

MULTIDIMENSIONAL PULSES BASED ON SPATIOTEMPORAL ENCODING CONCEPTS

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Introduction:

Multidimensional (nD) pulses have a variety of potential applications, including reduced field of view imaging and localised spectroscopy in arbitrarily shaped voxels. The design of nD pulses generally relies on the concept of excitation k-space [1] –intimately related to the single-shot “k-space walk” underlying EPI. Recently, an alternative approach to single-shot MRI has been introduced, in which images are acquired in direct rather than reciprocal space. This *spatiotemporal encoding* (SPEN) mode relies on a sequential rather than simultaneous excitation of the spins and, in its fast imaging mode, has been found to provide a high robustness against field inhomogeneity and susceptibility effects [2-4].

Here we introduce a class of nD pulses that relies on SPEN concepts to shape the spins’ excitation. In particular, we design 2D pulses that operate in a *hybrid direct and reciprocal space*. These “hybrid” 2D pulses can be made compatible with either SPEN MRI or, in combination with a refocusing chirp pulse, with conventional, k-space based Fourier MRI. A self-unfolding mechanism then makes it possible to suppress the contribution of excitation sidebands, in a single shot and even when these overlap with the targeted region of interest. Aspects deriving from this mechanism will be presented.

Methods:

Hybrid 2D pulses are designed in two steps [5]. First, a linearly frequency-swept (chirp) pulse, is replaced by a series of square subpulses, the phase and amplitude of which sample the continuous version but appear interleaved with gradient blips. Second, each square subpulse is replaced by a shaped, selective pulse and by an oscillating gradient waveform, played in an orthogonal dimension. The resulting pulse operates in a 2D hybrid direct/reciprocal space, as illustrated in Fig. 1a. The discretisation process associated with the chirp pulse results in a series of periodic excitation sidebands along the “slow”, direct dimension. These sidebands overlap with the region of interest if the pulse’s time-bandwidth product exceeds the number of subpulses. This is akin to what is known in conventional 2D RF pulses executed using a Cartesian trajectory [6]; a way of avoiding this complication that is unique to the SPEN-based approach is shown below.

Experiments were performed at 7T on a Varian VNMRS 300/89 vertical microimaging system (Varian associates, Palo Alto, CA) using a Millipede® probe, with a phantom consisting of a tube of 22 mm diameter filled with water.

Single-shot hybrid SPEN images were obtained after excitation by a hybrid 2D pulse. A super-resolution algorithm [7] was used for reconstruction in the SPEN dimension and Fourier transformation was used in the conventional dimension. 64 x 64 points were acquired with a field of view of 2.5 x 2 cm².

Spin-echo images were obtained after the combination of a hybrid 2D pulse and a continuous refocusing chirp pulse. An additional refocusing pulse was used for slice selection. The pair of frequency-swept pulses was set to remove non-linear contributions to the phase [8]. The sequential excitation of the spins results in a band-dependent linear phase. When the region of interest and the excitation sidebands overlap, each band forms a separate echo during acquisition provided that the overall excitation is small enough to remain in the linear regime. 256 x 64 points were acquired for a field of view of 2.5 x 2.5 cm²; 64 x 64 points centered around the echo of interested were filtered, zero-filled to 128 x 128 and Fourier transformed.

Pulse generation and image processing were done offline using Matlab® (The Mathworks, Natick, MA).

Results and discussion:

Phantom experiments illustrate the possibility to excite selectively a 2D region of interest that could not be obtained as the intersection of two slices, as shown in Fig. 1b. As the excitation pulse operates in direct rather than reciprocal space, no Fourier transformation is used in the slow dimension to generate the RF pulse. When a continuous refocusing chirp pulse is used after the hybrid 2D pulse, a conventional spin echo image is obtained, as shown in Fig. 2. The region of interest can be recovered despite the fact that excitation sidebands overlap with the centerband. As a result of this self-unfolding property, a stronger gradient can be used in the slow dimension and the shape excited by a hybrid 2D pulse is less distorted by field inhomogeneity than the shape excited by a conventional, Fourier 2D pulse.

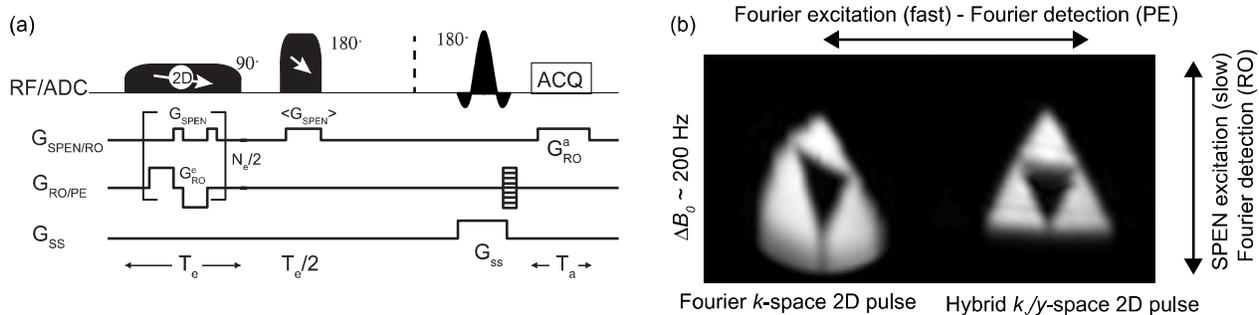


Fig. 2: (a) Pulse sequence that illustrates the use of hybrid 2D pulses for Fourier imaging. The frequency swept refocusing pulse removes the quadratic phase introduced by the hybrid 2D pulse. A linear-phase refocusing pulse is used for slice selection. (b) Comparison between a Fourier 2D pulse and a hybrid 2D pulse for the selective excitation of a region of interest in inhomogeneous fields. The gradient in the slow dimension is 4 times more intense for the hybrid 2D pulse and a self-unfolding mechanism is used to retrieve the region of interest.

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