Phase encoding without gradients using TRASE-FSE MRI

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Introduction

The development of fast MRI methods has focused on efficient single-shot or parallel acquisition of undersampled k-space trajectories. Recently, a new RF B1-field method of spatial encoding was introduced whereby k-space is traversed in the phase encoding direction without using magnetic field gradients, but by applying different B1-fields produced by a Tx-array, TRansmit Array Spatial Encoding (TRASE) [1]. Here we demonstrate a new TRASE-FSE method that accomplishes complete phase encoding with only two different transmit B1-fields, by MRI simulation as well as first experimental evidence using a switched 2-channel transmit array system.

Theory

If an array of Tx-elements are driven to produce a B1-phase variation along a particular direction, associated with a particular spatial harmonic of the form, $T_t(\mathrm{r}) = T_0 e^{i(2\pi t \Delta \mathbf{k}_t \cdot \mathbf{r})}$, then the NMR signal becomes spatially encoded by the transmit B1-field. If two elements of a Tx-array produce a B1-phase variation of $+\phi$ and $-\phi$ respectively over some distance in the phase encoding direction, a phase-difference of $\Delta\phi = 2\phi$ exists. Consider a single shot TRASE-FSE sequence with an echo train (N_{echoes}): $90^1 - 180^1 - 180^2 - 180^1 - 180^2 \ldots$ with no phase encode gradients applied. The 90° RF pulse applied with array-1, excites magnetization with encoded phase variation of $+\phi$ along the phase encode direction. The 180° pulse reflects the magnetization phase to $-\phi$ and adds an additional phase of $+2\phi$ (-2ϕ for array-2). Hence, data is acquired with successive phase jumps 4ϕ or $2\Delta\phi$. Applying the Nyquist condition, the spatial distance over which the two Tx-arrays produces a phase difference $\Delta\phi = \pi$, is the FOV over which an object can exist, to produce a single shot TRASE-FSE unaliased image. Defining this spatial distance (where $\Delta\phi = \pi$) as FOV_{shot}, the FOV per shot, then resolution $\Delta r_{TRASE} = FOV_{shot} / N_{echoes}$, and per shot $\Delta k_{shot} = 2\pi / FOV_{shot}$. To increase the FOV by N-fold, N_{shots}-shots are required, with a corresponding k-space shift, $+\Delta k_{shot} / N_{shots}$, in general accomplished with a pre-phase gradient. But a 2-shot, 2x-FOV, TRASE-FSE image can be obtained if for the second shot, the order of the RF pulse train is reversed to: $90^2 - 180^2 - 180^1 - 180^2 - 180^1 \ldots$

Methods/Results

A Bloch equation MRI simulation (T1=1sec,T2=75msec) of the TRASE-FSE method using a +2pi and a –2pi coil pair with uniform magnitude and linear phase distributions, which requires 4-shots for complete k-space sampling (*Fig.1a*), is compared to a standard 4-shot FSE image (*Fig.1b*). For experiments, two 10cm diameter, 25cm long, 300 MHz spiral birdcage coils were constructed, one with a 15cm $+\pi$ and the other a 15cm $-\pi$ phase distribution along the z-axis (*Fig.1c*). The phase difference ($\Delta\phi$) distribution was mapped (*Fig.1d*) by calculating the phase of the ratio of two separate gradient echo images, each obtained using a different Tx-coil. A low flip angle GE image from each coil was used to estimate each coils B1-magnitude distribution (*Fig.1e*). The simulation was repeated using these phase and magnitude distributions (*Fig.2d*). With a 4.5 cm diameter ping-pong ball saline phantom, a 32 echo train FSE image was acquired using only one transmitting coil: $90^1 - 180^1 - 180^1 - 180^1 - 180^1 \ldots$ first with normal phase encoding (*Fig.2a*), second without phase encoding (*Fig.2b*) and finally repeated where the $90^1 - 180^1 - 180^2 - 180^1 - 180^2 \ldots$ TRASE-FSE scheme was implemented by switching between the two spiral birdcage coils during transmission (*Fig.2c*).

