TRIPLET: Transmit and Receive fields reconstruction from a single Low-Tip-angle gradient-Echo scan.

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Introduction Knowledge of transmit (B_1^+) and receive (B_1^-) RF fields is fundamental for parallel imaging, parallel transmit MR and methodologies to correct images for inhomogeneous receive profiles. In the past years, many B_1^+ mapping techniques have been introduced with varying strengths and weaknesses. Difficulties most often encountered in these methods are limited dynamic range, sensitivity to off-resonances and need for high RF powers. B_1^- mapping is even more challenging as it is difficult to disentangle variations in coil sensitivity from spatially varying proton spin density. Here, we expand an idea introduced in [1]: singular value decomposition (SVD) of matrices constructed from Low-Tip angle, Gradient echo (LTA-GE) images. In this work, we show that 1) the fields obtained upon SVD are a spatially scaled version of the actual B_1^+ and B_1^- fields and 2) the scaling patterns can be calculated by solving an optimization problem. In this way, B_1^+ and B_1^- maps can be quickly reconstructed. Results from FDTD simulations and *in vivo* measurements confirm the validity and the speed of the new three step approach.

Methods With a pTx coil configuration consisting of N_t transmit channels and N_w receive channels, N_w LTA-GE images for each of the N_t transmit channels can be quickly acquired. Subsequently, the image values in each voxel, r, are stored in a matrix $\mathbf{S}^r$, where the entry $(\mathbf{S}^r)_{i,j}$ denotes the image value from the j^{th} Rx channel for the i^{th} Tx-combination at spatial position r. By construction: $(\mathbf{S})_{i,j} = \rho\, B_{1,i}^+ B_{1,j}^-$ **(1)** where ρ is the proton density value, possibly with a phase term due to B_0 variations and/or chemical shift. Here and in the following, all quantities are space-dependent but for simplicity of notation the superscript r is dropped. Upon SVD of $\mathbf{S}$, the dominant singular value σ with corresponding left and right singular vectors $(\mathbf{t},\mathbf{w})$ are assigned to each voxel [1] in a way such that $(\mathbf{S})_{i,j} = \sigma\, \mathbf{t}_i \mathbf{w}_j$ **(2)**. A crucial aspect of SVD is that it delivers unit length vectors, thus $\mathbf{t}$ and $\mathbf{w}$ are voxelwise normalized versions of the true B_1^+ and B_1^- maps. In other words: $B_{1,i}^+ = \alpha \mathbf{t}_i$ and $B_{1,j}^- = \beta \mathbf{w}_j$ **(3)** where α and β are the spatially varying normalization factors. From Eqs. **1-3** we conclude that $\sigma = \alpha\, \rho\, \beta$. Note that α and β are channel-*independent*. Figure 1 shows a plot of $\mathbf{t}_i$, α and $B_{1,i}^+$ (with i =1,...,8) for a FDTD simulated 8ch, transceiver body array coil at 7T loaded with a human model [2]. A similar scheme can be drawn for the receive fields: $\mathbf{w}_j$, β and $B_{1,j}^-$.

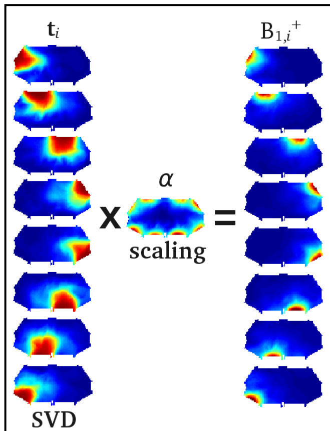

Fig. 1 *The scaling pattern* α *relates the* SVD *fields* $\mathbf{t}_i$ *to the* B_1^+ *maps.*

The key step is to find α and β. Once the scaling patterns are known, the complex B_1^+ and B_1^- maps can be reconstructed. Finding α and β can be solved as a total least squares problem once a model for the true B_1^+ and B_1^- fields is available. Previous work [3] has shown that the B_1^+ and B_1^- fields for frequently used coil geometries (e.g. striplines, birdcage) can be expanded in a very compressed manner by a few Bessel-Fourier functions, that is $B_{1,j}^+ = \mathbf{F}\mathbf{c}^+$ and $B_{1,j}^- = \mathbf{F}\mathbf{c}^-$ **(4)** where $\mathbf{F}$ denotes the Bessel-Fourier matrix, and $\mathbf{c}^+$ and $\mathbf{c}^-$ the expansion coefficients. This methodology is an example of a multipole expansion and is often used in electromagnetic problems. Applying this model, the resulting problem is: find α, β, $\mathbf{c}^+$ and $\mathbf{c}^-$ such that $\alpha\mathbf{t}_i = \mathbf{F}\mathbf{c}^+$ and $\beta\mathbf{w}_j = \mathbf{F}\mathbf{c}^-$ for each voxel in the image. The derived eigenvalue/eigenvector problem is solved by the fast Jacobi-Davidson algorithm. We end up with a 3 step method, called TRIPLET: 1) LTA-GE image acquisition, 2) SVD, 3) optimization for the determination of α and β. The reconstruction scheme is displayed in Fig. 2. For *absolute* B_1^+ scaling, an extra single point B_1^+ calibration is needed.

