Local TX and RX Shimming for Improved Conductivity Imaging

Jakob Meineke[1] and Ulrich Katscher[1]
[1]*Philips Research Europe, Hamburg, Germany*

Target Audience: Researchers interested in conductivity imaging, RF shimming, and mammography.

Purpose: Phase-based Electric Properties Tomography (EPT) can be used to measure the conductivity of tissue in vivo [1, 2]. However, the method is limited by the assumption that both receive (RX) and transmit (TX) radiofrequency fields are spatially homogenous. Here, it is shown that the systematic errors of phase-based EPT can be reduced by using a local, offline shimming procedure as outlined in [3,4]. It utilizes B_1-mapping and the additional degrees of freedom present in multi-TX/RX systems. A primary goal of the technique is to improve conductivity imaging of breast tumors (see, e.g., [5]).

Methods: (1) Numerical simulations: RF fields analogous to the two TX/RX channels of a 3T whole-body coil are simulated numerically for a spherical phantom with conductivity 1 S/m. The resulting fields are used to generate images according to $I_{MN} = f(|H_M^+|)\,|H_N^-|\exp\{i(\phi_M^+ + \phi_N^-)\}$, where *M, N* are labeling the different TX and RX channels, respectively, *H* and ϕ represent magnitude and phase of the RF fields, and *f* is a non-linear function describing the flip-angle dependence of MR image signal/contrast. For a given RX channel, say *A*, the transceive phase can be used together with the B_1-maps of the individual TX channels to locally shim the magnitude of the TX field by optimizing the shim coefficients w^+ according to $w^+ = \min_{w^+}\left(\left|\sum_{M\in\{A,B\}} w_M^+ |H_M^+|\exp\{i(\phi_M^+ + \phi_A^-)\}\right| - H^+\right)$, with H^+ the target field. In a second step, the RX field is shimmed accordingly via coefficients w^- by exploiting the relation between TX and RX fields imposed by the axial mirror symmetry of the system, which here is given by $H_A^+(x,y,z) \sim H_B^-(-x,y,z)$ and vice versa. The coefficients w^+/w^- are used to locally calculate the transceive phase for phase-based EPT [1,2]. (2) Phantom measurements: Data were acquired for a cylindrical phantom filled with 1.5L of an aqueous solution (1g/L $CuSO_4$, 2g/L NaCl, yielding electric conductivity $\sigma = 0.5$ S/m) employing a standard 3D TSE sequence (FOV: 352×176×200mm, acq. voxel 2×2×4mm, FA=90°, TSE factor=44) and using the two channels of the body coil for RX. B_1^+-maps were acquired using DREAM [6] over the same FOV (acq. voxel 4×4×4mm, FA=25°, nominal STEAM angle=60°). All data were acquired separately for the two TX channels of the body coil. TSE images were reconstructed separately for both RX channels, yielding 4 sets of images for all TX/RX combinations. (3) In vivo measurements: Breast images were acquired for a healthy volunteer using the same protocol as above except for the TSE factor=11. – All experiments have been performed on a commercial dual-TX 3T system (Ingenia, Philips Healthcare, The Netherlands), and shim coefficients have been optimized via maximizing the homogeneity of the reconstructed conductivity.

Results: (1) Numerical Simulations: Figure 1 shows (a) the calculated conductivity corresponding TX/RX quadrature channel combination, (b) local TX shimming / RX quadrature, and (c) local TX/RX shimming. The normalized root-mean-square error (NRMSE) of the conductivity is reduced from 20% for the quadrature combination, to 10% for local TX shimming, down to 2% for local TX/RX shimming. (2)-(3) Phantom and in vivo data: Reconstructed conductivity are shown in Figure 2 and Figure 3. The overall variation of the reconstructed conductivity can be reduced significantly by a local optimization of w^+/w^-. For the phantom, the effect is strongest close to the edges and coincides with strongest variations of the B_1-magnitude.

Discussion and Conclusions: Local TX/RX shimming offers a valuable possibility for improving conductivity imaging in applications with inhomogeneous B_1 fields, as, for example, in breast imaging at 3T. While the technique shows improved images even using only two TX/RX channels, stronger improvements are expected using more than two TX/RX channels.

References: [1] Voigt T et al., MRM 66 (2011) 456 [2] van Lier AL et al., MRM 67 (2012) 552 [3] Sodickson D et al., ISMRM 20 (2012) 387 [4] Shin JW et al., ISMRM 21 (2013) 4180 [5] Katscher U et al., ISMRM 21 (2013) 3372 [6] Nehrke K et al., MRM 68 (2012) 1517

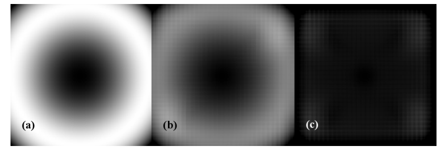

Figure 1: Conductivity calculated using phase-based EPT using numerically simulated RF fields for a spherical phantom with conductivity $\sigma = 1$S/m (identical grayscale: white: 1.25 S/m, black: 1 S/m). (a) no shim: NRMSE=20%, (b) TX-shim: NRMSE=10%, (c) TX/RX-shim: NRMSE=2%.

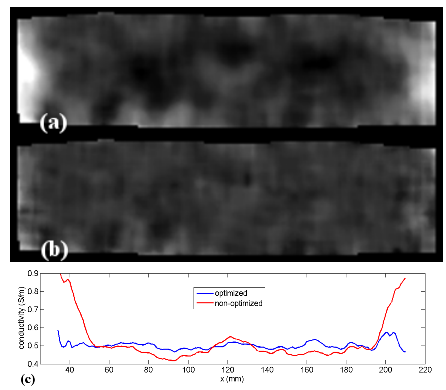

Figure 2: Conductivity for cylindrical phantom with σ = 0.5 S/m (black: 0.4 S/m, white: 0.85 S/m) (a) non-optimized, NRMSE=22%, (b) optimized, NRMSE=6%, (c) cut along horizontal axis through (a) and (b).

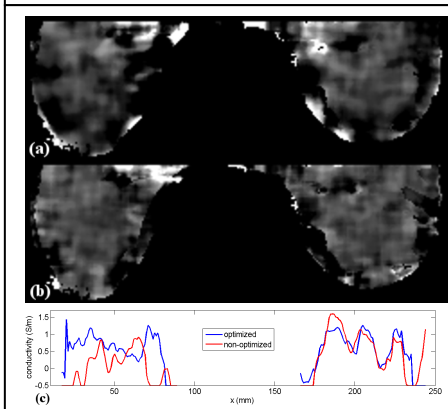

Figure 3: Conductivity for central slice of in vivo data. (a) non-optimized, (b) optimized, (c) horizontal cut through (a) and (b).