SNR Limit for Cryogenic Arrays

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Abstract

The purpose of this work was to determine SNR improvement achievable by using cryogenics arrays. We simulated the dependence of SNR gain on number of coils used in the arrays. Copper arrays operating at room temperature and cooled down to 77K as well as high critical-temperature superconducting (HTS) coils were included in the calculations. We studied the role of number of elements used in each type of the arrays in the SNR improvement. In these simulations we made distinction between body and coil resistance limitation regimes since it has strong influence on the SNR gain of the arrays. We present the evidence that the advantage of implementation HTS materials in the coil arrays in improving SNR is significant compared with the cooled copper arrays when the MRI performance is limited only by the coil resistance. However, it diminishes when body resistance starts to dominate the MRI system operation.

Introduction

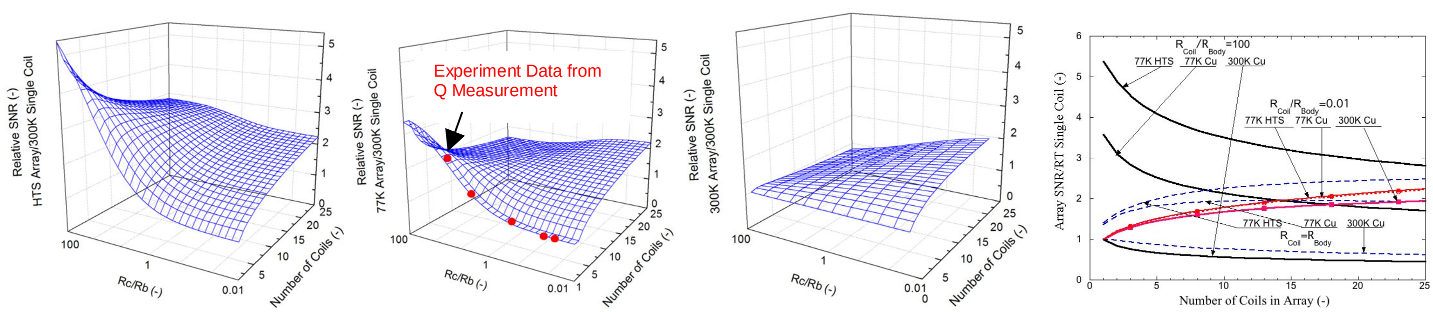
Parallel imaging techniques and their variants [1] provide faster imaging by using arrays of receiver coils, unfortunately, such methods have also their own limitations. Namely, SNR decreases with the square root of acceleration rates (number of coils) [3]. The latter limitation can be overcome, however, and SNR dramatically improved with the use of cryogenic normal metal or HTS arrays. One of the problems, which should be addressed, is how much and when HTS array will have advantage over cooled copper array. The other question is related to the SNR increase limit when using either cooled copper or HTS array.

Methods and Results

For studies of SNR gain due to increasing number of coils used in an array, we selected a square field-of-view array. The receiver coils number is ranging from 1 to NxN and it corresponds to decreasing array element sizes. Such division of total area to accommodate smaller size coils was included in our simulation by decreasing body resistance (R_b) of each scaled down coil by N^3 and the coil resistance (R_c) by N. The SNR was calculated for arrays operating at cryogenic temperature and SNR gain over a single coil, of the same size as that of the array, operating at room temperature was derived as:

$$\frac{Array\_SNR\_Array}{Single\_Coil\_SNR^{300K}} = \sqrt{\frac{R_b + R_c}{N^2(R_b/N^3 + \alpha R_c^{77K}/N)}} = \sqrt{\frac{R_b + R_c}{R_b/N + \alpha R_c^{77K} N}} = \sqrt{\frac{1 + R_c/R_b}{1/N + \alpha (R_c^{77K}/R_b) N}}$$

The results of such relative SNR calculations *vs.* number of coils in the array (up to 25) and coil-to-body resistance ratios (ranging from 0.01 to 100) are shown in Fig. 1.



(a) (b) (c) (d)

Fig.1. Dependence of SNR improvement for an array on coil-to-body resistance ratio and on number (N) of coils compared to a single coil (of the same size as the array) operating at room temperature. Calculations results are for arrays made of HTS thin films (a), Cu layers cooled to 77K (b), Cu layers operating at room temperature. (d) represents cross-sections of (a), (b) and (c) surface plots for coil-to-body resistance ratios 0.01, 1, and 100.

Experimental

To investigate conditions for significant SNR gains due to cooling of copper arrays or when using HTS array, a series of four square single 300 MHz coils was built, 5 mm to 40 mm in diameter. We have measured unloaded Q of each coil using one port Ginzton/Kajfez method [4] for room temperature and 77K, under unloaded (no body) and loaded (with two different lossy phantoms), conditions. The SNR gain for 77K single Cu coils was calculated using coil-to-body resistance ratio obtained from measured Q values. Calculated SNR gain values show excellent match with the simulations (Fig. 1b). Similar experiment is under way for HTS series of coils.

Conclusions

Simulation and experimental results indicate that as the number of coils N increases, the SNR gain of HTS coils compared to Cu coils operating at cryogenic or room temperatures is determined by the ratio of coil/body resistance. The SNR limits (Fig. 1) derived for both resistance regimes are shown for room temperature and cryogenic operations. In the R_c dominated region i.e. R_c/R_b=100, SNR decreases with the increasing number of coils N both at room temperature and 77K, however, it is always significantly larger than the SNR of cooled Cu coils. When body resistance limits the system performance, i.e. at $R_c/R_b \geq 1$, SNR increases with the increasing number N but the advantage of using HTS over cryogenic operation of Cu disappears.

References

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