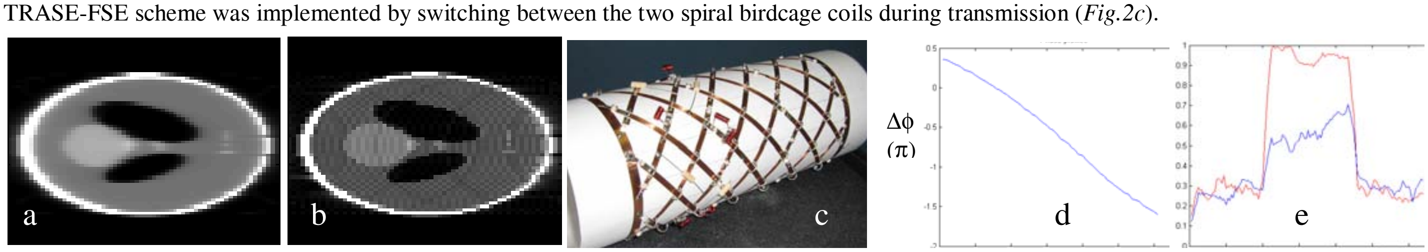

Fig. 1: MRI simulation (4-shots, T1=1s, T2=75msec) using (a) TRASE-FSE and a $\pm 2\pi$ coil pair; (b) standard FSE. (c) Constructed $+\pi$ and $-\pi$ two channel array. (d) B1 phase-difference map in units of π shows a $\Delta\phi = 2\pi$ over 15cm and FOV_{shot}= 7.5 cm. (e) B1 magnitude maps of two coils within ping-pong sample.

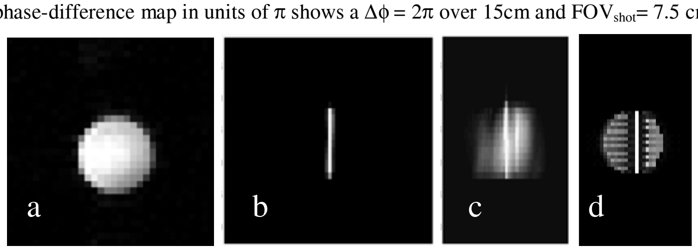

Fig. 2: Standard 1-shot, 32 echo, 15cm x 15cm FOV FSE image using $+\pi$ coil; (a) with phase encoding on, and (b) with phase encoding turned off. (c) Again with phase encoding turned off, but using the TRASE-FSE method $90^1 - 180^1 - 180^2 - 180^1 - 180^2 \ldots$ by switching between the two spiral birdcage coils during transmission. Notice that this phase-direction 1-shot FOV ~ 7.5cm. (d) Simulation of the same TRASE-FSE using the same B1 magnitude profiles shown in *Fig.1e*

Discussion/Conclusions

Using only two different B1-fields, with uniform magnitude and linear phase distributions, TRASE-FSE produces nice images (*Fig. 1a*) very comparable to images obtained using standard gradient encoding (*Fig. 1b*). The FOV relationship described is also shown in these results, as 4-shots are required for an object occupying the entire volume of a $\pm 2\pi$ coil pair ($\Delta\phi = 4\pi$), where FOV_{shot} = ¼ coil length. Although the first experimental image is not very good, this can be expected from using such an inhomogenous B1-field distribution (*Fig.2d)*, where it was found that B1-magnitude homogeneity and proper Tx-power scaling are the key to obtaining nice images. At these high field strengths, it is obvious that B1-shimming will be required, and the TRASE technique is better suited for lower frequency applications. The TRASE method offers many possibilities for novel 1D, 2D, or 3D k-space encoding trajectories, but the same method can also be used for any k-space excitation trajectory [2,3]. Future research will include multi-Transmitter experimental implementation and extension of the TRASE method to 2D spatial encoding as well as slice selection.

References: [1] S.B. King, et. al. Proc. ISMRM, p.2628, 2006. [2] J. Pauly, et al. JMR81:43-56(1989), [3] C.J. Hardy et al., JMR82:647-654(1989) .

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