A Novel Method for Amplitude and Phase Mapping of RF Transmit and Receive Fields

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INTRODUCTION: The acquisition of the transmit and receive fields of RF coils (respectively, B1+ and B1- maps) has become a central step in a modern MR exam employing parallel imaging and/or parallel transmit [1,2,3,4]. The mapping of the receive fields of coils has relied traditionally on the availability of a homogeneous receive field as reference [2]. Unfortunately, at higher magnetic fields such a homogeneous reference concept fails due to stronger RF interaction with the body. In this work we present a new approach for extracting complete complex information about the transmit and receive fields of a RF transmit coil from a B1+ amplitude measurement. The results obtained from FDTD simulations and *in vivo* measurements confirm the validity of the novel approach. **METHODS AND MATERIALS:** **Methods** The method was inspired by the following observations: 1) For volume coils with currents running in the z-direction, the B1+ field in a transverse plane of the body can be approximated by a Bessel/Fourier functions expansion derived from the Maxwell equations assuming a TM mode [5]. Simulations run by Van den Bergen et al [6] showed good agreement between the Bessel/Fourier model [6] and the FDTD simulations for 3T and 7T body coils. 2) The Bessel/Fourier model appears to describe well the magnetic fields inside the heterogeneous body even when the permittivity **ε** and conductivity **σ** are assumed to be constant [6] 3) just a small number of modes are required (about twenty) (see Fig 1). The analytic expression of B1+ in terms of Bessel/Fourier modes implies a symmetric formulation of B1- in terms of the same basis functions [5]:

$$B_1^+(r,\theta)=\tfrac{1}{2}i\xi\sum_{m=-M}^{M}x_m J_{m+1}(\xi r)e^{i(m+1)\theta} \quad \textbf{(1)}$$

and

$$B_1^-(r,\theta)=\tfrac{1}{2}i\xi\sum_{m=-M}^{M}x_m J_{m-1}(\xi r)e^{i(m-1)\theta} \quad \textbf{(2)}$$

where J_m denotes the first kind Bessel function of order m, $\boldsymbol{\omega}$ the frequency, $\xi^2=\varepsilon\mu\omega^2-i\omega\sigma\mu$ and x_m the (complex) expansion coefficient. Experimental data for the amplitude of B1+ can be obtained by standard techniques (denote the data set by ***d***). Combining equation **(1)** to the measured data ***d***, the non linear fitting function ***F*(*x*)=|| |Ex|-*d* ||** can be derived**,** where **E** is the Bessel/Fourier encoding matrix for the B1+ expansion. Minimization of ***F*(*x*)** gives then the coefficients which better fit the data. Back substitution of the calculated ***x*** into **(1)** and **(2)** gives complete phase and amplitude information for the B1+ and B1- maps. We assume that **ε** and **σ** are constant in the whole transverse slice. To determine their optimal numerical value, we iterate the described process over a range of realistic **ε** and **σ** values and plot the residual (Fig 1). The best choice of **ε** and **σ** is the one for which the Bessel/Fourier expansion better fits to the data. **Materials.** Magnetic fields for a 12 channels 7T (300MHz) head coil loaded with the Hugo model (Fig 2) were computed by FDTD method. The simulated data set ***d*** consisting of a single transverse |B1+| map was then derived. In the experiment transverse B1+ magnitude maps were acquired using the AFI method (TR1 = 50 ms, TR2 = 340 ms, 2.4 mm in plane resolution, 4 mm slice thickness) for the brain of a volunteer for the 2 channels of a 7T birdcage headcoil. The minimization of ***F*(*x*)** was carried out by a non linear minimization solver run with MATLAB 7.4.0. on an Intel Core Duo processor. The number of modes for the Bessel/Fourier expansion was set to be 21 (i.e. *M*=10). Contributions of higher order terms is not relevant for the quality of the reconstruction (Fig 1). **RESULTS**: The computation time for the calculation of ***x*** and the resulting B1+ and B1- maps was in both cases about 15 seconds. The best choice of **ε** and **σ** resulted to be 30 and 0.5 S/m, respectively. The fitted B1+ maps using the Bessel/Fourier expansion is able to describe the B1+ pattern quite accurately as seen by the comparison with the FDTD simulations (Fig. 3) and in vivo B1+ measurements (Fig 4). This means that the global B1+ pattern can be well described by a global interference of the RF field with a homogeneous approximation of the head. The derived B1+ phase and B1- phase patterns for the 12 elements coil are very similar to the FDTD results suggesting that this method can results in accurate B1+ and B1- phase maps. The derived B1- amplitude maps has some minor deviations with the FDTD simulated B1- map but the global pattern is well solved. In the measurement, the derived B1- maps appear to be a mirrored B1+ maps along the major axis of the head which corresponds to experiences from FDTD simulations. The correspondence between the measured and fitted B1+ maps provides a means to establish the fitting accuracy in a patient specific manner. **CONCLUSIONS:** Here we have presented a methodology that can reconstruct the complex B1+ and B1- fields from a B1+ amplitude map. We expect that this will be in particular useful for parallel imaging at high fields where normally a homogeneous reference coil is absent. For parallel transmit the resulting B1+ phase maps can serve as a check or even replace the mapping of relative B1+ phase among the different channels. The required B1+ measurement does not add very much extra time. As we only need information about the global phase pattern, a rather coarse resolution (5-10 mm) will be sufficient allowing the requirements with respect to acquisition time and receive performance of the coil to be softened. Receive maps of receive-only coils can be obtained by using the receive maps of the transmit coil as a reference. Based on the TM model, the methodology should also work for volume coils at 1.5 or 3 Tesla. For ultra high fields strength we expect that a Tx/Rx travelling wave setup will also be sufficient, possibly requiring a more complex TM/TE mode expansion model.

