Oscillating Steady States

K. Scheffler[1], S. Maderwald[2], M. Ladd[2], O. Bieri[1]

[1]MR-Physics, Radiology, Basel, Switzerland, Switzerland, [2]Radiology, Essen, Germany, Germany

INTRODUCTION

In this paper the influence of alternating RF pulse phases or alternating spin precession on different echo paths of non-balanced SSFP sequences such as FISP, GRASS, CE-FAST and variants thereof is analyzed, and applications to detect oscillatory motion (elastography) are presented.

THEORY AND SIMULATIONS

As described in detail by Freeman and Hill and depicted in the left column of Fig. 1, the distribution of the magnetization as a function of precession within TR is located on a tilted ellipse (on a circle for T1=T2). This symmetric distribution is disturbed with alternating RF pulse phases as shown in Fig. 1 for $\phi=\pm15°$, $\phi=\pm30°$, and $\phi=\pm45°$. The asymmetry of the distribution and of the corresponding frequency profile (bottom row in Fig. 1) gives a reduced amplitude of the integrated signal and thus a reduced echo amplitude for non-balanced SSFP. Besides a reduction of the echo amplitude also the phase of the echo is influenced by alternating RF pulse phases. In addition to the F_0^+ echo also higher order echoes are changed in amplitude. In general, the F_0^- and F_0^+ paths exhibit a signal reduction with increasing oscillating phases whereas F_{-1}^- and F_1^+ increase in amplitude. The highest possible signal change and the corresponding optimal flip angle α strongly depend on the T1/T2 ratio. The most effective signal change appears at T1=T2 for flip angles α between 60° and 140°, depending on the amplitude of the applied oscillating perturbation $\pm\phi$.

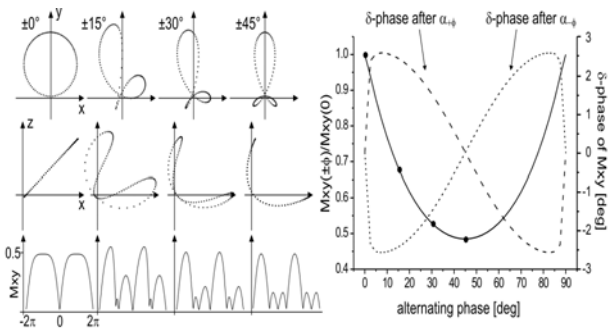

Fig 1: Left top: simulated steady state distribution of magnetization in x-y and x-z projection for different oscillating RF pulse phases (T1/TR=37.5, T2/TR=35, α=90°). Left bottom: corresponding transverse magnetization as a function of frequency. The right panel shows amplitude (solid line) and phase of the SSFP echo as a function of alternating phase $\pm\phi$.

IMPLEMENTATION AND EXPERIMENTS

Two types of SSFP sequences have been implemented according to the two different readout gradient patterns assigned as Gr1 and Gr2. Read out gradient For the experimental verification of the simulated results readout gradient Gr1 was used, and the oscillating phase of $\pm\phi$ was applied via the RF pulse phase. Gr1 produced four echoes F_1^+, F_0^+, F_0^- and F_{-1}^-, phase encode and slice selection gradients are balanced within the TR of 13.38 ms. Readout gradient Gr2: Similar to the BASEL sequence (1), an alternating precession can be produced by oscillatory motion $\Delta r(t)$ in combination with readout gradient Gr2. The cyclic motion $\Delta r(t)$ was generated by a piezoelectric actuator coupled into a 1% agar-agar cylindrical phantom (18cm height and 12cm diameter, T1/T2 = 150/65 ms with Gadolinium).

RESULTS

Readout gradient Gr2 and first-order motion compensated slice and phase encoding gradients were used to depict acoustic strain waves generated by a piezoelectric actuator at a frequency of 108 Hz. Acoustic strain waves images acquired with oscillating SSFP are shown in Fig. 2 for echoes F_0^+ and F_0^- and excitation flip angles of 60° and 90°.

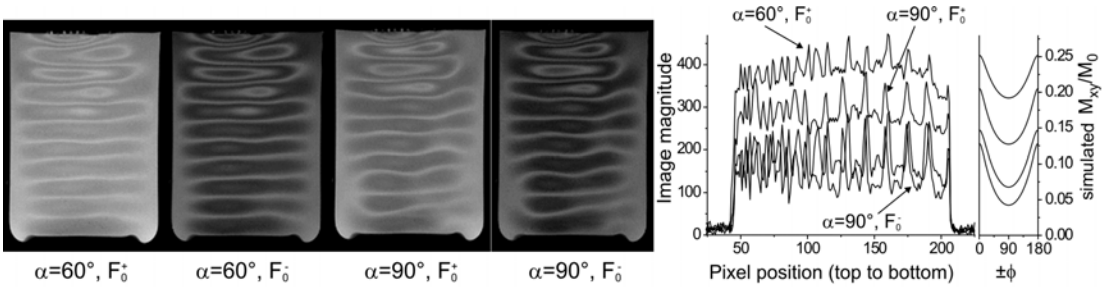

Fig 2: Left: Images of acoustic strain waves acquired with oscillating SSFP for different echo paths and flip angles. Right: corresponding image intensities along the center column.

DISCUSSION

It was demonstrated that the magnitude of non-balanced SSFP sequences can easily be modulated by application of alternating RF pulse phases or alternating spin precession. Depending on the observed echo path, a decrease or increase of the echo amplitude of up to 50% can be achieved. In general, oscillating SSFP can be used to detect oscillating phases produced by any suitable or useful mechanism.

REFERENCES

(1) Bieri O, Maderwald S, Ladd ME, Scheffler K. Balanced Alternating Steady-State Elastography. Proc ISMRM, 13th Scientific Meeting, Miami 2005 p. 97.