Amplitude-modulated continuous wave excitation
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TARGET AUDIENCE Researchers with an interest in continuous wave RF excitation.

PURPOSE There is renewed interest in continuous wave (CW) excitation for imaging samples with very short T2 times. CW techniques such as stochastic MRI and SWIFT have assumed that the spin system can be treated in a linear time-invariant framework, a valid assumption under certain conditions. Motivated by work in optics, it is our aim here to investigate the nonlinear interactions revealed by the use of amplitude modulated CW excitation. We demonstrate novel magnetization behavior not previously observed in magnetic resonance systems.

THEORY The spin system is excited with an RF field rotating at the Larmor frequency with an amplitude envelope given by $A(t) = A_0 + \alpha \cos(\omega_m t)$ where $\omega_1$ is the average Larmor frequency, $\alpha$ is the modulation factor and $\omega_m$ the modulation frequency. A solution to the Bloch equations was derived for $\omega_1 = \omega_m$ using averaging techniques. The transverse components of the steady-state magnetization are $m_y(t) = 0$ and

$$m_x(t) = A \sin(\omega_m t + \alpha \cos(\omega_m t)) \quad \text{where} \quad A = \frac{-2R_1 f_j(\alpha)}{R_2 + R_1 j_2(2\alpha)(R_2 - R_1)}$$

(1)

$R_1$ and $R_2$ are longitudinal and transverse relaxation rates, respectively, and $f_j$ is the $j$th order Bessel function of the first kind. Eq. (1) can be written as a Fourier series to emphasize the frequency components contributing to the observable magnetization.

$$m_x(t) = A \sum_{k=1}^{\infty} a_k \sin(k \omega_m t) \quad \text{where} \quad a_k = f_{k-1}(\alpha) - f_{k-1}(\alpha)$$

(2)

METHODS Experiments were performed with a spherical phantom of Gd-doped water ($T_1=342$ms, $T_2=139$ms) on a 4.7T Bruker BioSpec small bore MRL scanner. The steady state magnetization was measured using a series of FID experiments as follows. The sample was excited with an amplitude-modulated envelope for an initial duration of 2$s$. Immediately after the excitation an FID was acquired and the first point was extracted to reflect the state of the magnetization at that time. This process was repeated for 600 FIDs each following an excitation for 250$\mu$s longer than the previous excitation to accurately track the magnetization for 150ms. This proof-of-concept technique was implemented without additional hardware. A spectrum was obtained by a DFT of the signal waveform. The first experiment excited with $\alpha = 1$ and $\omega_m = 500$Hz. A second experiment excited with amplitudes defined by $\alpha_1$ ranging from 0 and 150Hz in 2Hz increments for a fixed $\alpha = 1$. The Rabi resonance frequency (i.e. 50Hz, 100Hz, 150Hz, etc.), establishing a secondary resonance condition is satisfied. We are currently developing new methods in MRI and spectroscopy that exploit these fundamental phenomena.

REFERENCES