Preserving the Excitation Profile of Small Flip Angle RF Pulses in the Presence of Rapid T_2^* Relaxation

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Introduction Most RF pulses are designed without considering the effect of relaxation. The effect of longitudinal relaxation can be safely ignored in many situations. However, the integrity of RF pulses is often severely compromised by rapid transverse relaxation [1]. Degradation of excitation profile of RF pulses by rapid T_2*relaxation has been a long-standing concern, especially for long pulses such as multidimensional spatial pulses [2] and spatial-spectral pulses [3]. Although parallel transmission techniques can shorten multidimensional, spatially selective pulses [4] it would be highly desirable to preserve the frequency selectivity of RF pulses in the presence of rapid T_2* relaxation by pulse design. Here we introduce a fast transform, under the small flip angle approximation, to convert existing RF pulses into ones that preserve frequency selectivity in the presence of rapid T_2* relaxation.

Theory Under the small flip angle approximation, the Bloch equation incorporating T_2* relaxation is given by

$$\frac{dM_+(\mathbf{r},\Delta\omega,t)}{dt} = -\{i(\gamma\mathbf{G}(t)\bullet\mathbf{r}+\Delta\omega)+\frac{1}{T_2^*}\}M_+(\mathbf{r},\Delta\omega,t)+i\gamma B_{1+}(t)M_0 \qquad [1]$$

Where $M_+(\mathbf{r}, \Delta\omega, t) = M_x+iM_y$ with explicit dependence on position vector **r** and chemical shift $\Delta\omega$, $B_{1+} = B_{1x}+iB_{1y}$. Eq. [1] can be solved by integration over 0~T with the initial condition $M_+(\mathbf{r}, \Delta\omega, 0) = 0$:

$$M_+(\mathbf{r},\Delta\omega,T) = i\gamma M_0\int_0^T e^{(t-T)/T_2^*} B_{1+}(t) e^{\int_0^t i(\gamma\mathbf{G}(s)\bullet\mathbf{r}+\Delta\omega)ds} dt \qquad [2]$$

The same $M_+(\mathbf{r}, \Delta\omega, t)$ is obtained when

$$B_{1+}(t) = e^{(T-t)/T_2^*} B_{1+}(t, T_2^* = \infty) \qquad [3]$$

Eq. [3] is the desired transform that converts a small flip angle pulse designed without considering transverse relaxation ($B_{1+}(t, T_2^* = \infty)$) into one that produces the same $M_+(\mathbf{r}, \Delta\omega, t)$ in the presence of T_2*relaxation (under the small flip angle approximation). The excitation profile is a function of the T/T_2* ratio for the same RF waveform.

Results and Discussion Fig. 1 compares the waveform of a SINC pulse (blue) and its transform by Eq. [3] for T/T_2* = 4 (red). As expected from Eq. [3] the initial time points of the original waveform are the most accentuated while the end time points are mostly suppressed. Fig. 2 top row shows the result of Bloch simulation for T2*>>T. T = 40 ms. Flip angle = 45°. The middle row shows the degraded M_{xy} and M_z profiles for T/T_2* = 4 using the original SINC pulse. When the transformed RF waveform (Fig. 1, red, whose area is made the same as the original SINC pulse to avoid a *de facto* large flip angle) is used, the top hat profile of M_{xy} is preserved despite T/T_2* = 4. Outside the transition band, the magnetization deviates from its equilibrium position during the execution of a pulse. As a result, longitudinal magnetization outside and close to the transition bands cannot be fully preserved (see Fig. 2, bottom-right panel). Eq. [3] is expected to fail when the flip angle becomes large. It is, however, possible to incorporate T_2* relaxation into the design of large flip angle pulses that convert longitudinal magnetization into transverse magnetization with a top hat profile using FIR filter methods. The top hat M_{xy} profile in Fig. 2 (bottom left panel) remains preserved with a linear phase when the peak pulse amplitude is increased by up to ~50%.

References [1] Norris et al, JMR, 92, 94 (1991). [2] Pauly et al, JMR, 81, 43 (1989). [3] Meyer et al, MRM, 15, 287 (1990). [4] Katscher et al, NMR Biomed, 19, 393, 2006.