Parallel transmission z-shimming to compensate GE-EPI signal voids at 7 Tesla

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Target audience: MR physicists, fMRI methodologists

Introduction and Theory

An obdurate limitation of GE-EPI for BOLD fMRI is through-plane signal dephasing (1). This is most prominent in regions with large susceptibility variation such as near the ear canals and frontal sinuses where the detection of BOLD signal changes becomes difficult. Beyond protocol optimizations for specific brain areas of interest (TE, slice thickness and tilt), so called z-shimming (2) actively corrects signal dephasing, but results in impractically long TR since it requires multiple scans at different z-shims to compose the final image. Typically a single shim is used as a compromise that somewhat corrects the artifact without dephasing the signal too much elsewhere (3); the applied gradient moment will always affect the entire image. Inserting a z-blip of size $G_z\Delta t$ is equivalent to unbalancing the slice-select and refocusing moments, or time shifting an excitation pulse B_1 by Δt on its slice gradient to affect the same moment:

$$B_1(t+\Delta t) \leftrightarrow p(z)e^{i\gamma G_z z\Delta t}$$

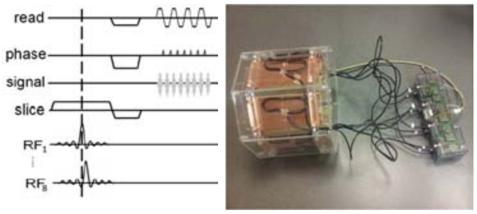

Fig 1. Left: pTX EPI sequence. RF pulses on each element can be individually time-shifted to create local z-shims. Right: 8ch pTX/RX meander array

This allows a local compensation in a single shot with "parallel transmission (pTX) z-shimming" (4,5). Applying unique time shifts on the pTX channel(s) closest to regions of signal loss exploits the coil elements' localized transmit sensitivity profiles, which also define the spatial extent of the shim. In this abstract we explore the approach at 7 T.

Methods

A Siemens 7 T with Step-2 pTX setup and a custom 8-channel pTX/RX meander head array (6) was used. Relative B_1^+ maps of each channel were obtained in a phantom and two brains using the double angle method (7) with turbo-flash readout. An EPI sequence was modified to apply channel and slice dependent time shifts to the RF pulses as specified in a text file. Short EPI timeseries and breathold fMRI (4min, 20s breathhold) with and without shims near the ear canals or frontal cortex were recorded under IRB approval (N=4). The slice-wise shim moments were estimated from susceptibility gradient maps, which were derived from conventional field maps (dual-echo FLASH) by numerical differentiation (3). Ear canal shims were applied on channels 2 and 6, frontal shims on channel 1 (see Fig. 2). Scan parameters for EPI were: $1.75\text{x}1.75\text{x}3\text{mm}^3$ voxels (matrix 128x128, 32 slices 20% gap, GRAPPA 2), TE 25ms, TR 2s, FA 90. Breathold data were analyzed in FSL FEAT with default settings (5 mm smoothing, $z > 2.3$, $p < 0.05$).

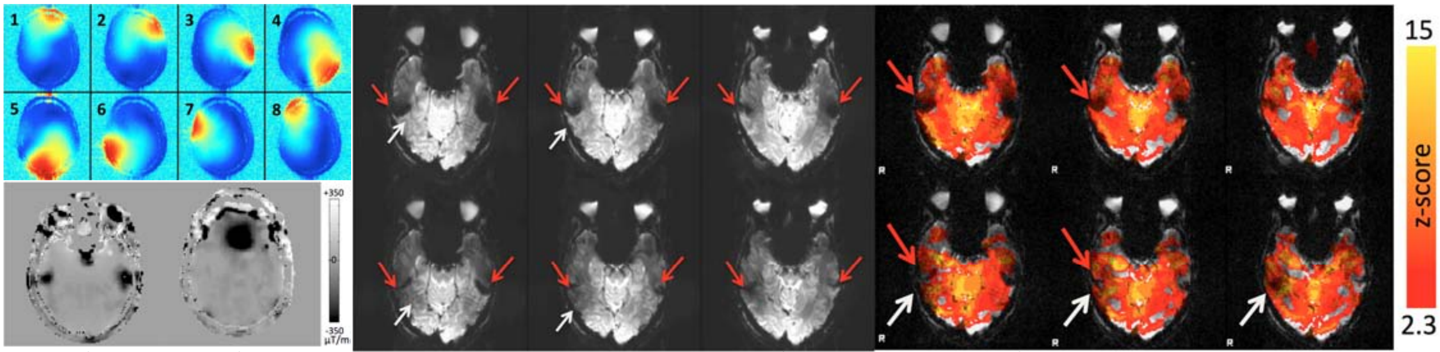

Fig 2. Left: in vivo maps of transmit sensitivities (top) and the through-plane component of the susceptibility induced field gradients. Center: images without (top) and with (bottom) bilateral pTX z-shims applied near the ear canals on channels 3 and 6. A successful reduction of the signal void is clearly visible (red arrows) but also some attenuation in the surrounding, originally intact signal (white arrows). Both effects are reflected in the corresponding breathold activation maps (right).

Results and Discussion

Transmission profiles for the eight pTX channels and maps of through-plane susceptibility near the ears and frontal cortex are shown in Fig 2 (left). The pTX shims could consistently reduce signal voids near the ear canals, as evident from the unshimmed vs. shimmed images and corresponding activation maps. Shim were applied to the three slices bilaterally on channels 3 and 6 and were adjusted to compensate for G_{sus} = 300, 250 and 200 µT/m, respectively, at the TE of 25 ms. Some signal and activation reduction is observed in the neighboring tissue that is originally unaffected by dropout but mainly falls into the shimmed channel's sensitivity profile. Note that this attenuation local, unlike for conventional gradient z-shims that affect the entire slice. Satisfactory signal recovery in frontal cortex without unacceptable loss in the vicinity was only achieved in one of the four subjects (hence not shown). This observation is attributable to the frontal void being not early as close to the skull's surface as the ear canals, and also relatively distant from the closest transmitter. Furthermore, the spatial properties of TX sensitivities at short RF wavelength (large extent and asymmetry) appear less favorable for this application than observed at 3 T (4); a more snugly fitting pTX coil than used here should improve the performance. The spatial selectivity of pTX z-shimming, albeit coarse, should still make it preferable to single-shot gradient z-shims, and the method is straightforward. However, we take the present results as indication that pTX z-shimming will be outperformed by more advanced B_0 corrections, including spectral-spatial or spokes RF pulses.

References [1] Constable RT, JMRI 1995;5:746 [2] Frahm J, JMR 1994;103:91 [3] Deichmann R, NI 2002; 15:120 [4] Deng W, MRM 2009;61:255 [5] Poser BA, ISMRM 2011 #3608 [6] Orzada S, ISMRM 2009 #3010 [7] Sled MRM 43(5), 2000. **Grants:** R01DA019912, R01EB011517, K02DA02056, DFG Po1576/1-1