HENSIR: Hadamard Encoded Simultaneous Image Refocusing

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Target Audience Researchers and developers interested in simultaneous multi-slice imaging.

Purpose Simultaneous multi-slice (SMS) imaging is becoming increasingly popular in the accelerated MR imaging field. While SENSE or GRAPPA based methods for separating the simultaneously acquired images have proven effective, slice-averaging (Hadamard encoding[1]) methods have been shown to improve SNR when compared with the images acquired one slice at a time, and do not require computationally intensive reconstructions. This approach also avoids the necessity for a phased coil array, and the reconstruction of the separated images can be done by adding and subtracting the complex, aliased images. Simultaneous image refocusing[2] allows the signal from two separately excited slices to be refocused using a single readout gradient. In this abstract we propose the HENSIR sequence (Hadamard encoded simultaneous image refocusing).

Methods To implement HENSIR (Fig. 1), single-band RF excitations in the SIR sequence were replaced with minimum-time VERSE[3,4] multi-band SLR[5] pulses. For the results shown in this abstract, two dual-band pulses were used for a total SMS factor of four. The pulses were designed with a peak gradient amplitude of 40 mT/m, maximum slew rate of 100 T/m/s, and a peak B1 amplitude of 20μT. The two aliased k-spaces are separated at the center of each frequency-encoding gradient. Over each repetition in an imaging time series, the phase on the excited slices for both excitation pulses is modulated according to a Hadamard matrix[1]. This allows the simultaneously excited slices to be separated by adding and subtracting combinations of the aliased images from different repetitions. A 4x SMS 1-D gradient echo Bloch simulation, written in MATLAB (Mathworks, Natick, MA), was performed to test the feasibility of this concept (Fig. 2). For the simulation, each of the RF excitations excited two one-dimensional objects at different slice locations. HENSIR is currently being programmed on a Siemens 3.0T Verio system and its use will be investigated in EPI, line scan sequences, and non-CPMG echo trains.

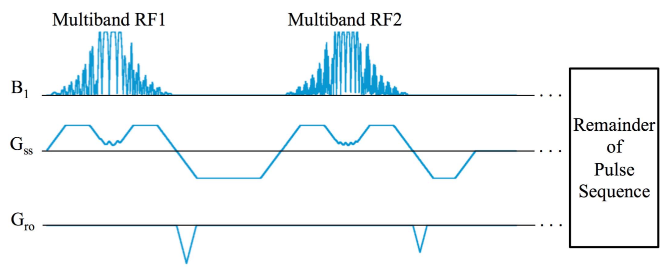

Fig. 1: HENSIR Pulse Sequence. The slice-rewinder and frequency-encoding prephaser areas were designed as outlined in reference two.

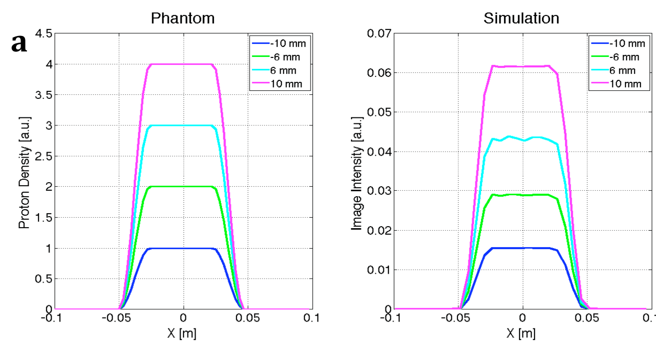

Fig. 2: Simulated multi-slice 1D object (left) and resulting images (right).

Results The images of the simultaneously excited 1D objects closely matched the phantom (Fig. 2). The small differences between the images and the object come from simulated off-resonance effects as well as small errors in gradient timing.

Discussion HENSIR is useful when designing sequences with high SMS factors. When using HENSIR in an EPI sequence, as with a regular SIR sequence. Splitting the multiband excitation into two separate excitations reduces SAR and peak B1, which are major safety concerns for SMS sequences at high field strengths. When a body coil is used for signal reception, separation of the images is possible by addition and subtraction of the phase cycled images. This sequence alone may be useful for animal imaging at ultra-high field strengths, as surface coils are difficult to design for these systems. If higher temporal resolution in the separated images is desired, a surface coil may be used. The Hadamard unaliased images can then be used as reference images to make sensitivity maps for SENSE unaliasing[6]. Combining HENSIR with blipped-CAIPI and SENSE unaliasing to create an auto-calibrating 8-band EPI sequence is a current avenue of research. It has been shown that a spin echo version of SIR can minimize non-CPMG artifacts[7]. HENSIR's use in this sequence will also be investigated.

Conclusion Hadamard encoded simultaneous image refocusing is a promising simultaneous multi-slice imaging method. HENSIR reduces scan time and SAR, and increases increases SNR (when compared with single-slice imaging), permits high SMS factors, and can be integrated into most Cartesian readout trajectories.

References [1] Souza, S.P., et al. *Journal of computer assisted tomography* 12.6 (1988): 1026-1030. [2] Feinberg, D.A., et al. *MRM* 48.1 (2002): 1-5. [3] Hargreaves, B.A., et al. *MRM* 52.3 (2004): 590-597. [4] Hargreaves, B., Cunningham, C., Minimum-Time Variable-Rate Selective Excitation (VERSE). http://mrsrl.stanford.edu/~brian/mintverse/. [5] Cunningham, C.H., et al. *MRM* 42.3 (1999): 577-584. [6] Jesmanowicz, A. et al. *Brain Connectivity* 1.1 (2011): 81-90. [7] Gunther, M., Feinberg, D.A., *MRM* 54.3 (2005): 513-523.