Design of Large-Flip-Angle Half Pulses

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Introduction: Slice-selective half pulse excitations use two RF pulses to define a slice [1]. Each pulse is half of a conventional slice-selective pulse, but is applied with an opposite gradient polarity. When combined with radial acquisition gradients, half pulses allow imaging of very short T2 tissues, such as cortical bone or tendons [2]. These pulses have been designed as half of a conventional small-tip-angle slice selective excitation. This works well for small tip angles, but the slice profiles degrade at 90°. Recent work using the inverse scattering transform has shown that high performance half pulses can be designed [3]. Here we show that these pulses can also be designed using the Shinnar-Le Roux (SLR) pulse design algorithm [4].

Methods and Results: An example of a RF half pulse based on a conventional small-tip-angle conventional pulse is shown in Fig. 1a. This is based on a time-bandwidth (TBW) 8 windowed sinc RF pulse. At 30° (b) the M_y component has the desired profile. The M_x component is suppressed when the two profiles with opposite gradients are combined. At 90° the M_y profile has degraded. It is less selecitive, and has undesirable sidelobes.

The SLR pulse design algorithm allows the design of large-flip-angle slice selective pulses based on the design of two polynomials that define the rotation, α and β [4]. The β polynomial is designed first, and determines the slice profile. The α polynomial is then chosen to be consistant and minimum power. The inverse SLR transform then produces the RF pulse. It has been difficult to apply this approach to large-flip-angle half pulses, because only the retained M_y component of the magnetization is specified. It isn't clear how to specify the suppressed M_x, which would determine β .

The recent paper on designing half pulses using inverse scattering transform [3] provided the key insight. When a small tip angle pulse is used as the basis (β) for a 180° pulse, there are several characteristic changes. The zero spacing become non-uniform, the mainlobe is narrowed by factor of two, and the peak amplitude increases substantially. The half pulses in [3] have these characteristics. This indicated that 90° half pulses could be designed as half of a 180° SLR pulse. This in fact is true, and works well.

An example is shown in Fig. 2. The TBW 8 windowed sinc pulse that was the basis of the half pulse in Fig. 1 was scaled and used as the β polynomial for a 180° pulse. The first half was then used as a 90° half pulse, Fig. 2a. The slice profile, Fig. 2b, is very close in shape to the small-tip-angle profile of Fig. 1b, with none of the degradation seen in Fig. 1c. Note that the main lobe of the RF pulse is much narrower. In addition, scaling the pulse of Fig. 1a to 90° would require a peak B_1 of 1 kHz, while the pulse in Fig. 2 requires almost twice that. These are as expected from [3].

The higher peak B_1 is less of a problem than it might appear. Half pulses are always applied with a trapezoidal gradient that is ramping down to zero at the end of the pulse. The RF pulse must be compensated for the time varying gradient using VERSE [5], and this substantially reduces the peak amplitude, as is shown in Fig 2c. We have assumed a 20 mT/m gradient, and a slew rate of 40 T/m/s. The peak B_1 is now less than the 1 kHz we can achieve with a head coil on our 1.5T GE Signa.

Discussion: Large-tip 90° half pulses can easily be designed with the SLR algorithm by first designing a small-tip angle pulse, and then using it as the basis for a 180° pulse. This results in very good slice profiles, but much higher peak power. However, after compensation for the trapezoidal slice select gradient, the peak power is within the limits of typical commercial scanners.

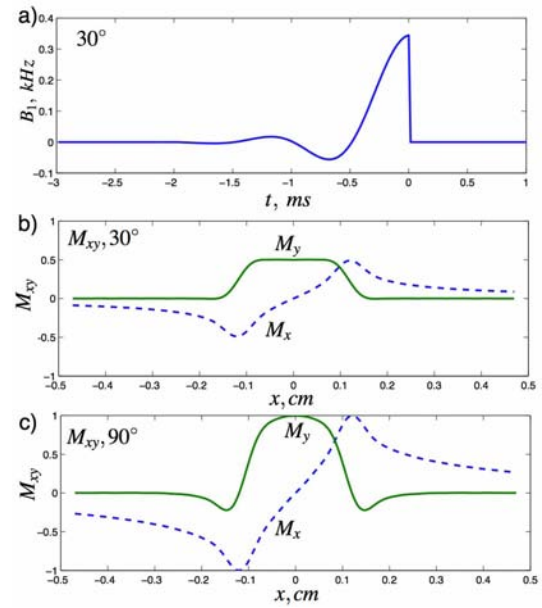

Figure 1: RF half pulse based on a TBW 8 windowed sinc small-tip-angle pulse (a). This performs well at 30°, but degrades at 90°. Note that the M_y components add when the two profiiles with opposite gradients are added, and the M_x profile is cancelled.

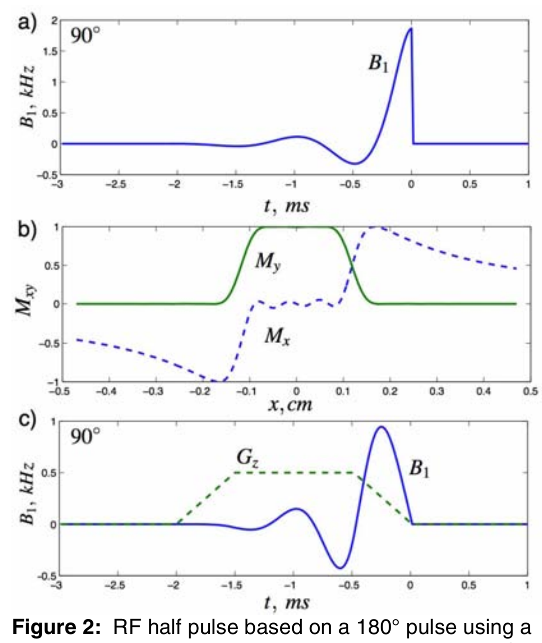

Figure 2: RF half pulse based on a 180° pulse using a TBW 8 windowed sinc as the beta polynomial in the SLR design (a). The pulse works very well at 90° (b). The peak power is increased significantly, but this is reduced when compensating for the trapezoidal slice-select gradient (c).

References: [1] Pauly *et al*, Proc. 8th SMRM, 28, 1989. [2] Gatehouse *et al*, Cl. Rad. 58:1-19, 2003 [3] Maglund and Epstein, JMR, 171(2):305-313. [4] Pauly, et al. IEEE TMI 10(1):53-65, 1991. [5] Conolly *et al.,* Magn Reson Med 1991; **18**: 28-38