Wave-number imaging at 7T: increasing accuracy of EPT at high field strengths

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Introduction: Recently, it was shown that human dielectric properties (permittivity ε_r and conductivity σ) can be mapped using MRI [1]. This method, named electrical properties mapping (EPT), relies on measurements of the B_1^+ amplitude and phase. This phase, however, cannot be measured directly; therefore, the assumption that the transceive phase is twice the B_1^+ phase (ϕ_+) is used in a transceiver setup [2, 3]. This assumption is acceptable at low field strengths (1.5 and 3T), however, leads to significant reconstruction errors at 7T [4]. Here, opposing errors were observed for the ε_r and σ mapping, which can be explained by the effect of the transceive phase error (ϕ_Δ) on the error in the reconstructed conductivity and permittivity ($\varepsilon_{r,\Delta}, \sigma_\Delta$, resp.). The error in the permittivity is caused by $\nabla\phi_\Delta \neq 0$, whereas the error in the conductivity is caused by $\nabla\phi_\Delta \neq 0$ and $\nabla^2\phi_\Delta \neq 0$ (see Equations). This abstract verifies if the wave-number , which combines the σ and ε_r ($|k| = \left|\sqrt{\mu\varepsilon_0\varepsilon_r\omega^2 + i\mu\sigma\omega}\right|$), benefits from this opposing error, and can be determined more accurately at 7T than the separate dielectric properties.

Methods: An elliptical phantom (σ = 0.58 S/m, ε_r = 80) was constructed with a cylindrical inner compartment (σ = 0.43 S/m, ε_r = 58); the inner compartment was placed off-axis [4]. The B_1^+ amplitude and transceiver phase were measured at 7 T (Philips Achieva, Best, Netherlands) using a quadrature Tx/Rx head coil (Nova Medical, Wilmington, MA, USA). For the B_1^+ amplitude measurement, AFI [5] was used (TR1/2=50/340 ms). The transceive phase was measured using SE measurements and corrected for eddy currents. Corresponding simulations have been conducted with the SEMCAD (SEMCAD X, SPEAG, www.speag.ch) implementation of FDTD.

$$\frac{\nabla^2 B_1^+ e^{i\phi_+}}{B_1^+ e^{i\phi_+}} = k^2 \Rightarrow \frac{\nabla^2 B_1^+}{B_1^+} - \nabla\phi_+ \cdot \nabla\phi_+ + i\left(\nabla^2\phi_+ + 2\frac{\nabla B_1^+ \cdot \nabla\phi_+}{B_1^+}\right) = \mu\varepsilon_0\varepsilon_r\omega^2 + i\mu\sigma\omega$$

	No error	**Error term due to phase error ϕ_Δ**
Permittivity	$\frac{\nabla^2 B_1^+}{B_1^+} - \nabla\phi_+ \cdot \nabla\phi_+ = \mu\varepsilon_0\varepsilon_r\omega^2$	$-\nabla\phi_\Delta \cdot \nabla\phi_\Delta - 2\nabla\phi_\Delta \cdot \nabla\phi_+ = \mu\varepsilon_{r,\Delta}\omega^2$
Conductivity	$\nabla^2\phi_+ + 2\frac{\nabla B_1^+ \cdot \nabla\phi_+}{B_1^+} = \mu\sigma\omega$	$\nabla^2\phi_\Delta + 2\frac{\nabla B_1^+ \cdot \nabla\phi_\Delta}{B_1^+} = \mu\sigma_\Delta\omega$

Results and Discussion: Fig. 1 shows the error terms for σ and ε_r (σ_Δ and $\varepsilon_{r,\Delta}$, resp.) that were derived in the Equations. Here it is observed that the largest error is expected in the σ-map. Furthemore, a partly opposing effect of σ_δ and $\varepsilon_{r,\Delta}$ is seen. As shown in Fig. 2, opposing errors in σ and ε_r can still result in a correct determination of $|k|$. In Fig. 3, σ, ε_r and $|k|$ are reconstructed based on simulated and measured data; here, equivalent errors were seen for both data sets. It was observed that the transceive phase assumption results in a large error in the σ-map; the relative error in the ε_r -map is more moderate, and the error in the |k|-map is smallest. To quantify the errors, the standard deviation of the reconstruction values (simulation data) in the outer compartment was determined. It was found that the relative standard deviation (std/input value) was 36% for conductivity mapping, 14% for the permittivity and 7% for the wave number. Thus, using the commonly accepted transceive phase assumption, the wave-number can be mapped more accurately at 7T than the permittivity or conductivity separately. The wave-number might be an interesting parameter to map in gliomas as it was already shown that it is feasible to measure the conductivity. Furthermore, it was shown *ex vivo* that the permittivity is also affected by the tumour growth [6], therefore also wave-number contrast is anticipated in the tumour tissue. As an example, Fig. 4 shows a measured $|k|$-map of a glioma patient; here an increased $|k|$ in the tumor is indeed observed.

