Increasing bandwidth of spatially selective transmit SENSE pulses using constrained optimization

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Introduction: Multiple-channel transmission has been shown to offer acceleration of multidimensional spatially-selective pulses. Main applications of such pulses would be performing a homogenous excitation in a varying B_1 field or localized spectroscopic imaging. A major problem is the small bandwidth of such localized pulses. Small off-resonances (either induced by B_0 inhomogeneities or spectroscopic frequency shift) deteriorate the resulting magnetization profile. On ultra high field systems (>4T) the off-resonance effects are especially problematic. It is therefore important to have explicit control of the bandwidth of multiple-channel transmission pulses for either imaging or spectroscopy.

Method: The method we propose is based on the spectral-spatial pulse design introduced in Ref. [1] and expanded to use the benefits of parallel RF transmission. In this method, the frequency axis is mapped to a virtual additional spatial axis applying a constant gradient in the new direction. The desired spatial pattern as a function of the frequency $m_{des}(f)$ is sampled in the frequency and spatial domain (see Figure 1 a). The virtual gradient applied in the frequency direction is calculated from the virtual field of view (FOV) and the desired bandwidth (BW): $BW = \gamma \cdot G_f \cdot FOV$. Using this formulation, the problem can be transferred to an existing multiple-channel transmission pulse calculation algorithm [2] with the only difference that the 2D pulse design becomes 3D and analogously 3D becomes 4D. The algorithm searches then within the existing SAR and power constraints for the best possible pulse of this vastly overdetermined problem.

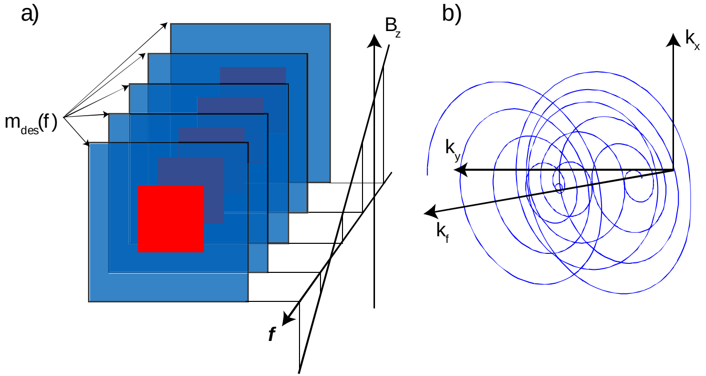

Figure 1

Simulations and Experiments: An example of an accelerated 2D 8-channel spatial-spectral pulse was simulated. A simple constant density spiral k-space trajectory was repeated three times producing the trajectory shown in Fig. 1 b) in the spatial-spectral k-space (resulting in 6 ms total pulse duration). Each spiral under-samples the spatial encoding by factor of 3. The B_1 patterns of the individual coils have been calculated using a FDTD simulation of a 8-channel microstrip coil array [3]. The pulse was optimized for a bandwidth of 1 kHz and the target profile was to excite a square ¼ FOV in the center and suppress the rest of the volume for the entire bandwidth (as shown in Fig. 1 a).

Fig.2 a) summarizes the results. It can be seen that the optimized spectral-spatial (unlike the unoptimized) pulse keeps the wanted flip angle in the center voxel and suppresses the volume outside over the entire bandwidth (plotted on the y-axis). The images on the left of the plots show the corresponding excitation profile for isochromats reaching from +500 Hz to -500 Hz frequency offset from center for the spatial-spectral approach, (1); for the pulse designed on the same trajectory without bandwidth optimization, (2); and for a pulse designed on a single pass of the spiral, (3) without repetitions lasting only 1/3 of the time of examples 1 and 2. It can readily be seen that only the bandwidth-optimized pulse reaches the bandwidth needed for most spectroscopic applications.

