Very High SNR Superconducting Receive-only 7 Tesla Coil for Rat Brain Imaging

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Introduction

In recent years, the design and application of cryogenic coils and coil arrays has become a subject of great interest in the field of magnetic resonance imaging (MRI) and has spurred new developmental studies in both array designs and fabrication [1-2]. It has been recognized that, in the case of a sufficiently small coil, the thermal noise of the system is coil dominated. Cooling receiver coils made of either Cu or HTS materials can provide very significant SNR improvement [3]. However, the practical implementation of these cryogenic/HTS arrays is both technologically and technically challenging and presents a number of design restrictions [4]. Practical cryogenic coil design requires capacitive coupling to the superconducting element and entails using a low loss electronic circuit. In addition, all frequency and matching adjustments should be done outside the cryostat and MRI magnet.

Method and Results.

We have designed a 300 MHz (both copper and HTS) single receiver coils according to the requirements imposed by cryogenics and to the superconductor coil design restrictions. For each coil, the two films on both sides of the substrate were patterned into a split quasi ring shape (as shown in Fig. 1b). The gaps in each quasi ring were rotated 180 degrees from each other. The HTS coil was patterned, using lithography and wet etching, on 2” YBCO films deposited on both sides of a 0.5 mm thick $LaAlO_3$ substrate. The closed cycle pulsed tube refrigerator (Cryomech) was custom-made to cool the coil and the associated electronics to 60 K. The matching/tuning and de-tuning circuit is based on Metelics GaAs varactor diodes and was integrated with the coil inside the cryostat (thus kept at 60 K). Such system allows for all necessary frequency and matching adjustments to be done outside the shielded room. The coil can be fine-tuned to 300MHz by changing the applied DC voltage across the tuning varactors and can be matched to 50 Ω by changing the DC voltage across the matching varactors. The coil was designed for the imaging of small animals and was extensively tested with the MRI of the rat’s brain.

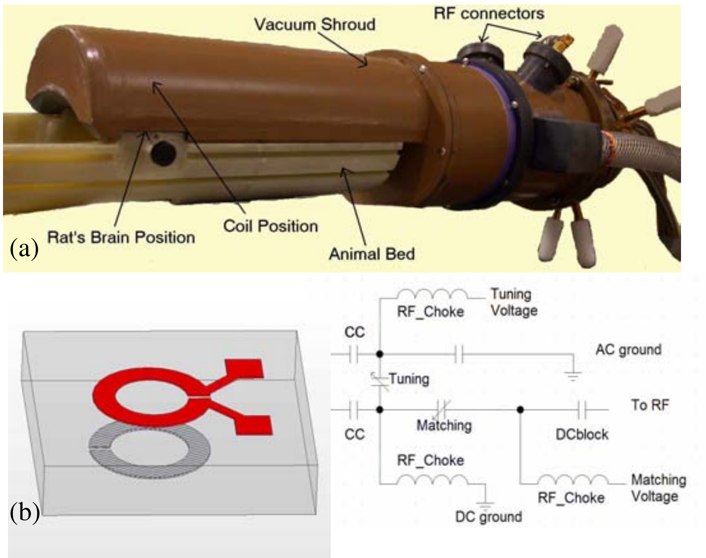

Figure 1. A picture of the cryostat cold head (a) and a sketch of the coil design and matching and tuning circuit using GaAs varactor diodes (b) are shown. CC denotes coupling capacitors (details are not shown).

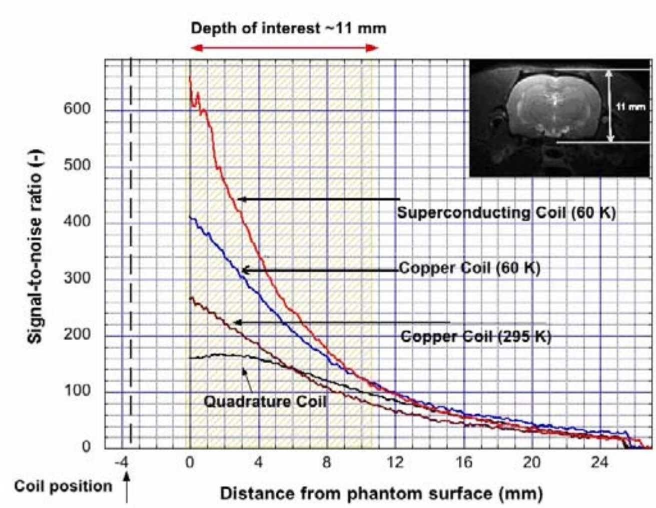

Figure 2. Comparison of the SNR of copper and HTS 300 MHz coils *vs.* distance from the phantom surface is shown. Both copper and HTS were cooled to 60 K during the tests. Note that for reference purposes the Bruker quadrature coil SNR is also included in the plot.

Discussion and conclusions.

The built cryogenic set-up was tested for coil detuning, tuning and matching, both for copper and the HTS coils at 295 K (for copper), and 60 K (for cooled copper and HTS coils). Obtained SNR gain of cooled Cu and HTS coil over room temperature copper, tested on both phantoms and a rat model at 300 MHz, were 80% (6dB) and 150% (8dB), respectively. High SNR of the coil was confirmed by the images acquired for an extracted spine of a rat (shown in Fig. 3) using MSME sequence. It is evident that even very thin slices can be used and still enough SNR improvement can be achieved to distinguish between the grey and white matters in the spinal cord, results which can not be achieved using any other commercial coils. Thinner slices can be acquired with sufficient SNR by using more averages; with the limit here of the scanner’s gradient being 0.15mm slice thickness. Maximum of Q and hence the SNR of the system is limited here by the electronics losses, thus further increase of the SNR will require use of cooled preamplifier and also further reduction of the tuning/matching circuit losses.

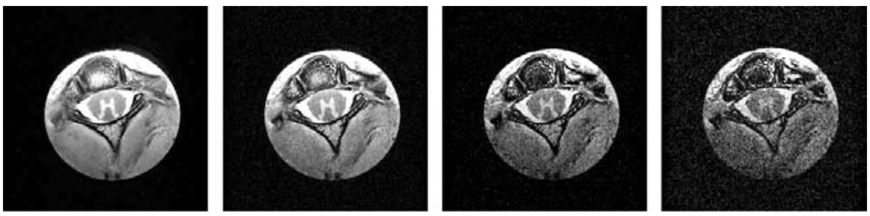

Fig. 3. MSME images of an extracted rat’s spine. Scan parameters: time= 13min. 20 sec., TR=3000ms, TE=13ms, single average. In-plane spatial resolution is 59x59 microns (FOV 1.5 x 1.5 cm) and the slice thicknesses for (a), (b), (c), and (d) were 1mm, 0.5 mm, 0.25 mm and 0.15 mm, respectively

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