Chimera Steady State Free Precession (Chimera SSFP)

O. Bieri[1], M. Klarhöfer[1], and K. Scheffler[1]
[1]Division of Radiological Physics, University of Basel Hospital, Basel, Switzerland

Introduction. A new type of steady-state free precession (SSFP) sequence is introduced, termed chimera SSFP. The sequence consists of two alternating SSFP kernels (Fig. 1): odd TR-intervals feature a balanced SSFP (bSSFP) type of protocol, whereas even TR-intervals undergo gradient dephasing (non-balanced SSFP) and hence the name. Chimera SSFP offers a peculiar frequency response profile with respect to the bSSFP interval that can be used, among others, for functional MRI (fMRI) or temperature mapping.

Theory & Methods. For chimera SSFP**,** a balanced SSFP kernel is alternated with non-balanced one. For illustration of a possible sequence scheme, see Fig. 1. Alternate dephasing has a peculiar impact on the ordinary bSSFP frequency profile (see Fig. 2) and generates for chimera SSFP a frequency response of near triangular shape (the amplitude of the triangle depends on the TR1/TR2 ratio and increases with decreasing ratios; not shown), as confirmed from measurements in the presence of a linear frequency offset (Fig. 2c).

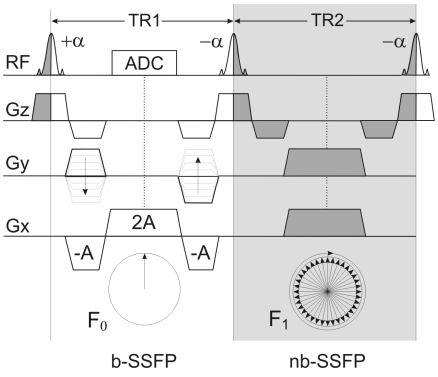

Fig. 1: Chimera SSFP consists of two alternating kernels: balanced SSFP (left) and non-balanced SSFP (right). For the applications presented herein only the balanced TR is used for readout.

FMRI: Chimera SSFP makes use of the frequency related shift, identical with the well-known existing frequency sensitive fMRI acquisition techniques based on SSFP [1,2]. Since nb-SSFP is sensitive to flow/motion, dephasing within TR2 was flow compensated (to TR). FMRI data was acquired on a 3T clinical scanner (Siemens Verio) with a standard block design (20s/20s on/off) using a visual stimulus (checkerboard). Chimera parameters were: TR1=3ms, TR2= 6ms, α=20° using two scans with phase offset of ±90° from on-resonance.

Temperature mapping: A test tube filled with a viscous aqueous solution (T1~1s, T2~40ms) equilibrated at ~5°C was mounted into a spherical holder (containing the same solution equilibrated at room temperature (20°C)). At 1.5T, a frequency shift of 0.01ppm/°C yields approximately 0.23°/ms phase advance. Temperature scans were acquired using TR1= 8ms, TR2=8ms, α=20° with a temporal resolution of 1sec/scan.

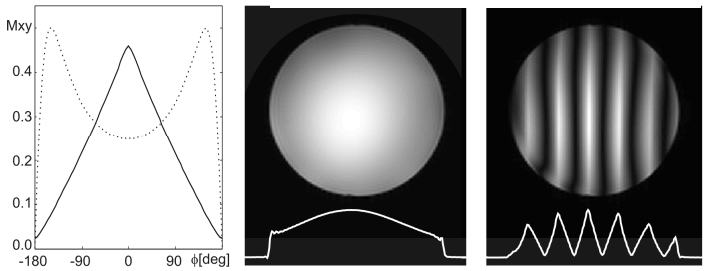

Fig. 2: (a) Chimera SSFP frequency response profile (T1~T2=300ms, a=30°). (b) Sample image and intensity profile using 0° phase offset. (c) Sample image and profile in the presence of a linear frequency offset (left-to-right).

Results & Discussion. Using the peculiar frequency response profile of chimera SSFP, temperature mapping and fMRI is feasible (Figs. 3 & 4). For fMRI, using the simple setup, chimera yields a BOLD response in the range of 10%, whereas temperature changes below 1° can be reliably detected. As expected, the BOLD response is inverted for positive as compared to negative RF phase offsets as a result of the triangular frequency response profile. Changes are larger for positive offsets as compared to negative ones, which might be due to oxygenation related changes in T2, which are known to modulate SSFP signal as well but on a much smaller scale (1-2%). However, effects from T2 should affect signal intensities independently on the RF phase offset, which must result in an increase or decrease of the frequency-related BOLD effect for ±90°, respectively.

Conclusion. A new steady state sequence was introduced termed chimera SSFP providing a peculiar frequency response profile of triangular shape. We have successfully demonstrated the use of the linear relation between off-resonance frequency and signal amplitude modulation for frequency selective fMRI or temperature mapping.

References. [1] Scheffler et al, NMR Biomed (2001). Miller et al, MRM (2003) [2].

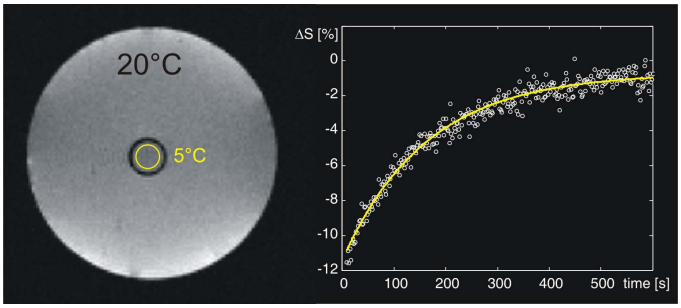

Fig. 3: Temperature mapping using Chimera SSFP with 90° phase offset. The temperature in the surrounding of the test tube is elevated by 15°. This corresponds to a phase advance of about 28°/TR (TR1=8ms). As a result, an initial signal difference (ΔS) of about ΔS=100%·(28/180)=15% can be expected. This is in good agreement with measurements. Dissipation followed an exponential behavior with a time constant of roughly 1/160sec.

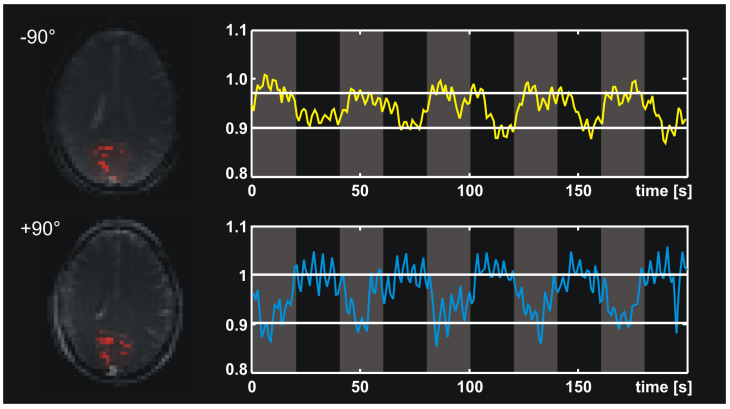

Fig. 4: Chimera fMRI. Pixels in the visual cortex that showed a correlation coefficient > 0.3 were classified as being active (left) with corresponding average signal time courses (right). The upper/lower row shows the results for a negative/positive phase advance of 90°. The time resolution of the chimera fMRI scan was 1sec using a slice thickness of 5mm and a 64x64 matrix (yielding 4x4mm in plane resolution)