Robust Transmitter Calibration during Continuous Table Movement

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Introduction: In MR imaging RF transmitter calibration is performed for each patient and due to the varying load for each table position to ensure that the RF pulses generate the desired B1 field and hence flip angles. In MR examinations that acquire the data at multiple different table positions it can be more efficient to perform this calibration (and others) during continuous table movement (e.g. during the time the patient is moved in the magnet towards the first scan position). This is in particular the case if the examination itself (or part of it) is performed during continuous table movement. A well established RF calibration method uses a three-pulse sequence [1]. The intensity of the up to 5 echoes of this sequence as a function of the flip angles α1, α2, and α3 (and relaxation times T1, T2) can easily be derived analytically [2]. Since the relative flip angles are known by sequence design (e.g. by the relative duration of otherwise identical RF pulses) the unknown absolute value of the flip angles can be determined by measuring the intensity of at least two echoes. When we used this original method during continuous table movement it failed. In this work reliable results during continuous table movement with 50 mm/sec are obtained with a three RF pulse sequence that employs a flow compensated gradient scheme along the direction of movement.

Methods: Figure 1 is a schematic plot of the original three RF pulse sequence, which acquires the first spin echo and the stimulated echo. The sequence can operate with selective RF pulses (e.g. SINC pulses) and non-selective RF pulses (rectangular pulses). In both cases it uses a constant gradient along the z-axis (feet-head direction of the patient). There are three major tasks of this gradient: Because it is on during readout it is possible to calculate a one dimensional profile of the excitation volume by a Fourier Transform and exclude the peripheral part (with decreased flip-angles) by evaluating only the central part. Second it serves as a crusher gradient which dephases the FID of the second RF pulse before the spin echo readout and the FID of the third RF pulse before the stimulated echo readout. Third, it limits the excitation volume as slice selection gradient during RF radiation. The constant gradient is in the direction of the table movement. Therefore, if the sequence of Fig.1 is used while the table moves the spins acquire additional phase. The phase of the measured transverse magnetization will therefore depend on the first gradient moment at the echo time and the table speed. The first moments of the spin echo and the stimulated echo are different.

Figure 2 shows a flow compensated variant of the sequence. The constant gradient is replaced by five trapezoidal positive lobes and 4 negative trapezoidal lobes. The positive lobes have equal amplitude and flattop time. The center of each positive lobe coincides either with the center of one of the three RF pulses or with one of the two echoes. The negative lobes are designed to have the same moment as one of the positive lobes. The center of each negative lobe coincides with the centroid of the adjacent two positive lobes. The first moment of this gradient scheme is zero at the isodelay points of the RF-pulses and at the echo times. This is most easily seen by considering the waveform consisting of one negative lobe and one half of it left and right adjacent neighbour, respectively. This waveform is symmetric and has zero net area. Hence its first moment is zero. Readout moment and the thickness of the excitation volume of both sequence variants are the same, if the amplitude of the positive lobes of Fig. 2 is chosen equal to the amplitude of the constant gradient of Fig. 1. The extension of the gradient scheme in Fig. 2 to readout additional echoes is straightforward. Since the net moment acquired between the isodelay point of the foregoing RF-pulse and the echo is now zero, crusher gradients are added along one of the two orthogonal directions to dephase the FID. If only the stimulated echo is readout past the last RF pulse the left crusher of this RF pulse may be omitted.

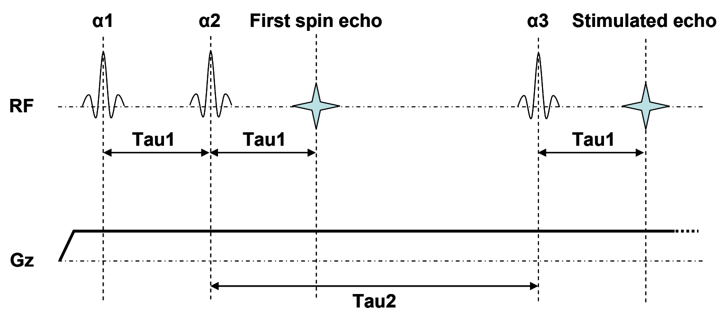

Figure 1: Sequence diagram of the three RF-pulse sequence from reference 1.

