Investigation of decoupling techniques for two-element cryogenic arrays

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Introduction: Conventional decoupling techniques used to minimize mutual inductance coupling between MRI coils rely either on optimal geometric overlapping between the nearest coils or, for non-nearest neighbors, on low-input preamplifiers [1]. For imaging, where partial special encoding is implemented, coil overlap should be avoided in order to sufficiently distinguish complex sensitivity maps. That calls for the development of other decoupling techniques such as capacitive decoupling network [2]. For cryogenic-high-Q arrays [3], where high SNR is achieved for each individual coil by reduction of thermal noise due to cooling, the decoupling techniques not only should work with high-Q circuitry but they should not degrade the SNR gain. In order to make an assessment of decoupling techniques useable for a cryogenic array, we identified the possible resonant modes in 2x1, 7 T (300.3 MHz) array and used them to analyze three different decoupling techniques.

Methods: Placing two coils close to each other creates coupling between them and causes splitting of a single coil mode's frequency. A system of two coupled coils has two stable resonant modes of higher frequency (f_+) and lower frequency (f_-) when *rf* currents flow in the same (even mode) and in the opposite directions (odd mode) in the coils, respectively. They are described by $f_\pm = 2\pi(1/(L \pm M_{12})C)^{1/2}$ where, L is the inductance and C is the capacitance of the resonator. Calculations and measurements of the frequency for both modes as a function of coil center distance D (changing from "fully overlapping" to "fully apart" positions) are shown in Fig. 1a. To isolate coils we choose three different methods of decoupling (Fig. 2). The total area of the array was kept constant as 17 mm x 36 mm with 2 mm gap between the coils (the frequency split at 2 mm is equivalent to ~2.2 D/R value in Fig. 1a). In the first method, geometrical overlapping of 17 mm by 21 mm coils was used, in the second an "eight shape" wire loop was placed above two 17 mm x 17 mm coils, and in the third one, two capacitors marked as CD1 and CD2 were employed. Figs. 2b and 2c show plots for two other methods: calculated and measured frequencies of two modes *vs*. distance of "eight shape" wire loop from the center of the array and *vs*. decoupling capacitance, respectively. In order to estimate possible SNR gain from cooling of the array we have used a simplified model assuming that the signal stays constant for room (RT) and 77 K (LN) temperatures. The SNR for a decoupled Nx1 surface coil array can be expressed by $SNR \sim S(N)/(\alpha\beta R_{coil} + R_{Body})N)^{1/2}$; where N is the number of elements in the array, R_{Body}, and R_{Coil} are the body and coil resistances, respectively, α is the ratio of coil to body temperatures ($\alpha = T_{Coil}/T_{Body}$) and β is the coil resistance ratio at T_{Coil} and 300K [4]. The SNR depends on δ, the RT ratio of R_{coil} over R_{Body} of the single coil. For estimation of the SNR gain of cryogenic over RT coils/arrays we used an alternate formula $SNR_{Gain} = ((1+\delta_A)N/(1+\alpha\beta\delta_B))^{1/2}$. The δ parameter was obtained from Q-factor measurements at RT and LN as well as with and without phantom (for rat) load. We made three arrays using a double-sided distributed capacitance structures (two rotated 180° split-loops resonator) [5]. Double-sided Cu laminate with $\varepsilon = 2.2$ and thickness of 0.38 mm was used for the surface coil fabrication. The coil and electronic circuit layout was patterned using a milling machine LPKF PhotoMat C60. The high-Q electronic circuit (not shown here) able to sustain LN was attached to the each array for tuning (T), matching (M), and

