Improving RF Shimming via non-linear Sub-image Combination

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Introduction RF shimming is a widely discussed technique to overcome B1 inhomogeneities at high main fields via optimizing the drive weights of multiple transmit channels [1]. However, due to the limited degrees of freedom in this approach, residual B1 inhomogeneities might occur for particular anatomies. This study tries to mitigate residual B1 inhomogeneities by a suitable, non-linear combination of images obtained from different sub-images. The sub-images have been acquired using different drive weights of the transmit channels, leading to complementary inhomogeneities in the different sub-images. The subsequent combination of the sub-images can be optimized with respect to constant total B1 and constant image contrast.

$$\delta = \min_{m\le M}\left(\alpha_{\text{nom}} - \alpha_m(\mathbf{r})\right)^2 \qquad (1)$$

$$\alpha_m(\mathbf{r}) = \left|\sum\nolimits_{n\le N} A_{nm} S_n(\mathbf{r})\right| \qquad (2)$$

$$I_{tot}(\mathbf{r}) = \frac{\sum_{m\le M}\left(\alpha_{nom} - \alpha_m(\mathbf{r})\right)^{-2}\left|I_m(\mathbf{r})\right|}{\sum_{m\le M}\left(\alpha_{nom} - \alpha_m(\mathbf{r})\right)^{-2}} \qquad (3)$$

Theory In this study, complex drive weights $\underline{A}_{nm} = A_{nm}\exp(i\varphi_{nm})$ of N transmit channels and M sub-images are determined via minimizing the error function δ (see Eqs. (1,2), α_{nom} the desired flip angle, S_n the B1 map of transmit channel n). Minimization of δ means to get at least one of the sub-images with a flip angle as close as possible to the nominal flip angle in each voxel. Thus, residual B1 inhomogeneities can be mitigated as long as they are in different locations in different sub-images. The final image I_{tot} can be reconstructed, e.g., by a weighted superposition of the sub-images I_m (see Eq. (3)). To reduce the computational effort of optimizing $2NM$ degrees of freedom simultaneously, it is possible to start with the standard RF shimming M=1, i.e., calculating first A_{n1} via optimizing Eqs. (1,2) to obtain $\alpha_1(\mathbf{r})$. Using this result, $\alpha_2(\mathbf{r})$ is calculated via optimizing A_{n2}. This procedure can be repeated until the desired number of sub-scans is defined.

Methods The transmit sensitivities of an eight-element transmit array at 3T [2] have been simulated for an "abdominal" cylinder phantom (radii 20×15cm, length 40 cm, σ = 0.35 S/m, ε_r = 60) using FEKO (EMSS, Stellenbosch, South Africa). Using the above-described sequential procedure, the drive weights of M=4 sub-scans have been determined. To test the resulting image contrast, T1 = 300 ms was assigned to a "fat rim" of the phantom and T1 = 1200 ms (muscle / blood mixture) to the remaining phantom. Using the optimized drive weights, sub-images were simulated for an FFE scan with TR = 100 ms and α_{nom} = 30° [3].

Results Quadrature excitation is shown in Fig. 1a. Residual inhomogeneities of an eight channel shim (Fig. 1b) are partially compensated by a second sub-scan (Fig. 1c) with complementary inhomogeneities. Discontinuities appear in the "effective" B1 map (Fig. 1d, upper row), showing for each pixel the B1 map which is closest to the ideal B1 map. These discontinuities do not appear in the combined image (Fig. 1d, lower row) due to the weighting performed by Eq. (3). Further sub-scans improve the resulting image only marginally (Fig. 1e), approaching the ideal case (Fig. 1f). Figure 2 shows corresponding quantitative results.

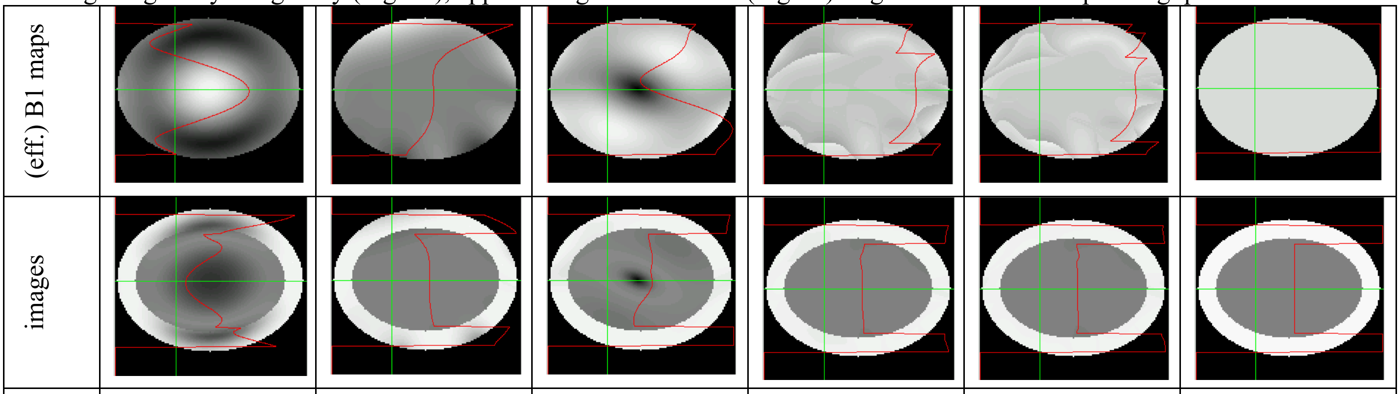

Fig. 1 (a) quadrature (b) 8 channel shim (M=1) (c) sub-scan m=2 (d) combined M=2 sub-scans (e) combined M=3 sub-scans (f) ideal scan

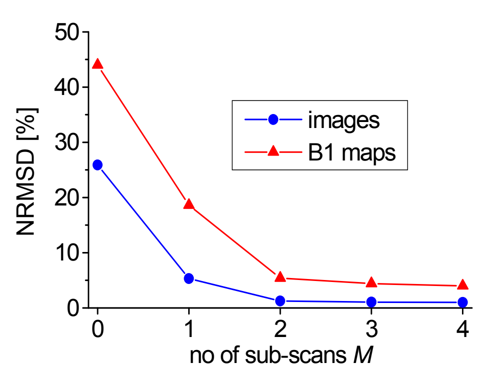

Fig. 2: Quantitative analysis of the shimming results of Fig. 1. The Normalized Root-Mean-Square Deviation (NRMSD) from the ideal case (Fig. 1f) is plotted as a function of the number of sub-scans. The case M=0 denotes the quadrature excitation.

Discussion / Conclusion In the presented study, M=2 sub-scans yield significantly better image quality than standard RF shimming (i.e., M=1). More than M=2 sub-scans does not seem to be useful for the investigated case of N=8 transmit channels. In contrast, for N<8 transmit channels, M>2 sub-scans might become reasonable. Of course, total scan time is proportional to M; however, sub-scans could replace scan averages without increasing total scan time. In future studies, the approach shall be investigated *in vivo*.

References [1] Ibrahim TS et al., MRI 18 (2000) 733
[2] Vernickel P et al., MRM 58 (2007) 381
[3] Vlaardingerbroek MT et al., *Magnetic Resonance Imaging*, Springer, Berlin 1996