Excitation of Variable-Phase Profile for Efficient Saturation

J. M. Santos[1], C. H. Cunningham[1], J. M. Pauly[1]

[1]Electrical Engineering, Stanford University, Stanford, California, United States

Introduction: In this abstract we present a method for designing RF pulses with diverse phase and magnitude profile characteristics as a function of spatial location. These pulses can be used for applications where short TR is required and the uneven characteristics can be exploited. Applications include perfusion imaging, time-of-flight angiography, and black blood imaging, among others.

Method: The SLR algorithm is a tool that enables design of RF pulses using traditional filter design techniques [1]. RF pulses traditionally are designed based on general phase properties, such as linear or minimum/maximum phase. The method presented here allows the design of mixed characteristic pulses for applications that require different phase and magnitude profiles. We have designed pulses with even and uneven magnitude profiles, as well as mixed minimum/maximum phase and linear phase bands. A slice selection gradient is chosen to refocus the linear portion of the profile.

Mixed linear-maximum phase: A pulse is designed such that part of its profile has linear phase, while other parts have maximum phase. First, a linear phase pulse is designed with relatively high time-bandwidth product. In the example a value of 17 was chosen. Once the profile has been designed, the roots of the transfer function are extracted. For the portions of the profile where a maximum phase characteristic is required, roots lying outside the unit circle are inverted so as to overlap the counterpart lying inside the circle (Fig.1) [2]. In this way, the portion of the profile with overlapping roots will present a maximum phase characteristic. In addition, this has the effect of distributing the RF energy between the linear phase and the maximum phase portions, thus allowing a reduced pulse duration [3]. For subject studies, a 3 ms version of the pulse was utilized. This pulse can be used for multislice saturation applications and for real-time steady-state perfusion. In the first case, sweeping the profile allows to image on a slice presaturated by the previous acquisition. In the second case, the RF profile is flipped every acquisition, thus two separate images are obtained where static material is saturated and incoming flow is enhanced depending on the direction of the flow.

Mixed maximum-linear-minimum phase: For black blood applications where incoming flow is to be suppressed, a 3.5 ms symmetric pulse with dual saturation bands was designed (Fig. 3(i)). The saturation bands were designed with opposing phase to obtain maximum dephasing of incoming flow.

Uneven magnitude: Additionally, using complex filter design algorithms, a 3 ms uneven and asymmetric profile pulse was designed (Fig. 3(ii)). As different locations experience different flip angles, this kind of pulse can be utilized in saturation-recovery sequences where the saturation profile is excited beyond 90 degrees to produce a slight inversion.

Results: Phantom studies were performed to demonstrate the profile of the pulses. Figure 2 shows the measured profiles for the linear-maximum phase pulse. Excellent correlation was achieved between the designed and measured profiles.

A subject study was performed with two different pulses and acquisition schemes. Figure 4(a) show an acquisition with a regular RF pulse. Figure 4(b) shows the same slice acquired using the symmetric pulse depicted in Fig. 3(i) for black blood applications. Figures 4(c) and (d) shows the venous and artery-enhanced portions of a real-time angiograph done by alternating the slice selection profile of figure 2. Figure 5 shows a carotid study using the alternating RF profile.

Conclusions: This work describes a method to design RF pulses with varying magnitude and phase profile. Phase and magnitude characteristics are designed independently with standard SLR techniques followed by phase manipulation. Single short pulses can be designed for applications that usually require separate pulses like black blood and saturation angiography.

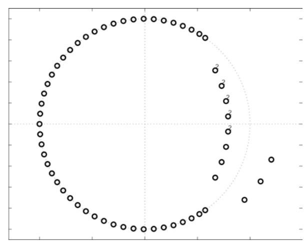

Figure 1: Transfer function of the slice profile

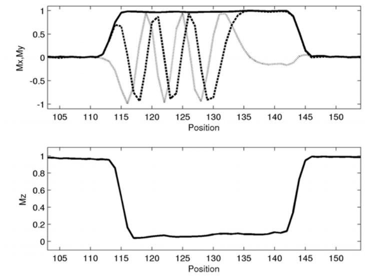

Figure 2: *Measured profile* for Mxy and Mz components

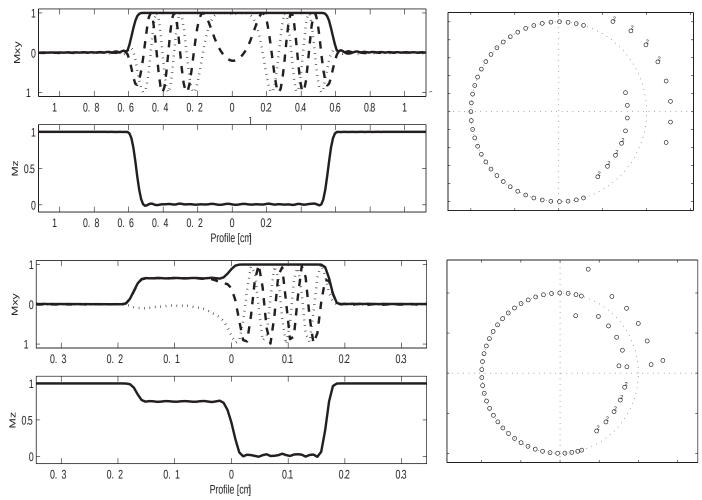

Figure 3: Alternative pulse designs (simulations). (i) Even magnitude, max-linear-min phase. (ii) Variable magnitude, linear-max phase.

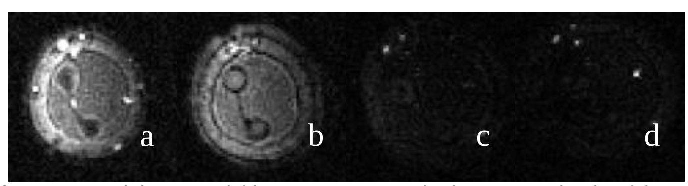

Figure 4: Real time acquisitions on an extremity for a normal pulse (a), double saturation band (b) and oscillating asymmetric pulse (c) and (d).

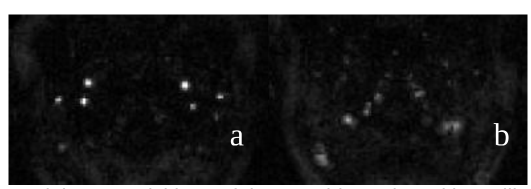

Figure 5: Real time acquisitions of the carotid arteries with oscillating asymmetric pulse. The images show slightly offset profiles and flow direction dependency. Both images were acquired in an interleaved fashion.

References: [1] Pauly, J. et al., IEEE TMI, 10, 53. 1991. [2] Pickup, S, et al. MRM 33(5):648-55, 1995 [3] Shinnar, M. MRM 32(5):658-60, 1994