Impact of coupling in Tx-array coil design for transmit SENSE at 3T

Pei-Shan Wei[1,2], Michael J. Smith[2], Christopher P. Bidinosti[3], Jarod Matwiy[2], and Scott B. King[1,2]
[1]Department of Physics and Astronomy, University of Manitoba, Winnipeg, Manitoba, Canada, [2]National Research Council of Canada, Winnipeg, Manitoba, Canada, [3]Department of Physics, University of Winnipeg, Winnipeg, Manitoba, Canada

Introduction: The RF coil array of parallel transmission[1-3] systems determines the sensitivity profiles used for transmit SENSE RF pulse calculation and the E-field distribution for specific absorption rate (SAR) estimation. In previous work[4], we have shown that the mutual inductance coupling in Rx-arrays can be manipulated and incorporated into the simulation model by using a preamplifier model with appropriate input impedance termination. For determining an optimal Tx-SENSE Tx-array design through simulations, it is vital to accurately simulate excitation and SAR distributions. Therefore, the mutual inductance coupling and coil termination must be accurately modeled. In this study, we investigated how mutual inductance coupling influences Tx-SENSE RF pulse determination and the accuracy of excitation and SAR evaluation of a simulated Tx-array design.

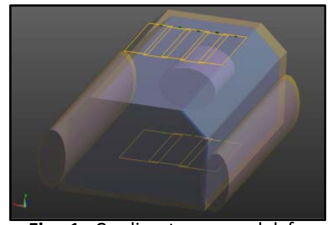


Fig. 1: Cardiac torso model for Tx-Array simulation

Methods: **A)** FDTD (SEMCAD X v14.8, SPEAG, Zurich, Switzerland) simulations were performed with a cardiac torso model (60 cm x 47.4 cm x 24 cm) for an 8-ch cardiac Tx-array coil (**Fig. 1**). The coil was composed of anterior and posterior section designed as five and three overlapping loop coils respectively. Each coil element consisted of seven/six capacitors (28/20 pF) and tuned to 123 MHz. Electromagnetic fields were calculated for two scenarios; "isolation" where each element was simulated separately without mutual inductance coupling, and "coupled" where each element was simulated in the presence of other coupled elements terminated in 50 Ω. **B)** Our RF pulse designer[5] which is based on a pseudoinversion spatial domain method[6] determined two sets of RF pulse waveforms with Tx profiles from either isolation or coupled simulations. The target excitation is a 12 cm*12 cm homogenous box covering the heart region. The parameters used for pulse calculation were: FOV=55.5 cm*35.8 cm, object matrix size=140*91, max. gradient amplitude=40 mT/m, slew rate= 200 T/m/s, number of spiral turns (N_t)=16, and RF pulse length (T_p)=5.1 ms, 3.9 ms, 3.1 ms and 2.6 ms associated with α=1, 2, 3, and 4 in variable density k-space trajectory[7] (Full Nyquist sampled spiral: N_t/T_p=70/46.3 ms). **C)** We used a Bloch simulator to evaluate Tx-SENSE excitation error from overlooked coupling, by separately applying each set of RF pulses calculated from the isolated and coupled cases to the more realistic coupled Tx-array system to mimic a situation of applying RF pulses determined from either an incorrect or correct simulation condition respectively. **D)** Global and peak SAR were investigated as the function of pulse length.

Results and Discussions: Simulated excitation profiles show that applying RF pulses determined from an incorrect isolated coupling condition produce poorer excitation **(Fig. 2-right)** compared to RF pulses determined in the correct coupled condition **(Fig. 2-left)**. SAR distributions from E-field simulations in the two cases **(Fig. 3)** shows that RF pulses determined from incorrect coupling conditions significantly alters both average and peak SAR estimation, and may lead to misinterpretation of hot spot locations. Both Tx-SENSE performance and SAR are affected by the RF pulse length. **Fig. 4** illustrates that the coupling condition affects average SAR and peak SAR differently with increase in T_p. Both coupled conditions have a minimum mean and peak SAR values at T_p=3.9 ms. Notably, average SAR is over-estimated by up to 23% at T_p=2.6 ms when the incorrect coupling condition (isolated) is used, whereas Peak SAR is underestimated using the incorrect coupling condition from 18% at T_p=3.9 ms to as much as 26% at T_p=3.1 ms. Similarly, the ratio of peak SAR to average SAR for the incorrect coupling condition (isolated) case is always underestimated with an error that increases with T_p=5.1 ms to T_p=2.6 ms (20%, 31%, 40%, and 33%).

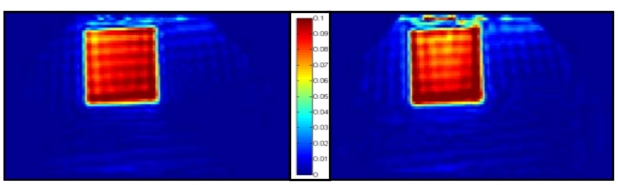


Fig. 2: Small FOV excitations from the "coupled" RF pulses (Left) and the isolated pulses (Right)

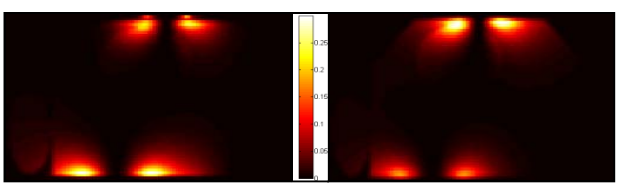
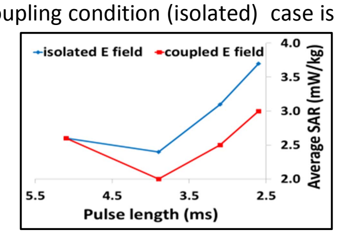
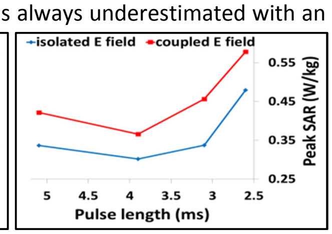


Fig. 3: SAR distribution maps (axial slice) computed from coupled (Left) and isolated E-field (Right)





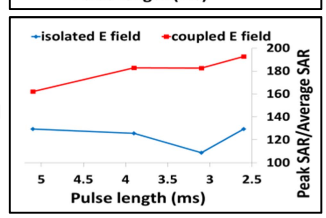


Fig. 4: SAR as a function of pulse length for global SAR (Top-Left), peak SAR (Top-Right) and ratio of peak to global SAR (Bottom) for flip angle=5^0.

Conclusion: In this study, the necessity of incorporating mutual inductance coupling in simulated Tx-array design strategy used for 2D Tx-SENSE RF pulse calculations has been demonstrated. With incorrect coupling models, average SAR was over-estimated by as much as 23%, peak SAR under-estimated by as much as 26%, and peak SAR/Average SAR underestimated by as much as 40%. Therefore, proper coupling in simulations is absolutely necessary for RF coil designers to optimize the Tx-array design for Tx-SENSE applications and for accurate prediction of peak local SAR distribution.

References: 1. Katscher U, et al., Magn Reson Med 49:144-150 (2003) 2. Zhu Y, et al., Magn Reson Med 51:775-764 (2004) 3. Ullmann P, et al., Magn Reson Med 54:994-1001 (2005) 4. Wei, et al., ISMRM, p2721 (2012) 5. Smith M.J. et al., ISMRM, p1086 (2008) 6. Grissom W, et al., Magn Reson Med 56:620-629 (2006) 7. Kim et al., Magn Reson Med 50:214-219 (2003)

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