Local TX and RX Shimming for Improved Conductivity Imaging
Jakob Meineke1 and Ulrich Katscher1
1Philips 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 B1-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

\[ I_{MN} = f \left( |H_{MN}^T| |H_{MN}^R| \exp \left[ i \left( \phi_{MN}^T + \phi_{MN}^R \right) \right] \right), \]

where M, N are labeling the different TX and RX channels, respectively, \( H \) and \( \phi \) 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 TX channel, say A, the transceive phase can be used together with the B1-maps of the individual TX channels to locally shim the magnitude of the TX field by optimizing the shim coefficients \( w^A \) according to

\[ w^A = \min \left( \sum_{\mu \in \{x,y,z\}} \left| H_{\mu}^A \right| \exp \left[ i \left( \phi_{\mu}^T + \phi_{\mu}^R \right) \right] - H^A \right), \]

with \( H^A \) the target field. In a second step, the RX field is shimmed accordingly via coefficients \( w^R \) by exploiting the relation between TX and RX fields imposed by the axial mirror symmetry of the system, which here is given by \( H_A^*(-x,y,z) = H_A^*(x,y,z) \) and versa. The coefficients \( w^A/w^R \) 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 CuSO4, 2g/L NaCl, yielding electric conductivity \( \sigma = 0.5 \text{ S/m} \)) 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. B1+-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 \( w^A/w^R \). For the phantom, the effect is strongest close to the edges and coincides with strongest variations of the B1-magnitude.

Discussion and Conclusions: Local TX/RX shimming offers a valuable possibility for improving conductivity imaging in applications with inhomogeneous B1 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.


Figure 1: Conductivity calculated using phase-based EPT using numerically simulated RF fields for a spherical phantom with conductivity \( \sigma = 1 \text{ S/m} \) (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 \( \sigma = 0.5 \text{ S/m} \) (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).