Validation of Transmit SENSE with Reciprocity

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Introduction: Reducing multi-dimensional tailored RF (TRF) pulse lengths with parallel exciters and transmit SENSE (XSENSE) is of current interest (1,2). Progress in developing XSENSE techniques, however, is hampered by the lack of hardware and validation techniques often rely on simulations. We present a simple method using reciprocity to validate XSENSE pulse algorithms and sequences on an MRI scanner using a standard receiver array. Valuable proof of concept work on a scanner is possible with this approach, facilitating the use parallel transmitters when they become commercially available. Phantom images including the possible application B1 inhomogeneity reduction at high field are presented as examples.

Theory: In the small tip angle approximation, the RF pulse $B_1(t)$ is related to the magnetization $M(\mathbf{r})$ by

$$M(\mathbf{r}) = \alpha(\mathbf{r})\int_0^T B_1(t)e^{-i\mathbf{k}(t)\cdot\mathbf{r}}dt \ . \qquad [1]$$

The transmit sensitivity $\alpha(\mathbf{r})$ is included for generality. Reciprocity equates the acquired image $I_n(\mathbf{r})$ to $M(\mathbf{r})$ times the receiver sensitivity $C_n(\mathbf{r})$:

$$I_n(\mathbf{r}) = C_n(\mathbf{r})M(\mathbf{r}) \ . \qquad [2]$$

The index n designates receiver coil number. The final image $\Psi(\mathbf{r})$ is defined as the complex sum of the image from each individual coil:

$$\Psi(\mathbf{r}) = \sum_{n=1}^{N} I_n(\mathbf{r}) = \alpha(\mathbf{r})\sum_{n=1}^{N} C_n(\mathbf{r})\int_0^T B_1(t)e^{-i\mathbf{k}(t)\cdot\mathbf{r}}dt \ . \qquad [3]$$

This equation is identical to what is proposed for XSENSE (3) except we are summing over multiple receivers instead of transmitters. Writing this as a matrix equation, least squares minimization approaches can be used to estimate the N RF pulses that are needed (4):

$$B_{est} = \arg\min_{B} \left\| \Psi - \mathbf{C}B \right\|^2 . \qquad [4]$$

One would implement this technique on a scanner by first measuring the receiver sensitivities and then using Eq. [4] to solve for the pulses for each coil. Any appropriate RF k-space trajectory can be used. Each pulse is then utilized in a separate scan and the final image is constructed with Eq. [3] using only the image corresponding to the coil of the particular pulse.

Methods: R=2 XSENSE stacked-spiral 3D TRF pulses were designed to excite 2 cm slices in a uniform NiCl phantom on a GE 3T scanner. A body coil was used for excitation and a four-channel array (Nova Medical) for reception. A spiral sequence was used for acquisition. Figure 1 shows the k-space and one of the four pulses. The rows (top to bottom) are the real and imaginary parts of the RF, and the x, y, and z gradients. The first example was to design a pulse that excited a picture of a girl's face in the phantom. Figure 2 (a) shows the input 32x32 image. Sensitivity maps were obtained from fitting the ratio of the coil image to a body coil image with a 2D polynomial. The second example explored the possibility of using XSENSE to excite a slice with reduced B1 inhomogeneity. Sensitivity maps were obtained directly from images acquired from each receiver such that both transmitter and receiver sensitivities were corrected. Eq. [4] was solved using a standard conjugate gradient algorithm with 15 iterations for both examples.

(a) **(b)**

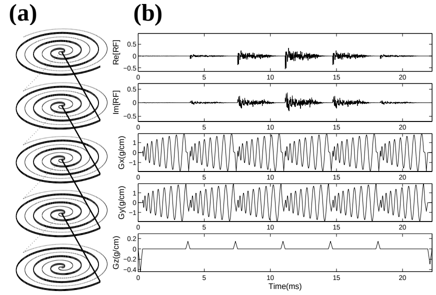

Figure 1. (a) Undersampled stacked-spiral k-space (b) 3D TRF R=2 XSENSE pulse.

Results: Figure 2 (b) and (c) shows the images of the girl's face. Figure (d) through (e) show the B1 inhomogeneity reduction results.

(a) **(b)** **(c)** **(d)** **(e)** **(f)**

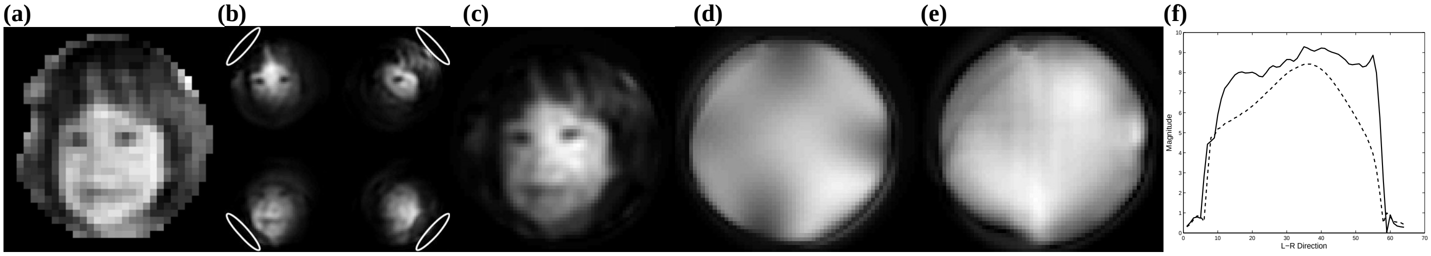

Figure 2. (a) Input 32x32 image. **(b)** Images acquired from each coil (indicated by ellipses). **(c)** Final XSENSE image obtained by taking the complex sum of images in (b). Slice in phantom using a **(d)** sinc and **(e)** R=2 XSENSE pulse. **(f)** Profile of image magnitude. The XSENSE pulse produces a flatter image because sensitivity is built into pulse design.

Conclusions: Lack of parallel transmitter hardware hinders proof of concept work for XSENSE. This work demonstrates that a phased array receiver can be used to validate XSENSE pulse algorithms and sequences on a scanner. Although the pulses need to be applied sequentially, this technique should help in the development of XSENSE methods. One possible application is for reduced B1 inhomogeneity at high field. Future work will involve *in vivo* demonstrations of XSENSE.

References: (1) Katscher U, Bornert P, Leussler C, van den Brink J. Magn Reson Med 2003;49:144-150. (2) Zhu Y. Magn Reson Med 2004;51:775-84. (3) Grissom W, Yip C-P, Noll DC. Second International Workshop on Parallel MRI, Zurich, Switzeralnd, 2004. (4) Yip C-P, Fessler J, Noll D. In: Proc 12th Annual Meeting ISMRM, Kyoto, 2004. p 188. Work supported by the R01 MH66066 and R21 DA015900.