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Towards a cryogenic RF coil array for ^{13}C human head imaging: first experience

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Synopsis

A cryogenic coil and a dedicated cryostat for ^{13}C human head imaging is developed. A 1.90-fold SNR enhancement over a room temperature coil is observed experimentally. To verify the retention of SNR enhancement in arrays, a 4-channel cryogenic coil array and another cryostat are also developed. The superior performance to a room-temperature array is confirmed experimentally.

Introduction

Cryogenically cooled coils can improve SNR in magnetic resonance imaging (MRI) especially at low frequencies[1]. However, up to present, use of cryogenic coils for human-sized coils for ^{13}C imaging remains barely explored[2]. In this work, cryogenic setups for human head MRI of ^{13}C at 3 T (32 MHz) are proposed. First, the performance of a single element is characterized using a cryostat where the coil is cooled to -169°C (104 K). Then, a 4-channel array is built and mounted on a full-head cryostat where the coils are cooled to -162°C (111 K). A 1.54-fold SNR improvement is observed on MR images of a head phantom.

Methods

Two experimental setups are made. Setup 1 is for single coil evaluation and shown in Fig. 1(a), (c). A copper coil of 81.6 mm outer diameter, 69.2 mm inner diameter and 0.64 mm thickness is matched to a preamplifier (WMA32C, WanTCom, Chanhassen, USA) as described by Reykowski et al[3]. The output impedance of the matching network is 50 Ω. The maximum decoupling is achieved at 32.13 MHz. The circuit schematic is given in Fig. 2. Later, the coil is installed on a self-developed cryostat where the temperature reaches -169°C (104 K) after 20 min of cooling. In this cryostat, the coil-to-sample distance is approximately 22 mm. After cooling for 30 min the temperature on the phantom surface is 4.9°C without an external supply of warm air. The Q factors of coils are measured before and after cooling to estimate possible SNR improvement following the approach described by Ginefri et al[4].

Setup 2 is prepared for a 4-channel coil array experiment, shown in Fig. 1(b), (d). Coils identical to the one described above are overlapped to minimize mutual magnetic coupling. Afterwards, the array is installed on another self-developed cryostat supporting a higher number of elements. The temperature in that cryostat reaches -162°C (111 K) within 40 min. After another 30 min, the temperature on the phantom surface is 8.5°C. This cold temperature can be easily compensated by external warming[2]. The inner and outer surfaces of the cryostat are clad in Aerogel layers for thermal insulation, which gives a coil-to-sample distance of approximately 13 mm.

MR imaging experiments are performed on a human head phantom of ethylene glycol (99.8%, natural abundance ^{13}C) and NaCl (17 g/L). A CSI sequence (24×24 acquired points, TR 1000 ms, FOV 360×360×20 mm^3) is used. SNR measurements are conducted for both setups 1 and 2, under both room and cryogenic temperature. For comparison, the same coil in setup 1 is tested when placed 2 mm from the head phantom. A 28-channel array at room temperature built with identical loop coils is used as a reference.

Results

In setup 1, the measured Qs of the coil are Q_{lr} = 225, Q_{ur} = 405, Q_{lc} = 286, Q_{uc} = 706, where subscripts "l" and "u" denote sample loaded and unloaded cases, "r" and "c" denote room and cryogenic cases, respectively. By calculation, a 1.31-fold SNR gain can be obtained by cooling.

The SNR maps obtained are shown in Fig. 3. SNR values along central axes of the phantom are plotted in Fig. 4. The highest SNR values are 247 for 1-channel cryogenic coil, 130 for the room-temperature coil 22 mm from the phantom, 296 for the room-temperature coil 2 mm from the phantom, 417 and 270 for the 4-channel array at cryogenic and room temperature, 265 for the 28-channel array at room temperature. The ratio of cryogenic to room temperature SNRs are 1.90 for the 1-channel coil 22 mm from the phantom and 1.54 for the 4-channel array, respectively. The 4-channel array at cryogenic temperature has a 1.57-fold SNR gain over the 28-channel array at room temperature.

