Ultra-short 2D RF pulse for reduced field-of-view SSFP imaging

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Introduction:

2drf pulses have been used for reduced field-of-view (rFOV) imaging to spatially select an ROI and thereby shorten the scan time by reducing the number of phases. In order to achieve an rFOV excitation without aliasing artifact, high sampling density and long pulse duration are required. The long duration not only makes the pulse sensitive to field inhomogeneity and tissue susceptibility, it also restricts its application for some fast sequences such as balanced SSFP where short TE and TR are critical. Although parallel excitation has been introduced to reduce spatially selective RF pulse duration, this requires delicate and expensive transmit arrays, which are still not available for commercial clinical systems. In our work, we implemented ultra-short 2drf pulses for SSFP imaging in a reduced FOV. The 2drf pulse is played out concurrently with both gradient ramps and plateaus to enhance the time efficiency, and the RF amplitude is weighted in proportion to the gradient amplitude.

Methods and Results:

The small-tip-angle model shown in Eq. (1) [1] is used for the 2drf pulse design. The B1 weighting function W(k) is dependent on the gradient

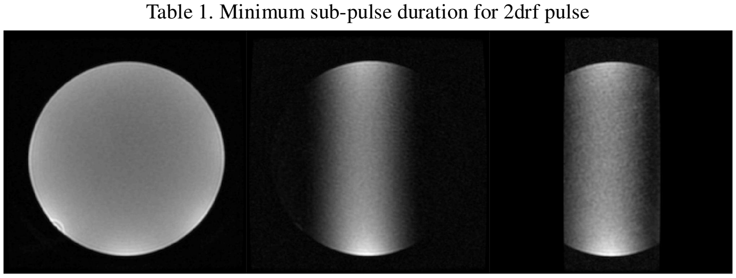
$$M_{xy}(r) = i\gamma M_0 \int W(k)S(k)\exp(ir\cdot k)dk \quad \text{with} \quad k(t) = -\gamma\int_t^T G(s)ds \tag{1}$$

G(t) by W(k(t)=B1(t)/|γG(t)|. A trapezoidal gradient is employed with maximum gradient slew rate. B1(t) and G(t) are both appropriately time-stretched to keep the same slice thickness. Amplitudes for each sub-pulse are modulated by a sinc function envelope, and scaled according to the duration and amplitudes of the original RF pulse to ensure the same flip angle is excited. Due to the discrete sampling along the phase encoding (PE) direction, periodical side excitations appear along the PE direction. Therefore, the FOV reduction achievable without aliasing is dependent on the sampling density.

The ultra-short 2drf pulse has been tested for rFOV imaging on GE 1.5T and 3T Signa scanners with maximum slew rate of 150T/m/s and maximum gradient strength of 4G/cm. The minimum sub-pulse duration of the 2drf pulse as a function of slice thickness is listed in Table 1. By taking the advantage of the ultra-short sub-pulse duration, very sharp transition edge and large side excitation distance could be achieved to significantly improve the rFOV performance. A 2.5x acceleration factor has been successfully demonstrated, as shown in Fig.2, by the use of this 2drf pulse (5 sub-pulses, each 420us, 0.5cycle sinc-type envelope) for modified GE FIESTA sequence with imaging parameters of TE/TR =2.4/4.5ms, Matrix=128^2, FOV=21cm and slice thickness=8mm. The scan time in this case is significantly reduced from 0.65s to about 0.26s for rFOV FIESTA.

Slice thickness(mm)	3	5	6	8	10
Min duration (us)	536	504	464	416	384

Table 1. Minimum sub-pulse duration for 2drf pulse



(a) Normal b-SSFP without 2drf phasefov=1 (b) 2drf exicitation phasefov=1 (c) 2drf exicitation phasefov=0.4

Fig.1. Reduced field-of view imaging by 2drf pulse for b-SSFP sequence

Discussion:

The minimum TE and TR increase due to the use of the 2drf pulse. The minimum TR increases by the increase in pulse width which is (N-1)*pw, where N is equal to the number of sub-pulses and pw is the sub-pulse duration. The minimum TE increases by half this amount. Thus, for a 3-subpulse 2drf pulse used for a 10mm Gaussian slice and a Gaussian-like profile in the PE direction, the increase in minimum TR is only (3-1)*384 = 768usec. With this 2drf pulse, the FOV can be reduced by a factor of about 2 in the PE direction without aliasing. Thus, the acceleration is still significant even when the increased TR is considered. Although we only demonstrate the 2drf pulse for balanced SSFP here, the pulse could be useful for other fast sequences like single shot FSE and EPI. The 2drf excitation can be combined with other methods such as UNFOLD [2] and parallel imaging [3] to further reduce scan time. In additional to rFOV imaging, the 2drf pulses can also be used for spatial-spectral selection and line scan imaging. We are applying this technology for applications in image-guided therapy such as real-time catheter tracking, focused ultrasound temperature mapping, and biopsy needle detection.

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References:

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