Localized High-resolution MR Imaging of Rat Brain Architecture Using Micro-fabricated Receive-only RF Coil

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***Abstract*—This study introduced a localized approach for magnetic resonance microscopy (MRM) of the rat brain. A single-loop radiofrequency (RF) receiver coil designed for micro-imaging was developed by using electromagnetic simulation software widely used in communication fields. With transmit-only and receive-only (TORO) configuration, receive-only surface coil can achieve higher signal-to-noise ratio (SNR) at localized brain region. Corpus callosum and hippocampus were landmarks to evaluate the capacity of the proposed coil. On a 3T MRI system, high-resolution MRI of the dissected rat brain was acquired with spatial resolution of 117 × 117 × 500 μm^3. The achieved high local SNR and spatial resolution will provide valuable information for resolving the architecture of the rat brain.**

I. Introduction

Since 1970's MRI has been invented and shows its potential in neuroimaging and various clinical applications. Besides T1, T2 and chemical shift image, it also provides application such as functional MRI, phase contrast MR Angiography and diffusion tensor image (DTI), etc.

Among all, temporal resolution and spatial resolution are the two mainstreams of technical improvement in MRI development. Higher temporal resolution reveals the subject's real-time behavior and higher spatial resolution depicts the details accurately. But how to determine these two factors is trade-off, higher spatial resolution often results in lower temporal resolution in practical application. In order to achieve high spatial resolution, we can consider the following factors. The spatial resolution depends on (1) main magnetic field strength, (2) the size of RF coil, (3) the total average time. With fixed total average time, the coil size can be optimized for the target sample to achieve high signal-to-noise ratio (SNR) and spatial resolution [1].

With smaller sample, the SNR increases linearly as the coil size decreases [3]. As the coil size is reduced, the spatial resolution achieved in a given scan time will be improved. Thus resolution of hundreds of achieved on objects the size of humans can be improved to a few microns or at least tens of microns on samples a few millimeters in size.

The goal of this study is to develop a micro-fabricated receive-only surface coil for imaging the dissected rat brain to enhance the localized signal-to-noise ratio (SNR). The RF coil was designed by using the electromagnetic simulation in advance and the resulting B1 filed was also discussed. With this simulated approach, the receive-only coil can be fabricated in a simplified and accurate way.

Manuscript received April 16, 2007.

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II. Material and Method

A. Analysis and Simulation

Solving Maxwell's equation with specific boundary condition yields appropriate results. Numerical calculations of three-dimensional (3D) field distribution were performed using personal computer with the commercially available High Frequency Structure Simulator (HFSS, Ansoft Corp.). Calculations were performed for sinusoidal steady-state fields, and a complex phasor representation was used for the electric and magnetic field quantities. Because only transverse component of the RF field was interested, the z-component of the phasor was subsequently set to zero because it had no effect in the MR system. To maximize the sensitivity while maintaining sufficient RF homogeneity, we engineered the structure with the highest possible symmetry

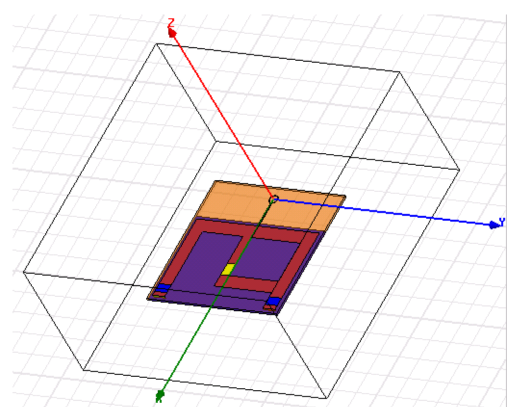

Fig. 1. Scheme of the single port RF micro-coil. A single loop coil with 5-mm diameter on the substrate of the material FR4. The white box outside the RF coil is an air model and those faces of the box is set up radiation boundary condition. Positions of tuning and match capacitors are indicated in yellow and in blue.

and structure elements located as close as possible to the sample [6]. The simulation was illustrated in Fig. 1.

In order to get the best signal, we fit the unbalanced coaxial cable to balanced load of the surface coil, tune and match capacitors were used. The excitation port is tuned at 125.3MHz (H^1 resonance frequency in 3T magnetic field). Post-processing of the simulated results was performed to demonstrate the RF field distribution of different coil diameters. Fig. 2 A and B showed the B_1 magnitude of the field on the yz-plane across the coil. In numerical results, the smaller coil has a stronger RF field, but a less proportion of homogeneous area.

