Extended Chimera SSFP

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Introduction. Only recently, a new type of steady-state free precession (SSFP) sequence was introduced, termed chimera SSFP (1). The chimera 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 profiles with respect to the bSSFP interval that can be used, among others, for functional MRI (fMRI) or temperature mapping.

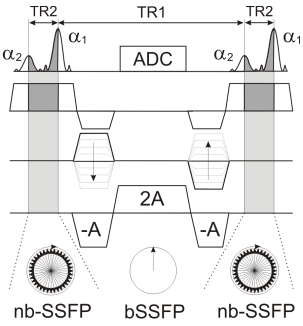

Fig. 1: Extended chimera SSFP sequence scheme: variable flip angle and short TR_2.

Theory & Methods. For chimera SSFP**,** a balanced SSFP kernel is alternated with non-balanced one. A possible 2D sequence scheme is illustrated Fig. 1. In contrast to the recently proposed initial chimera sequence (1), the nb-SSFP kernel is played out with minimal $TR_2 \rightarrow 0$ and the constraint of identical flip angles for both kernels is discarded. Thus, in general, the phase as well as the flip angle can be different for each kernel.
An extended chimera SSFP sequence was implemented on a 3T system (Siemens verio) and frequency response functions were acquired on an aqueous phantom having a T_2/T_1=260ms/290ms. The TR_1 was set to 5ms and TR_2 to 800µs. The echo was acquired at $TE=TR_1/2$. Dephasing in TR_2 was along the slice encoding direction as indicated in Fig. 1 and allows marginal prolongation of the TR as achievable without the dephasing kernel. Simulations were performed using the piecewise constant Bloch equations with essentially identical protocol parameters.

Results & Discussion. Alternate dephasing has a peculiar impact on the ordinary bSSFP frequency profile (Fig. 2, top) and was shown to generate for chimera SSFP with $\alpha_1=\alpha_2=20°$ a frequency response of near triangular shape (Fig. 2, middle), whereas for $\alpha_1=10°$ or 60° and $\alpha_2=60°$ or 10° the frequency response oscillates about an amplitude offset (Fig. 2, bottom). The phase of the steady-state with chimera SSFP is identical to the bSSFP phase profile for identical flip angles but increases linearly for diverging flip angles, similar to gradient echo sequences. Amplitude modulations for chimera SSFP with diverging flip angles are near harmonic, being a consequence of the rotation of the magnetization configuration as displayed in Fig. 3.

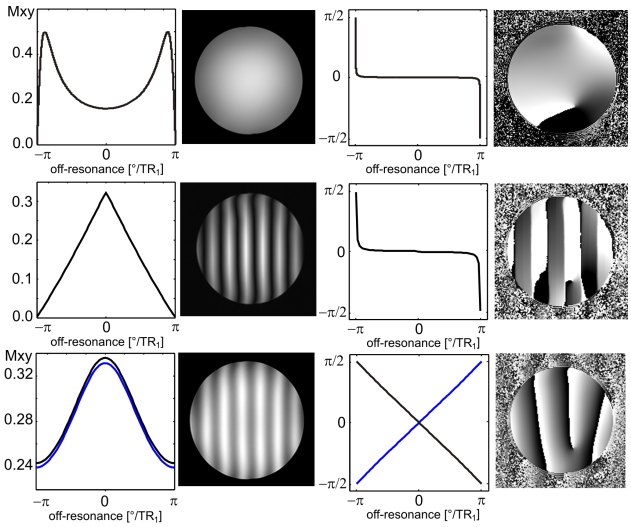

Fig. 2: Simulated phase and amplitude modulations of chimera SSFP as a function of off-resonances (top): balanced SSFP with TR=2TE=5ms, α=20° and $T_1=T_2$=1sec. (middle): chimera SSFP with TR_1=5ms, TR_2=0.5ms, α_1=20° and α_2 =20°. (bottom): chimera SSFP with TR_1=5ms, TR_2=0.5ms, α_1=10°, α_2=60° (shown in blue) and α_1=60°, α_2=10° (shown in black). In addition, chimera SSFP phase and magnitude images (aqueous probe with T2/T1=260/290ms) are shown with scan parameters identical to the simulation,

Conclusion. An extended chimera SSFP sequence scheme was introduced providing peculiar modifications to the well-known bSSFP frequency response profile. Possible applications of this new sequence scheme may be, among others, functional MRI, temperature mapping or spectroscopy.

References. (1) Bieri & Scheffler, Proc. ISMRM Hawaii (2009), p. 2767.

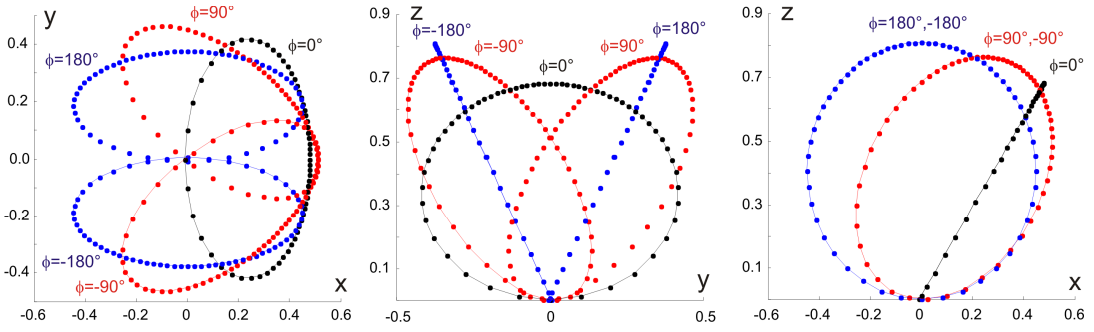

Fig. 3: Steady-state configurations for chimera SSFP as shown in Fig. 1 as a function of off-resonances (ϕ) for diverging flip angles (α_1=10° and α_2=60°). With increasing off-resonances, the on-resonance configuration is rotated around the longitudinal axis (z-axis) by $\phi/2$. As a result a near harmonic signal oscillation is induced (see Fig. 2, bottom).