A Simulation Based Validation of a pTx Pulse Design Strategy Using Implant-Friendly Modes for Patients with DBS Implants

Yigitcan Eryaman[1,2], Bastien Guerin[2], Can Akgun[3], Joaquin L. Herraiz[1], Adrian Martin[1,4], Angel Torrado-Carvajal[1,5], Norberto Malpica[1,5], Juan A. Hernandez-Tamames[1,5], Emanuele Schiavi[1,4], Elfar Adalsteinsson[6,7], and Lawrence L. Wald[2,7]

[1]Madrid-MIT M+Vision Consortium in RLE, MIT, Cambridge, Massachusetts, United States, [2]Martinos Center for Biomedical Imaging, Dept. of Radiology, MGH, Charlestown, MA, United States, [3]Invenshure, MN, United States, [4]Dept. of Applied Mathematics, Rey Juan Carlos University, Madrid, Spain, [5]Dept. of Electronic Technology, Rey Juan Carlos University, Madrid, Spain, [6]Dept. of Electrical Engineering and Computer Science, MIT, Cambridge, Massachusetts, United States, [7]Harvard-MIT Health Sciences and Technology, MIT, Cambridge, MA, United States

Target Audience MR researchers studying patients with active implantable devices

Purpose Previous work showed that SAR around metallic implants could be reduced in a uniform phantom model using the implant-friendly modes of a transmit array [1]. Here we outline a method where the implant-friendly modes, determined empirically from the B1+ artifact visible in low-SAR scanning is used to lower SAR at the implant. A local SAR constraint RF pulse design (without knowledge of the implant) is used to achieve the uniform flip angle target and further reduce local SAR elsewhere. We validated this strategy in a realistic head model simulation containing the DBS lead.

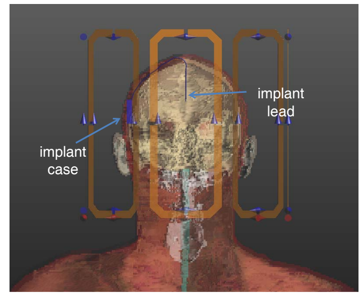

Figure 1 Eight Channel transmit array and a generic implant model in a head model (DUKE) is shown

Methods We calculated the electromagnetic (EM) fields due to unit voltage excitation of each element of an 8 loop transmit array using the SEMCAD FDTD solver. The Huygen's simulation approach is used in place of the empirically measured field at the DBS lead tip. The DBS is modeled as an insulated copper wire (insulation removed at the tip) electrically connected to a copper implant case. We generated implant-friendly modes similar to a previous work [1] by exciting the loop array with the given excitation pattern:

$$\alpha_i = A_m \cdot [\cos(\phi_o) \cdot \cos(m \cdot [\, 2\pi(i-1)/N\,]) + \sin(\phi_o) \cdot \sin(m \cdot [\, 2\pi(i-1)/N\,]) \cdot \exp(j \cdot \theta)]$$

Here $\boldsymbol{i}$ is the channel index, $\boldsymbol{N}$ is the number of channels, ϕ_o is the steering angle for the field pattern, θ is an additional phase factor introduced to control B1+ artifact around the tip, m is the implant-friendly mode index and j is $\sqrt{(-1)}$. A_m, ϕ_o and θ are the coefficients the latter two are optimized by modeling the B1+ artifact near the lead tip. A_m is optimized in pulse design. Similar approach for B1+ artifact cancelation was previously demonstrated with a two channel transmit system for reducing implant tip heating [2]. In order to control 10g SAR variation in the head, SAR matrices due to each mode are compressed to a smaller set of VOP (Virtual Observation Points) [3] in an implant free model. Using the implant friendly modes, the optimum least square 3-spokes pulse design solution is calculated using an optimization approach which explicitly constrains both global and local SAR[4].

