Reduction of B1 inhomogeneity using transmit SENSE slice-select pulses

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Introduction: A major limitation of high field MRI is B1 inhomogeneity due to RF standing wave and attenuation behavior. Transmit SENSE (XSENSE) methods (1,2) have been suggested as a means to address this limitation due to the inclusion of the spatially varying transmit sensitivity in the tailored RF (TRF) pulse design (3). As of now, however, there has been no proof of this concept *in vivo* using pulses with practical slice-select implementations. Below we present brain images at 3T with reduced B1 inhomogeneity that were acquired using a novel small-tip-angle fast-k_z XSENSE 3D TRF pulse that is 4.3ms in length with a 5mm slice thickness.

Theory: XSENSE pulses can be designed in the image domain where $C_n(x,y)$ is the sensitivity for one of N transmitters (4):

$$M(\mathbf{r}) = \sum_{n=1}^{N} C_n(x,y) \int_0^T B_n(t) e^{-i\mathbf{k}(t)\cdot\mathbf{r}} dt \; .$$

Here $M(\mathbf{r})$ is the desired slice profile and $B_n(t)$ is the RF waveform for each transmitter. Approximate solutions for $B_n(t)$ can be obtained by least squares minimization:

$$B_{\text{est}} = \arg\min_B \left\| M - \mathbf{C}B \right\|^2 .$$

The inclusion of $C_n(x,y)$ in the pulse design allows for a reduction R in pulse length and will create an excitation that is spatially homogeneous. Due to the smooth spatial variation of $C_n(x,y)$ and the desire for thin slices, the 3D TRF pulse design necessitates low in-plane (*x*-*y*) resolution and high resolution along the slice-select (*z*) direction. This is accomplished with the fast-k_z pulse design which consists of a train of slice-select sub-pulses along *z* separated by phase-encoding blips in *x* and *y* (5,6). Figure 1 (a) shows the *k*-space trajectory, which was chosen to be hexagonal for optimal sampling. The XSENSE acceleration factor *R* can be used to scale the phase-encoding blip area if an increase in excitation resolution or a decrease in pulse length is desired.

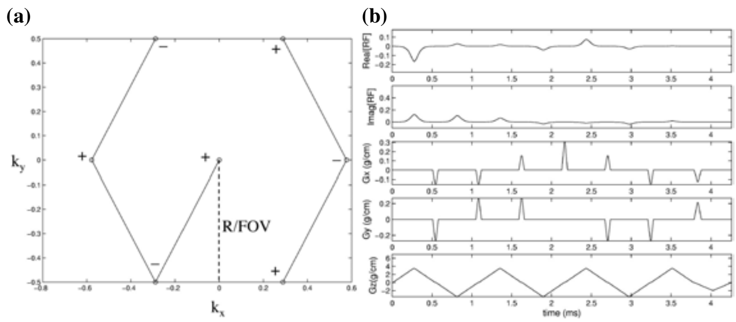

Fig. 1. (a) The *k*-space trajectory. A slice-select pulse is applied at each point (polarity given by sign). **(b)** One of 8 4.3 ms *R*=2 XSENSE 3D TRF pulses. The rows are the real and imaginary parts of the RF, and the *x*, *y*, and *z* gradients.

Methods: The XSENSE 3D TRF pulses were implemented on a Siemens 3T Trio (Siemens Medical Systems, Erlangen, Germany) scanner (200T/m/s slew rate and 4mT/m peak gradient). Due to a lack of parallel transmit hardware, the scanner's eight-channel receiver was used to mimic XSENSE with reciprocity (7): each pulse was applied sequentially with the body coil and acquired by its corresponding receiver. The eight resultant complex images were added after the scan. The coil sensitivity maps were determined using a body coil image and the individual receiver coil images. The pulses consisted of seven Gaussian slice-select sub-pulses and seven *x-y* gradient blips giving a total length of 4.3ms and a slice thickness of 5mm. Pulses were generated with *R*=1 and *R*=2 such that the in-plane excitation resolutions were 11cm and 5.5cm over a 22cm excitation FOV, respectively. A conjugate gradient technique was used to solve for the RF waveforms. Figure 1 (b) shows an example pulse for one of the coils. A gradient echo FLASH sequence with fat saturation was used for the acquisition (TE=15ms, TR=300ms, FA=30^{o}). A Gaussian slice-select pulse with the same slice thickness, profile, and flip angle was used for comparison. Final images from the Gaussian pulse were obtained from either the complex or magnitude summation of the individual coil images; representing either a simultaneous excitation with multiple transmitters, but without XSENSE, or the standard receiver array image, respectively. Three human subjects were scanned.

