Spatial Receive Sensitivity Assessment using MPI Transfer Function Measurements

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Abstract: Upscaling Magnetic Particle Imaging (MPI) to human scale introduces regions of interest within the coil where sensitivity inhomogeneities arise. These inhomogeneities affect both image reconstruction quality and model-based system matrices. In this work, we present an approach for measuring these inhomogeneities using only a few spatial MPI transfer function measurements.

Introduction: The field-of-view (FOV) in receive coils of human-sized MPI systems [1] extends beyond the homogeneous region, with conductive material potentially distorting the sensitivity profile. Accurate coil sensitivity information is crucial for enhancing image reconstruction, especially when using model-based system matrices. Extending MPI receive path calibration from the coil center [2] to all spatial positions using smart sampling methods [3], the field profile can be assessed.

Methods: For the dedicated gradiometric receive coil of the aforementioned MPI system [1], the transfer function $\widehat{\boldsymbol{S}}_{21,\mathrm{in,cal}}$, from the input of 3D calibration coil to MPI systems analog signal input, was measured at 86 positions arranged on a spherical t-design [3]. Using solid harmonic expansions, the field profile can be determined by

$$\mathbf{P}_{\mathrm{rx}}(\boldsymbol{r}) \propto \widehat{\mathbf{G}}(\boldsymbol{r},k) = \widehat{\mathbf{G}}(\boldsymbol{r}_0,k)\mathbf{P}_{\mathrm{rx}}(\boldsymbol{r}_0)^{+}\mathbf{P}_{\mathrm{rx}}(\boldsymbol{r}) \approx \left(\frac{R}{NA}\right)\widehat{\boldsymbol{S}}_{21,\mathrm{in,cal}}(\boldsymbol{r},k) \propto \widehat{\boldsymbol{S}}_{21,\mathrm{in,cal}}(\boldsymbol{r},k), \quad \text{Eq. 1}$$

Where, $\mathbf{P}_{\mathrm{rx}}$ is the coil sensitivity, $\widehat{\mathbf{G}}$ is the MPI transfer function, $\boldsymbol{r}_0$is the coil center, R is the coil resistance, N is the number of turns, and A is the coil surface area. To measure the transfer function, a 3D calibration coil, with 10 turns in each direction and a coil radius of 2.5 mm, was moved to each of the 86 positions. The output of the network analyzer (DG8SAQ VNWA3, SDR-Kits, U.K.) was sequentially connected to each spatial direction of the 3D calibration coil, and the transmission signal at the end of each receive chain was recorded. To preserve the magneto-quasistatic approximations, the spatial position should only scale the transfer function's amplitude, not its phase. Once this condition is met, a single frequency component with sufficient signal can be used to determine the field profile.

Results and discussion: In Fig. 1, the field profile in form of a single transfer function index $|\,\widehat{\boldsymbol{S}}_{21,\mathrm{in,cal}}| = \left[\mathrm{sgn}(\cos\,(\arg\,(\hat{S}_{21,\mathrm{in,cal},i}))) \cdot |\hat{S}_{21,\mathrm{in,cal},i}| \text{ for } i = \mathrm{x,y,z}\right]$ of the gradiometric receive coil of a human-sized MPI system is shown [1]. Spatial field orientation and homogeneities become prominent. Due to feedthrough cancellation with more cancellation turns than receive turns a sensitivity field-free-point is found in the FOV.

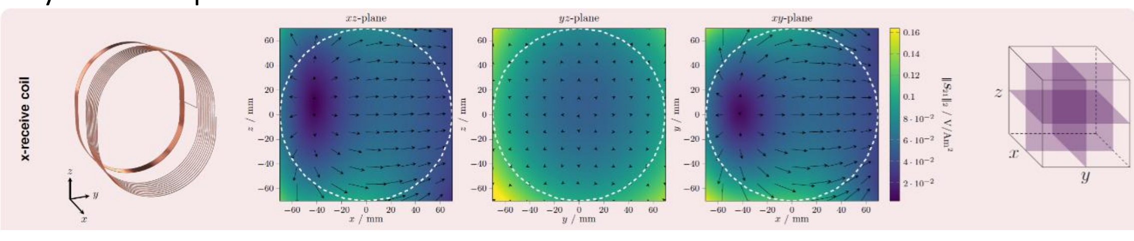

Fig. 1: Measured field profile for a dedicated receive coil. A rendering of the receive coil is shown with the measured corresponding transfer function profile of one frequency component. The dashed white circle indicates the edge of the sphere. On the right, the respective planes are illustrated.

Conclusion: The presented measurement-based method enables the assessment of spatial receive coil sensitivities. In addition to enhancing image reconstruction, it provides a foundation for the iterative improvement of receive coil design.

References: [1] Thieben et al. , IEEE TIM. (2023) doi: 10.1109/TIM.2022.3219461. [2] Thieben et al. , Commun. Eng.Phys. (2024) doi: 10.1038/s44172-024-00192-6. [3] Boberg et al. EJAM (2024), doi: 10.1017/S0956792524000883.