Combined shim-RF array for highly efficient shimming of the brain at 7 Tesla

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TARGET AUDIENCE: RF and Systems Engineers

PURPOSE: B_0 shimming of local susceptibility fields is challenging because the field perturbations are subject-dependent and localized in space, rendering them difficult to cancel with low order polynomials. While 3rd-5th order shim insert coils[1] might be of benefit, multi-coil (MC) arrays of local shim loops are likely a more efficient way to synthesize the necessary field shapes. However, previous MC approaches[2,3] have been limited by the need to leave space for RF receive coils, forcing the shim coils further away from the body. In this work, we solve the "real estate" problem by using the same loop for both DC shim currents and RF receive, exploiting the fact that MC shimming and RF detection work most efficiently when elements are placed as close to the body as possible. We demonstrate the ability of a 9.5cm dia. loop array to provide both functions without loss of SNR and with enough shim efficiency to effectively shim the brain at 7T with < 5A current when used as a 32ch close-fitting helmet array.

METHODS: Design: We convert a conventional single-turn, 9.5cm dia. 7T surface coil into a shim-RF coil by bridging the tuning capacitors with toroidal inductor chokes, creating a DC current path (Fig. 1). Toroidal inductors are ideal because their shape confines magnetic flux and resists induction from RF transmit fields. The coil uses conventional PIN diode detuning and preamplifier decoupling.

Simulations: We simulate the ability of a 32ch array to shim experimental 7T brain field maps acquired after conventional 2nd order shimming using the loop geometry shown in Fig. 2. A constrained optimization uses Biot-Savart-generated[4] DC field maps to find the optimal shim current weights for global and slice-by-slice "dynamic" MC shimming of the inhomogeneity, subject to a max of 5 amperes per element.

Experiments: We built and evaluated a single 9.5cm shim-RF coil and a geometrically-matched conventional RF coil using AWG16 copper wire and evaluated them at 7T on an anthropomorphic brain phantom. Field maps were acquired with and without 1A DC flowing in the shim coil. The SNR maps and loaded-to-unloaded quality factor (Q) ratio of the shim-RF loop and conventional loop were compared.

RESULTS: The shim-RF loop's modifications did not lower its SNR (Fig. 3) or significantly change the Q ratios (Table 1). The single turn loop produced about 300 Hz max. shift in the brain with 1A current (Fig. 4). No coil heating was observed with 5A DC current applied. Fig. 5 shows the full array simulation. As hypothesized, the 32ch helmet-geometry MC shimming simulations show significantly tighter field distributions both within slices and across 20 slices.

DISCUSSION: These results demonstrate that shim-RF arrays can provide synergistic MC shimming and RF detection without any adverse impact on SNR or shimming performance, and that even single-turn loop coils become efficient enough for shimming at 7T with < 5 A current.

CONCLUSION: We demonstrate a combined RF and shim functionality in a single conducting loop close to the body to maximize the efficiency of both functions and validate it with a combination of single-loop measurements and 32ch simulations. Future work will validate the full 32ch array *in vivo* and test its ability to reduce susceptibility-induced distortion and signal loss in echo-planar and SWI scans of the human brain at 7T.

REFERENCES: [1] Pan JW, MRM 2012. [2] Juchem C, JMR 2011. [3] Juchem C, MRM 2011. [4] Lin FH, http://www.nmr.mgh.harvard.edu/~fhlin/ 2012.

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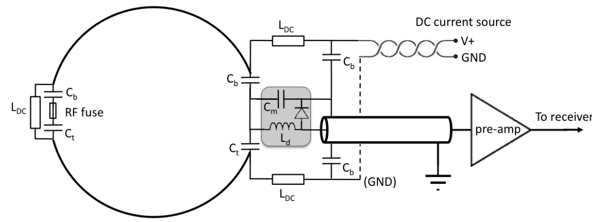


Fig. 1 RF-shim loop with active detuning and preamplifier decoupling. Toroidal chokes (700 nH) bridge DC across RF tuning capacitors (C_t) and fuse. Blocking capacitors (C_b=1000 pF) pass RF and block the DC. Additional inductive chokes (not shown) prevent RF from leaking onto the DC twisted pair. PIN diode bias is supplied on the RF coaxial cable to turn on the diode between L_d and C_m to detune the coil during TX.

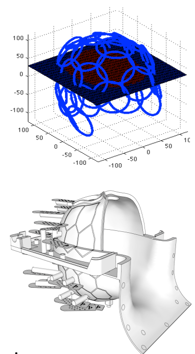
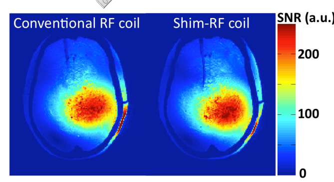


Fig. 2 32ch loop geometry for Biot-Savart law simulations of the B_0 shim field generated by elements in a close-fitting 32ch head array to be built on a 3D-printed helmet (bottom).



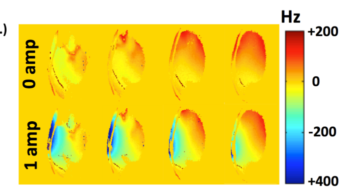


Fig. 3 (Left) SNR comparison measured at 7T of the shim-RF and conventional control coil shows no detectable loss of SNR due to the presence of the inductive chokes.

Fig. 4 Measured field maps at 7T using the shim-RF coil as both a shim coil (0 and 1 amp DC) and as the receive coil. Four slices are shown. The maximum field shift in the brain is around 300 Hz/amp.

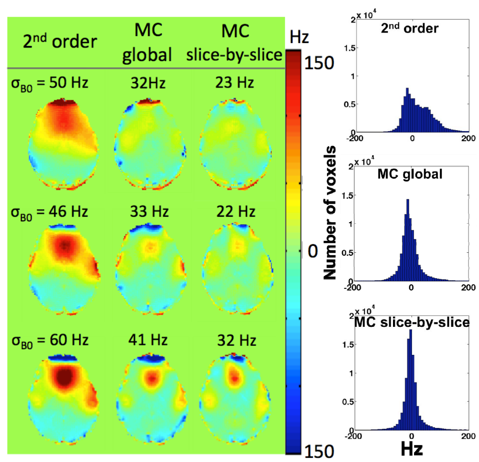


Fig. 5 Shimming simulation for 32ch shim-RF array (5 amps max). Experimental B_0 maps after 1st and 2nd order shimming were acquired and the shim currents calculated based on Biot-Savart field map models for the element geometry (see Fig. 2). Multi-coil shimming greatly reduces the standard deviation of voxel frequencies both within a slice and across all 20 slices (histograms).

# of tuning capacitors	*Conventional coil*			*Shim-RF coil*		
	Q_{UL}	Q_L	Q_{UL}/Q_L	Q_{UL}	Q_L	Q_{UL}/Q_L
2	95	10	9.5	120	13.5	8.9
3	120	10	12	130	11	11.8
4	120	10	12	145	12.5	11.6