GrIP: Gradient Iterative Predistortion for Multidimensional and Parallel Excitation

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Introduction Parallel excitation pulses are highly sensitive to gradient imperfections, and it has been demonstrated that designing pulses on measured trajectories dramatically improves excitation accuracy [1]. This solution, however, is incompatible with schemes in which RF and gradient waveforms are designed jointly, such as parallel excitation VERSE [2] and sparsity-based spoke pulse design [3], or for methods that are too computationally intensive to be performed online. Inspired by recent work in RF preemphasis [4], we introduce a predistortion technique called Gradient Iterative Predistortion (GrIP), that iteratively compensates deviations between target and measured gradient trajectories, and demonstrate that it improves multidimensional and parallel excitation accuracy, without requiring pulses to be (re-) designed on a measured trajectory.

Methods Given a target gradient $G(t)$, GrIP is implemented by the following algorithm:

1) Set $l=0$, $G^l(t)=G(t)$.
2) Deploy $G^l(t)$, yielding measurement $\tilde{G}(t)$.
3) Correct delays, set $G^{l+1}(t)=G^l(t)+\lambda\left(G(t)-\tilde{G}(t)\right)$.
4) Goto 2.

The step size λ is initially 0.5, and divided by 2 if the RMS error between $G(t)$ and $\tilde{G}(t)$ is not decreased by the previous λ. In our implementation, iterations cease when $\lambda = 2^{-4}$.

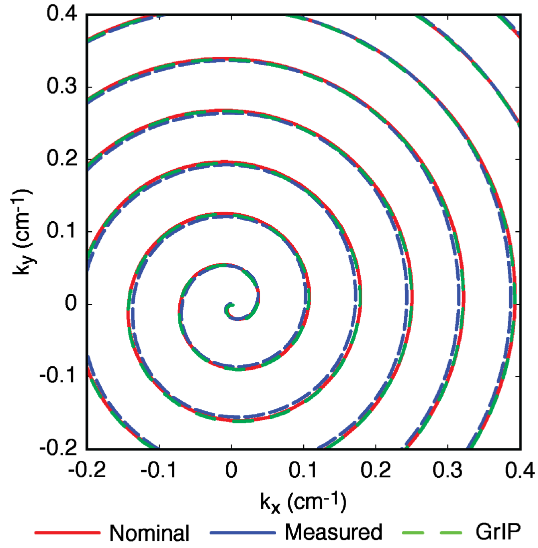

Figure 1: Excitation k-space trajectories. *The initial measured trajectory deviates significantly from the nominal one (RMSE=0.0182 G/cm), while the GrIP trajectory is nearly coincidental (RMSE=0.0039 G/cm).*

Experiments and Simulations We implemented the GrIP method on a GE 1.5T Signa Excite scanner (GE Healthcare, Waukesha, WI, USA), using a modified Duyn method for gradient measurement [5]. We applied it to an 8.7ms spiral-in trajectory (FOV 14cm, res 0.45cm), for 9 iterations. Two single-channel pulses were then designed using Ref. [6] on both the nominal and initial measured (no predistortion) trajectories. The target excitation pattern was a 4cm square with flip angle 30° and with equal error weighting in the pass and stop bands [7]. Using a spin echo 2DFT sequence and a 12cm bottle phantom, we imaged patterns excited by 1) a pulse designed on the nominal trajectory and deployed on the original gradients, 2) a pulse designed on the measured trajectory and deployed on the original gradients, and 3) a pulse designed on the nominal trajectory and deployed on the GrIP gradients. All pulses were compensated for the measured $\Delta B_0(t)$, since this does not require redesign. Delay between RF and gradient channels was compensated. We also performed a simulation of 8 channel parallel excitation in a 22cm phantom [8]. Pulses were designed using Ref. [9] to excite the same square as in the single channel experiment.

Results Fig. 1 compares the k-space trajectories. The measured trajectory (dashed blue line) deviates significantly from the nominal one, while the GrIP'd trajectory (dashed green line) is nearly coincidental. Fig. 2 shows the one channel excitation results. The uncompensated pulse's pattern contains significant blooming around the square and other erroneous stopband excitation. The pulse designed on the measured trajectory excites an accurate pattern, with errors at or below the pulse's intrinsic ripple level. The pulse excited on the GrIP'd gradients creates a pattern of similar accuracy to the measured case. Fig. 3 shows analogous results in the parallel excitation case, except that the uncompensated pulses also suffer incomplete aliasing cancellation.

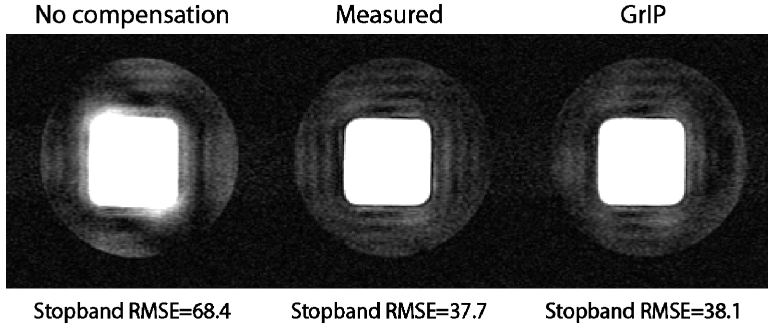

Figure 2: One channel excitation experiment. *(Images windowed to highlight stopband excitation) A pulse designed on the nominal trajectory creates a distorted square and significant erroneous stopband excitation. A pulse designed on the measured trajectory excites an accurate pattern, with stopband errors at or below the pulse's intrinsic ripple level. A pulse designed on the nominal trajectory and deployed on the predistorted one is nearly as accurate as the pulse designed on the measured trajectory.*

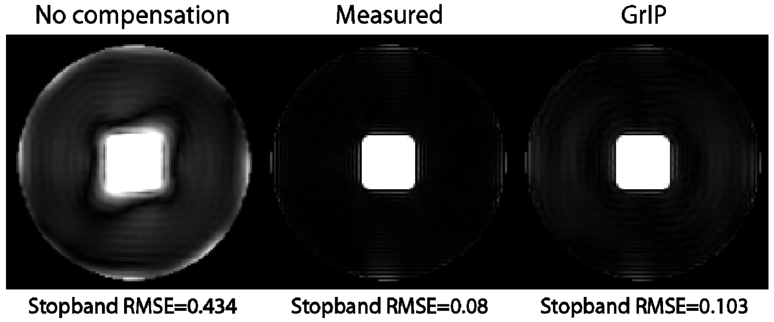

Figure 3: Parallel excitation simulation. *Results are analogous to one channel case.*

Conclusion We have introduced a method for iteratively compensating gradient field distortions in multidimensional and parallel excitation. The method obviates the need to design pulses along a measured trajectory. In practice, it could benefit from the use of gradient measurement probes that are currently under investigation [10].

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References [1] P Ullmann et al. 16th ISMRM, p. 1313, 2008. [2] D Lee et al. MRM 61:1471-79, 2009. [3] AC Zelinski et al. IEEE TMI 27:1213-29, 2008. [4] PP Stang et al. 17th ISMRM, p. 395, 2009. [5] JH Duyn et al. JMR 132:150-153, 1998. [6] CY Yip et al. MRM 54:908-917, 2005. [7] WA Grissom et al. MRM 62:1242-50, 2009. [8] SM Wright. 10th ISMRM, p. 854, 2002. [9] WA Grissom et al. MRM 56:620-9, 2006. [10] PT Sipilä et al. 17th ISMRM, p. 2076, 2009.