Superconducting Arrays for Parallel Imaging

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INTRODUCTION:

In recent years, the design and application of phased arrays for partial parallel acquisition (PPA) has become a subject of great interest. One of the significant problems encountered with PPAs is the decreasing overall signal-to-noise ratio (SNR) from the array, by the square root of the time reduction factor [1]. It has already been recognized that a significant SNR improvement can be achieved, for small enough array elements, through the array cooling or by using high temperature superconductors (HTS) [2-4]. However, implementation of cryogenic/HTS arrays is both technologically and technically very challenging. It is known that significant SNR gain of normal metal arrays is achieved close to the array but it decreases to almost zero when the distance from the array reaches array diameter [5]. In this work we show simulations, design, and fabrication of cryogenic arrays.

METHODS:

A cylindrical phantom model was used to analyze the relation between SNR and the number of coils in the array. SNR was calculated for a voxel placed inside a cylindrical loss body at a distance z_v from the body surface (Fig. 1) using the Biot-Savart law. The square coil/array was placed at z_p equal to 5 mm away from the body, corresponding to the average coil/array-body distance in our cryogenic systems.

We have designed two and more element arrays (both copper and HTS) according to requirements imposed by cryogenics as well as those due to design restrictions related to currently available superconducting technology (planar epitaxial HTS films) [6]. Such arrays were integrated with a custom built either liquid nitrogen or closed cycle pulsed tube cryo-cooler. A matching, tuning and de-coupling circuit was built with varactor diodes and integrated with the array inside the cryostat. HTS array was made out of 2” YBCO films deposited on both sides of 0.43 mm thick sapphire substrate

RESULTS:

An example of calculations at 200 MHz of relative SNR distribution for normal metal and superconducting arrays is shown in Fig. 1. Varying size coil arrays were compared to a single 30x30 mm coil having the same overall dimension. Simulations were done for a lossy phantom having diameter 60 mm and σ=0.8 S/m.

The cryogenically cooled array was used to acquire moderately T_2 weighted (TE_{eff}=45ms, TR=3s) axial and coronal slices. The animals were positioned prone in the 4.7 T magnet with tumors adjacent to the cryostat, with a thin layer of gauze acting as a cushion.

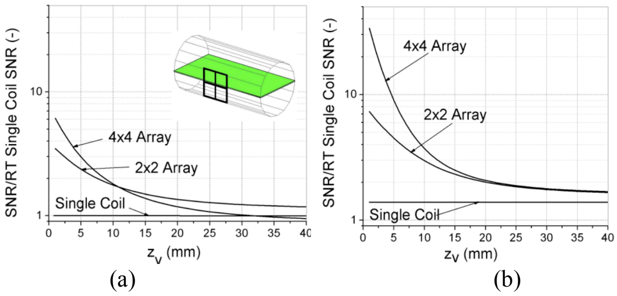

Figure 1: Normalized SNR improvement, for room temperature (RT) copper (a) and for HTS material (b), *vs.* voxel distance to the center of the array is shown.

Animal body temperatures were maintained per standard operating procedure using a circulating warm water bath, with no evidence of abnormal heat loss. One animal was placed under each element of the array and both FOV were acquired simultaneously.

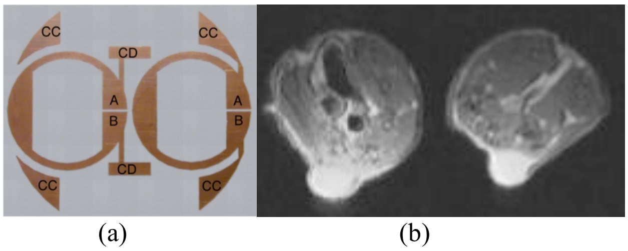

Figure 2: (a) A picture of the upper side of an 2” by 1” array cooled to 77 K for imaging shown in (b), CC and CD denote de-coupling and coupling capacitors, respectively, (b) axial slices (acquired simultaneously for two mice) of subcutaneous tumors present in a murine model of colon cancer.

DISCUSSION:

Simulations show that arrays made of HTS have outstanding performance close to the array and, in addition, their normalized SNR does not degrade with distance as it does in the case of copper arrays.

The array was tested on a phantom for coil decoupling, tuning and matching, both at room (Cu) and liquid nitrogen temperatures (Cu and superconductor). Obtained SNR gain of cooled copper two-element array was 100%. Tests with HTS arrays are underway.

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