Self-Calibrated Transmit SENSE

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Introduction: Transmit SENSE allows accelerated excitation pulses to achieve similar profiles as those obtained with conventional single-coil excitation pulses. One caveat however is that the coil transmit sensitivity profiles must be known in order to design the multi-coil RF pulse. Previous demonstrations of transmit SENSE [1-2] have relied on having an additional transmit coil (such as a body coil) with uniform sensitivity to provide a reference, but this cannot generally be assumed to be available. We describe a method that is not limited by this requirement and works robustly over a large dynamic range. Our method was validated by testing a 90° transmit SENSE cylindrical excitation.

Methods: A modified version of a double-angle B_1 mapping sequence [3] was developed as shown in Fig. 1. This includes a non-selective RF pulse that is stepped by factors of 2 from α to $2^{N-1}\alpha$. Following each RF pulse is a gradient-recalled echo using either a 2DFT acquisition in *x,y* with projection in *z*, or a 3DFT acquisition. A TR >> T_1 is chosen to allow T_1 effects to be ignored.

The complex image value $I_k(x,y,n)$ at location (*x,y*) for coil *k* using a nominal RF tip of $2^{n-1}\alpha$ can be modeled as in (1). Coil-independent effects such as proton density, T_2 decay, receive-coil sensitivity, and any other B_0 or imaging-related phase/amplitude modulation are encapsulated in *R(x,y)*. The coil-dependent term $\alpha_k(x,y)$ is related to the transmit coil sensitivity as: $\alpha_k(x,y) = \gamma\tau B_{1,k}(x,y)$, where τ is the duration of the RF pulse. As shown in (2) the ratio of two successive images can be used to determine $|\alpha_k(x,y)|$.

$$I_k(x,y,n) = R(x,y)\sin\left(\left|2^{n-1}\alpha_k(x,y)\right|\right)e^{i\angle\alpha_k(x,y)} \quad (1)$$

$$\left|\alpha_k(x,y)\right| = 2^{1-n}\cos^{-1}\left|\frac{I_k(x,y,n+1)}{2I_k(x,y,n)}\right| \quad (2)$$

An initial estimate for $|B_{1,k}(x,y)|$ is obtained by solving (2) for successive images where the magnitude ratio indicates that $|2^{n-1}\alpha_k(x,y)|$ corresponds to a 30-60° tip. This solution is refined by using it to seed a nonlinear search (Matlab, The MathWorks Inc.) to find $|\alpha_k(x,y)|$ and constant c(x,y) that minimizes the error:

$$\varepsilon = \sum_n \left(\left|I_k(x,y,n)\right| - \left|c(x,y)\sin\left(2^{n-1}\left|\alpha_k(x,y)\right|\right)\right|\right)^2 \quad (3)$$

Phase maps $(\angle I_k(x,y,n) - \angle I_1(x,y,n))$ yield the relative phase $\angle B_{1_k}(x,y)$, where *n* is chosen on a pixel-by-pixel basis such that $|2^{n-1}\alpha_k(x,y)|$ is closest to 90°.

Note that once a single coil has been fully mapped, we can subsequently solve for *R(x,y).* This can allow each of the following coil sensitivity profiles to be determined using only a single RF tip value α, or can be selectively applied in regions where the local tip for a coil never exceeds some minimal threshold.

To validate the self-calibration method, a spiral-based cylindrical excitation pulse was designed using the methods outlined in [4].

Results: The frequency and phase-locked multi-transmit platform [1] based on an integrated set of four GE Excite II system electronics was used for our experiments. An eight-channel transmit-only array (Fig. 2) was used to excite a thin-slice phantom oriented in the axial plane, with a body coil used for receive. Fig. 3a-d show the last 4 of a set of 8 2DFT projection images acquired while geometrically increasing the RF pulse amplitude by a factor of 2 (TR was ~ $5T_1$). Fig. 3e-f show the B_1 obtained for a sample coil with a dynamic range over 120.

