Decoupling of Strongly Coupled MRI Surface Coils using Virtual-Shielding Method

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Introduction: In some multiple coil MRI applications, RF coils are necessarily strongly coupled. One such example can be configured for breast MRI where ideal coil geometry would use two coils on parallel surfaces surrounding each breast (Figure 1). In this geometry, the medial coils tend to be highly coupled as they may be in close proximity for smaller patients dictated by the space D. In order to overcome coil coupling, a number methods have been proposed using decoupling capacitors or additional coupled inductors. However, these systems are highly dependent on the coil geometry and must be retuned for each coil position. The purpose of this work was to investigate a decoupling method, which can work over a wide range of geometries without the need for individual adjustment. In this abstract we'll briefly report this new method based on a virtual shielding concept.

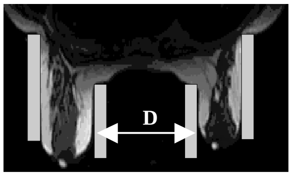

***Figure 1** Breast imaging using parallel surface coil. Inner surface coils placed with distance D.*

Theory and Method: Decoupling surface coils by shielding approaches have been reported for transmit-receive coil geometries. The principle is based on an induced eddy current, which serves to cancel the local magnetic field that is generated in the shielding conductor. By this means, the magnetic field remote from the shield is greatly reduced or eliminated. However, for receive-only coil geometries where the body transmitter to excite magnetization this type of shield would affect the homogeneity of the excitation RF field. On contrast, with a virtual-shielding method, a shielding coil is added to the surface coil to form a parallel or virtual image coil. This shield coil is a multi-turn open loop structure. Along with its intrinsic distributed capacitance, this open loop exhibits finite impedance. The shield coil is then mounted parallel to the surface coil on the side of the coil to be decoupled as shown in Fig. 2a. . However, the surface coil is tuned to compensate the additional inductance of the added shield. When the surface coil detects the NMR signal, currents are set up in the shield in opposition to that of the surface coil and serves to cancel out the magnetic field remote from the shield. By this means, the effective mutual inductance between a pair of such surface coils with intermediary shields is greatly reduced.

To test the idea, two pairs of rectangular surface coils (3.5" x 6.5") were made on plastic frames. On one pair the shield was located on one side of the surface coil at a distance of 4mm. The second pair had no additional shield. To test for coil coupling the splitting of the resonance of the surface coil was measured on a spectrum analyzer. In the MRI experiments, each pair of coils was placed in a parallel geometry in a 'sagittal' orientation with tissue equivalent phantom placed on either side of the coil pair as shown in Figure 4a&b. All MR images were taken on a GE 1.5T scanner using fast SPGR (TR/TE/angle=10/3.5/20) sequence. The image signal/noise (SNR) for the two coil structures for measured for varying spacing D for the shielded and unshielded coil structures and compared to a single surface coil with and without the shield. The signal was averaged over the phantom area while the noise was determined in the air region between the two phantoms. .

Results: With the shield in place, we note that the resonance splitting characteristic of the coupled, unshielded coils was virtually eliminated for all intercoil spacing D larger than 2 cm. To demonstrate the effect of the shield on the sensitivity of the surface coil, a small search coil was used to probe the field along the central axis orthogonal to the coil surface. As such in Fig. 3, the sensitivity profile for the unshielded coil is symmetric about the coil plane while the shield coil shows a marked reduction in the sensitivity on the side of the coil carrying the shield. This demonstrates the effectiveness of the shielding structure to make the coil sensitivity asymmetric while maintaining the sensitivity of the coil on the unshielded side. Figure 4a-b showed an example of MR images made with a pair of unshielded surface coils in comparison to the same geometry for the shielded coil pair. This shows that the uniformity of the response of the two coil geometries is virtually identical. Careful inspection shows that the SNR of the unshielded coils is approximately two fold less. To quantify this effect, the average SNR as a function of the intercoil space D is shown in Figure 4c. When using a single coil, the SNR of the unshielded coil reached a maximum of ~ 30 while the addition of the shield reduced this by 25%. However, when two coils are introduce, the unshielded coil SNR dropped to a value of 10 for the smaller value of D and gradually improved with increasing spacing D. In contrast, the shielded coils showed in improved SNR for the same range of D with a two-fold increase in SNR at the smallest intercoil spacing. These data show that the use of the shielded surface coils showed a uniform SNR over the range of intercoil spacing studied.

Discussion and Conclusion: A method for creating a set of decoupling surface coils that operate in a parallel geometry with large mutual inductance is proposed. The advantage of this concept is that the coils can assume arbitrary spacing without the need for coil adjustment or tuning while maintaining an approximately constant and modest coil coupling. Preliminarily studies demonstrate the advantages of this structure to improve SNR over coupled coil geometries over a range of coil spacing. While coil coupling was reduced the addition of the shield caused a reduction of SNR over a single coil by approximately 25%. However, by placing the shielding coil further from the surface coil, the shielding current would be reduced and thereby degrade the coil SNR less. These measurements demonstrate a new concept for coil decoupling which allows a flexible intercoil geometry for phased array structure.

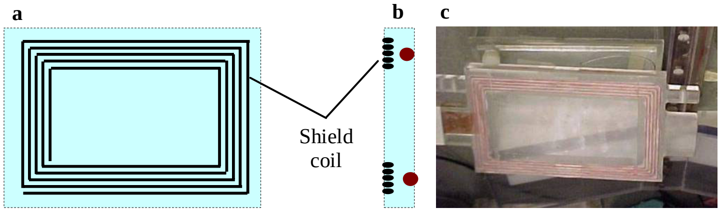

***Figure 2.** Schematic of the-shielded surface coil (a), and the cross section showing both shield and surface coils (b), A picture of the shielded surface coil (c).*

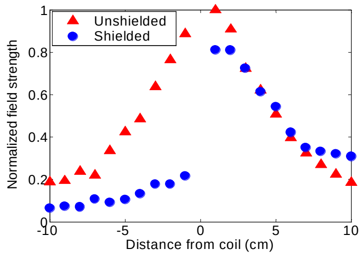

***Figure 3.** Normalized magnetic field measured with a small search probe on both sides of the coil. On the shielded side, the field strength is greatly reduced. Therefore, the mutual inductance between two such coils was greatly reduced (Error bars omitted in all figures).*

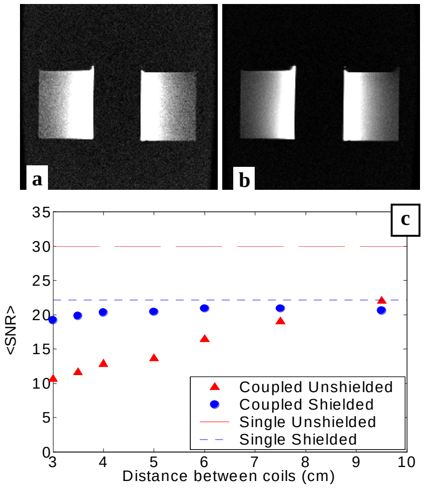

***Figure 4.** (a) Axial MR image of two rectangular phantoms with two coupled normal surface coils. (b) Same image with two shielded coils with much improved quality. (c) Average SNR of images as function of distance between the pair of coils.*