Transmit field fitting at 9.4 T using analytical solutions to Maxwell’s equations

Michael Stephen Poole¹, Desmond H Y Tse¹, Arthur W Magill², and N Jon Shah¹,²

¹INM-4, Forschungszentrum Jülich, Jülich, Germany, ²Department of Neurology, RWTH Aachen University, Aachen, Germany

Target Audience
Researchers using parallel transmit arrays at UHF.

Purpose
We aim to reliably produce accurate complex maps of the transmit fields of a parallel transceiver array at 9.4 T. These maps are used for $B^+_{1}$ static shimming, kt-points homogenised excitation¹ and are intended for spokes homogeneous slice selective excitation and full parallel transmit RF pulse design. We investigate a recently proposed method for modelling complex RF fields using low order analytical solutions to the Helmholtz wave equations in a homogeneous sphere in a spherical polar coordinate system.

Methods
Following the method proposed by Sbrizzi et al., we produce spherical Bessel functions of low order that are analytical solution to the magnetic Helmholz wave equation¹; $\nabla^2 B + \omega^2 B = 0$ where $\omega = \epsilon \mu_0^2 - \sigma \mu_0 r$. We then use these basis functions to fit relative $B^+_{1}$ maps (RB1)² of an 8-channel transceiver array at 9.4 T in a 180 mm diameter spherical 50 mM phosphate buffered saline (PBS) phantom and also in vivo. In all cases, five orders of spherical bessel functions were used with $\omega 2\pi = 400$ MHz. Relative permittivity, $\epsilon$, and conductivity, $\sigma$, were allowed to vary and chosen to minimise the fit error to the measured data. These fitted transmit maps (Maxwell) were qualitatively compared to absolute $B^+_{1}$ maps acquired using DREAM² and the AFI². Static shimming (CP mode at the centre) and kt-points² were performed using DREAM and the resulting RF pulses were used to predict the excitation using the RB1, AFI, Maxwell and DREAM transmit maps. The accuracy of the DREAM prediction was previously validated using measured AFI and FLASH data to remove the receive weighting from kt-points and CP mode excited FLASH data.

Results
Figure 1 shows the fit errors as a function of $(\sigma, \epsilon)$ with the optimal values: $(0.55 \pm 0.5$ S/m, $\epsilon = 78 \pm 5$) and $(0.33 \pm 0.5$ S/m, $\epsilon = 60 \pm 5$) for the PBS phantom and brain respectively.

Discussion
The fit error in the spherical PBS phantom was well behaved and provided a clear minimum that was coincidental for the error between the RB1 and Maxwell maps, and the AFI and Maxwell fields (see Fig. 1). The literature³ gives $(\sigma, \epsilon)$ values of $(0.74, 57)$, $(0.44, 42)$, and $(2.25, 71)$ for grey matter, white matter and CSF respectively. The in vivo fit error minimising values of $\epsilon$ are reasonable, but $\sigma$ appears to be low. Comparing in vivo Maxwell with AFI fields failed, probably due to poor quality AFI data (Figs. 1d and 4c). Figures 4b and 4d qualitatively compare well.

Maxwell fields predict the CP mode excitation with sufficient accuracy (Fig. 3c). Some radial weighting is evident in the kt-points excitation prediction (Fig. 3d); this may be due to an incorrect estimate of $\epsilon$ or $\sigma$.

This method also reveals the receive fields and the unmixed transmit and receive phases. The absolute transmit phase (Fig. 2d) was made relative to channel 8 (Fig. 2f) for the comparison to the RB1 phase (Fig. 2b). No study was made of the receive maps, but this might be done by using them in SENSE reconstruction of artificially undersampled data and comparison with fully sampled data.

Conclusion
A method of forcing the relative B1 maps to obey Maxwell’s equations was used to obtain more correctly scaled transmit maps. Although a flip angle calibration measurement is still required. The minimum fit error is proposed to find $\epsilon$ or $\sigma$, which appears to work well in phantom and less well in vivo. More investigation is needed so this method can be used routinely in vivo at 9.4 T.

References