Accelerated B1 Mapping for Parallel Excitation

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Introduction: Parallel RF excitation is a novel technology that can significantly accelerate multidimensional selective excitation and reduce SAR [1-3]. One caveat however is that the transmit array B_1 sensitivity profiles must be known. Previous experimental demonstrations [4-5] have relied on having a uniform transmit reference (such as a body coil), or a uniform phantom [6], but this cannot generally be assumed. We have previously described a general approach for B_1 mapping [7] that works robustly over a large dynamic range but is limited in speed. We report an enhancement to this technique here that can acquire volumetric B_1 maps in less than 40 seconds. The B_1 maps are validated by demonstrating a 2x accelerated 90° parallel excitation.

Method: A multi-angle volumetric B_1 mapping sequence was developed as shown in Fig. 1. The sequence includes two 8-ms BIR4 [8] non-selective adiabatic pulses, each followed by a gradient spoiler on the X and Y axis respectively. This effectively "resets" the longitudinal magnetization (as in [9]) to a fixed state, independent of the initial condition prior to the sequence. The longitudinal magnetization then experiences some recovery during the refractory period T_{ref}, before the application of a non-selective RF hard pulse and gradient-echo readout. The non-selective RF pulse is stepped by factors of 2 from α to 2^{N-1}α between TRs, with the whole process being repeated enough times to acquire N images, one for each tip-angle.

With the RESET component, the TR for this sequence can be set to much less than T_1, which otherwise must be much greater than T_1 to avoid T_1-effects disturbing the B_1 calculation. This assumes however that complete saturation of the volume is obtained with the RESET pulses. Ideally, this could be obtained with a single pulse, but this is typically not achievable with a single coil from a transmit array (due to B_1 dropoff) nor robustly from a phased-transmit from all coils (due to focal null regions in the composite B_1 profile). The approach used here is to transmit the RESET pulse in parallel, first with the odd then the even elements of the array. As long as the mutual volume saturated by either RESET pulse covers the imaging volume, then T_1-effects will not disturb the B_1 calculation. The parameters for the RESET BIR4 pulse are also carefully chosen to provide a wide operating adiabatic region of 0.07G to over 7G.

The imaging sequence uses a three-interleaf spiral acquisition with 12-ms readouts (40 mT/m, 150 T/m/s) providing 2.8x2.8-mm resolution over a 28-cm FOV. A 3D acquisition was also implemented as a stack of spirals with this trajectory. A nonlinear search [7] is used to determine absolute amplitude and phase of the B_1 maps from the set of images acquired at the progressive tip-angles. No assumptions are made with regards to the receiver coil arrangement which may be either a body coil, or a phased-array receive if the transmit array is transmit-and-receive.

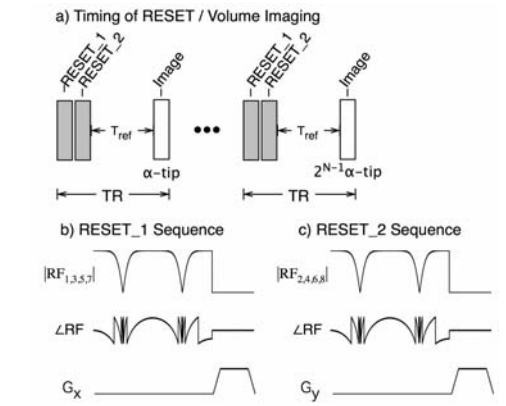

Figure 1: Schematic of B_1 mapping pulse sequence

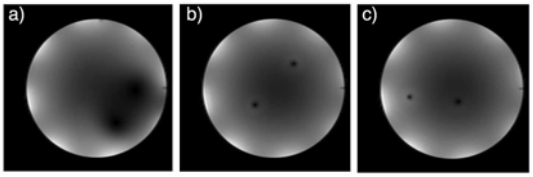

Figure 2: Phantom images acquired with 8-coil Tx/Rx array using RESET pulse as excitation on a) coil 1, b) odd coils, c) even coils.

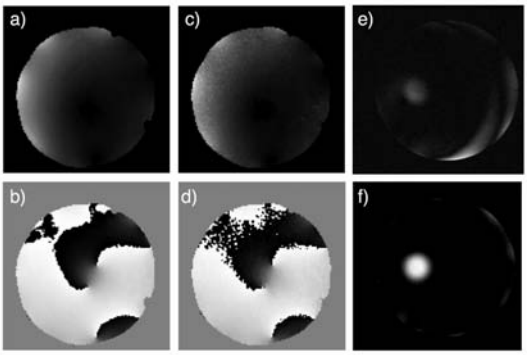

Figure 3: (a-d) B_1 magnitude and phase maps of a coil determined using the RESET sequence with long and short TR (a-b) $T_{ref} = 5\ T_1$ (c-d) $T_{ref} = T_1/5$ (T_1 = 80 ms). (e-f) Projection images of a) single-coil excitation using conventional 2D pulse 2x undersampled for the 28-cm image FOV; b) eight-coil parallel 90° excitation.

Results: The frequency and phase-locked multi-transmit platform [4] based on an integrated set of four GE Excite II system electronics was used for our experiments. An eight-channel transmit-and-receive array was used to image a thin-slice phantom oriented in the axial plane. Figure 2 demonstrates the region that can be saturated by the RESET pulse when applied to a single element or multiple elements in parallel. The B_1 profile of a single coil is insufficient to allow for total saturation of the volume, but the even and odd coil combinations are mutually sufficient.

Figures 3 a-d demonstrate that B_1 maps acquired using the RESET approach with a short $T_{ref}=T_1/5$ can accurately reproduce B_1 maps acquired with a long $T_{ref}=5T_1$. A sequence of 8 tip-angles were used for these measurements, allowing accurate quantification of the B_1 profile over the dynamic range of ~120 shown by a single coil in the array. For a T_1 of 1 second, this would require a total time of 38.4 seconds for a 3D acquisition with 8 slices.

To validate the self-calibration method, a spiral-based cylindrical excitation pulse was designed using the methods outlined in [10]. Fig. 3e-f illustrates the excitation profiles from a 2x undersampled conventional 90° cylindrical excitation and the parallel excitation. The sidelobes in Fig. 3e are nearly completely removed when using the parallel transmit excitation, except for some residual effects near the edges of the phantom. This is likely due to the high B_1 near the array invalidating the assumptions of linearity [11] for the spiral-based excitation.

Discussion: Rapid self-calibration methods for parallel excitation have been developed and validated with a successful parallel transmit excitation. The method does not depend on having a uniform transmit reference and has accelerated the B_1 mapping process by a factor of 25. In conjunction with fast imaging methods, a volumetric B_1 map can be acquired in less than 40 seconds.

References: [1] Zhu, Mag. Res. Med., 51:775-84, 2004. [2] Katscher, Mag. Res. Med., 49:144-50, 2003. [3] Ullmann, P. ISMRM, p. 601, 2006. [4] Zhu, P. ISMRM, p. 14, 2005. [5] Ullmann, Mag. Res. Med., 54:994-01, 2005. [6] Setsompop, Mag. Res. Med., 56:1163-71 [7] Kerr, P. ISMRM, p. 2561, 2006. [8] Garwood, J. Magn. Res., 153:155-77, 2001. [9] Cunningham, Mag. Res. Med., 55:1326-33, 2006. [10] Grissom, P. ISMRM, p. 19, 2005. [11] Pauly, Mag. Res. Med., 82:571-87, 1989.