A 32ch combined RF-shim brain array for efficient B0 shimming and RF reception at 3T

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PURPOSE: Multicoil (MC) shimming shows great promise as an alternative to spherical harmonic shimming for compensating higher-order B_0 inhomogeneity *in vivo*. Previous realizations [1] left space near the body for RF coils, pushing MC shim loops further away, reducing their efficiency. The shim loops also caused modest SNR loss due to their proximity. Recently it has been shown that shim currents can flow on single-turn RF coil loops without compromising the function of either subsystem [2-4]. Both RF reception and MC shimming benefit from (a.) close proximity to the body and (b.) maximal spatial degrees of freedom (large coil arrays). This suggests the most space-efficient design is to let DC and RF share the same conducting loops in a close-fitting array. Simulations show excellent shim performance with arrays of single-turn loops using < 3A of current per loop [2,4]. RF-shim integration has thus far been demonstrated in individual [2] and a pair of coils [3,4]. In this work we extend the approach to a full 32ch brain array for *in vivo* 3T MC shimming.

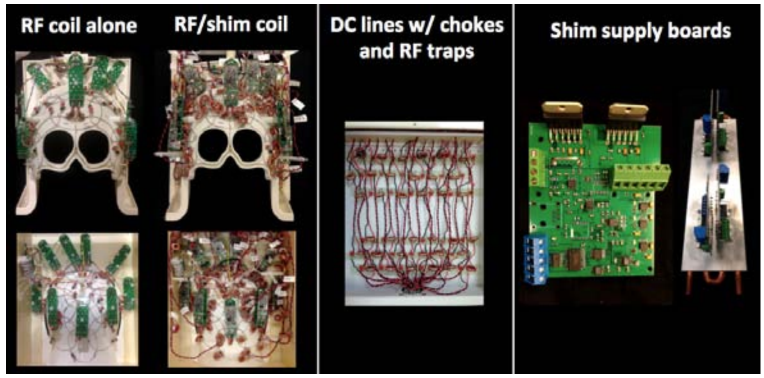

Fig 1. Conventional 32ch head coil for 3T (left) is modified using feed lines and toroidal chokes to block RF from flowing on the DC path in the shim array. Chokes and traps (center) prevent RF transmit power from being picked up by the DC feed wires. At right, close-up of the current-feedback, digitally-programmable shim supply board along with four boards mounted on a heat sink.

METHODS: Design: A conventional 32ch RF coil mounted on a close-fitting 3D printed polycarbonate helmet (Fig. 1) is adapted for MC shimming. RF and DC are both carried on 10cm dia. AWG16 loops with 1μH toroidal chokes to block RF from the DC feed wires and 1000 pF capacitors to block the DC from the RF coaxial feed. Toroidal inductors are chosen to cancel flux across the choke, limiting induction from both gradient slewing and B_1^+ transmit RF fields. Chokes and traps are used every 20cm on the DC feed lines to block RF common mode currents during transmission. Shim currents are supplied by OPA549-based digitally programmable current sources (Fig. 1) with a current sense resistor for feedback loop control. Shim settings are updated by a MCP2210 USB-to-SPI converter which updates the LTC1592 DACs on the shim supplies. The shim supplies are mounted on water-cooled aluminum heat sinks.

Experiments: SNR maps [5] are acquired on a Siemens Skyra 3T scanner with the 32ch shim array and with a geometrically-similar 32ch commercial head coil. B_0 field maps are also acquired with 1A flowing through an individual loop using a 19cm dia. balloon phantom (with the same loops also used for RF receive). Back EMF is measured with a test loop on the surface of the helmet as an EPI sequence plays. B_0 brain field maps are then acquired in a human volunteer after conventional second-order shims have been applied. Twenty slices of the field maps are shimmed off-line using the experimental coil field maps to demonstrate the array's ability to improve B_0 homogeneity.

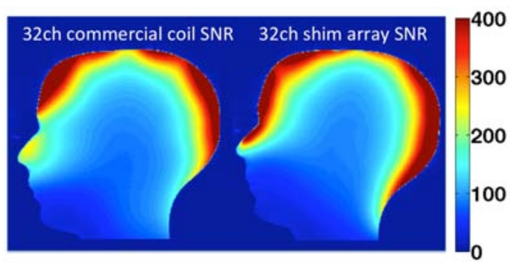

Fig 2. SNR maps show equivalent performance for the shim array and a geometrically similar commercial 32ch coil.

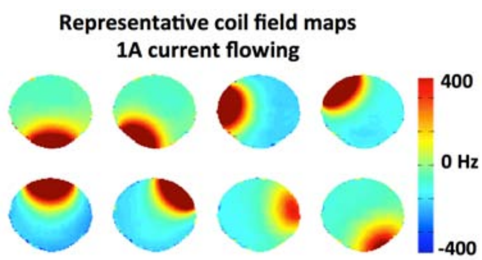

Fig 3. Transverse field maps acquired in phantom for eight representative shim coils at the mid-plane of the helmet with 1A of test current flowing.

RESULTS: The coil passed standard safety tests including transmit RF power absorption, gradient eddy current heating, and RF heating. No significant heating of the coil assembly was observed with 1A flowing through all 31 channels. The B_1^- SNR is equivalent to the commercial 32ch coil with similar helmet geometry (Fig. 2) and B_0 maps show the desired spatial variation in the sample (Fig. 3). Off-resonance in the sinus region is mitigated and the standard deviation across all 20 slices falls from 74 to 59 Hz (Fig. 4). Liquid cooling was unnecessary for shim supply operation below 2A. The maximum back EMF during the EPI sequence is ±0.25V, well within the ability of the shim supplies to maintain a stable current output.

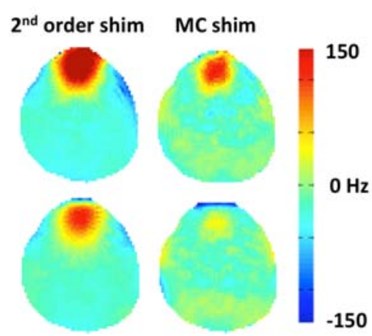

Fig 4. Two representative slices of off-line global brain shimming performed using acquired field maps from each shim coil. MC shimming reduces the standard deviation from 74 to 59 Hz across twenty slices. Mean/total required shim current amplitudes are 0.26/7.2A.

DISCUSSION: Many of the engineering obstacles to RF/DC integration have been successfully overcome. We demonstrate hardware for integrating RF reception with MC B_0 shimming at 3T without compromising the performance of either system. Using single-turn loops with < 3A, field maps show sufficient B_0 offset in the brain to achieve shim performance comparable to 4th order spherical harmonics. The B_0 field maps demonstrate the high sensitivity of the shim loops, providing > 400 Hz field offset within the FOV using just 1A of current. The inductance of each shim channel and cabling is only ~9μH, permitting fast switching and minimizing back EMF caused by scanner gradient slewing. This low inductance combined with the negligible settling time of the shim supplies makes the hardware well-suited for dynamic shimming.

CONCLUSION: Integrated RF/shim arrays provide a more efficient alternative to spherical harmonic shimming and independent MC shim arrays. Applications to be explored include global shimming, slice-optimized shimming, and dynamic shimming to compensate for eddy currents and other time-dependent B_0 effects.

REFERENCES: [1] Juchem C, JMR 2011. [2] Stockmann JP, ISMRM 2013 #665. [3] Hui H, ISMRM 2013 #664. [4] Hui H, MRM 2013. [5] Kellman P, MRM 2005.

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