Parallel Transmission in Human Brain at 9.4T Counteracting Eddy Current Induced Excitation Errors in RF Pulse Design

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Introduction: Parallel transmission (pTX) [1-4], which consists of playing different RF pulses through independent transmit (Tx) channels, has been shown to be able to mitigate Tx B1 (B1+) non-uniformity [5] and to achieve multidimensional spatially selective RF excitation [6] at ultra high magnetic field. We have previously reported successful implementations of 2D pTX in the human brain at 9.4 T using 8 and 16 channel coils, which required methodological issues such as k-space inaccuracies and large susceptibility induced ΔB0 to be addressed [6,7]. Our previous study also showed a deleterious impact of eddy currents on the excitation quality when using 3D pTX pulses for homogeneous RF excitation [7]. Therefore, the purpose of this study was to achieve B1+ homogenization with 3D pTX pulses when used for brain imaging at 9.4T. To achieve this goal the time evolution of eddy current B0 variations induced by the slice selective gradients applied during the 3D RF pulses had to be characterized and corrected for in the RF pulse calculation.

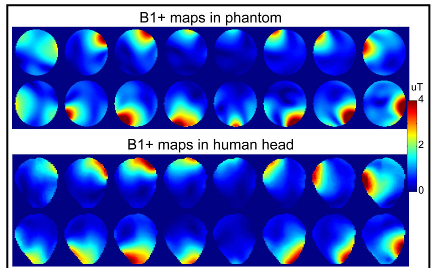

Fig. 1. Tx B1 maps for a 16Ch transceiver coil.

Materials and Methods: In this study 3D pTX RF pulses were designed to achieve uniform excitations within an axial slice of the human brain and were corrected for the eddy current B0 (spatially invariant component) variations induced by the slice selective gradient. The corrected RF pulses were calculated in three steps. First, slice selective RF and gradient pulses were designed based on a magnitude least square optimization [5] without eddy current compensation. Then, eddy current B0 variation associated with the slice selective gradient was measured on the fly using a technique similar to that in Ref. [8]. Finally, a phase modulation was applied on each time point of the initially calculated RF pulses in order to generate the equivalent of a carrier frequency sweep, based on the eddy current measurements, to compensate for the corresponding excitation phase errors. 2-spoke RF pulses were generated with Gaussian shaped RF sub pulses with a time-bandwidth-product of 2. The slice-selective gradient (Gz in this case) was designed for a slice thickness of 5 mm. All experiments were conducted on a 9.4 T MR human scanner (Magnex, UK) driven by a console with 16 independent Tx RF channels (Varian, USA), each powered with a 500 W RF amplifier (CPC, USA). A 16-channel transceiver stripline array [9] was used for both transmission and reception. A doped spherical phantom was imaged for preliminary measurement. Healthy volunteers who signed an IRB approved consent form were scanned. B1+ maps (Fig. 1) were obtained for individual channels using a fast multi-channel B1+ mapping technique [10]. ΔB_0 maps obtained with the dual TE method were incorporated into RF pulse design to minimize off-resonance effects. Excitation patterns were imaged using a modified 3D gradient echo (GE) pulse sequence with relevant parameters being FOV=220×220×32 mm3, matrix=128×64×32, and TR/TE=80/4.7 ms. For comparison, images were also obtained using uncorrected RF pulses designed without eddy current compensation. All images shown here were normalized by the estimated product [Proton Density]×[Receive B1 profile] (ρ|B1-|) in order to better identify the Tx B1 component. All computations were performed in Matlab.

Results: Large eddy current induced B0 variations (>1kHz) were observed on our system during the rapid switch of the 2-spoke slice selective gradients (Fig. 2). Without correction of such eddy current, excitation quality in terms of homogenization was drastically degraded with obvious signal voids observed in both the phantom and the human brain (left column, Figs. 3 and 4). By contrast, those signal loss was effectively recovered with satisfactory excitation homogenization when using RF pulses designed with eddy current compensation (right column, Figs. 3 and 4). In addition, our Bloch simulations using uncorrected and corrected pulses provided good predictions of signal variations for the respective image results.