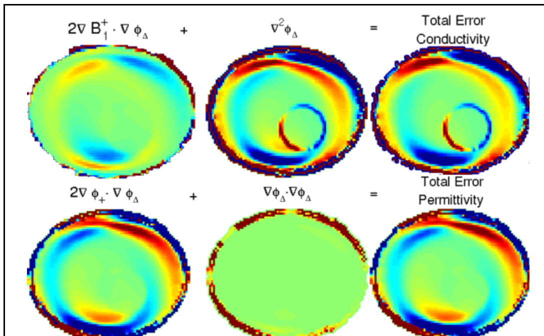

Figure 1: Simulated error in conductivity (σ_Δ, *upper row)* and permittivity ($\varepsilon_{r,\Delta}$, *bottom row)*. The errors in the columns cancel each other partly, which will lead to a reduced error in the wave number $|k|$ (see also Fig. 3).

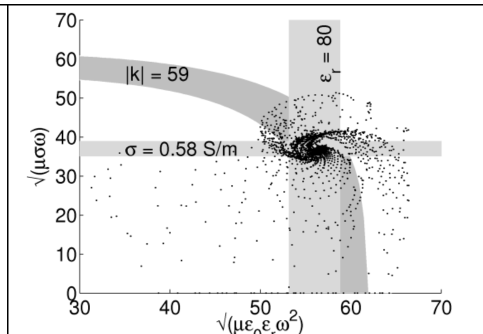

Figure 2: The real and imaginary part of $|k|$ per voxel (black dots) in phantom and regions with constant ε_r, σ and $|k|$ (in gray with error margin of ± 5%). It is shown that an increase in σ and a decrease in ε_r per voxel (or v.v.) does not necessarily affect $|k|$.

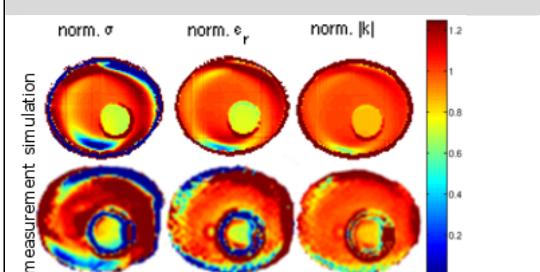

Figure 3: Comparison of normalized conductivity, relative permittivity and wave-number imaging (k) in elliptical phantom based on the simulated or measured B1+ amplitude and transceive phase. All images were normalized to the input value of the depicted parameter.

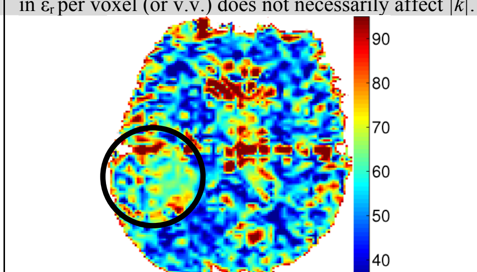

Figure 4: Wave-number map at 7T of a glioma patient. The tumor (circle) has a higher wave-number than the surrounding tissue, which is expected as ε_r and σ in tumor tissue is elevated.

References: **1.** U. Katscher, et al. IEEE Trans Med Imaging 2009 28:1365-74 **2.** A. L. van Lier, et al. Magn Reson Med 2011 *in press* **3.** T. Voigt, et al. Magn Reson Med 2011 66:456-66 **4.** A. L. van Lier, et al. In: Proceedings of the 19th Annual Meeting of ISMRM Montreal, Quebec, Canada 2011:125 **5.** V. L. Yarnykh Magn Reson Med 2007 57:192-200 **6.** A. L. van Lier, et al. In: Proceedings of the 19th Annual Meeting of ISMRM Montreal, Quebec, Canada 2011:4464 **7.** T. Voigt, et al. In: Proceedings of the 19th Annual Meeting of ISMRM Montreal, Quebec, Canada 2011:127 **8.** Y. Lu, et al. Int J Hyperthermia 1992 8:755-60