An integrated head array for B_0 shimming and B_1 reception

MR SCIENCE Lab

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Introduction

- **Multicoil (MC) B_0 shimming** systems employ a multitude of **individually driven loops** to flexibly and effectively control B_0
- MC systems improve B_0 homogeneity compared to spherical harmonic (SH) systems, especially in brain regions that suffer from strong B_0 distortions due to drastic changes in magnetic susceptibility (i.e. prefrontal cortex) [1]
- The need for close **proximity MC hardware and radio-frequency (RF) coils could lead to interactions**, impacting the signal-to-noise ratio (SNR)
- Using the same elements for RF transmission and/or reception and B_0 shimming can be advantageous in terms of coupling and space management, however, due to the lower current and number of turns and other design trade offs, achievable B_0 homogeneity has been suboptimal
- The purpose of this work is to explore the potential of **an integrated RF and B_0 shimming head array** in which shimming is enabled by driving the RF receive elements with direct current along with using dedicated shim-only elements

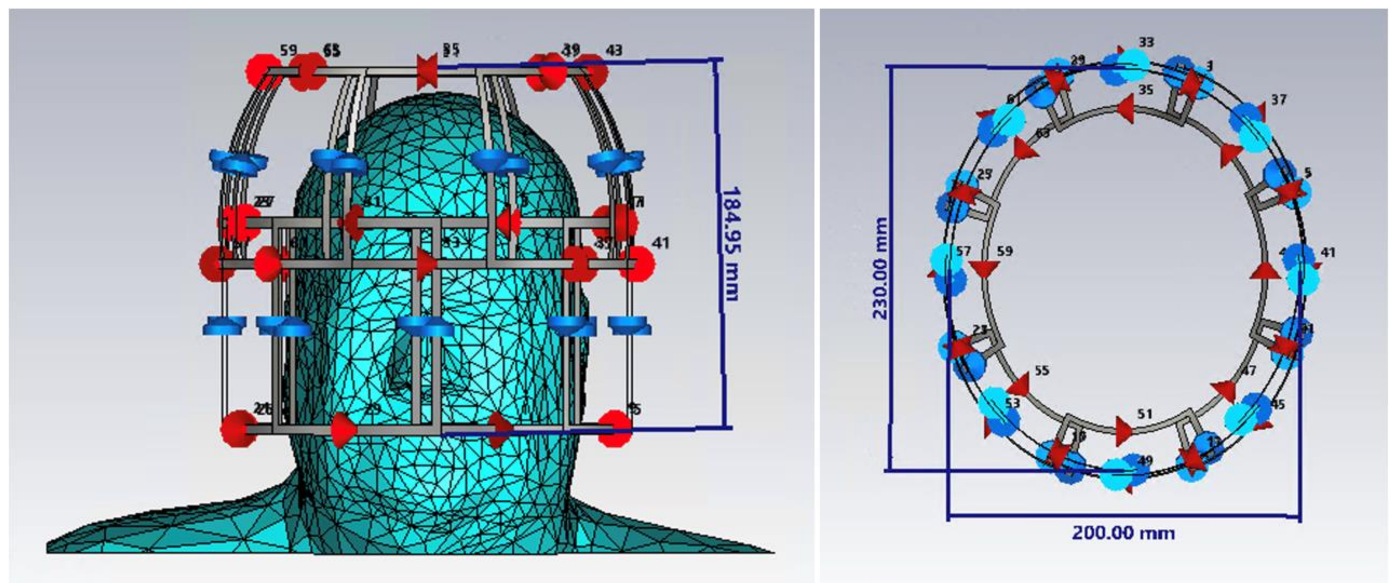

Figure 1. RF receive array simulation setup.

