 ms, resolution 10x10x80 µm^3) are acquired with and without the LNA attached (Fig.4), resulting in factor of SNR improvement of 3.53. To achieve the same results without the LNA, the measurement time increases form 11:42min to approx. 142 min, since the number of signal averages have to be increased. To characterize the TR system further a 3D GE-based image was acquired with a 20 µm isotropic resolution, covering a volume of approx. 1 mm^3 in a very short measurement time of 50 min. One plane of the 3D image is displayed in Fig. 5. A SNR of 60 was calculated for the image.

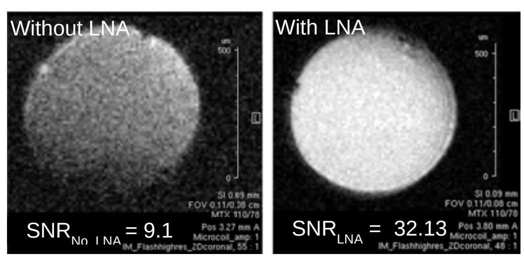

Fig. 4: For comparison an image with the same boundary conditions was acquired without and with an LNA attached to the MR system. Sample: ionized water (1 g/l $CuSO_4$), image resolution: 10x10x80 µm^3, TA 11:42 min, NEX 30, SNR_{LNA} / SNR_{No_LNA} = 3.53

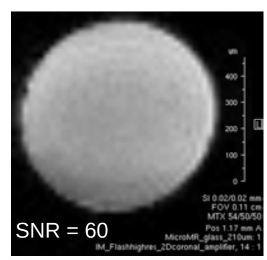

Fig. 5: 2D plane of high-resolution 3D GE image. Sample: ionized water (1 g/l $CuSO_4$), resolution 20 µm isotropic (matrix size: 54/50/50), TR/TE = 300/5.2 ms, TA 50 min, NEX 4, SNR 60

Conclusion: The presented results demonstrate the current capability of the custom-built TR MRI system. Compared to our previous MRI publications where no LNA was used, the acquisition time is significantly reduced, allowing **high resolution imaging** in a **short period of time**. crucial for high-throughput MR applications.

Acknowledgment:

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References:

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