B1 correction in SPatiotemporal ENcoding (SPEN) MRI

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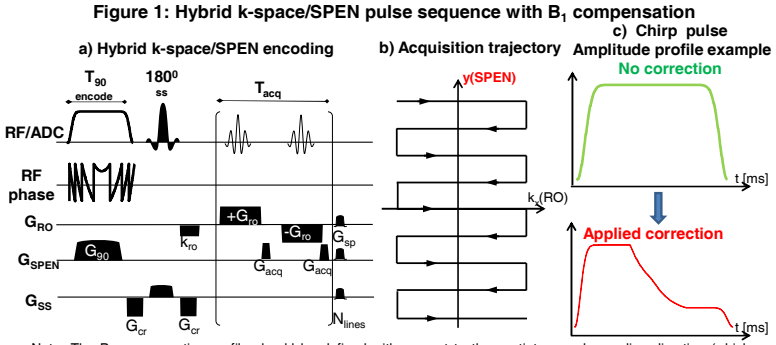
Target audience: Scientists and radiologists who are interested in rapid MRI acquisitions in inhomogeneous B_1 RF fields.

Figure 1: Hybrid k-space/SPEN pulse sequence with B_1 compensation



Note: The B_1 compensation profile should be defined with respect to the spatiotemporal encoding direction (which varying with the chirp pulse phase modulation and the gradient signs)

Introduction: A general challenge of doing MRI with surface coils arises from the strong inhomogeneity of the radio-frequency (RF) field. This challenge also arises in ultrahigh field human MRI applications. These B_1 inhomogeneities can be attenuated by using adiabatic RF pulses; however, when incorporated into imaging sequences such as Echo Planar Imaging (EPI), this results in longer echo times that lead to a need for segmented acquisition [1]. Hybrid spatiotemporal encoding (SPEN) sequences are an alternative for ultrafast acquisition [2, 3], which can provide higher immunity to B_0 inhomogeneities vis-à-vis to EPI. Such robustness is vital for applications like diffusion, functional MRI and perfusion [5,6]. Typically, SPEN pulse sequences include a linearly-swept "chirped" RF pulse applied in the presence of a magnetic field gradient. This results in a sequential excitation/inversion profile of spins with their position, which can be read-out by a spatial dependent acquisition. The aim of the present work was to exploit the intrinsic spatial dependence of the SPEN scheme to correct for the B_1 inhomogeneity associated with surface coils. We show that by modulating a chirp pulse's amplitude along the main degrading dimension of the B_1 field, can compensate for this RF inhomogeneity and thus improve image fidelity and sensitivity. This is demonstrated both in phantom and rats experiments.

Methods: Measurements were carried out on a 9.4 T/ 31 cm actively shielded animal scanner (Varian/Magnex) using a custom-designed ^{1}H quadrature butterfly coil. Field inhomogeneity was corrected using the FASTMAP protocol. *In vivo* tests were performed on Sprague-Dawley rats. Animals were anesthetized using 1.5% isoflurane and their physiology was monitored. Hybrid single shot pulse sequence (k-space encoding in readout direction and spatiotemporal encoding along the low-bandwidth direction) was implemented utilizing a chirped pulse combined with a gradient for excitation and echo planar imaging acquisition [2,6]. The chirp pulse includes phase modulation with a frequency range of $BW = \gamma G_{90} FOV$ for covering the relevant FOV (field-of-view) (G_{90} being the gradient applied in the SPEN dimension) and RF amplitude enveloped by a suitable amplitude modulation. Such encoding imparts parabolic phase, which allows spin density profile acquisition applying matching gradient ($G_{90}T_{90}=G_{acq}T_{acq}$). Since the RF pulse excites each of the spin packets separately [7], the amplitude of the pulse can include B_1 compensation. Figure 1 shows the pulse sequence, the acquisition trajectory and an example of B_1 compensated RF amplitude profile. This profile was extracted from a set of single shot SPEN scans with alternating power. From such set, the profile for the pulse was estimated and smoothed to eliminate possible measurement glitches.

Results: Signal profiles along the SPEN dimension measured on a tap water phantom without and with B_1-compensation are shown in Fig. 2. Note that when no B_1 correction is applied, the area that reaches maximal intensity moves deeper into the sample with higher RF power. In the B_1-compensated experiments a uniform and stable profile is obtained versus applied power, demonstrating the efficiency of the RF correction. *In-vivo* result acquired on rat brain is demonstrated in Fig 3, which compares single shot SPEN versus single shot EPI result. These experiments clearly show how, on top of SPEN's higher immunity to B_0 inhomogeneity that has already been documented, higher spatial coverage arises when performing B_1 compensation.

Conclusions: B_1 compensation is a new tool in the arsenal of single shot SPEN sequence, offering higher spatial coverage and sensitivity while preserving immunity to B_0 inhomogeneity. Although in demonstrated implementation only performs a 1D correction, the method could be extended to a plane using 2D spatiotemporal RF pulse implementations [8,9].

Figure 2: Phantom measurements of signal profile versus power

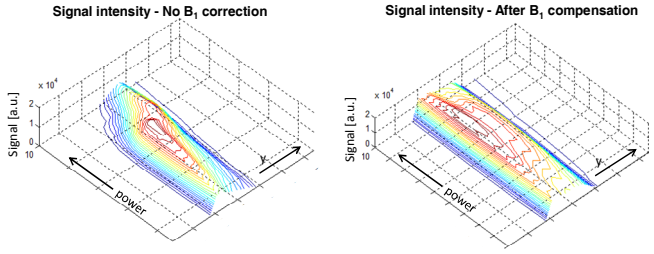
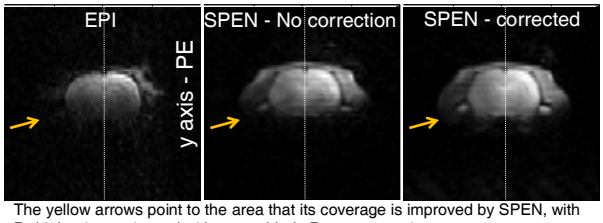
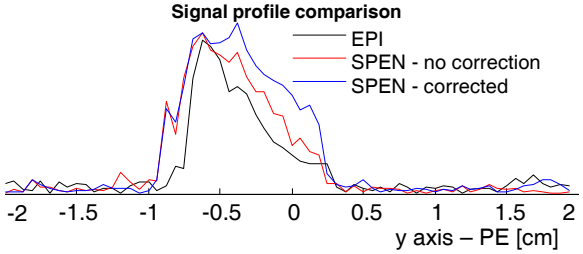


Figure 3: I*n-vivo* animal experiment B_1 compensation verification



The yellow arrows point to the area that its coverage is improved by SPEN, with B_0 higher immunity and with new added B_1 compensation

Signal profile comparison



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