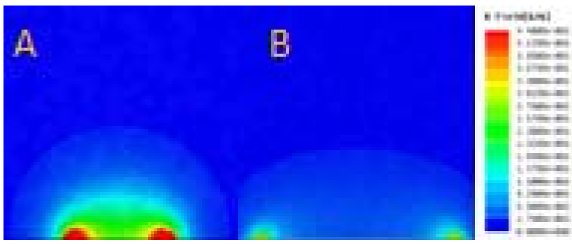

Fig.2. B_1 distribution along the transverse direction of the coil. Simulation (A) Diameter 5-mm and (B) 10-mm of RF coils.

B. Transmit-only and Receive-only RF coil

In transmit-only and receive-only mode, the transmitter coil and the receive coil have to be isolated for each other to prevent the crosstalk of the RF field [1]. RF homogeneity of excitation is critical for anatomical imaging. A transmit-only volume coil was shown in Fig.3. Using this volume coil can excite sample with uniform RF to avoid non-uniform B_1 of small loop coil.

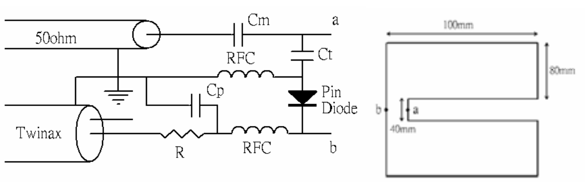

Fig.3. Schematic drawing of transmit homogenous volume coil used in our 3T MRI system. The design of the volume coil was determined by constraints of achieving maximum SNR (as close to the sample as possible).The coil shown here was constructed by 3mm width copper strip. The active decoupling tune/match network shown on left panel and the pin diode driven via radiofrequency chokes was used to activate the coil during transmission.

Receive-only surface coils have the advantage that reception of the NMR signal is independent from the excitation B_1 and can achieve higher SNR in the sensitive area. For proper operation, an orthogonal placement to the excitation coil is often not sufficient for decoupling and therefore additional electronic detuning is a requirement. As shown in the schematic drawing (Fig.4.), typically a PIN diode is utilized in the circuit that detunes the resonance frequency during transmission of the excitation pulse [1].

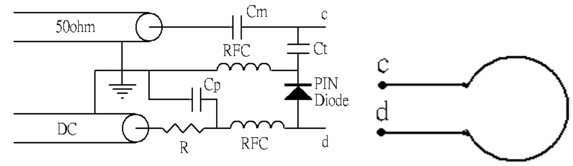

Fig.4. Schematic drawing of receive RF coil. Circuit for manually tune/match network is on left panel including pin diode for active switch. The inductor loop c and d is connected in parallel to the Ct and pin diode at point (c) and (d), respectively, thereby forming the resonating structure of the coil which is connected to Cm to the transmission line. The in-line pin diode in loop is a switch which is activated by a DC current during the rf transmission period. DC is applied via two rf chokes (rfc) that prevent rf leakage. The resistor (R) limits the current that is applied to pin diode at constant voltage.

The 5mm loop receive-only surface coil was layout on a 1.2mm double-sided printed circuit board. Frequency response measurement is performed on a network analyzer. From frequency response, it showed that the coil resonated at different frequency by feeding different DC voltages (Fig.5). The coil Q value is close to 90 at 125.3MHz.

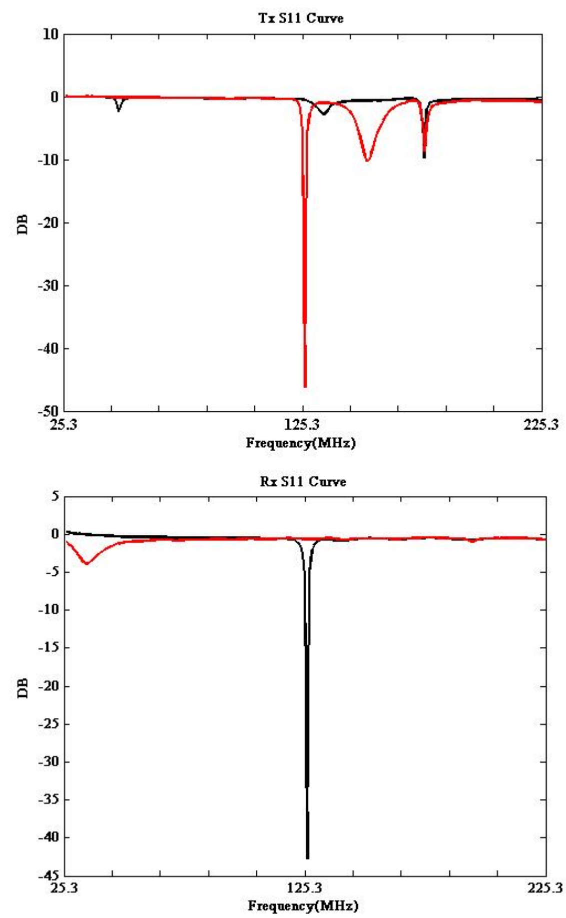

Fig.5. Different frequency response utilized pin diode switching controlled by DC current. The top figure is. frequency response of transmit volume coil and bottom is receive coil. The red curve is while DC is positive and black one is while DC is negative. It shows transmitter and receiver operate between transmission and reception.

