An eigenvalue/eigenvector analysis of decoupling methods and its application at 7T MR imaging

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Introduction Non-overlapped multi-channel RF array coils for signal detection and encoding are desired for fast parallel magnetic imaging techniques because of their better geometry factor (g-factor). One of the challenges of designing such coil arrays is the coupling among closely placed resonant elements in coil arrays. Some decoupling methods for non-overlapping design have been proposed, such as the method using lumped L/C decoupling circuits (1, 2). However, the decoupling analysis methods in these works did not disclose the generalized conditions of decoupling. In this work, we report an eigenvalue/eigenvector analysis method for designing non-overlapped coil arrays and one of its immediate applications as a novel decoupling method. Bench test and preliminary imaging results are shown using a proposed method at 7T.

Methods The eigenvalue/eigenvector analysis was applied widely in volume coil designs. The volume coils generally have different eigenvalues or modes along with different eigenvectors or electrical current/magnetic field distributions. As an application, the decoupled array coils have only one eigenvalue or mode along with different eigenvectors or electrical current/magnetic field distributions. The currents form current loops in order to generate magnetic fields. These current loops comprised two parts: current loops within coil elements and current loops within decoupling elements. The circuit model of an array coil is shown in Fig.1, consist of two coil elements and one decoupling element. The mutual inductance and capacitance between each element are represented by M_{cc} and M_{dc} within coil-to-decoupling-element and coil-to-coil respectively. Based on the Kirchhoff's voltage law (KVL), in this circuit mode, the currents satisfy $\begin{bmatrix} X_T & X_{Mcc} & X_{Mdc} \\ X_{Mcc} & X_T & X_{Mdc} \\ X_{Mdc} & X_{Mdc} & X_D \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_D \end{bmatrix} = 0$, [1] where *X's* are the impedances. X_D in the impedance matrix is the impedance of the decoupling element at the frequency ω. X_T is the impedance of the coil elements. X_{Mdc} and X_{Mcc} are the mutual impedance of M_{cc} and M_{dc}. Theoretically, the impedance matrix has eigenvalues $\lambda = X_T - X_{Mcc}$ [2]. Because eigenvalues are function of frequency ω, $\lambda = 0$ will educe resonant frequency. The array is decoupled when one eigenvalue could have two current eigenvectors. This decoupling condition is satisfied if and only if $X_D = \frac{X_{Mdc}^2}{X_{Mcc}}$ [2]. Fig.2(a) showed an example by using capacitor decoupling, where only mutual capacitances between coil and decoupling elements(1). As an application of this analysis, Fig.2(b) showed a new decoupling method, where mutual inductances between coil and decoupling elements. A microstrip array coil, consisted of 2 microstrip resonators and one microstrip decoupling line, was built on a Teflon cylinder with dimensions of 6.6cm O.D by 5.2cm I.D by 10.2cm length. The gap between two coils is 2cm. Bench test on the resonant modes and decoupling between two microstrip coils were implemented on a network analyzer (Agilent E5070B), shown in Fig.3. The termination capacitance measurement was conducted on a RCL meter (Fluke PM6303A). The MR imaging experiments were performed on a GE 7T/90cm magnet (GE Healthcare, Waukesha, WI). A bottle of pure water was used as a phantom in this preliminary study. A set of gradient echo images in axial orientation were acquired using the coil array. Acquisition parameters were –TR = 30ms, TE = 6.8ms, thickness = 3mm, flip angle = ~20^0, FOV = $100cm^2$, no average.

Results and Conclusions Each coil element was matched to system 50 Ohm by a series capacitor working at 298.144MHz for Proton MR imaging at 7T. In Fig.3, the decoupling between the two elements was 26.6dB. No resonant peak split is observed for both elements. These results indicate that the two channels are decoupled sufficiently. Fig 4 shows the MR images from each resonant element, in which no signal is observed from other coil, indicating the effectiveness of the proposed decoupling technique at ultrahigh field of 7T. The proposed design provides a robust approach to design of parallel imaging arrays at ultrahigh fields. The future work will be focused on investigation of the proposed decoupling technique with more resonant elements and evaluation of the g-factor of the design.

Reference (1) Wu B, et al, Thirteenth Annual Meeting of ISMRM: 949 (2005); (2) Wu B, et al, J Magn Reson 182:126–132 (2006).

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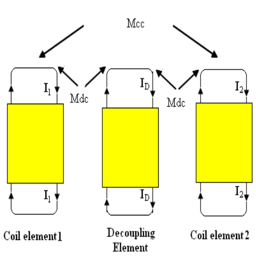

Fig.1 A diagram of resonant coil elements and a decoupling element.

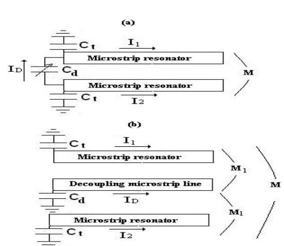

Fig.2 Diagrams of (a) capacitor decoupling, (b) new magnetic wall decoupling methods.

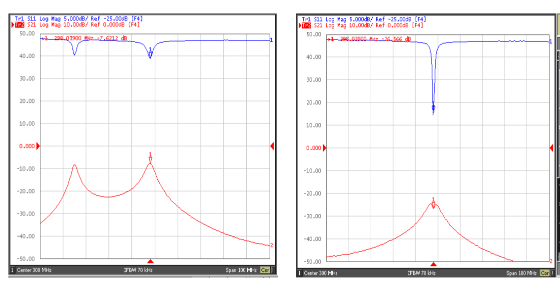

Fig.3 Bench test results results: before decoupling (left) and after decoupling by using magnetic wall method. Working frequency is 298.144MHz.

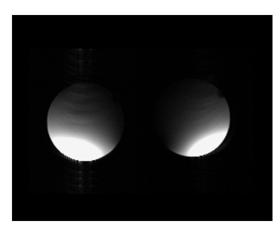

Fig.4 Proton MR images of 2 channel at 7T.