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 B1 field or localized spectroscopic imaging. A major problem is the small bandwidth of such localized pulses. Small off-resonances (either induced by B0 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 mdes(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 = γ·G·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.

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 B1 patterns of the individual coils have been calculated using a FDTD simulation of a 8-channel microstrip coil array [3]. The pulse 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 B1 patterns of the individual coils have been calculated using a FDTD simulation of a 8-channel microstrip coil array [3]. The pulse 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).

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 system (>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.

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 B0 distribution [4]. Furthermore the pulse becomes robust also against through-plane and intra-voxel B0 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.