Eigenmode Analysis of Transmit Coil Array for SAR-reduced B_1 Mapping and RF shimming

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Introduction

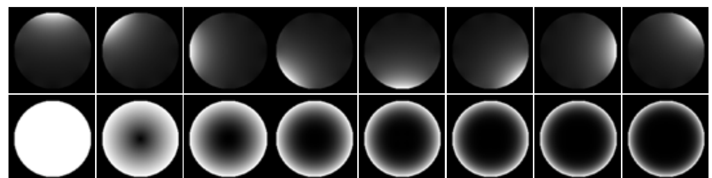
The B_1 transmit field inhomogeneity represents a serious problem in whole-body high field MRI (≥3T). B_1 shimming based on measured B_1 maps is a promising approach to cope with this problem and represents the primary application for parallel transmission at this point in time [1,2]. However, B_1 mapping is still an error-prone and time consuming process [3], potentially resulting in a SAR issue caused by the shimmed RF pulse and the mapping scan itself. In the present work, an eigenmode analysis of the transmit sensitivities is employed to accelerate the B_1 mapping process and reduce the SAR of the shimmed RF pulses.

Theory

The coil sensitivities **S** of a transmit array can be given by its singular value decomposition (SVD) $\mathbf{S}=\mathbf{U\Sigma V}^H$. The columns of **S** form vectors that contain the spatial sensitivities of the *N* individual Tx coils. The orthogonal matrix **V** represents a transformation from the *N* physical coil elements to the *N* normal (eigen) modes of the coil arrays, represented by their orthonormal transmit sensitivities stored in the columns of the matrix **U**. The *N* singular values σ_i, held by the diagonal matrix $\mathbf{\Sigma}$, describe the conditioning of the coil array with respect to its normal modes, and hence, are characteristic properties of the array for both, the mapping and the shimming procedure. Small singular values result in a less precise mapping of the corresponding modes, and hence, in larger mapping errors. Apart from that, those contributions of the shimmed B_1 originating from modes with smaller singular values need larger RF power ($\sim\sigma_i^{-2}$), and hence, will contribute disproportionately high to the SAR (Fig.1). On the other hand, RF shimming is often a rather benign problem, and the normal modes are, at least approximately, known in advance. This opens the potential to restrict the problem to a few significant modes, thus accelerating the B_1 mapping and regularizing the RF shimming process. Introducing the diagonal matrix **R**, with zeros for the modes to be discarded and ones for the remaining, $\mathbf{V}^H\mathbf{RV}$ represents a transformation matrix for the drive scales of the coil elements to filter out the discarded modes, and hence, to restrict both mapping and shimming to the desired modes.

Methods

Experiments were performed on a 3T MRI system (Philips Medical Systems, Best, The Netherlands) equipped with eight transmit channels [5] and an 8-element TX/RX body coil [6]. The AFI (Actual Flip Angle Imaging) technique [3] was used for B_1 mapping (450 mm FOV, 64 scan matrix, alpha = 40°, TR_1 = 20 ms, TR_2 = 100 ms) in water phantoms. Due to the circulant symmetry of the coil array, a good guess for the matrix **V** is known beforehand and represented by the discrete Fourier transform. The six least significant coil modes were discarded, keeping only two major modes. The strongest mode (i.e. uniform mode) was further enhanced to decrease the noise level in the maps [7]. Two such conditioned B_1 maps were measured from opposite coil configurations and used for B_1 shimming as virtual coil elements. Optimal shim weights were derived using least-squares fitting based on the the Levenberg–Marquardt algorithm. Subsequently, a shimmed B_1 map was acquired and compared to a second map acquired with default weights for the 8 transmit elements.



σ =1	0.88	0.67	0.48	0.33	0.23	0.15	0.10
E=1	1.29	2.23	4.34	9.18	18.90	44.44	100

FIG. 1. **Simulated transmit coil array**. The modulus of the B_1 transmit field is shown for the eight individual transmit elements (top row) and for the normal modes of the coil, obtained by SVD (bottom row). The fields were calculated from coil geometry parameters (coil radius = 300 mm, shield radius = 320 mm) using a simple Biot-Savart model [4]. The table shows the corresponding singular values for the given FOV (radius = 200 mm). In addition, the energy equivalent to a given RMS B_1 field is indicated for the different eigen-modes.

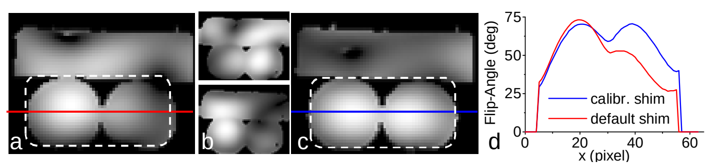


FIG. 2. B_1-maps are shown using default shims (a) and calibrated shims (c). The calibrated shims were obtained from the B_1-maps of a virtual 2-channel array (b). The dashed frames in (a) and (c) indicate the target region used for shimming. The colored horizontal lines indicate the positions of the profiles plotted in (d). The calibrated shims result in strongly improved homogeneity, compared to the default shims.

Results

The B_1-maps acquired with default shim values show a visible left-right B_1 inhomogeneity well-known from mamma MRI at 3T (Fig.2a). In contrast, B_1 shimming based on the maps of the two virtual coil elements (Fig.2b) results in excellent homogeneity of the target region (Fig.2c). Although the calibrated shim values resulted in about 50% RF power reduction, the average flip-angle in the target region was even higher than the flip-angle obtained with the default shim (Fig.2d).

Discussion

The presented eigenmode approach uses a-priori knowledge on the employed coil array and the targeted application to select a favourable reduced virtual coil system for the B_1 mapping scan. In this way, the B_1 shimming procedure is regularized already from the beginning, resulting both in accelerated B_1 mapping and more reliable and SAR-reduced shimming procedure.

References

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