Rapid Mapping of the RF Field

G. Morrell[1]

[1]Utah Center for Advanced Imaging Research, University of Utah, Salt Lake City, Utah, United States

Introduction: Parallel excitation has been recently introduced as a method of performing multidimensional RF excitation with reasonably short excitation times (1,2). This concept has been applied to correction of RF field (B1) inhomogeneity (3,4), which has become an important problem for imaging at field strengths greater than 1.5T. B1 inhomogeneity correction requires measurement of the B1 field to determine the compensating multidimensional excitation profile. Parallel excitation also requires knowledge of the RF field profile produced by each of the contributing excitation coils in order to optimally design the separate RF waveform for each exciting coil. Coil sensitivity mapping (which is equivalent to B1 mapping for transmit-receive coils) is also needed for parallel imaging. Since the B1 field (and coil sensitivity) changes as each patient differently loads the RF coil, it is reasonable to expect that better results will be obtained in all of these applications if the B1 field can be accurately measured during each MRI study rather than assumed to have a constant configuration based on coil geometry.

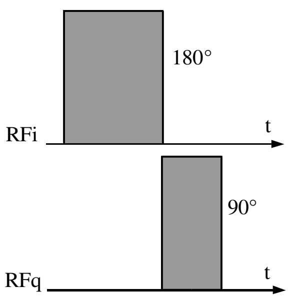

Figure 1: Excitation used for B1 mapping. RFi = in phase, RFq = quadrature component of RF

Methods of B1 mapping have been proposed (5,6) which derive flip angle estimates from functions of image magnitude. A phase-sensitive method of B1 mapping has been proposed (7) which shows promise for imaging a wide range of B1 variation. We present an improved implementation of this method which utilizes very rapid RF pulses, obviating the need for multiple acquisitions described in (7).

Methods: The phase-sensitive method of B1 mapping consists of a hard pulse with nominal flip angle of 180° followed immediately by a second hard pulse with nominal flip angle of 90° about an orthogonal axis, as illustrated in Figure 1. The transverse magnetization created by this sequence of pulses is shown in Figure 2A for various actual flip angles of the nominal 90° pulse. The phase of this transverse magnetization is a nearly linear function of the B1 field over a wide range of flip angles, as shown in Figure 2C.

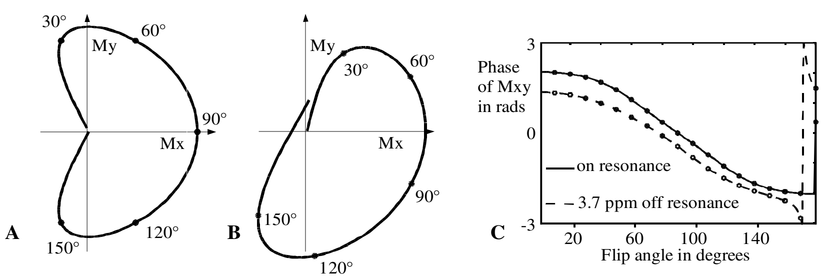

Figure 2: A) Transverse magnetization for spins on resonance for various actual flip angles (i.e. values of B1). B) Transverse magnetization for spins 3.7 ppm off resonance (i.e. fat). C) Plot of phase of transverse magnetization versus actual flip angle on resonance and at 3.7 ppm.

The phase and magnitude of the transverse magnetization are affected by inhomogeneities in the main field B0 as well as by resonant frequency differences caused by chemical shift. Compensation for these effects required a second acquisition in the previously implemented method described in (7). In the current implementation, this limitation is overcome by making the RF pulses very short. If the total excitation time is short, the effect of B0 inhomogeneity and chemical shift is limited. We have implemented the B1 mapping sequence with RF excitation requiring only 360 μsec. Figures 2B and 2C show the transverse magnetization achieved at an off-resonance frequency of 3.7 ppm with this total excitation length of 360 μsec. Because the excitation is rapid, the phase of the transverse magnetization remains a good function of flip angle at large off-resonance offsets. Separate mapping of resonant frequency can be achieved rapidly and allows for exact correction of inaccuracies in B1 mapping caused by B0 inhomogeneity and chemical shift.

Results: The B1 map of an axial section through a cylindrical phantom occupying most of the volume of a transmit-receive extremity coil is shown in Figure 3. This image was calculated from phase images obtained by a three-dimensional echo-planar sequence utilizing the B1 mapping RF pulse described above at 3.0 T.

Conclusion: A phase sensitive method of B1 mapping is presented which is suitable for a wide range of B1 variation. Implementation with rapid RF pulses obviates the need for multiple acquisitions described in a previous implementation of this method. Rapid B1 mapping allows the design of B1 compensating pulses, facilitates optimal multidimensional excitation with multiple simultaneous transmit coils, and gives accurate coil sensitivity profiles for parallel imaging.

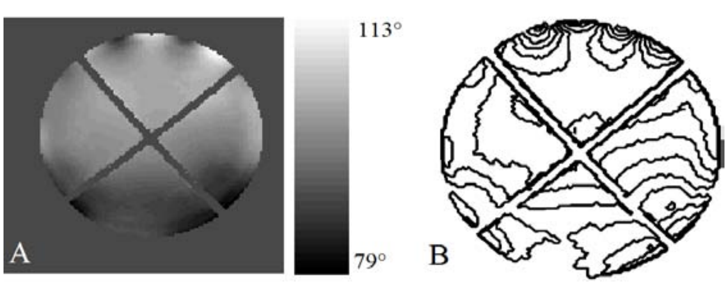

Figure 3: A) B1 map. B) Contour map of B1 with 3° intervals. X shape in phantom is a plexiglass structural element.

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