High Resolution 2D Imaging without Gradients with Accelerated TRASE

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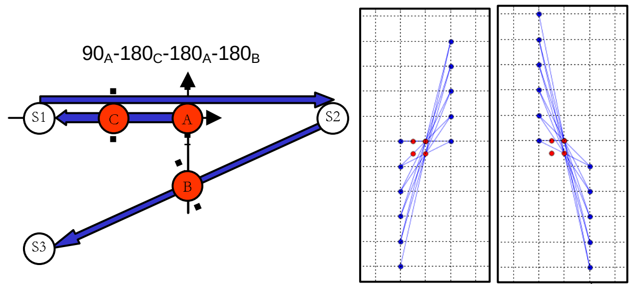
Introduction: A large fraction of the costs incurred by MR systems are due to the gradient system (including amplifiers, filters, cables, coils). We are developing a k-space based RF imaging method that produces high resolution images without the need for a gradient system. We present here the extension of the TRASE (Transmit Spatial Encoding) method to 2D imaging, including an acceleration approach. TRASE replaces the role of a gradient in resonant frequency with gradients of B1 phase. We have previously demonstrated one dimensional 1D encoding using the TRASE method (1,2). Slice selection with TRASE is discussed elsewhere.

K-Space Traversal by TRASE: TRASE is based upon an array RF coils, each with uniform B1 magnitude, but different linear B1 phase gradients. Let us assign a k value, k_C, to each coil, equal to the number of cycles/mm of the phase gradient, thus $k_C = G_C /360$, where G_C is the phase gradient in deg/mm. We term this the *"k-space origin"* of the coil. The effect of excitation with a coil A is the creation of magnetization at the coil k-space origin k_C^A. Likewise, the effect of refocusing with coil A is a jump about its k-space origin, k_C^A. Coil origins are represented by red dots (labeled A,B,C) in the diagrams (left). In the first panel a 4-pulse sequence is shown. In the second panel this sequence is extended with 4 more A-B refocusing pairs. In the third panel the identical sequence, but with AB replaced by BA is shown. Taken together these two trajectories map out two lines in k-space.

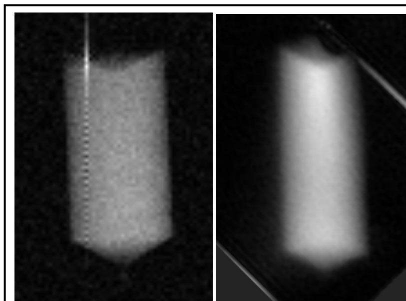


Extending this process to refocusing sequences of the form $C\text{-}(AC)_N\text{-}(AB)_M$ and $C\text{-}(AC)_N\text{-}(BA)_M$ allows the mapping of full 2D k-space. By use of a 4th coil this is generalizable to 3D.

In general for a coil pair, successive refocusing pulses applied alternately to two coils A & B move excited magnetization in k-space along an encoding access defined (in both direction and magnitude) by $(k_C^A - k_C^B)$. A train of alternating refocusing pulses (i.e. ABAB…) then serves to produce a k-space traversal, with a spatial resolution proportional to echo train length. For an AB train of N pulses using a pair of fields with k values +/- k_C, the maximum k-value is $4Nk_C$. The FOV (aliasing period) is given by the reciprocal of the k-space point separation, which in the simplest 1D 2-coil case is $1/4k_C$. FOV shift is achieved by shift of coil origin(s) in real space by applying a phase shift to all RF pulses using the coil of G.dx for a spatial shift of dx along G.