Results: Figure 2 shows example images from one of the human volunteers.

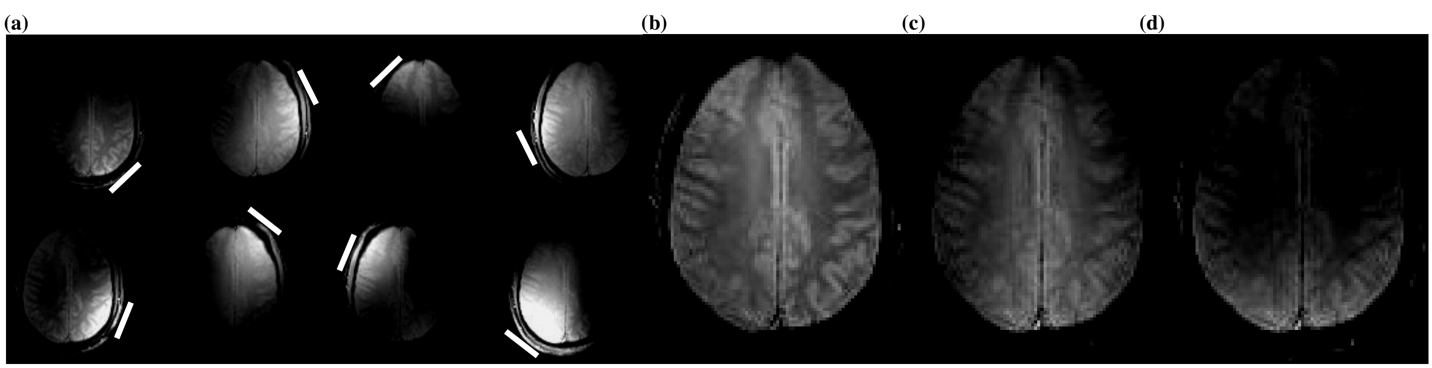

Fig. 2 (a) Individual coil images using the *R*=2 XSENSE pulse. The white lines are the approximate coil locations. **(b)** Complex sum of (a) representing the composite XSENSE excitation. **(c)** Complex sum of coil images acquired using the Gaussian slice-select pulse. **(d)** Magnitude sum of coil images acquired using the Gaussian slice-select pulse. By visual inspection, the XSENSE image (b) is more homogeneous than both the complex sum (c) and the standard magnitude sum image (d).

Conclusions: We have demonstrated proof of concept for the use of XSENSE to reduce B1 inhomogeneity with multiple transmitters in the human brain at 3T. Furthermore, the pulse design is practical, allowing for 3-5mm slices and 4-5ms pulse lengths. The reduction factor was used to increase the excitation resolution but could have been used to reduce pulse length as well. Future work includes implementation at 7T.

References: (1) U. Katscher *et al.* MRM 2003;49:144. (2) Y. Zhu MRM 2004;51:775. (3) V. A. Stenger *et al.* In: Sec. Int. Workshop on Parallel MRI, Zurich, Switzerland, 2004. (4) W. Grissom *et al.* In: Sec. Int. Workshop on Parallel MRI, Zurich, Switzerland, 2004. (5) C-P Yip *et al.* In: Proc 13th ISMRM, Miami, 2005, 2350. (6) S. Saekho *et al.* In: Proc 13th ISMRM, Miami, 2005, 22. (7) Z. Zhang and V. A. Stenger, In: Proc 13th Annual Meeting ISMRM, Miami, 2005, 2434. Work supported by the R01 MH66066 and R21 DA015900.