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Introduction

In fMRI experiments, the presence of slow B0 resonance frequency drift is often observed. Several factors, including instrumental instability [1], physiological shifts and subject motion-related-noise are suspected for the causes of this drift. Henry et al. [2] reported that the heating of the gradient amplifiers coupled with the passive shims could induce up to 0.5 ppm/hr B0 field change. In conventional fMRI, this drift is often removed by using linear modeling, polynomial fitting or high pass filtering. Transition-band SSFP fMRI is a recent functional technique that enables high-resolution functional studies by providing high SNR efficiency and high readout duty cycles [3]. However, since the activation is only detectable near on-resonance regions (about 4 Hz activation bandwidth at 1.5T) where the signal is high, transition-band SSFP fMRI usually requires repeating the experiment with slightly shifted center frequencies (2Hz – 4Hz) to cover the desired ROI. Therefore, maintaining the same field distribution over all the experiments is very important to avoid missing spatial regions. In transition-band SSFP fMRI, the slow B0 resonance frequency drift not only causes time-series fluctuations but also shifts the activation region (Fig. 1: the high signal regions are the activation bands where functional contrast can be detected. The non-uniform signal distribution comes from the small-flip-angle balanced-SSFP profile). This results in a varying functional contrast and poor activation spatial coverage. Moreover, once the activation band is shifted, the post-processing methods cannot restore the functional contrast. Therefore, it is crucial to remove the field drift in real time. Here, we present a real-time technique to compensate for the slow B0 field drift in transition-band SSFP fMRI.

Methods

The slow B0 frequency drift changes the field distribution over time and in small-flip-angle balanced SSFP, it can be measured by the phase of FID (Fig. 3-(b),(e) and (f)). A 3D spiral-trajectory balanced-SSFP sequence (TR = 16.7 ms, FA = 8°, TE = 0 ms, BW = 125 kHz, Ninterleaves = 10, resolution = 1x1x1 mm³ and Nslices = 12) was modified to have an FID period between the RF refocusing gradient and the slice encoding gradient (Kz encode) as shown in Figure 2. The FID period was 64 samples (= 256 μs) and the average phase value of the samples was used to estimate the drift. To remove the eddy current-induced spin dephasing effects, the interleaves and Kz encodes were ordered in the opposite polarity sequence (interleaves order: 0°, 180°, 36°, 216°, ..., Kz encode order: 6, -6, 5, -5, ...). As the drift is much slower than one TR, a total of 120 TRs (one 3D volume period) was averaged to reduce phase errors. This averaged phase value was further filtered with a low pass filter (cutoff = 0.04 Hz) to remove any rapid phase change from other sources including respiration. For compensation, the RF phase and the receiver phase were changed in accordance with the measured phase after scaling it to the corresponding resonance frequency offset. Hence, a feedback loop was constructed to track the drift in real time [4]. The RF phase change method changes the center frequency in balanced SSFP [5]. The scaling factor was manually chosen at the beginning of the experiment by observing the compensation results. The experiments were performed seven times: (a,g) with imaging gradients plus compensation, (b,e,f) with imaging gradients but no compensation effectively, and (c,d) without imaging gradients. Each experiment ran for ten minutes. The field distribution was restored to the original position in each experiment.

Results

Figure 4 shows the drift compensation results. Without compensation, the white band had gradually moved to the outer side of the phantom over ten minutes (upper figures). With compensation, the band stayed at the same location (lower figures). Figure 3 shows the phase measurements from the FID. In the uncompensated experiments, the measurements changed 20 to 30 degrees (b,e,f). Without imaging gradients, the phase changes were smaller (c,d). In the drift compensated experiments, the measured phases stayed constant throughout the experiments (a,g). The measured B0 drifts in the compensated experiments were 0.26 and 0.23 ppm/hr.

Discussion and Conclusion

The proposed method successfully compensated for the slow B0 field drifts in real time. The scaling factor can be calculated by estimating the actual frequency offset by using a long FID period before the experiment or shortly after a warm-up scan. Picking the scaling value is not critical since the feedback loop can tolerate a range of loop gains. The initial value can be calculated based on the previously found frequency offset.

References

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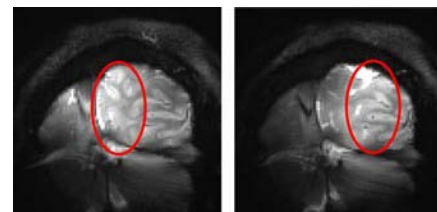


Figure 1. Slow scanner drift: first image (left) and after 10 minutes (right). The activation band (high signal region) is clearly shifted.

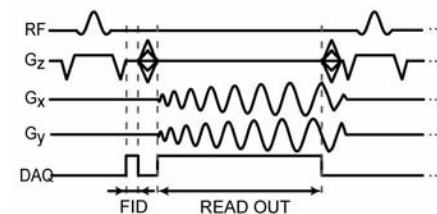


Figure 2. Modified balanced-SSFP

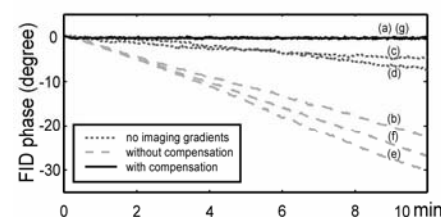


Figure 3. FID phase measurements: The phase drifts without compensation (b,e,f). It becomes stationary with compensation (a,g).

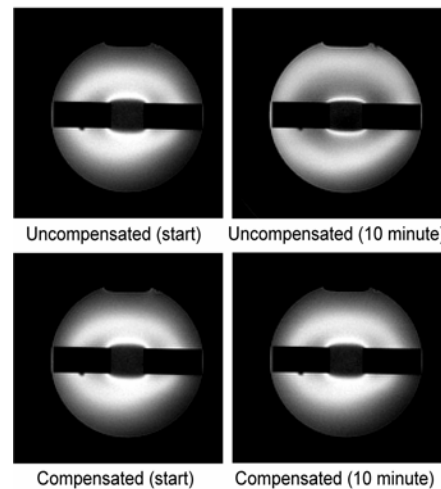


Figure 4. Phantom experiments