Multi-Slice B1+ Shimming for 7T MRI

A. T. Curtis[1], K. M. Gilbert[1], M. L. Klassen[1], J. S. Gati[1], and R. S. Menon[1]
[1]Centre for Functional and Metabolic Mapping, University of Western Ontario, London, Ontario, Canada

Abstract: We examine the potential improvements in achievable transmit homogeneity and efficiency via leveraging the additional degrees of freedom present in multi-slice acquisitions, by performing B1+ shimming on a slice-by-slice basis with multi-channel transmit arrays. It is demonstrated that compared to simple scaling of the flip angle to compensate for *rf*-coil induced B1+ falloff, calculation of B1+ shim solutions can improve homogeneity and markedly reduce transmitted power (and consequently global SAR) by shimming to recover efficient excitation modes.

Methods: All imaging was performed on a Varian/Magnex 7T head-only, 68cm-bore MRI scanner (Agilent, Inc), equipped with 16 independent transmit and receive channels, and Siemens AC84 gradients. All volunteers signed a written consent form for the study in accordance with the University of Western Ontario REB. A 16-element conformal transmit/receive coil with multiple elements in each Cartesian direction was used for all experiments. Five volunteers were scanned, and all B1+ maps and shim locations were fixed with respect to the *rf* coil and magnet position.

B1+ Mapping: Transmit field maps were acquired covering the entire head at 4-mm isotropic resolution using the method of (1), modified to map linear combinations of the array elements (in a DFT phase modulation mapping scheme) for improved SNR and decreased T1 saturation bias.

CP Mode: The circularly polarized driving mode was calculated from the B1+ maps as the set of phases that led to constructive interference of all channels at the centre of the coil volume. This is analogous to 'around the clock' phase splitting in multi-port cylindrically symmetric coils. We examined both the CP driving mode (CP^{vol}), as well as a situation where the flip angle is adjusted on a per slice basis to compensate for B1+ falloff (CP^{slice}).

B1+ Shimming: Two shim solutions were investigated: i) **"abs"**, where the shim goal is the ideal non-interacting superposition of transmit maps (e.g. sum||B1+||) and ii) **"gauss"**, where a smooth 3d Gaussian was fit to the absolute value sum to smooth out coil induced fluctuations and to provide *a-priori* knowledge of shim behavior (i.e. mild centre brightening). In both cases the shims were optimized by finding complex-valued weights that minimized a nonlinear least squares fit to the target distribution, starting from the CP mode as an initial point. For each method, shims were calculated i) over the entire volume and ii) over each individual 5mm thick slice in 3 stacks of 40 slices covering the same total 200-mm^3 volume (each stack oriented axially, sagittally, or coronally). After shimming, transmit power was calibrated to the 90th percentile of the resultant B1+ distribution.

Results: All results are benchmarked against the volume CP driving mode, as this is analogous to a typical B1+ distribution utilizing a single-channel quadrature birdcage coil. Figure 1 demonstrates the mean in-slice standard deviation (std) of B1+ (mean=1) and average transmit power per slice for an axial stack. Table 1 summarizes the global worst-case SAR and std of B1+ over the entire head volume *relative to the CP mode*. In all cases it is seen that shimming for the "abs" solution yields equivalent or higher uniformity (by the std metric) compared to CP mode, with significantly reduced relative SAR. Visually examining the B1+ shim solutions (Figure 2) demonstrates robust shim behavior of the stack of slices. The smooth "gauss" target solution yields markedly improved uniformity over the volume, albeit at an increase in global SAR.

Shim Sol'n	SAR	STD
CP Vol	1.00	1.00
CP Slice	0.89	0.80
Abs Vol	0.60	0.77
Abs Slice	0.46	0.79
Gauss Vol	0.96	0.68
Gauss Slice	1.97	0.52

Conclusion: The data presented shows that in all situations examined, shimming slice-by-slice allows much better performance in the standard deviation of the B1+ field, and/or markedly improved efficiency vs. shimming over the entire volume. Secondly, shimming a transmit array to recover efficient excitation modes results in markedly reduced global SAR and improved transmit-field uniformity compared to a CP drive.

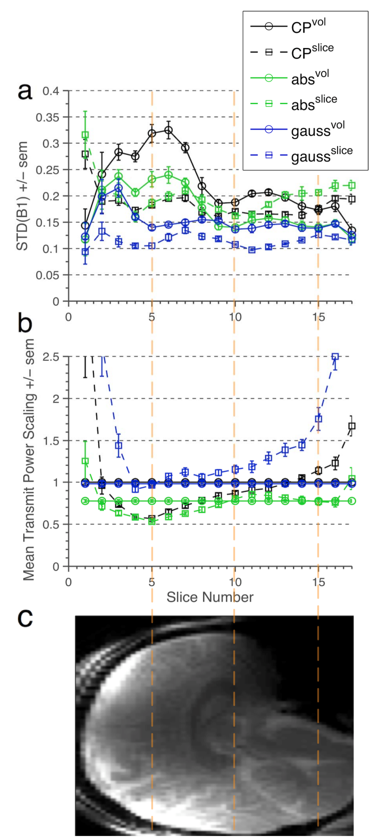

Figure 1: a) std(b1) vs slice. b) relative scale factor normalized to CP volume excitation
c) approx. location of slices

References: (1) Moortele PF et al. Proc ISMRM 2009. p 366.

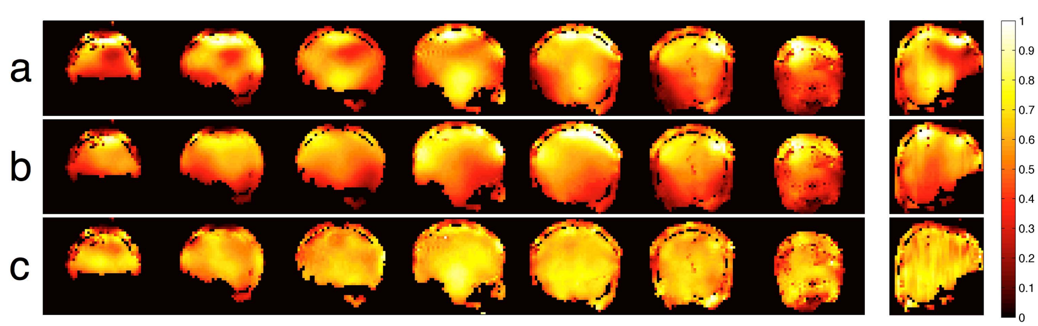

Figure 2: Shimmed B1+ maps for a stack of coronal slices. *Left*: a) CP mode (typical volume shim), b) "abs" solution per-slice shim, c) "gauss" target per-slice shim. (see text for description of shim solutions). *Right*: re-slicing of the shimmed stacks in a sagittal view.