Four-element 300 MHz Superconducting Array for Parallel Imaging

J. Wosik[1], K. Nesteruk[2], M. Kamel[1], L. Xue[1], L-M. Xie[1], K. H. Bockhorst[3], P. A. Narayana[3]

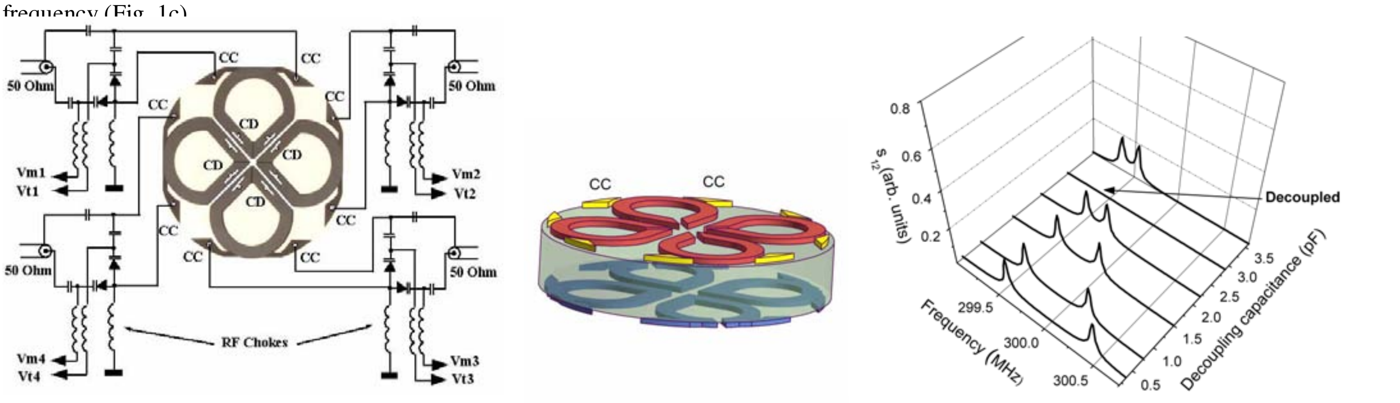
[1]Electrical and Computer Engineering Department, University of Houston and Texas Center for Superconductivity, Houston, Texas, United States, [2]Institute of Physics Polish Academy of Sciences, Warsaw, Poland, [3]Department of Radiology, The University of Texas, Health Science Center, Houston, Texas, United States

Introduction

In recent years, the design and application of coil arrays for partial parallel acquisition (PPA) has become a subject of great interest and has spurred many new developmental studies in both array designs and fabrication [1]. One of the intrinsic problems encountered with the PPA method is the decrease in the overall SNR from the array, by square root of the time reduction factor [2]. Such decreased SNR limits the ability to distinguish the signals from each coil, which prevents reliable decoding of the spatial information created by the small offsets between the coils. In the case of an array with sufficiently small elements, it has been recognized that a significant SNR improvement can be achieved by cooling the receiver coils made of either Cu or high critical temperature superconductors (HTS) [3], thereby reducing the system noise in the coil loss dominated regime. The potential advantage of cryogenically cooled receiver arrays increases with the number of elements. In designing a cryogenic array, it is important to know when maximum SNR gain is achieved by using only cold copper arrays and when an additional SNR gain can be achieved by using an HTS array. The practical implementation of cryogenic/HTS arrays is technologically much more challenging than the implementation of cryogenic Cu arrays. In this study, we report on further development and improvements of our work on superconducting arrays [4] by presenting a 300-MHz HTS array for use with parallel MRI, which was designed for imaging small animals. (Bruker scanners).

Method and Results

We have designed two four-element arrays according to the requirements imposed by the cryostat design, with one made of copper and the other with HTS epitaxial $YBa_2Cu_3O_{7-x}$ thin films. The 0.5 μm thick YBCO films were deposited on both sides of each $LaAlO_3$ substrate by the co-evaporation method. These films were patterned using standard positive photoresist and wet etching processes. We used two different chrom photolithographic masks, one for each side of the substrate, in order to make array integrated with coupling and decoupling capacitors. The only difference between the Cu and HTS array layouts was how the coupling capacitors were built. For the Cu array, the coupling capacitor plates were placed on opposite sides of the substrate. The HTS array, on the other hand, was built with a sandwich capacitor (YBCO/dielectric/copper or gold) on only one side of the substrate. For each coil of both arrays, the films were patterned into a split quasi ring shape (18-mm outer diameter). The gaps in each quasi ring were rotated 180 degrees from each other. Picture of the top-side of the array is shown in Fig. 1a. Similar structures are sometimes referred to as twin-horse-shoe resonators and are also used in MRI [5]. Measurements of the unloaded Q of each coil Cu coil at room temperature and 77 K yielded *Q*'s of 300 and 900, respectively. The HTS coil had an unloaded *Q*, at 77 K, of the order of 27,000. This array was integrated with a custom built G-10 plastic cryostat, designed to fit together with an animal bed inside of a 76 mm inner diameter Bruker transmit coil. The closed cycle pulsed tube refrigerator (Cryomech) was used to cool the array and the associated electronics to 55 K. Parts of the cold-head and helium hoses of the cryocooler were made out of nonmagnetic materials (titanium and/or stainless steel). This system required only 30 minutes of cooling to be fully operational and stable at a temperature of 55 K. The matching/tuning/decoupling circuit (Fig.1a) is based on GaAs varactor diodes (Metelics) and was integrated with the array inside cryostat (thus kept at 55 K). Note that the decoupled frequency is equal to the lower mutual inductance split frequency, thus each coil has to be designed to resonate at higher than 300 MHz frequency (Fig. 1c).



(a) (b) (c)

Figure 1. **(a)** Shows a matching and tuning circuit using varicap GaAs diodes. By changing the applied, $V_{m1,2,3,4}$ (matching) and $V_{t1,2,3,4}$ (tuning), voltages for the varicap diodes both 300 MHz tuning and 50 Ω rf coaxial cable matching can be achieved for all channels. In the center, the upper side picture of an array consisting of four 18 mm single coils is shown. CC and CD denote coupling and de-coupling capacitors, respectively. **(b)** Shows a sketch of the array. Note that CD capacitors, which are built on both sides of each coil upper gap are not shown. **(c)** Shows plot of the measured s_{21} transmission for two channels for different values of decoupling capacitors (CD).

In order to estimate the SNR gain due to the use of a 77K Cu or HTS coil, we used the formula for relative SNR derived in [4], which assumes that the signal is the same for both cases. Such calculations were in very good agreement with the SNR gain from Q measurements.

Discussion and conclusions

The arrays were made for the imaging of small animals (rats) for functional MRI of a rat brain and for high resolution imaging of spine injuries. Both arrays were tested for decoupling, tuning and matching, both at room (Cu) and at cryogenics temperatures (Cu and superconductor). The obtained SNR gain of the cooled Cu and HTS four-element arrays over room temperature Cu, tested on phantoms at 300 MHz, were 100 % and 160%, respectively. Optimization for g-factor and tests of both copper and HTS arrays for PPA are underway using the four channels Bruker 7.0 T system. Presented above the HTS array design with built-in high Q capacitors allows to make the array on four separate substrates in order to increase the filling factor.

References

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