References: [1] Sodickson et al. Magn Reson Med 38: 591-603(1997) [2] Preussmann K et al. Magn Reson Med 42:952-962 (1999) [3] Katscher U et al. Magn Reson Med 49:144-150(2003) [4] Zhu Y. Magn Reson Med 51:775-784(2004) [5] van den Berg CAT et al. http://www.staff.science.uu.nl/~bisse101/Articles/proc2007.pdf [6] van den Bergen B et al Phys. Med. Biol. 52 (2007) 5429-5441.

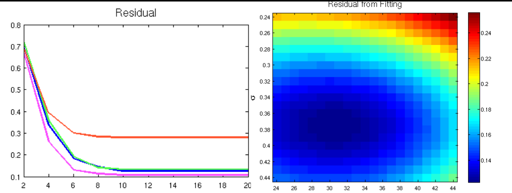

Fig 1 left: *Residual as function of M for 4 transverse slices, each represented by a different color* . Right: *As a function of* ***ε*** *and* ***σ*** *(right)*

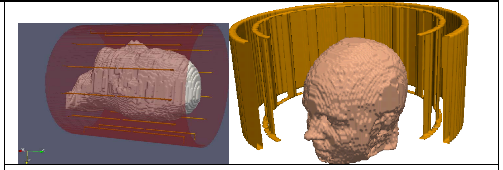

Fig. 2: *The 12 elements TEM headcoil for the FDTD simulation (left) and the 7T birdcage headcoil used for the in vivo experiment (right)*

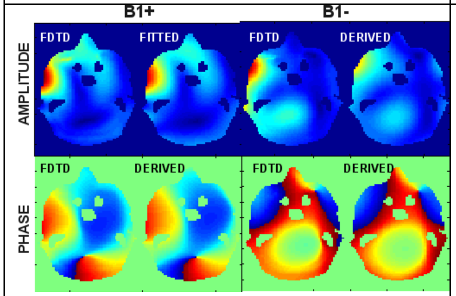

Fig. 3: *Comparison between FDTD simulation and the derived maps*

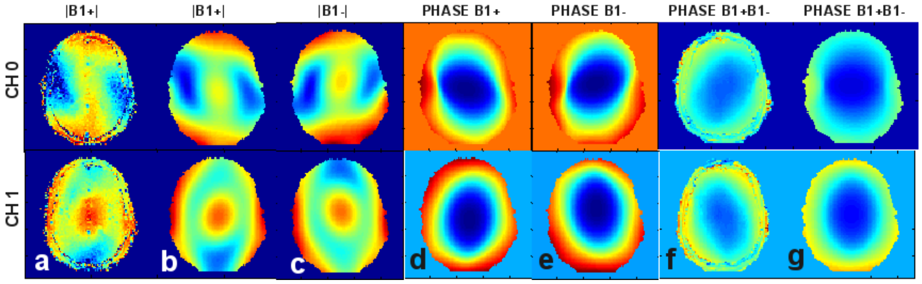

Fig. 4: *Comparison between the measured data and the derived maps. Measured and derived maps for the phase of the B1+B1- product are also displayed.*