Improving Slab Excitation by Parallel Transmission

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Introduction: Transmit SENSE [1-3] is usually 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. For these RF pulses, Transmit SENSE is applicable in case of large B1 variations across the slice or slab to be excited. Typically, such large B1 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 RF power and the related specific absorption rate (SAR). Since the involved RF pulses have the same duration as standard slice-selective pulses, they can easily be incorporated in standard sequences without changing sequence timing. The approach was tested using synthetic and realistic coil sensitivity profiles.

$$P_{des}(z) = \sum_{n \le N} S_n(z) P_n(z) \quad (1)$$

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

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

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) can be solved by, e.g., regularized pseudo-inversion, Eq. (2). In this study, 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 particularly, to reduce the total RF power, Eq. (3). A trade-off between P_{tot} and NRMSE between desired and obtained excitation pattern is achieved by the regularization parameter λ in Eq. (3) [2-4].

Methods & Results: A constant target profile in the excited slab ($P_{des} = const$, "tailored" RF shimming) was chosen for the two studies described in the following. *Two channel scenario:* Two linear sensitivities are investigated with different through-plane variations (sensitivity slopes) from ±5% to ±50% (Fig. 1, inlay). Variation of λ yields a trade-off between P_{tot} and NRMSE (Fig. 1). The two linear sensitivities allow NRMSE = 0 for all possible slopes. Depending on this slope, the required RF power is ~10% below the RF power required for "basic" RF shimming, means the optimal choice of amplitude and phase in each individual TX channel, using standard slice-selective excitation. Allowing NRMSE > 0, the RF power further decreases down to ~25% below basic RF shimming. The 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. *Eight channel scenario:* For an 8-channel whole body coil [5], sensitivities of the transverse cross-section of an arm are simulated with FDTD (Fig. 2, inlay). Here, the proposed method improves the optimum B1 homogeneity from NRMSE = 2.6% for basic RF shimming to NRMSE = 1.9% (Fig. 2). More important, for a given NRMSE, the required RF power is up to a factor 10 lower for the proposed method compared with basic RF shimming. For large λ (i.e., large NRMSE), P_{tot} is the same for both methods.

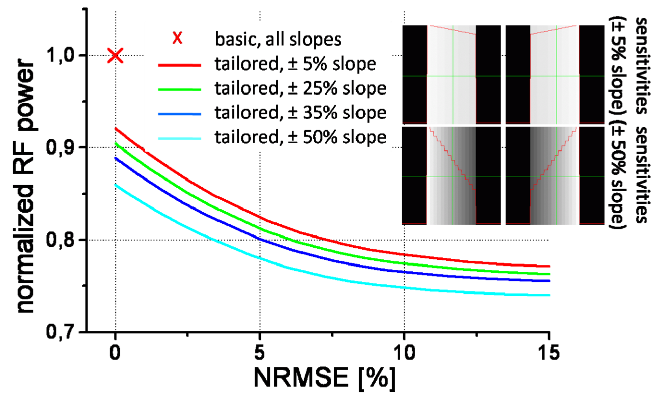

Fig. 1: Trade-off between P_{tot} and NRMSE for 2-channel system (linear sensitivities). Solid curves: linear sensitivities' slope of ±5/25/35/50%. For NRMSE = 0, the required RF power is ~10% below the RF power required for "basic" RF shimming (red cross) and reduces further for NRMSE > 0.

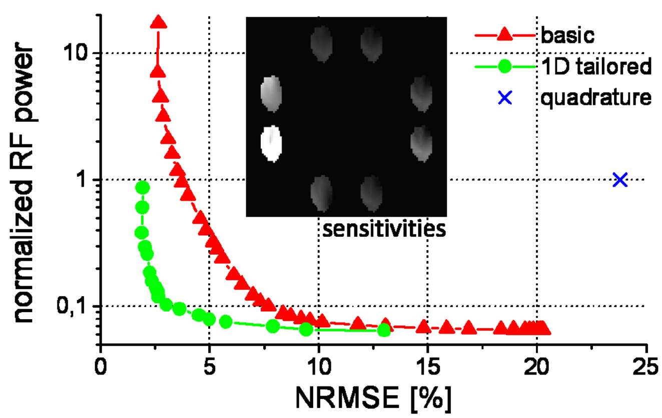

Fig. 2: Trade-off between P_{tot} and NRMSE for 8-channel system (sensitivities of one arm). The proposed method (green curve) improves the optimum B1 homogeneity from NRMSE = 2.6% for basic RF shimming (red curve) to NRMSE = 1.9%. Required RF power is up to ~10 times lower for the proposed method compared with basic shimming. Both methods outperform quadrature excitation (blue cross).

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). 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] Börnert P et al., ISMRM 17 (2009) 2600 [5] Vernickel P et al, MRM 58 (2007) 381