Sampling Strategies for MRI with Simultaneous Excitation and Acquisition

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Introduction

Imaging of samples with very short T2 requires data acquisition to start immediately after excitation. In the SWIFT technique [1] this is accomplished by playing out a gapped frequency-swept pulse while concurrently acquiring data during the gaps. At the same time gradients are applied permanently and stepped in a 3D radial mode. Thus SWIFT combines the short-T2 capability of the silent radial FID method [2] with the ability of swept RF pulses to cover large bandwidths under B1 restrictions [3, 4]. Within the general concept of simultaneous excitation and acquisition (SEA) introduced with the SWIFT technique, we suggest a number of improved sampling strategies, addressing reconstruction stability, SNR, and artefacts related to pulse errors [3, 5].

Methods

SEA acquisition was implemented on a 4.7 T Bruker BioSpec animal spectrometer with an AVIII console. A transmit/receive (T/R) volume coil was modified such as to yield minimal signal background from the coil materials. Switching from RF signal transmission to signal reception and vice versa amounts to a total of 5 µs per sub-pulse. Data sampling runs continuously with the receive input blanked during pulsing. Reconstruction of SEA data is accomplished with a general inversion approach incorporating all encoding aspects such as the RF pulse shape, suspended acquisition, and oversampling [6]. Generally, for robust reconstruction the acquisition scheme must define a well-conditioned inverse problem. Furthermore accurate knowledge of the pulse shape is essential [3]. To these ends we propose the following methodological deviations from the original SWIFT technique.

a) Prolonged Acquisition: Instead of ending the acquisition together with the pulse (Fig. 1a), it is prolonged by one pulse duration (Fig. 1b). Thus, the signals excited late in the frequency sweep are also received with full gradient encoding. This stabilises the reconstruction as demonstrated in Fig. 2. Inversion reconstruction from slightly noisy data breaks down with the original approach or, when regularised, suffers from reduced resolution, while the prolonged data gives excellent results with minor Gibbs ringing as the only artefact.

b) Reduced pulse duration: Shortening the pulse with respect to the duration of the nominal acquisition (Fig. 1c) reduces the influence of pulse errors. Besides improving image quality it also increases the SNR efficiency due to higher acquisition duty cycle coming along with fewer breaks. However, shortening the pulse requires higher B1 and is thus constrained by applicable system limitations. The extreme case of this strategy is the hard pulse FID method [2].

c) Acquisition oversampling: In the current SWIFT technique one data sample is acquired per pulse element. Oversampling the data has several advantages. It offers better control over T/R switching and the group delay of the receive chain. These details (Fig. 3) are taken into account by the reconstruction. Furthermore, oversampling facilitates implicit data extrapolation into the pulse intervals, which otherwise require first-order phase correction and create baseline artefacts [7, 8].

d) Automated zero-order phase correction: To speed up image acquisition, real-valued profiles can be reconstructed from half *k*-space data, requiring initial zero-order phase correction [1]. For an automated procedure this phase is obtained from a single profile acquired without gradient.

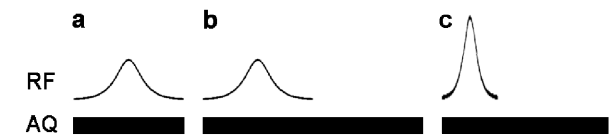

Figure 1 SEA sampling schemes. a) Original SWIFT. b) Prolonged acquisition. c) Reduced pulse duration.

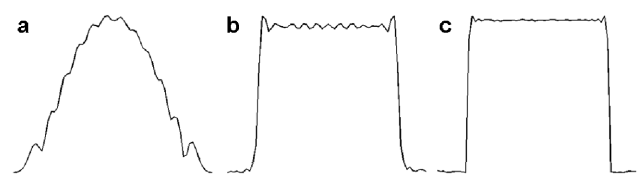

Figure 2 SEA profiles reconstructed from noisy, simulated data of a rectangular object, obtained with a) the scheme in Fig. 1a, b) the scheme in Fig. 1a and regularisation, and c) the prolonged acquisition in Fig. 1b.

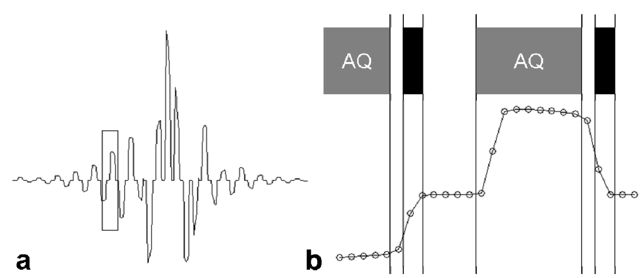

Figure 3: Oversampled SEA time-domain data. a) Data acquired during pulse. b) Zoomed data along with the sequence details sub-pulse (black), acquisition (AQ), and the switching periods in-between. The ramps in the data originate from the group delay of the digital filter.

Results

Figure 4 shows a slice from a 3D SEA data set acquired with the proposed strategies. The internal structure of the individual rubber pieces as well as the tube sections can be readily distinguished, while the artefact level is very low. In summary, simultaneous excitation and acquisition with the proposed modifications, combined with adaptive reconstruction by inversion of the effective net encoding, yielded high-quality images from short-T2 samples.

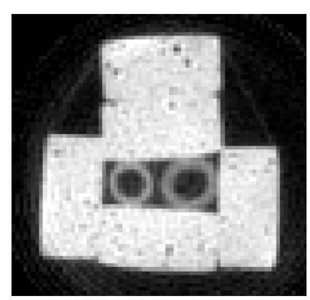

Figure 4: SEA image of a stack of rubbers and tubes with T2* ≈ 500 µs. Parameters: bandwidth 100 kHz, matrix size 96, acquisition oversampling factor 16, nominal acquisition duration 480 µs, hyperbolic secant sweep pulse of 120 µs duration during total readout duration of 600 µs.

References

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