Whole Body Screening Using High-Temperature Superconducting MR Volume Coils:

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Abstract Previous studies on HTS coils can be put into two categories: tape surface coils and thin-film surface coils[1-4]. In this study, we build a whole new $Bi_2Sr_2Ca_2Cu_2O_3$ (Bi-2223) superconducting volume coil (length of 8 cm) designed for the mice whole body imaging at Bruker 3T MRI system. The HTS volume coil has 2.3 folds higher S/N than that of the HTS volume coil at 300K for the mice body screen.

Introduction The design and construction of a superconducting probe are considerably more complex and expensive than traditional radiofrequency coils due to the special constraints imposed by the material and the need to maintain the coil at low temperature[3]. In 2006, the superconducting volume coil was demonstrated by Nouls et al[1]. The superconducting volume coil consists of two spiral thin-film coils in Helmholtz pair configuration, which is expensive and is very difficult for tuning and matching. We present here a $Bi_2Sr_2Ca_2Cu_2O_3$ (Bi-2223) superconducting saddle coil (length of 8 cm) designed for magnetic resonance image for the mice whole body at Bruker 3T MRI system.

Materials and Methods To build a RF surface coil, the tape has to be bent into a simple circle loop with a diameter larger than the critical diameter of the tape, given in Table I, otherwise its critical current will decrease. A non-magnetic capacitor (American Technical Ceramics, US) with high Q (>1000) is soldered directly at both ends of the tape to form an LC resonant loop. Figure 1(a) shows the coil configuration, where the matching and signal pick-up coil (500 mm in diameter) with a tuning variable capacitance. Both sliver and Bi-2223 were used as saddle coils with the same size in MRIs. Contrary to capacitor tuning and matching circuit used in the MRI system with the copper coil, a mutually inductive coupling between the HTS receiver and the pick-up coil was used. In Figure 1(b), with L_1 the matching coil inductance and L_2 the surface coil inductance, the input impedance is given by $Z_{in} \cong j\omega L_1 + \frac{\omega k L_1 Q}{1 + 2jQ(\delta\omega / \omega_c)}$, where $\omega_c = 1/\sqrt{L_2 C_2}$ and k is the coupling constant. In order to create a pure resistive impedance of 50 ohm at Larmor frequency (ω_c), the coupling constant k must be set at an appropriate value and has to be offset from the Larmor frequency to compensate the reactance created by the inductive loop. A trimmer capacitor used in the signal pick-up loop was tuned to the value $C_1 = 1/\omega_0^2 L_1$ so that the imaginary part in Z_{in} was cancelled out at the resonant frequency. Thus pure resistive impedance $Z_{in} \equiv Qk^2\omega_0 L_1$ can be generated during the coil resonance. A HTS coil with 5 cm diameter and 8 cm length was implemented. MR experiments were performed on the Bruker Biospec 3T system (Bruker, Germany). The images were acquired by using the fast spin echo sequence with TR/TE = 3506/62 ms. The in-plane resolution was 234 um and the slice thickness was 1.24 mm. The scan time is seven minute and twenty-eight seconds.

Results SNR between the cortical regions and the background noise of both images were calculated to compare the performance of HTS volume coil in 77K and in 300K. The comparison of mice whole body images from HTS saddle in 77K and in 300K were shown in Figure 2, where Figure 2(c) represents the image acquired from HTS saddle coil in 77k and where Figure 2(a) represents the image acquired from the HTS coil in the room temperature. The SNR of using the HTS tape coil in 77K was 27, 2.33 folds higher than that of using the HTS coil in 300K, which is 13. From Figure 2(d), the structure of kidney can be observed clearly. To follow it, the 3D sequence of GEFI was used to cut down the thickness of image. In Figure 3, the SNR of using the HTS saddle coil at 77K was 23, 2.3 folds higher than that of using the HTS saddle coil in 300K, which is 10. IN this study, slice thickness is 0.3125 mm and the scanning time is 16 minutes.

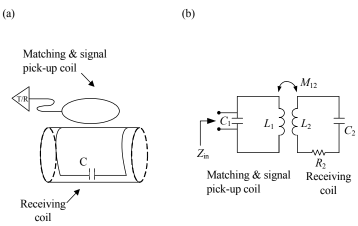

Figure 1. Concept of the inductive coupling method. (a) Coupled coil and pick-up coil are indicated by the bottom one and the above one. (b) the equivalent circuit of the inductive coupled design shows that RF signal is picked up by using the mutual inductance coupling.

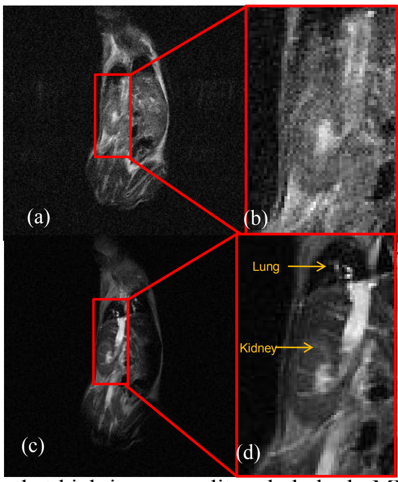

Figure 2 Images of the whole body of mice with (a) HTS saddle coil in 300K with SNR was 13, and (b) the HTS saddle coil in 77K with SNR was 27. The SNR gain of 2.33 by using the HTS saddle coil with the same acquisition time of different temperature.

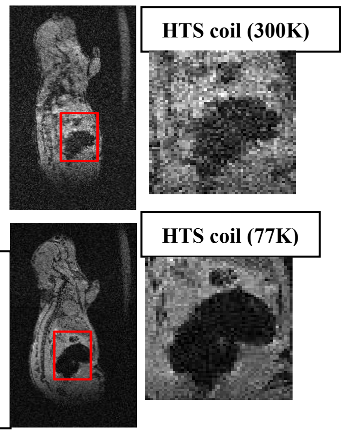

Figure 3. The images using 3D GEFI sequence to acquire The slice thickness is 0.3125 mm. The SNR of HTSC is 23. And the SNR of HTS coil at 300K is 10. The SNR gain is 2.3 folds.

Conclusions The results demonstrate that high image quality whole body MR imaging can be obtained with an HTS volume coil in 77K. The imaging time was greatly reduced while maintaining the same image quality. The potential benefits justify the development of practical HTS Bi-2223 saddle coil for imaging systems despite of considerable technical difficulties and challenges involved in the usage of cryostat and coil design. This high-temperature superconducting saddle coil system opens a new door for animal's whole body oncology screen. Further applications of fMRI and dynamic contrast enhanced (DCE) MRI are under investigation to test the applicability of this high-temperature superconducting coil system at 3T.

References [1] J. Nouls, *et al.*, *Journal of magnetic resonance,* vol. 191, pp. 231-238, 2008. [2] H. Lee, *et al.*, *IEEE Trans Appl Superconductivity,* vol. 15, pp. 1326-1329, 2005. [3] L. Darrasse and J. Ginefri, *Biochimie,* vol. 85, pp. 915-937, 2003.[4] R. Black, *et al.*, *Science,* vol. 259, p. 793, 1993.