C. Experiment setup

For MRI experiments, the dissected rat brain was fixed. The sample was put under the 5mm loop RF surface coil and focused on the hippocampus at the center of the loop of RF surface coil [2]. It was essential to remove all air bubbles from the samples to prevent susceptibility artifacts; this was accomplished by carefully dislodging any bubbles on the sample surface. The experiment configuration was shown in Fig. 6. All the experiments were performed on the Bruker Biospec 3T MRI system (Bruker, BioSpin, Germany) and micro-gradient with strength of 1000 mT/m. T2-weighted images were acquired by using the fast-spin-echo sequence with TR/TE = 4000/50ms, field-of-view = 1.5cm, matrix size = 128×128, slice thickness = 500um, and number of average = 120.

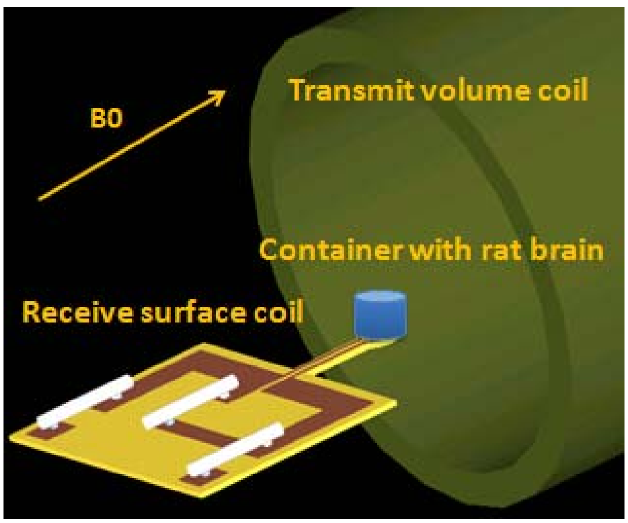

Fig. 6. MRI experiment setup. The 5mm loop receive surface coil is inserted into the transmit volume coil indicated in green, and the container with rat brain is indicated as the blue cylinder above the surface coil.

III. RESULTS

High-resolution images of the rat brain were shown in Fig. 7. As shown in the figure, the localized SNR was highly enhanced due to the micro RF coil sensitivity. Corpus callosum was clearly shown indicated by the yellow arrow. The sub-regions of hippocampus, CA1, CA2, CA3 and dentate gyrus, were also shown in the high-resolution image, indicated by the white arrow.

It showed that the left slice close to coil reveals artifact. The artifact was due to non-homogeneous RF field. According to Fig.7, we could know that is apparent in small loop coil. In addition to artifact, the high-resolution MRI show more tissue detail and add valuable information to the discussion of rat brain anatomy.

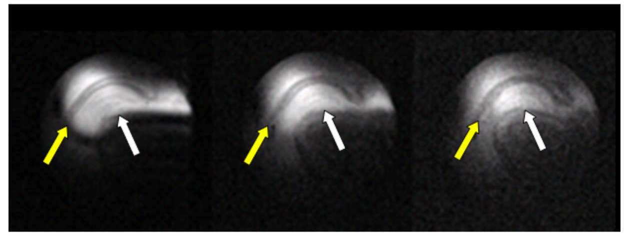

Fig.7. High-resolution hippocampal MR images. The actual resolution is 117 × 117 μm^2 and the thickness is 500 μm. Image parameter: FOV: 1.5cm ; Matrix size: 128 × 128; T_E: 50ms; T_R: 4000ms; NEX= 120; flip angle: 30. The left image is closer to the coil and the right is far. It clearly showed the detail structure of the rat brain.

IV. DISCUSSION AND CONCLUSION

The aim of this study was to introduce a micro-imaging MR system for localized high-resolution imaging. By numerical simulation, the optimized coil configuration and size can be determined for this purpose. Receive-only surface coil of diameter of 5mm was implemented to achieve sufficient SNR and contrast-to-noise ratio for high resolution images. The preliminary result showed that transmit-only and receive-only mode can achieve higher localized SNR of interesting region. In anatomical experiment, the high-resolution anatomical images revealed more details of the corpus callosum and hippocampus, but the non-homogeneous RF field degraded the image quality and has to be improved in the following study.

V. FUTURE WORK

In the future, micro array RF coil can improve the temporal resolution by utilizing the parallel imaging technique. With high localized SNR, the micro array coil system can enhance the image quality and increase the sensitivity of probing the small structure. Furthermore, the localized improved SNR can help molecular imaging applications to reveal its potential.

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