Fig. 4a-b illustrate the excitation profiles from a 2x undersampled conventional cylindrical excitation and the transmit SENSE excitation. As described in [5], we can simply scale the transmit SENSE pulse to provide a 90° excitation. The sidelobes in Fig. 4a are nearly completely removed when using the transmit sense excitation, except for some residual effects near the edges of the phantom. This is likely due to partial voluming and the off-resonance shift introduced by the large off-resonance present in these regions of the phantom.

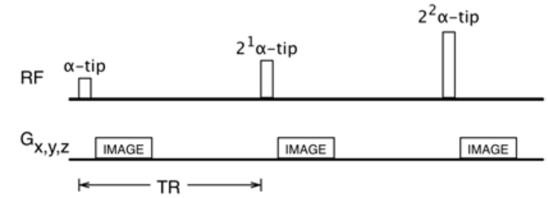

Figure 1: Schematic of B_1 mapping pulse sequence

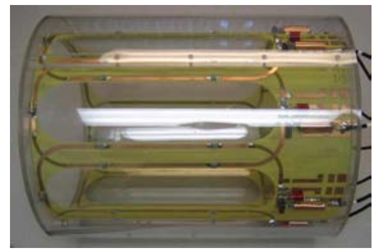

Figure 2: A transmit-only head-sized array of 8 13.4x31.0-cm loop coils azimuthally distributed on a 28-cm dia. cylinder.

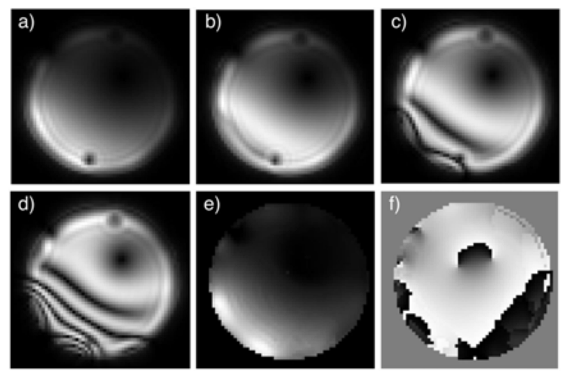

Figure 3: Measuring B_1 on single coil: a-d) Projection images (64x64, 28-cm FOV) through disk phantom for α, 2α, 4α and 8α RF pulses; e-f) B_1 magnitude and phase images.

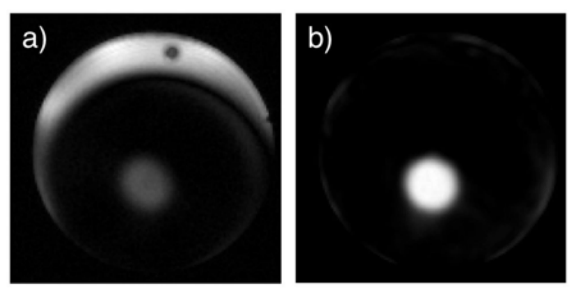

Figure 4: Projection images of: a) Single-coil excitation using conventional 2D pulse 2x undersampled for the 28-cm image FOV; b) Eight-coil transmit SENSE 90° excitation.

Discussion: A self-calibration method for transmit SENSE has been developed and validated with a successful transmit SENSE excitation. While a body coil was used for receive, this is not an intrinsic requirement for the method. A single coil or complex sum of the array coil images from the transmit array would have sufficed had it been configured for receive. The method can be extended to be slice-selective with the use of selective RF pulses.

References: [1] Zhu, P. ISMRM, p. 14, 2005. [2] Ullman, Mag. Res. Med., 54:994-1001, 2005. [3] Wang, Mag. Res. Med., 53:408-417, 2005. [4] Grissom, P. ISMRM, p. 19, 2005. [5] Pauly, J. Mag. Res., 82:571-587, 1989.