Phase-Sensitive B1 Mapping with Adiabatic Excitation

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Introduction. The knowledge of the spatial distribution of the radio frequency field amplitude (B1) is required for a number of MRI applications such as B1 shimming or transmit-SENSE. Most B1-mapping methods rely on the dependence of the NMR signal amplitude on the B1 field in sequences employing variable excitation flip angles or variable repetition times. Recently, Morrell proposed to derive B1 from the phase of the signal to improve the sensitivity and the dynamic range of the measurement (1). His method uses two RF pulses: the first one producing a B1-dependent nutation about the x-axis, the second one rotating this state to the x-y plane where it can be detected as signal phase in an imaging experiment. The dynamic range of this method is limited by the ability of the second pulse to generate transverse magnetization: its effect is best at 90°, and vanishes close to 180°. We propose a way of generating the B1-dependent signal phase with a higher dynamic range using an adiabatic half passage excitation pulse.

Methods. The adiabatic half-passage starting on resonance is known to produce a pure transverse magnetisation and has been used as an initial segment of the B1-tolerant BIR-1 excitation pulse (2). The pulse applied in our experiment is a cosine-modulated, sine-swept version:

$$B1(t) = B1(0) \cos(\pi t/2T), \quad f(t) = f_{max} \sin(\pi t/2T).$$

The action of this pulse in the RF-bound frame is presented in Fig.1 for three values of B1(0). The initial Mz magnetisation rotates with a constant rate round an axis changing its direction from x to z. The final position is always in the transverse plane disregarding B1(0). However, the final phase depends on the initial twist around x, and thus on B1(0). Bloch equations have been simulated to find the phase-vs.-B1(0) relation for a cos-sine pulse with the sweep f_{max} = 1.6 kHz and duration T = 2ms (Fig.2). This pulse has been applied for the excitation in a 3D gradient echo imaging experiment with a 3cm circular transmit-receive surface coil on a 7T Bruker BioSpec system. The phase has been reconstructed, unwrapped and corrected for the B0-dependent phase accrual during the echo time (measured in an additional experiment with an ordinary excitation pulse). This correction does not address the off-resonance effect of the cos-sine pulse itself, which is the matter of an on-going investigation. The B1(0) map has been calculated from the phase map using the Bloch simulation results as a lookup table. Since the phase map has an unknown constant offset despite the unwrapping, a point in space for which the B1 had been determined independently (by 180° excitation nulling) was used as a reference. For a visual verification, another 3D image was measured with a rectangular 1ms pulse of the same peak amplitude as the cos-sine. This pulse produces black bands where $\gamma B1/2\pi = n \times 0.5$ kHz, i.e., where the effective flip angle is a multiple of 180 degrees. A comparison with the multiple saturation flip-angle B1 mapping method (3) has also been made.

Results and Conclusion. The positions of the n×0.5 kHz contours of the measured B1 map agree with the n×180° bands on the reference image. The map could be determined in a higher dynamic range than it was possible with the multiple saturation flip-angle method. Compared to other phase sensitive methods (1,4,5) the proposed method benefits from the adiabatic 90° excitation giving a potentially superior spatial coverage in experiments with surface transmission coils.

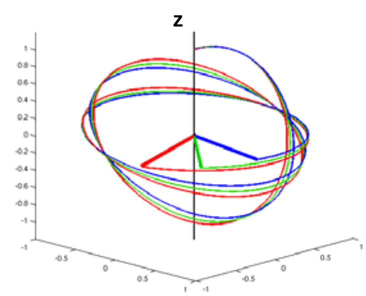

Fig.1: The action of the cos-sine pulse of B1 = 0.9, 1.0, and 1.1 kHz shown in the RF-bound frame.

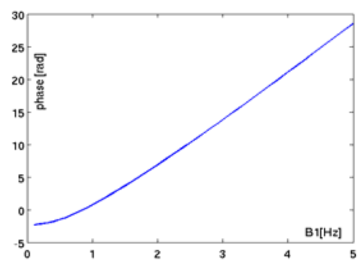

Fig.2: Simulated dependence of the excitation phase vs. the amplitude of the cos-sine pulse.

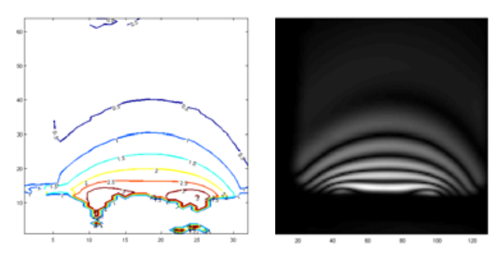

Fig.3: Comparison of the measured B1 map to an image acquired with a 1ms square excitation pulse. Note the excellent agreement of the N × 0.5kHz contours with the N ×180° bands.

References

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