Transmit Array Spatial Encoding (TRASE): A New Data Acquisition Method in MRI

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Introduction

In parallel MRI, data collected simultaneously with multiple receivers is purposely undersampled in the phase encode direction. The complex spatial sensitivity of the Rx-array elements is used to fill in missing lines (SMASH) or points (GRAPPA) in k-space, or to unfold signal in the image domain (SENSE). These techniques are used to speed up data acquisition in standard single echo sequences as well as multi-echo imaging methods such as fast spin echo (FSE). While the research focusing on further acceleration of the acquisition is well advanced there is a possibility of an improvement. Here we propose a new method of spatial encoding using a transmit-array system, called TRansmit Array Spatial Encoding (TRASE). TRASE provides a new way of moving around in k-space without the need for phase encode gradients. An example of the application of TRASE to gradient echo (GE) and FSE pulse sequences is described.

Theory

The NMR signal, $S_m(\mathrm{k_n})$, received by a coil array element m of M receive coils is given by,

$S_m(\mathrm{k}_p) = \int d\mathrm{r}\rho(\mathrm{r})e^{i(2\pi\mathbf{k}_n\cdot\mathbf{r})}C_m(\mathrm{r}) = \int d\mathrm{r}\rho(\mathrm{r})e^{i(2\pi\mathbf{k}_n\cdot\mathbf{r})}C_0 e^{i(2\pi\mathbf{k}_m\cdot\mathbf{r})}$, where $\mathrm{k_p}$ is the p$^{\mathrm{th}}$ spatial encoding k-space trajectory in the spatial dimension r, of the n^{th} gradient k-space line, $C_m(\mathrm{r})$ is the sensitivity distribution of a receive array element or a combination of receive array elements that can be used to produce the phase variation in the phase encode direction required to fill in the missing p^{th} line of k-space, and ρ(r) represents the spatial distribution of spin density. Although we describe here a SMASH analogy, the same applies to other parallel imaging techniques. Suppose, we use an array of Tx-elements that can be independently driven to produce the appropriate B1-phase variation associated with a particular spatial harmonic, $T_t(\mathrm{r}) = T_0 e^{i(2\pi\mathbf{k}_t\cdot\mathbf{r})}$. Then such a transmit B1-field, like the receive B1-field in SMASH, may be used to produce a phase encoding step without the need of a phase gradient pulse. In this case, the MR signal can be expressed in the form,

$S_m(\mathrm{k}_p) = \int d\mathrm{r}\rho(\mathrm{r})f_{TC}(\mathrm{k}_p,\mathrm{r}) = \int d\mathrm{r}\rho(\mathrm{r})T_0 e^{i(2\pi\mathbf{k}_t\cdot\mathbf{r})}e^{i(2\pi\mathbf{k}_n\cdot\mathbf{r})}C_0 e^{i(2\pi\mathbf{k}_m\cdot\mathbf{r})}$, where $T_t(\mathrm{r}) = T_0 e^{i(2\pi\mathbf{k}_t\cdot\mathbf{r})}$ is a new term introduced by the TRASE method into the Fourier transform kernel (f_{TC}). In fact, a single phase encode step can be achieved from a TRASE RF pulse defined as $\theta^{\varphi(\mathbf{r})}$, where θ is the flip angle associated with the magnitude of the B1-field and φ(**r**) is the phase variation across the FOV in the spatial direction **r**. A $90^{2\pi}$ excitation or a 180^{π} refocusing TRASE RF pulse produce 2π- and π-B1 phase variation respectively across the FOV in the phase encode direction. This can be achieved by successively transmitting into separate array elements that intrinsically produce the appropriate phase variation such as spiral birdcage array coils [1], but in general this could be accomplished by using a multi-transmit array system with separate Tx amplifiers delivering power (magnitude and phase controlled) to separate Tx-array elements simultaneously during a particular RF pulse to produce the desired B1 phase encoding kernel. Other encoding functions could also be used (such as wavelet encoding) which would require excitation of each element of the Tx-array to produce magnitude/phase B1 distributions associated with the particular encoding kernel.

Fig. 1: Full Bloch equation MRI simulation of a standard GE imaging sequence with 8-phase encodes. K-space and FT image for gradient phase encoding (a,b) and TRASE method with no gradient phase encode steps but with 8-Tx-Array B1 fields (c,d).

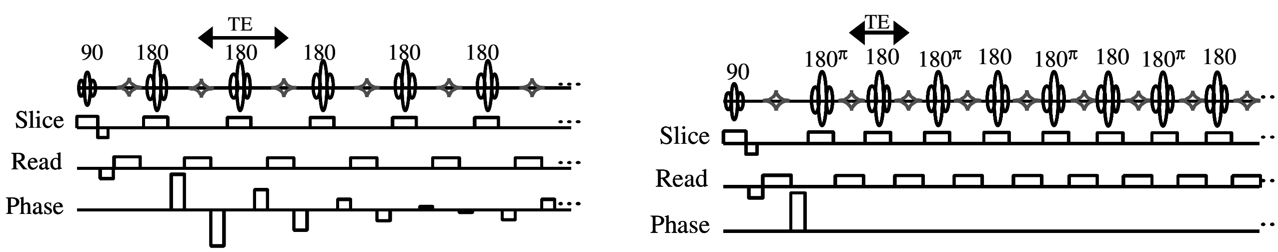

Fig. 2: Standard FSE imaging sequence (*left*) and one possible SE-TRASE method allowing shorter TE and hence more echoes per TR (*right*).

Results/Discussion

MRI simulations were performed using a full Bloch equation MRI simulator [2] with multi-transmit capability using a standard GE pulse sequence (8-phase encode steps) and an equivalent GE-TRASE pulse sequence where phase encode gradient steps are replaced with 8-Tx-Array B1 fields, with -6π,-4π,-2π,0,2π,4π,6π,8π phase variations across the FOV. Although only 8 phase encode steps were used for practical implementation of the TRASE method, the k-space data and MR image were nearly identical for both methods. Although the required multi-transmit MRI system is not currently available, the requirements for transmit-SENSE and B1 shimming at high B0-fields are moving MRI systems in this direction. While in its infancy, TRASE may provide faster data acquisition (by allowing shorter TE in fast spin-echo MRI (*Fig2*), could reduce acoustic noise by eliminating one gradient, enable shorter TE thus higher SNR, eliminate dB/dt in phase direction and reduce eddy current and motion artifacts associated with phase gradient pulses. The TRASE method offers many possibilities for novel k-space trajectories. Future research will include fast spin echo simulations and multi-Tx experimental implementation.

References: [1] T. Taves, et. al., "The SNR of Spiral Birdcage Coils", Proc. ISMRM, p.40, 2004. [2] J.C. Sharp, et al. Proc ISMRM p.1146 (2001).

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