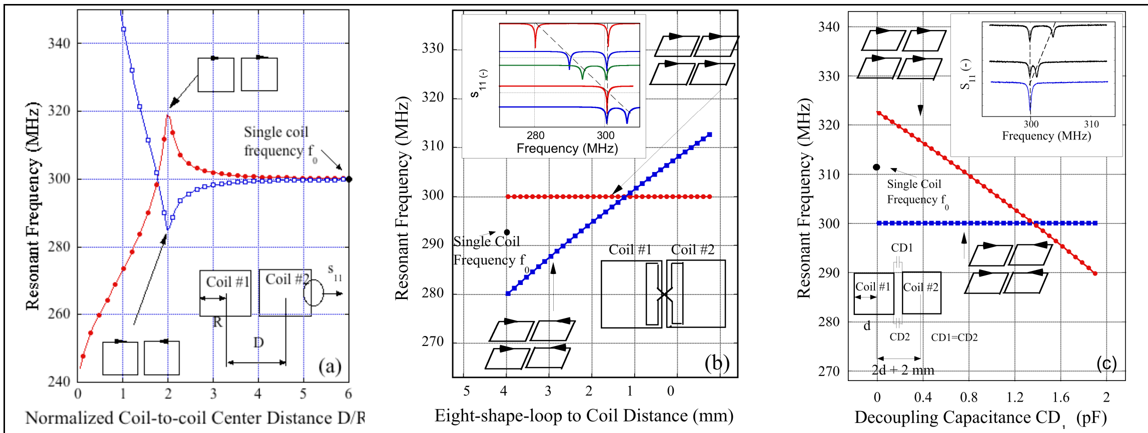

Fig. 1. Calculated frequencies of 2x1 array plotted *vs*.: (a) the "eight shape" loop distance from the center of coils; (b) coils separation distance D/R; (c) decoupling capacitance. Insets show measured s_{11} from coil #1 for each case.

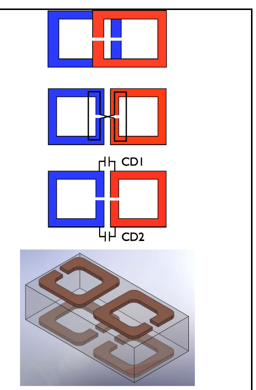

Fig. 2. Three methods of decoupling . Bottom side of the substrate is presented. Sketch of the array is shown.

active detuning (DT). The array was cooled using a closed cycle pulsed tube refrigerator made to fit Bruker 7 T transmit volume coil [6]. For SNR measurements the following parameters were used: TR 1s, TE 13 ms, 20 1 mm thick slices, FOV 9 by 9 cm, scan time of 4 minutes with MSME sequence.

Results: For the "eight shape" loop decoupling technique only odd mode is influenced (flux cancellation) by the loop (Fig. 1b). This is in contrary to the capacitive decoupling case when only the even mode is influenced by the decoupling capacitance (Fig. 1c). In the odd mode, due to the same voltage, there is no *rf* current in the CD capacitors while in the even mode, when the currents in the coils are in phase, the *rf* current flows in the capacitor. Therefore, by changing the CD capacitance, decoupling is achieved by making the higher mode's frequency equal to that of the lower mode. For capacitive decoupling the decoupled frequency is equal to the lower mutual inductance split frequency, thus each array element has to be designed to resonate at 307 MHz, whereas for geometrical decoupling case each single element of the array has to be designed for 300 MHz (see Fig. 1a). The "eight shape" loop decoupling method requires the single element of the array to be designed for 290 MHz, because in the decoupled state, the lower frequency mode is equal to higher frequency mode. The decoupling of two coils was verified experimentally by acquiring images when only one channel (either #1 or #2) of the Bruker 7 T scanner was on. For all cases, an image from only one coil was seen while the other coil was not excited. The s_{12}, measured by vector analyzer for decoupled coils #1 and #2 connected to T/M/DT electronics, was around -25 dB for capacitive and "eight shape" loop and -19 dB for overlapping methods. Unloaded Qs, for both capacitive and "eight shape" loop cases, were measured as 200 and 530 for RT and LN, respectively. Measurements of Q with phantom resulted in values 150 and 300 (5 mm array-phantom distance introduced by the cryostat). Simplified model calculations resulted in almost the same SNR gain for capacitive and eight-shape loop decoupling and 15% reduction of the gain for the overlap method. Images SNR (Bruker macro was used) confirmed these results, however, more reduction of the gain was observed for the geometrical overlapping method.

Discussion and Conclusion: In order to preserve relatively high Q in cryogenic arrays, the decoupling system should have low loss. A comparison of SNR gain (the same FOV) for three decoupling methods indicates that capacitive-only decoupling network seems to fulfill such requirements. Also the "eight shape" loop method introduced only small increase in R_{coil}/R_{body} ratio due to additional R_{coil} loss. On the other hand, overlapping increases both R_{coil} and R_{Body} leading to 15-20% loss of SNR gain. Future studies will compare the measurements presented here with corresponding measurements using low input impedance preamplifiers.

References: [1]. R. F. Lee et al., MRM 48:203-213 (2002). [2]. J. Jevtic, Proc. Intl. Soc. Mag. Reson. Med. 11, 428, 2003. [3]. J. Wosik et al., *Proc. Intl. Soc. Mag. Reson. Med.* **16**, pp. 443 (2008). [4]. L. Xue, Ph. D. thesis, Dec. 2007, Univ. of Houston, ECE Dept. [5]. P. Gonord and S. Kan, *Rev. Sci. Instrum.,* **65**, 509 (1994). [6]. M. R. Kamel et al., Proc. Intl. Soc. Mag. Reson. Med. 15 (2007) p. 337.