RF pulses with built-in saturation sidebands

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INTRODUCTION Normally, the signal enhancement due to freshly magnetized blood flowing into the imaging slice is a desirable effect in MR angiography. However, when the goal is to detect the arrival of a bolus of gadolinium-DTPA, the signal variation due to in-flow is a source of uncertainty. This is a particular issue in applications such as auto-triggered MR angiography [1] where the statistics of the signal are used to automatically determine contrast arrival. RF saturation pulses can be applied adjacent to the imaging slice prior to each data acquisition to reduce in-flow enhancement, but this typically requires a longer TR and a loss in temporal resolution. Temporal resolution is an issue in applications such as intracranial MR angiography where the transit time from the arterial to the venous system is short and precise timing minimizes venous contamination. In this abstract we present the design and implementation of RF pulses that simultaneously excite a slice and de-phased saturation slabs, allowing a reduced TR.

THEORY The Shinnar-Le Roux (SLR) transform [2] maps the sampled RF pulse waveform to two polynomials, commonly called alpha and beta. The SLR transform is useful because beta is related to the excitation profile by the Fourier transform. Because of this linear relationship, the dual-purpose pulse described below can be created by designing separate beta-polynomials for a saturation pulse and an excitation pulse, and simply summing them together.

METHODS The beta-polynomial for the saturation bands was designed with the Parks-McLellen (PM) digital filter design algorithm using a time-bandwidth product (TB) of 8 and a linear-phase design. Non-linear phase was created across the saturation band by computing the complex roots of the beta-polynomial, and flipping a subset of the passbands roots across the unit circle [3]. The beta-polynomial for the slice excitation was designed with the PM algorithm using a TB of 3.5 and a minimum phase [2] design. These two beta-polynomials were then combined with the steps shown in Fig.1. The inverse SLR transform was then used to compute the RF pulses (see Fig.2).

The new RF pulses were implemented in an auto-triggered 3D MRA acquisition sequence [1] and compared to the conventional RF saturation method. Images of volunteers were acquired on a 1.5T GE Signa using a standard head coil. An axial slice containing the cavernous carotid arteries and some portion of the large dural venous sinuses was chosen in accordance with our clinical auto-triggered protocol. Saturation bands were turned on and off via a real-time interactive interface designed for the auto-triggered studies. The conventional saturation bands were achieved through the application of separate RF excitations and gradient spoilers for the superior and inferior bands followed by a standard gradient echo acquisition. With the new pulses, the excitation pulse was changed based on the desired saturation band(s), with the pulse-sequence timing unchanging. Saturation bands were applied every TR to achieve maximal blood suppression.

RESULTS The time to acquire each 256x128 image was measured and was approx. 0.8 sec/image without saturation bands (and with saturation bands using the new RF pulses). With the conventional saturation method, this increased to approx. 1.5 sec/image with one saturation pulse, and to 2.2 sec/image with both superior and inferior saturation bands. This corresponds to a 275% increase in temporal resolution using the new pulses. Also, for intracranial MRA where the transit time between arterial and venous systems is about 8s, this increase in temporal resolution will give up to 1.4s of extra imaging time. Signal levels from one of the cavernous carotid arteries and the large dural sinus are compared in table 1. We were able to achieve comparable levels of vascular signal suppression while avoiding the large increase in background signal levels that occurs with the conventional method due to increased TR.

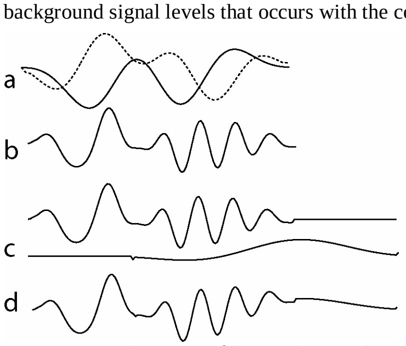

Figure 1: Combination of beta-polynomials. (a) Beta-polynomial for the sat band resulting from the root-flipping process. To move the sat band adjacent to the imaging slice, the beta-polynomial in (a) is modulated by a complex exponential, and the imaginary part is discarded (b). This creates two sat bands, one on either side of the imaging slice; for a pulse that excites only one sat band, the imaginary part is retained. The beta-polynomials for the sat band and the imaging slice are padded with zeros to further de-phase the sat band (c). Finally, the two polynomials in are summed (d).

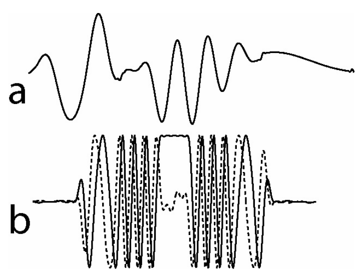

Figure 2: RF pulse with built-in saturation sidebands. (a) The RF waveform was 3.1ms in duration, with a peak amplitude of 25uT. (b) The profile excited by this pulse consists of a 5mm slice in the center, and de-phased saturation bands that extend +/- 16mm from the slice.

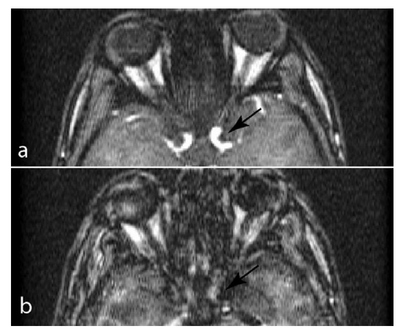

Figure 3: Performance of new saturation method. (a) With the saturation bands turned off, in-flow enhancement is seen in the cavernous carotid arteries (arrow). (b) With the saturation bands turned on, the signal in the carotid arteries is reduced. Some image degradation is seen, presumably due to contamination from the saturation bands.

	Artery	Vein	Tissue
New	35.9%	35.0%	87.2%
Old	38.1%	16.9%	137.5%

Table 1 - Signal levels following the application of superior and inferior RF saturation bands (percent of signal with no saturation). Note that incomplete (30-40%) saturation is desired so that same steady state is achieved in the monitoring sequence as in the high-resolution angiography sequence.

CONCLUSIONS We have designed and implemented new RF pulses with built-in saturation sidebands. We have demonstrated the concept with pulses designed for triggered Gd-MRA studies, but similar pulses may be useful for other applications such as peripheral angiography and coronary artery imaging. Using the new pulses afforded a 275% increase in temporal resolution. This will allow for more accurate detection of contrast arrival.

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