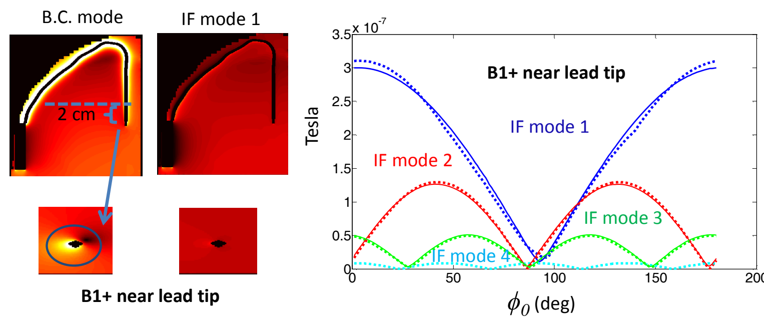

Figure 2 Variation of B1+ artifact with excitation modes is shown

Results Figure 2 shows the variation of B1+ artifact around the lead tip with respect to ϕ_o. By finding the best solution that fits the B1+ variation around the lead, we were able to calculate the optimal parameters for ϕ_o and $\boldsymbol{\theta}$ that reduces B1+artifact and local SAR near the lead tip**.** Figure 3 shows the local SAR and the B1+ distribution of the implant-friendly modes that are generated by using the optimal values of ϕ_o and $\boldsymbol{\theta}$ Figure 4 shows the SAR distribution in the head model due to implant friendly SAR pattern calculated by 3-spokes pulse design. The uniform 60^o flip angle profile due to the same solution is also shown. Peak 10 g average SAR and global SAR due to pulse design is calculated as 4.52 W/kg and 0.48 W/kg respectively. Peak 1 g average SAR around the implant is calculated as 0.1 W/kg.

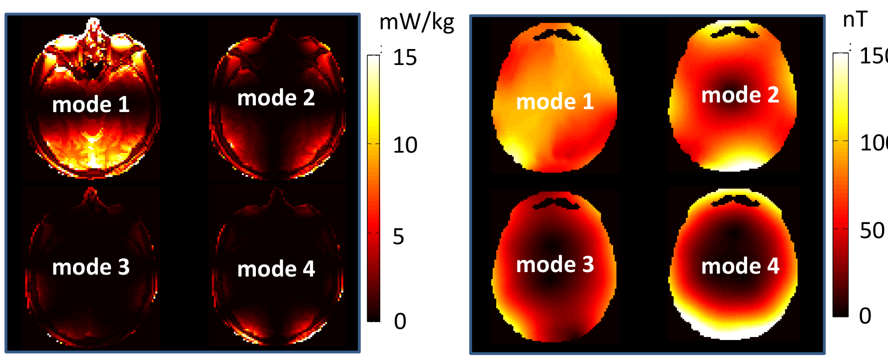

Figure 3 SAR patterns (left) and the B1+ patterns (right) due to IF modes are shown

Discussion & Conclusion We describe a pulse design strategy based on generating implant-friendly modes**.** In a previous work parallel transmit null-modes were proposed to cancel the induced currents on metallic leads [5]. In a different work, Butler modes of pTx arrays were used for pulse design in the literature for B1+ mitigation [6]. In this work we utilize implant-friendly modes, which are constructed with specific excitation parameters that null the B1+ variation and the local SAR in the vicinity of the lead tip. We believe that this strategy is robust because the pTx pulse design does not rely on a detailed electromagnetic model of the implant, in which small changes have been shown to drastically alter the tip SAR. As a result, the local SAR around a generic implant in a multi-tissue realistic head model is reduced below SAR limits. A uniform axial flip angle distribution is obtained.

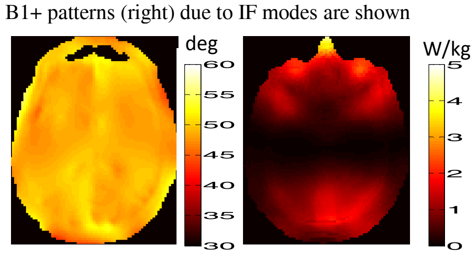

Figure 4 A uniform flip angle profile (RMSE=2.6%) is obtained in the head model (left) as a result of 3 spokes pulse design. Implant friendly SAR pattern is shown on the right.

Reference [1]Eryaman,Y.(2013)Proc.ISMRM 20: 4412 [2]Eryaman,Y. (2012) MRM doi: 10.1002/mrm.24316 [3]Gebhardt, M. (2011). MRM **66**(5): 1468-1476 [4]Guerin B. (2012)Proc.ISMRM 20:2215 [5] Etezadi-Amoli M. Proc.ISMRM 18:777[6]Setsompop K.(2008)MRM 60:1422–1432 **Acknowledgements:** R01EB006847. Siemens-MIT CKI Alliance. This project is also supported by the Comunidad de Madrid and the Madrid MIT M+Vision Consortium