Experiments were performed on a Philips Achieva 7T system using an 18 cm diameter flat water phantom in transverse orientation and a single-channel volume T/R coil. In order to generate severe off-resonances, the shimming was turned off leading to the off-resonance distribution shown in Fig. 2 b). The trajectory was a unaccelerated 5-turn spiral that was repeated 3 times for a 6 ms total duration (analogue to Fig. 1 b) . The target pattern used was the same as in the previous simulation. Fig. 2 c) shows the gradient echo image using the unoptimized localization pulse for excitation. Fig. 2 d) shows the corresponding image using the optimized spatial-spectral pulse optimized for 300 Hz bandwidth. It can be seen that without optimization applied severe profile degradation occurs since the desired flip angle is not reached (marked by arrow 1), and the signal is not properly suppressed (arrow 2). Applying the optimization the pulse can cope with most of the B_0-induced off-resonance (except a small artifact marked by arrow 3).

Conclusion: It was shown that spatial-spectral pulse design can be applied to multiple-channel RF-transmission in order to increase the bandwidth of resulting pulses. The simulation results show that such pulses can be used for spectroscopic localization (e.g. in conjunction with outer volume suppression) even at 7T. Also the robustness with respect to off-resonance of pulses used for excitation of single species was increased significantly without a specific correction to a previously measured B_0 distribution [4]. Furthermore the pulse becomes robust also against through-plane and intra-voxel B_0 variations. It was noticed that multiple-channel transmission not only allows to accelerate the spatial encoding but that the additional freedom in pulse design allows the design of pulses with large bandwidth.

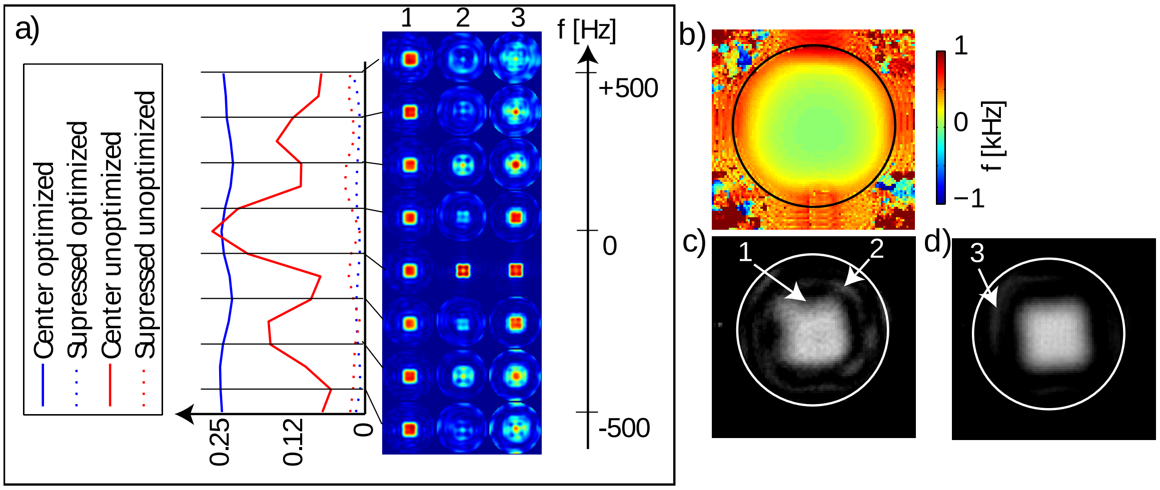

Figure 2

References:[1]C. H. Meyer et al. *Simultaneous Spatial and Spectral Selective Excitation,* MRM15,287-304 (1990) [2] Brunner et al. *Enforcing strict constraints in multiple-channel RF pulse optimization***,** Proc. Intl. Soc. Mag. Reson. Med. 15 (2007) p. 1690 [3] Brunner et al. *A symmetrically fed microstrip coil array for 7T***,** Proc. Intl. Soc. Mag. Reson. Med. 15 (2007) p. 448 [4] Grissom W. et al, MRM. 2006;55:620