A New Method for Tailored 2-D Excitation Using Frequency and Gradient Modulation Based on Rapid Passage

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Introduction: As transmit array coils and higher field magnets increase in popularity, pulse sequences which compensate for B_1 inhomogeneity have become more important. Here we describe a new compensation scheme based on a spatial excitation accomplished with a frequency-swept pulse and a matching shaped gradient sequence. This new approach is based on the principles of rapid-passage in the linear region (1). These new 2D pulses are different from previous 2D pulses for although both use gradient modulation, these pulses are frequency-modulated instead of solely amplitude-modulated. The method offers an alternative way to tailor multi-dimensional excitation and has the potential to compensate for B_1 inhomogeneity in, for example, high field applications and transmit SENSE (2). This work introduces the theoretical principles and shows proof-of-principle using Bloch simulations.

Methods: The basic sequence (figure 1) employs a chirped RF pulse of constant B_1 amplitude with a linearly swept frequency $\omega_{RF}(t)$ which terminates at zero offset. During RF irradiation, sinusoidal gradients are played on two axes (eg, x and y), which creates a rotating linear gradient. In the present implementation, the time-dependent gradient works in concert with the sweeping pulse frequency to move the resonance point in space in a spiral trajectory toward the center. Excitation is accomplished in the rapid-passage, linear region defined as

$$|d(\omega_{RF})/dt| >> (\gamma B_1)^2, \qquad [1]$$

which is different from the familiar adiabatic condition,

$$|d(\omega_{RF})/dt| << (\gamma B_1)^2. \qquad [2]$$

By satisfying Eq. [1], spins outside of the narrow band of resonance will not be excited by the pulse. When the sweep of the gradient is sufficiently rapid, only spins in the locality of the moving resonance point will become excited. Thus, the sequence creates a sequential excitation along a spiral trajectory through space.

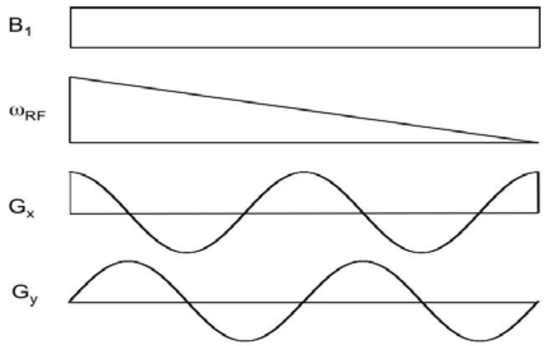

Figure 1: Pulse sequence diagram.

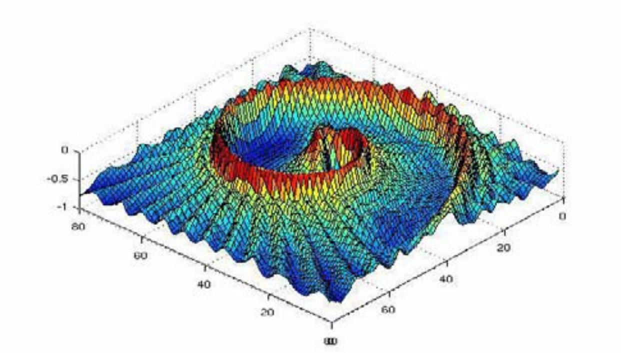

Figure2: The simulation above displays the effect of the pulse on the M_z magnetization of a uniform field of isochromats The negative M_z magnetization is displayed for clarity. The maximum value shown corresponds to a 90° flip.

Results: We have tested the concept using a Bloch simulation program that allows shaped gradients and displays the resulting magnetization as a function of spatial coordinates. As an example, figure 2 displays the final longitudinal magnetization (M_z) resulting from the frequency-swept 2D spiral excitation. The simulations demonstrate time-dependent excitation along a spiral trajectory can be produced by rapid-passage in the linear region.

Discussion: This new excitation procedure is expected to be advantageous for rapid imaging using sequences similar to those described by Shrot and Frydman (3) which use time-dependent excitation and echo formation, instead of Fourier transformation, to decode spatial frequencies. Additionally, it may be possible to modify this sequence to selectively excite specified regions in space. In principle, the speed of the on-resonance trajectory and/or the amplitude of the B_1 can be varied to produce uniform excitation in the presence of a spatially inhomogeneous B_1. The latter feature will be advantageous for multi-coil transmit applications and in ultra high field MR.

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References:

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2) Katscher et al, *Magn. Reson. Med.* 49, 144-150 (2003).
3) Y Shrot and L. Frydmann, *J. Magn. Reson.* 172, 179-190 (2005).