Discussion and Conclusions: In this study, we have demonstrated the first successful 3D spoke pTX with eddy current induced B0 compensation, resulting in satisfactory excitation homogenization in the human head at 9.4 T using a 16-element coil. Our results show that such B0 compensation are necessary to obtain homogeneous excitation patterns using 3D pTX pulses when severe eddy currents due to slice selective gradients are present. For technical reasons, the preemphasis typically used to counteract eddy currents was not activated during this study, which explains the large amplitude of B0 variations. However, even when preemphasis is applied, substantial B0 variations persist on this system. Furthermore, it is significant to demonstrate that even such large B0 variations can reliably be addressed during the RF pulse design. Our results also indicate that eddy current induced B0 variations can be calibrated in-vivo in a very short time, providing good consistency with phantom measurement and allowing for efficient RF pulse correction.

References: 1. Katscher et al., MRM 49:144-50(2003). **2**. Zhu, MRM 51:775-84(2004). **3**. Ullman et al., MRM 54:994-1001(2005). **4**. Grissom et al., MRM 56:620-629(2006). **5**. Setsompop et al., MRM 59:908-915(2008). **6.** Wu et al., MRM, 63:524–529(2010). **7.** Wu et al., ISMRM 2010, p107. **8.** Papadakis et al., MRM 44:616-624(2000). **9.** Adriany et al., ISMRM 2009, p3005. **10.** Van de Moortele et al., ISMRM 2007, p1676.
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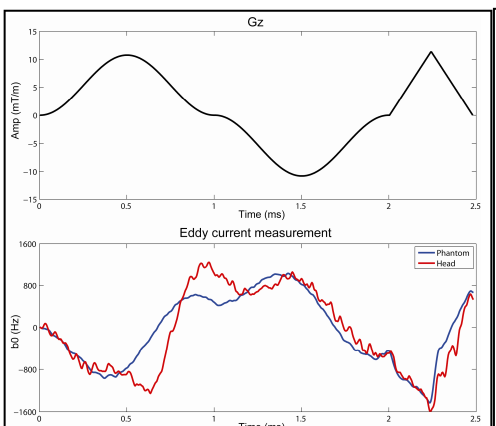

Fig. 2. Slice select gradient (top) and resulting EC B0 (bottom) measured in phantom (blue) and in head (red).

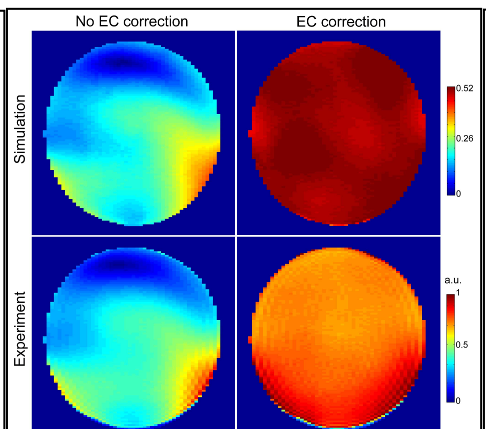

Fig. 3. Excitation patterns in phantom using RF pulses designed with and without EC correction.

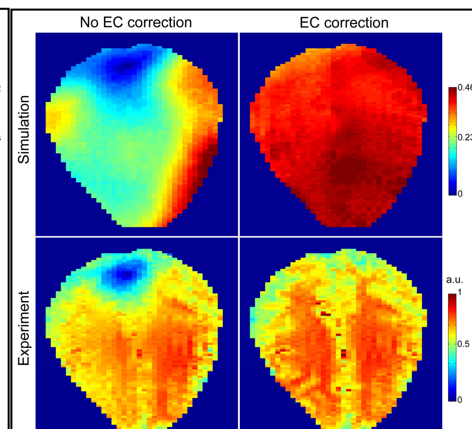

Fig. 4. Excitation patterns in human head using RF pulses designed with and without EC correction.