Note that for a single transmit channel system, the SVD step is not necessary to reconstruct the multi-channel B_1^- fields.

Materials The method is applied in the following setup: 1) FDTD simulated dataset (Semcad X, SPEAG, Zurich) for a 8ch, 7T, transceiver, surface body array coil loaded with an adult male body model (Duke, virtual family) and 2) an *in vivo* measurement of a volunteer's head with a 8ch, transceiver, degenerate birdcage head coil at 7T. The algorithm is implemented in Matlab on a PC with 4 CPU's at 3.10 GHz.

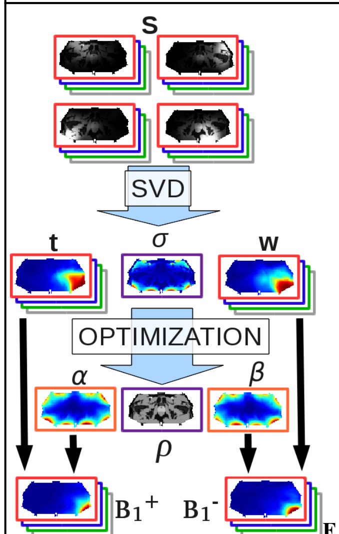

Fig. 2 *The* TRIPLET *scheme.*

Results The TRIPLET B_1^- maps for setup 1 and the B_1^+ maps for setup 2 are shown in Fig 3 and 4, respectively. The true fields (FDTD simulated: REF) for setup 1 and the measured B_1^+ fields (AFI method) for setup 2 are reported for benchmarking. For comparison, also the SVD based maps are reported. Only the magnitude maps are displayed. The α and β patterns for both setups are displayed in Fig. 5. Note that they are more quickly decaying for setup1 than for setup 2. This can be explained by the geometry of the coil array: the relative strengths of all the channels in the volume coil of setup 2 vary much less over the object than for the surface abdomen array from setup 1. Note also the mirror symmetry between the α and β patterns, which recalls the well known B_1^+ and B_1^- mirror symmetry. The LTA-GE acquisition (step 1) takes about 1 minute, while the total processing time (step 2+3) is about 30s. The TRIPLET maps exhibit a steeper profile than the SVD fields. In setup 2, this is indicated by the arrow a). For the same setup, artifacts due to limited dynamic range in the AFI method are corrected. See arrow b). The solution of step 3 is sensitive to noise in the data. In this work, TRIPLET was successfully applied to images with SNR ≈40.

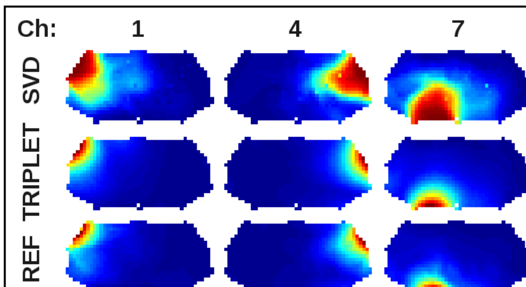

Fig. 3 SVD, TRIPLET *and Reference fields for setup 1.*

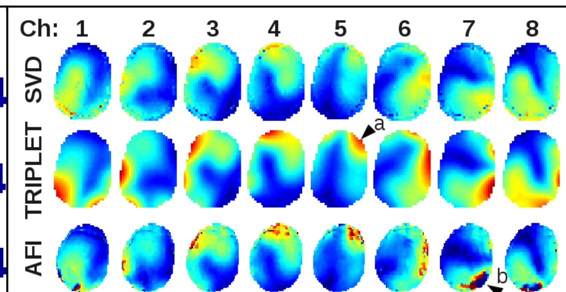

Fig. 4 SVD, TRIPLET *and* AFI *fields for setup 1.*

Conclusions TRIPLET exploits the information intrinsic in the SVD decomposition of LTA-GE images to reconstruct the B_1^+ and B_1^- maps of pTx coils by first computing the spatial scaling patterns α and β. The method produces all necessary RF field information for a parallel transmit and parallel imaging experiment in a very short time and with use of minimal RF power. In addition, the methods results in receive sensitivity maps per channel without the need for a homogeneous receive reference. These maps can be used for image correction due to inhomogeneous receiver profiles, for instance to create a purely proton density weighted image. The method is generic and will also work in case of a single transmit channel combined with several receive channels.

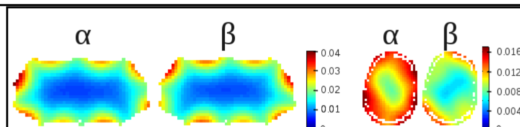

Fig. 5 *The scaling patterns for setup 1 and 2.*

References [1] Brunner et al, ISMRM 2010 p.242 [2] Raaijmakers A et al, MRM 2012 [3] Sbrizzi et al, ISMRM 2012 p.3359.