Mutual Coupling Effect Precompensation for Spatial Domain Method Based Parallel Transmission

Yong Pang[1], Daniel Vigneron[1,2], and Xiaoliang Zhang[1,2]
[1]Radiology and Biomedical Imaging, University of California San Francisco, San Francisco, CA, United States, [2]UCSF/UC Berkeley Joint Graduate Group in Bioengineering, San Francisco & Berkeley, CA, United States

Introduction: The mutual coupling effect on the excitation profile of transmit SENSE [1] can be reduced using the precompensation method previously proposed [2] by introducing the mutual coupling coefficient matrix into the RF pulse design procedure. In this project, we extended this method to other commonly used parallel transmission methods such as the spatial domain method [3]. To investigate its feasibility and efficiency, a 4-element coil array was used and 90° pulses were designed using both the spatial domain method and the precompensation method for comparison. The results show that the mutual coupling effect can be effectively compensated, yielding enhanced tolerance to insufficient mutual decoupling of RF arrays in parallel excitation, and ultimately, providing improved performance and accuracy of parallel transmission.

Theory and method: Based on the method proposed in reference [2] and the spatial method [3], the excitation pattern from multiple coils with mutual coupling efficient $c_{m,n}$ can be written as:

$m(\mathbf{x}) = i\gamma M_0 \sum_{m=1}^{R} S_m(\mathbf{x}) \int_0^T \sum_{n=1}^{R} c_{m,n} B_{1,n}(t) e^{i\mathbf{x}\cdot\mathbf{k}(t)} dt$ (1), where M_0 is the initial magnetization, $B_{1,n}(t)$ denotes the RF pulse of the nth element of the array. $\mathbf{k}(t)$ is the k-space trajectory defined by the gradient function. R is the element number, $S_m(\mathbf{x})$ is the complex sensitivity pattern of the mth coil. Then, by discretizing time to N_t samples and space to N_s samples as that in the spatial domain method [3], we can rewrite:

$m = \sum_{r=1}^{R} D_r A B_r$ (2), where A and B_r are defined as same as that in the spatial domain method, while D_r is defined as:

$D_r = diag\{S_n^*(\mathbf{x}_i)\}$ (3), where $S_n^*(\mathbf{x}_i)$ is:

$S_n^*(\mathbf{x}) = \sum_{m=1}^{R} c_{m,n} S_m(\mathbf{x})$ (4). Eq.(2) is the same as that of the spatial domain method, the difference is the sensitivity $S_n(\mathbf{x}_i)$ is replaced by $S_n^*(\mathbf{x}_i)$ which equals the sum of all the individual sensitivity pattern multiplied by the corresponding mutual coupling coefficient. This corresponds to compensation for the mutual coupling effect in the excitation procedure. To investigate the feasibility of the proposed method, a simple example of parallel transmission is simulated by solving the Bloch equation. Excitation pulses were designed using the spatial domain method and the precompensation method respectively for comparison. The desired excitation pattern was a cylinder with 10 cm diameter and was excited using a 4-element array with the reduction factor of 2. The sensitivity pattern of each element is shown in Fig.1. The mutual coupling coefficient matrix between the elements is shown in Fig.2. The proposed precompensation method was applied to design the excitation pulses for implementing parallel transmission using the RF arrays with non-negligible mutual coupling between elements.

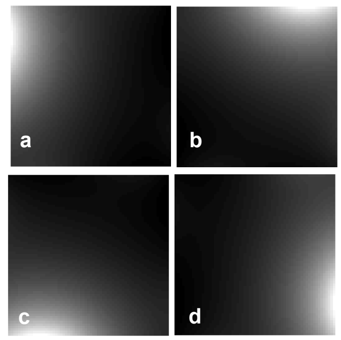

Fig. 1 Sensitivity pattern of each array element.

	1	2	3	4
1	1	0.18	0.1	0.2
2	0.18	1	0.14	0.11
3	0.1	0.14	1	0.16
4	0.2	0.11	0.16	1

Fig.2. Mutual coupling coefficients between array elements.

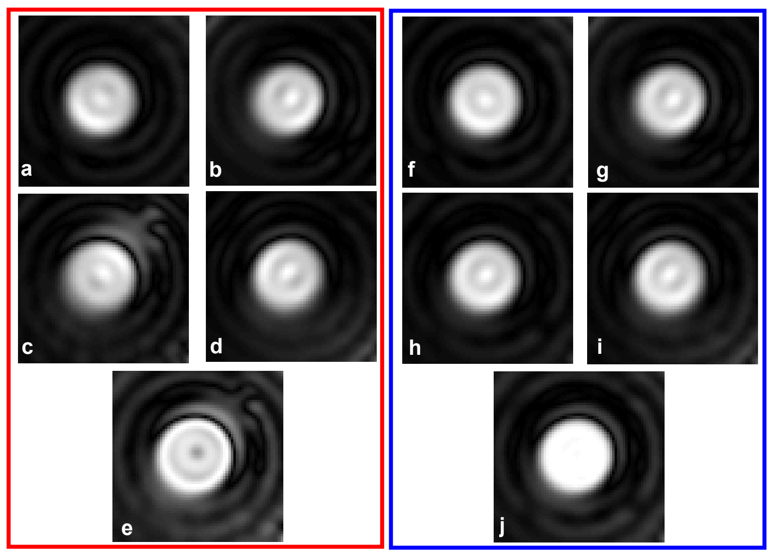

Fig.3. Simulation results of the excitation profiles using a 4-element coil array in the existence of mutual coupling: (a – d) individual excitation pattern of each element by using spatial domain method; (e - h) individual excitation pattern of each element by using the precompensation method; (i) by using the original spatial domain method in the existence of the mutual coupling, the aliasing can't cancel each other which lead to artifacts; (j) by using the precompensation method, the artifacts caused by the mutual coupling were effectively reduced.

Results: The excitation pattern of each array element was generated and plotted, as illustrated in Fig. 3 (a)-(d). When the pulses were designed based on spatial domain method with existence of mutual coupling, the artifacts in the resulting excitation pattern is unable to be cancelled by each other. This leads to the deteriorated excitation pattern with the residual aliasing artifacts, as shown in Fig.3.(e). With the use of the proposed precompensation method, the specific RF pulses were designed by taking the mutual coupling coefficients into calculation for each array element. Using these RF pulses, the mutual coupling between the elements is able to compensated, resulting in reduced artifacts in the excitation pattern of each element shown in Fig.3.(f)-(i) and in the resulting excitation pattern shown in Fig.3.(j). This demonstrates that the mutual coupling effect of imperfectly designed transmit arrays can be efficiently corrected by the precompensation technique.

Conclusions and discussions: In this work, the precompensation method has been applied to the spatial domain method for parallel transmit to overcome the mutual coupling effect in transmit coil arrays and improve the parallel excitation pattern. Its performance has been investigated. The results demonstrate that the precompensation method is feasible to reduce the artifacts caused by mutual electromagnetic coupling between array elements, making the parallel transmission more tolerant to mutual coupling in RF transmit array. This is very helpful for parallel transmission because current decouple methods are usually not able to thoroughly eliminate the mutual coupling in RF transmit arrays.

References: [1] Katscher U, et al, Magn Reson Med 2003; 49: 144-150. [2] Pang Y, et al, ISMRM 2005: p887. [3] Grissom W, et al, Magn Reson Med 2006; 56: 620-629.

Acknowledgements: This work was partially supported by NIH grants EB004453, EB008699, EB007588-03S1 and P41EB013598, and a QB3 Research Award.