2D Composite Pulses: A novel method for spatially selective excitation

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Introduction: 2D selective RF pulses have been introduced already in the early days of MRI to excite any spatial pattern within the field of view [1]. However, the typical pulse durations made multi dimensional excitations prone to artifacts and hindered a wide spread use in routine MRI. Parallel transmit is capable to accelerate multi dimensional RF pulses [2]. A promising application is the so called zoomed imaging. The field of excitation (FOX) is reduced to speed up the spatial encoding and image acquisition of a smaller field of view. However, despite the acceleration capabilities of parallel transmit ,excitation fidelity and sharpness of the inner volume excitation is still limited by the sparse k-space sampling during the RF pulse. Applying conventional 1D slice selection based on a limited frequency bandwidth of the RF pulse along with a slice selection gradient seem to have some advantages over 2D selective pulses regarding slice definition and background suppression. The idea of this study is to transfer these qualities of a 1D slice selective RF pulse to a 2D selective excitation. Therefore, a small number of slice-selective RF pulses are concatenated with alternating gradient directions to form a 2D composite pulse. A non-linear solver is used to optimize amplitude and phase of each sub-pulse to excite only the intersection of the created magnetization of all sub-pulses and suppress anything else.

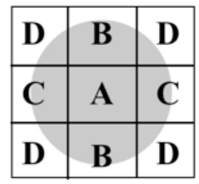

Fig 1: Schematic field of view segmented into 4 areas

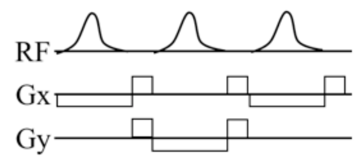

Fig 2: Sequence diagram of a 2D composite pulse

Methods: The basic idea of the proposed method is to consider as a reduced FOX the overlap of two non-parallel (typically orthogonal) slabs. In a series of RF pulses either slab can be selectively excited by conventional means of applying an RF pulse of limited frequency bandwidth along with a slice selection gradient. This divides the total FOV into 4 different areas as shown in Fig. 1. The FOX (area A) is excited by each RF pulse. Areas B and C are excited only when selecting the corresponding slap. Area D is never excited. This excitation scheme translates into a sequence diagram as shown in Fig. 2. The total RF pulse consists of several concatenated slice-selective RF pulses with alternating gradients in x and y direction and is therefore called a 2D composite RF pulse. In each area, these pulses are similar to composite pulses for parallel transmission [3].
The target of the pulse design is then to find optimal magnetization trajectories on the Bloch sphere for the different areas such that the magnetization in area A is excited by the target flip angle and the flip angle of the magnetization in the areas in B and C is zero. Area D doesn't need to be considered, as it is never excited during the 2D composite pulse. This problem can be modeled by providing two sets of flip-angle maps to a pulse design algorithm. For each set the measured B1+ maps of the total FOV are weighted with the known slice profile along the x and y gradient directions correspondingly. That way, the details of the gradient trajectory and the pulse shape of each sub-pulse does not need to be modeled explicitly in the optimization routine. For the different sub-pulses, the solver then uses the corresponding flip-angle maps to flip the magnetization on the Bloch sphere with the correct spatial distribution. The algorithm to optimize the 2D spatial selective composite RF pulses is based on a non-linear pulse design method we presented earlier [4] which uses the Levenberg-Marquardt algorithm for non-linear systems of equations. B1+ maps of a water phantom were measured on a 7T human scanner equipped with an 8 channel transmit array (Siemens Healthcare, Erlangen, Germany). The phantom has a conductivity similar to the human head.

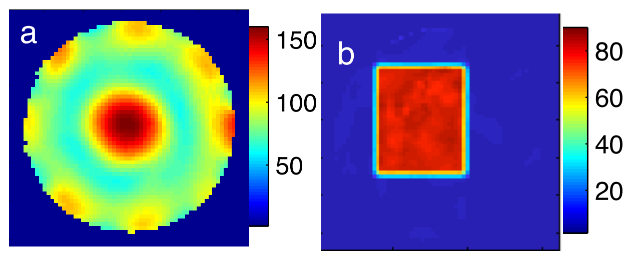

Fig 3: Flip-angle distribution in degrees created by an RF shimmed excitation pulse (a) and a 2D composite pulse for spatial selective excitation (b)

Results: In figure 2, the flip-angle distribution created by an RF shimmed pulse (a) and a spatial selective 2D composite pulse (b) is shown for a phantom. The RF shimmed pulse creates a flip-angle distribution with a peak-to-trough ratio of 2.5:1. The spatial selective composite pulse excites a rectangular region of interest with a flip-angle of 90° and a standard deviation of 3°. The peak flip-angle in the background is 4°, the mean flip-angle in this area is 1.2° and the standard deviation is 0.7°. The background was weighted 15 times higher than the excited area in the optimization procedure to increase background suppression. The steepness of the transition area is mostly defined by the slice profiles of the sub-pulses. The total pulse length was 6ms. The optimization took approximately 10s using a Matlab only prototype implementation. The shown flip-angle distributions were obtained by simulating the full Bloch equations for the designed RF pulses and gradient shapes with measured B1+ maps.

Conclusion: We presented a novel method to create a spatial selective excitation on a transmit array using 2D composite pulses. They consist of several slice-selective sub-pulses with alternating gradient directions. Using only four sub-pulses a very good 90° excitation homogeneity was achieved in the field of excitation and an excellent background suppression outside. Especially in area D (see figure 1a) where no sub-pulse creates magnetization, signal is suppressed as good and robust as when using a conventional slice-selective excitation. The steepness of the transition band is also defined by the underlying slice-selective pulses and is not limited by sparse k-space sampling as it is known from spatial selective excitation using EPI gradient trajectories. Furthermore, the excitation shape is not limited to a rectangular shape but can also be a diamond shape depending on the angle between the used gradient directions. As the proposed pulses rely on highly non-linear magnetization trajectories on the Bloch sphere, a non-linear solver for the pulse design is key to design such 2D selective composite RF pulses.

References: [1] Pauly et al. MRM 81:43-56 (1989), [2] Katscher et al. MRM 49:144-150 (2003), [3] Collins et al. MRM 57:470-474 (2007), [4] Gumbrecht et al. ISMRM 2010, 101