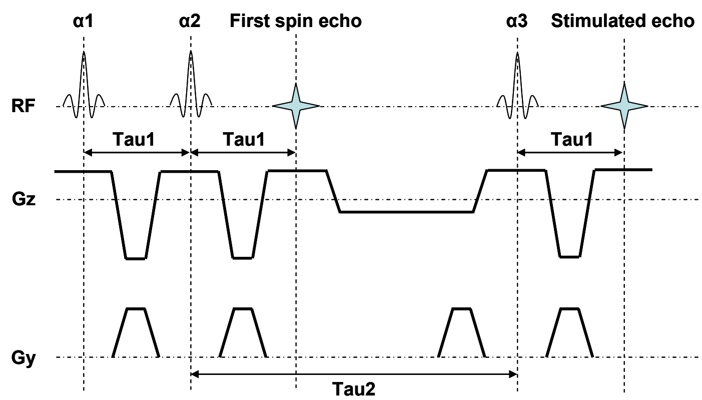

Figure 2: Sequence diagram of a three RF-pulse sequence with flow compensated gradient scheme along the direction of table movement.

Results and discussion: Figure 3 compares the results of the transmitter calibration obtained with the sequence of Fig.2 during continuous table movement with 50 mm/s (blue diamonds) with the results of the stationary (standard) transmitter calibration of our 3T MAGNETOM Skyra at different table positions (orange circles). The horizontal axis is the table position. The vertical axis is the calculated transmitter voltage needed to generate a 180° rectangular reference pulse of one millisecond duration. The standard transmitter calibration uses multiple iterations, if the flip angle calculated from the projections differs significantly from the desired flip angle (180°). It serves as a reference. The transmitter calibration during continuous table movement does not iterate to keep the time per calibration step constant. Nevertheless, the results match quite well. The results obtained during continuous table movement using the original sequence without flow compensation are not shown. The output is a value around 300V independent of the actual load. We also tested other variants of the three RF pulse sequences that resolved the excitation profile along the left-right direction with similar results: Flow compensation appears to be mandatory. Our system uses a phase sensitive evaluation of the two projections. This method will output incorrect results, if the first moment at the echo times are different and if the extra phase due to the movement is not corrected. However, even when only the magnitudes of the projections were evaluated the non flow compensated sequence did not work during continuous table movement. At the time of abstract submission the phenomena is not fully understood. The reason may be that the actual gradient strength within the huge projection volume varies due to system imperfections so that spins at different positions acquire different phase due to the movement. If the first gradient moment or the speed is so large that the phase dispersion across the projection volume becomes in the order of 2 π the signal may be totally dephased.

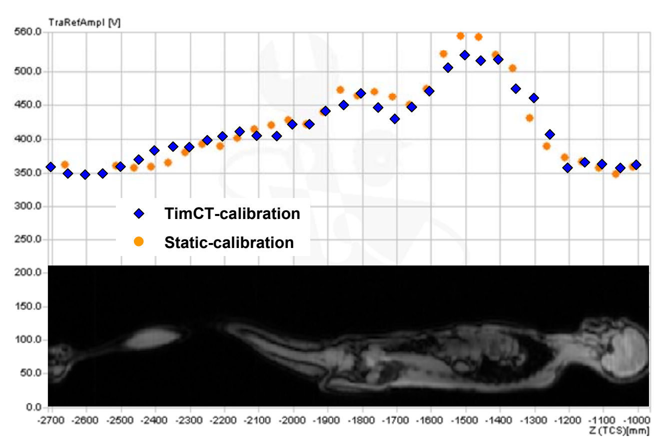

Figure 3: Comparison of the transmitter calibration results obtained with the sequence of Fig. 2 during continuous table movement with 50 mm/s (blue diamonds) with the stationary transmitter calibration of our 3T MAGNETOM Skyra (orange circles) at different table positions.

References:
[1] P. van der Meulen et al. SMRM 1986; p. 1129. [2] “Principles of Magnetic Resonance Imaging”. Z.-P. Liang and P.C. Lauterbur. IEEE Press (2000)