Discussion

The SNR measurement results demonstrate that the cryogenic 1-channel coil has a better performance compared with a room-temperature coil with the same separation of 22 mm. Cryogenic coils can be extended to an array with the SNR improvement largely retained.

For the 1-channel coil, the SNR gain is predicted to be 1.31 but turns out to be 1.90. An explanation is that the component values in the matching circuit are selected for cryogenic temperature. At room temperature, the matching circuit is off the optimal noise matching while contributing more noise itself, which decreases the room-temperature SNR by an extra amount.

In addition, Fig. 3 and Fig. 4 indicate that a coil 2 mm from the phantom at room temperature outperforms a coil 22 mm from the phantom at cryogenic temperature. This emphasizes the importance of putting coils as close to objects as possible. The detrimental large distance is caused by suboptimal design of the cryostat in setup 1. This is improved in setup 2, where the coil-to-phantom distance is reduced to 13 mm.

Conclusion

Cryogenic coils can provide significant SNR improvement for ^{13}C human head MRI at 3 T. The superior performance can be largely retained when coils are extended to a 4-channel array. The results open the possibility to develop highly sensitive cryogenic coil arrays for ^{13}C human head MRI.

Acknowledgements

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Figures

Fig. 1. Experiment setups. (a) Setup 1. The cylindrical ceramic part stands in liquid nitrogen (LN_2) and cools the coil to -169°C (104 K). (b) Setup 2 for the 4-channel array. The fiberglass LN_2 chamber underneath is connected to a LN_2 tank, and the inner and outer surfaces are clad in Aerogel layers, as shown in (d). The temperature goes to -162°C (111 K). Coil-to-sample distances are around 22 mm for (a) and 13 mm for (b). (c) Setup 1 and (d) setup 2 at an MR scanner.

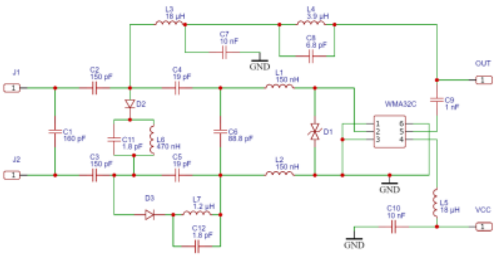

Fig. 2. The schematic of the matching network and preamplifier bias. J_1 and J_2 connect a coil.

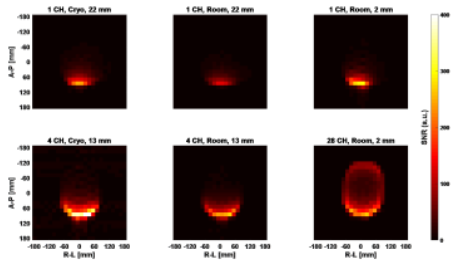

Fig. 3. SNR maps of 1-, 4-, and 28-channel coils at cryogenic and room temperatures. The SNR has an arbitrary unit. The peak SNRs are 247 for 1-channel cryogenic coil, 130 and 296 for room-temperature coils separated from the phantom by 22 mm and 2 mm; 417 and 270 for 4-channel cryogenic and room-temperature arrays separated from the phantom by 13 mm; 265 for 28-channel array. The ratio of cryogenic SNR to room-temperature are 1.90 for the 1-channel coil and 1.54 for the 4-channel array.

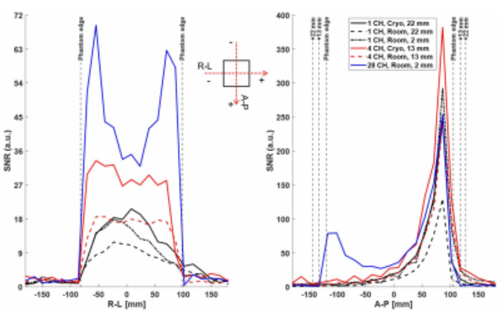

Fig. 4. Cross-section SNR profiles of imaging experiments. The SNR has an arbitrary unit. The SNR values are averaged between two nearest pixels. The inset shows the positions of cross-sections.