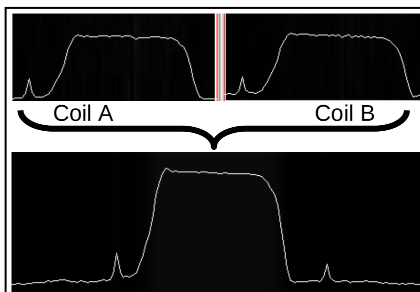
Experimental Results: Experiments were performed using a 0.2 Tesla open MRI system controlled by an NRC TMX MRI console (3). An array of 3 RF coils was used consisting of two spiral birdcage coils (1.25deg/mm) and one crossed Helmholtz-Maxwell combination coil (1 deg/mm). Coils were selected and enabled sequentially under pulse sequence control by use of PIN diode networks. A single transmitter channel and a single receive channel were used for all experiments. The phantom was a 25mm syringe filled with water to a length of 50mm. All experimental implementations were verified by integrated simulation utilizing the TMX console software (3). Shown left are two projection images (no slice selection): a conventional SE sequence (*left*) (128x128, BW=10kHz, TR=1s, TE=18ms), and 2D TRASE (*right*) (800us square refocusing pulses; 128x128, 5ms echo spacing, TR=1s, BWeff=3.3kHz).

Images are very similar, with the TRASE RF image exhibiting higher SNR, (due to the lower effective bandwidth), and some blurring, mainly due to T2 loss during the echo train. The acceleration process described next offers a way to reduce the echo train length (ETL).



SE (Freq) TRASE (RF)

Receive Coil Serial k-Space Acceleration: By making use of the phase gradient coil array in receive mode k-space traversal can be accelerated, allowing shorter echo trains. All coils in the array are volume coils with uniform magnitudes but unique phase gradients. Note that a signal received with a phase gradient coil is referenced to that coil's k-space origin. Thus for example spins that are fully in-phase, yet detected by a phase gradient coil will appear as off-center in k-space. So for an array of N_C phase gradient coils, at any given point in the pulse sequence we may rapidly switch between them to acquire N_C distinct k-space data points. We refer to this as "*serial acceleration*" (single receiver channel) to distinguish it from parallel acceleration techniques. This is of considerable practical benefit in TRASE experiments in allowing echo train lengths to be reduced and/or improved k-space coverage. The acceleration is demonstrated experimentally (*left*), where 1D data acquired from coils A & B are interleaved in k-space to double the FOV. The acceleration doubles the k-space density and the FOV (aliasing period) relative to reception with a single coil only. Artifacts at the edge of the original FOV are visible in 1D and 2D results.



Data combined to double FOV

From an SNR point of view, serial coil switching is analogous to k-space traversal using a frequency gradient: a stronger gradient results in more k-space data points, acquired at higher bandwidth (and lower SNR per point). Similarly, coil switching also corresponds to more data points acquired at higher bandwidth and lower SNR per point. Accelerated SNR will also depend upon the individual coil sensitivities. Since only one coil is active at a time, coupling between coils is not an issue – unlike for parallel methods using simultaneous acquisition on multiple receive channels.

For N_C receiver coils, N_C signals may be measured. From these an additional N_C signals can be generated using k-space symmetry, however for signals within an echo train two of these will be the same as the previous and following echo so are not unique. The maximum acceleration available is therefore 2 for N_C=2 and ($2N_C$-2) for NC>2. So for example for a 1D readout using 3 coils (+X, -X, uniform) 4 signals are available per refocusing pulse (i.e. 128 signals in 32 echoes). For an array of 7 coils (+/- X,Y,Z and uniform) 12 signals are potentially available per pulse (384 in 32 echoes).

Conclusions: We have introduced a new RF-only method which requires neither resonant frequency gradients nor shaped RF pulses. The combination of 2D, 3D and acceleration techniques requiring simple electronics (single transmit channel, single receive channel and a switchable coil array) offers exciting opportunities for low cost MRI and other applications.

References: 1) S.B. King, , P. Latta, V. Volotovskyy, J.C. Sharp, B. Tomanek, ISMRM p.680 May 2007; **(2)** S. B. King, D. Yin, S. Thingvold, J.C. Sharp, B. Tomanek, ISMRM, Seattle, p.2628 2006; **(3)** J. Sharp, D. Yin, R. Tyson, K. Lo, B. Tomanek, ISMRM, Seattle, p.1351 2006;

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