Optimization of 1D RF pulses with parallel transmission

Ulrich Katscher[1], Kay Nehrke[1], and Peter Boernert[1]
[1]Philips Research Europe, Hamburg, Germany

Introduction: Usually, Transmit SENSE [1-3] is applied to improve spatially selective RF pulses in two or three dimensions. This study investigates the application of Transmit SENSE to one-dimensional RF pulses [4]. For these RF pulses, the Transmit SENSE concept is applicable in case of large B_1^+ variations across the slice or slab to be excited. Typically, such large B_1^+ variations are found across the slabs excited in 3D volume imaging or in the framework of the REgional Saturation Technique (REST). 1D Transmit SENSE can improve the excitation slab profile, and particularly can result in a significant reduction of the required RF power. Since those RF pulses can be designed to have the same duration as standard slice-selective pulses, they can easily be incorporated in standard sequences without changing sequence timing. This approach was tested *in vivo* in the framework of a 3T system with two transmit channels using the ultrafast B_1^+-mapping technique DREAM (Dual Refocusing Echo Acquisition Mode) [5].

Theory: The general 3D equation of Transmit SENSE is reduced to the through-plane direction assumed to be along z (see Eq. (1), P_{des} the desired target pattern, S_n the spatial sensitivity profile of TX element n, P_n its spatial excitation pattern, N independent TX elements). After Fourier transformation $z \rightarrow k_z$, discretization $k_z(t) \rightarrow k_z(t_k)$ on $k \le K$ time steps, and summarizing $\underline{s}_n(k_z)$ and $\underline{p}_n(k_z)$ to $\underline{\underline{s}}_{full}(k_z)$ and $\underline{p}_{full}(k_z)$ [1], respectively, Eq. (1) was solved by regularized pseudo-inversion, Eq. (2). Note, here Eq. (2) is not used to shorten the duration of the individual pulses as in [1-3], but to reduce the normalized root-mean-square error (NRMSE) between the desired and obtained excitation pattern P_{des} and to reduce the total RF power (see Eq. (3), [4]). A trade-off between P_{tot} and NRMSE is achieved by adjusting the regularization parameter λ in Eq. (3). Magnitude least square optimization has been applied according to [6].

$$P_{des}(z) = \sum\nolimits_{n \le N} S_n(z) P_n(z) \qquad (1)$$

$$\underline{p}_{full}(k_z(t_k)) = \left(\underline{\underline{s}}_{full}^H \underline{\underline{s}}_{full} + \lambda\right)^{-1} \underline{\underline{s}}_{full}^H \underline{p}_{des}(k_z(t_k)) \qquad (2)$$

$$P_{tot} = \sum\nolimits_{n \le N} \sum\nolimits_{k \le K} \underline{p}_n^2(k_z(t_k)) \qquad (3)$$

Methods & Results: The study is aiming to excite two coronal REST slabs, anterior and posterior of the heart with constant profiles, for subsequent transverse cardiac scanning (Fig. 1). Thus, the 1D trajectory along z is oriented along the anterior-posterior axis. B_1^+ maps of the two transmit channels of the 3T system used (Achieva TX, Philips Healthcare, Best, The Netherlands) were measured with the recently developed DREAM [5] using $TR/TE_{FID}/TE_{STE}$= 3.8/2.4/1.4 ms, voxel size 3.5×3.5×10 mm³ (Fig. 1). The resulting trade-off curve between RF power and NRMSE is compared with RF shimming and quadrature excitation (Fig. 2). For intermediate regularization, NRMSE is roughly 5% lower than RF shimming (10% lower than quadrature excitation) and RF power is roughly 20% lower than RF shimming (40% lower than quadrature excitation). Resulting REST excitations are shown for exemplary cases in Fig. 3.

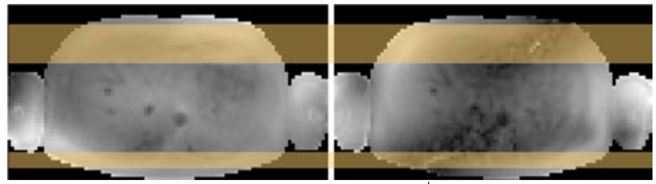

Fig. 1: Two abdominal, transverse B_1^+ maps measured with DREAM [5]. The orange bars indicate the location of the REST slabs corresponding to P_{des} (Eq. (1)).

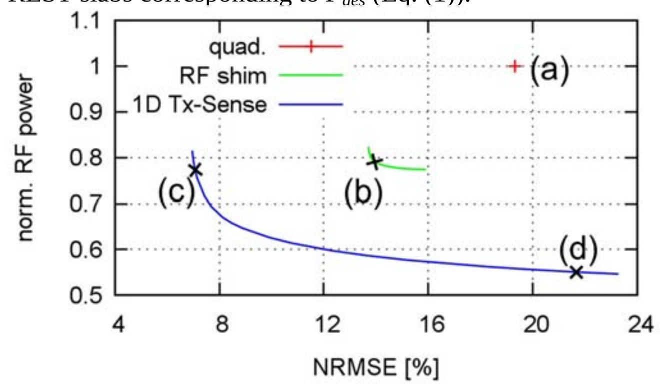

Fig. 2: Trade-off between P_{tot} and NRMSE for 1D Transmit SENSE (blue curve), outperforming RF shimming (green curve) and quadrature excitation (red cross). The labels (a) to (d) correspond to the examples shown in Fig. 3.

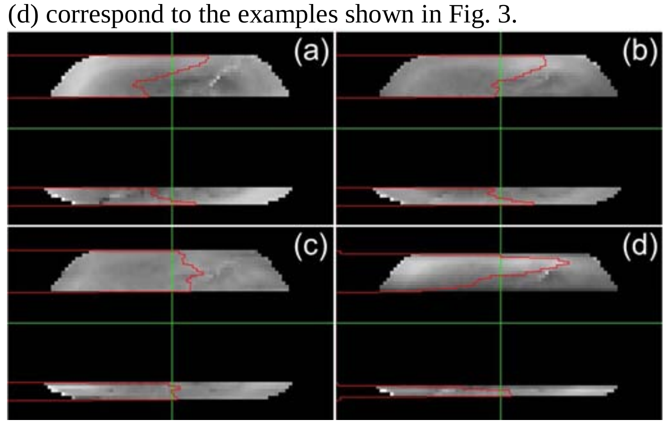

Fig. 3: Exemplary REST excitations. (a) Quadrature excitation, (b) RF shimming, (c) 1D TX SENSE / low NRMSE, (d) 1D TX SENSE / low RF power. The labels (a)-(d) are indicated correspondingly to Fig. 2. The red lines are profiles along the vertical green lines.

Discussion & Conclusion: Without changing sequence timing, Transmit SENSE can be applied to slab-selective 1D RF pulses. The resulting degrees of freedom can be applied to achieve a better performance, where the slab profile is critical (e.g., in 3D imaging), or to reduce RF power (e.g., for REST slabs). This power reduction arises from the ability of the individually tailored RF pulses to excite only the part of the slab with high sensitivity in each individual TX channel. In the future, the approach shall be applied to reduce also local / global SAR by including an appropriate SAR model.

References: [1] Katscher U et al., MRM 49 (2003) 144 [2] Zhu Y, MRM 51 (2004) 775 [3] Grissom W et al., MRM 56 (2006) 620 [4] Katscher U et al., ISMRM 20 (2012) 3458 [5] Nehrke K et al., MRM 68 (2012) 1517 [6] Setsompop K et al., MRM 59 (2008) 908