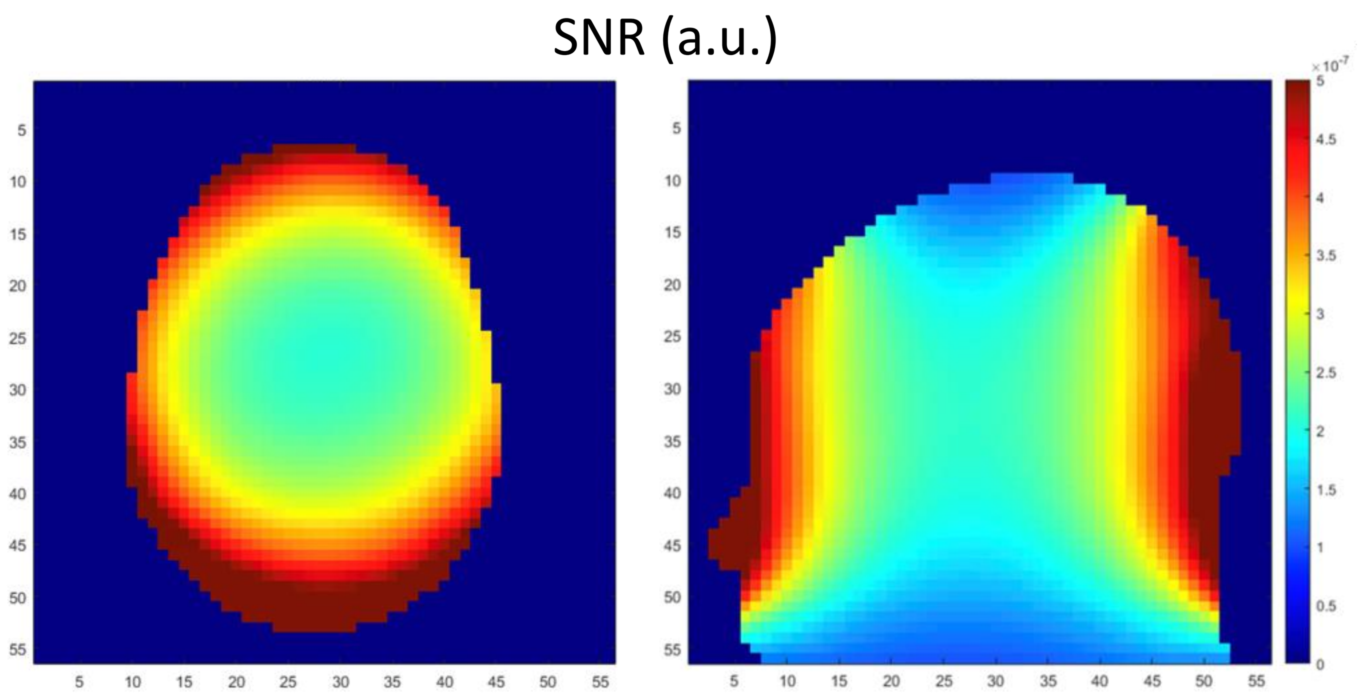

Figure 2. Simulated SNR (a.u.) of the 16-channel receive array.

Methods

RF SIMULATION

- A 3T 16-channel head RF receive array was simulated in CST Studio Suite (Dassault Systèmes, France) (Fig. 1):
  - Two rows of 8 elements each
  - Overall dimensions: 23 cm (AP diameter) x 20 cm (LR diameter) x 18.5 cm (z-coverage)
  - Tuned to 123 MHz and matched to 50 Ω in co-simulation
  - Geometric decoupling was used for nearest neighboring elements
  - Loaded with an anatomical phantom with dielectric properties $\boldsymbol{\varepsilon}_r$=68.5 and $\boldsymbol{\sigma}$=0.44 S/m (average of brain white and gray matter at 123 MHz)
- SNR was calculated as $SNR = \sqrt{B_1^{-*} R^{-1} B_1^{-}}$, where $R = \int \sigma E_i \cdot E_j \, dV$ is the noise correlation matrix

RF-to-MC COUPLING

- To guide the placement of the MC element **to mitigate the MC-to-RF coupling** due to mutual inductance, **the magnetic flux** through three cylindrical surfaces was calculated from the simulated magnetic fields
  - cylindrical surfaces with radii 125, 135 and 145 mm
  - The flux was sampled using a circular mask (radius: 25 mm) and multiplied by 40 MC turns
  - For each surface, a flux map was obtained by assigning to each coordinate the magnitude of the flux through the circular mask centered in that location

B_0 SHIMMING PERFORMANCE

- The **B_0 capability** of an array constituted by the RF elements driven with DC and by 18 additional shim-only MC elements distributed frontally above and below the RF array was investigated (Fig. 4).
  - The best possible MC shim for 139 in vivo full brain B_0 maps retrospectively collected [2] was calculated
  - Biot-Savart simulations were performed assuming maximum currents in each element of ±1 A [3]
  - RF elements were modeled with one turn of wire, while MC elements were modeled with 40 turns each

Results

- The simulated SNR for the 16-channel array is shown in Fig.2.
- Fig. 3 shows the magnetic field flux through three cylindrical surfaces surrounding the RF coil.
- Fig. 4 shows the shimming performance of the RF array used in shimming mode with 18 additional shim-only elements: the average standard deviation across the volume of the brain was reduced from 19.3 Hz (baseline) to 15.7 Hz for 2nd order spherical harmonics (SH) and to 10.2 Hz for dynamic MC shimming.

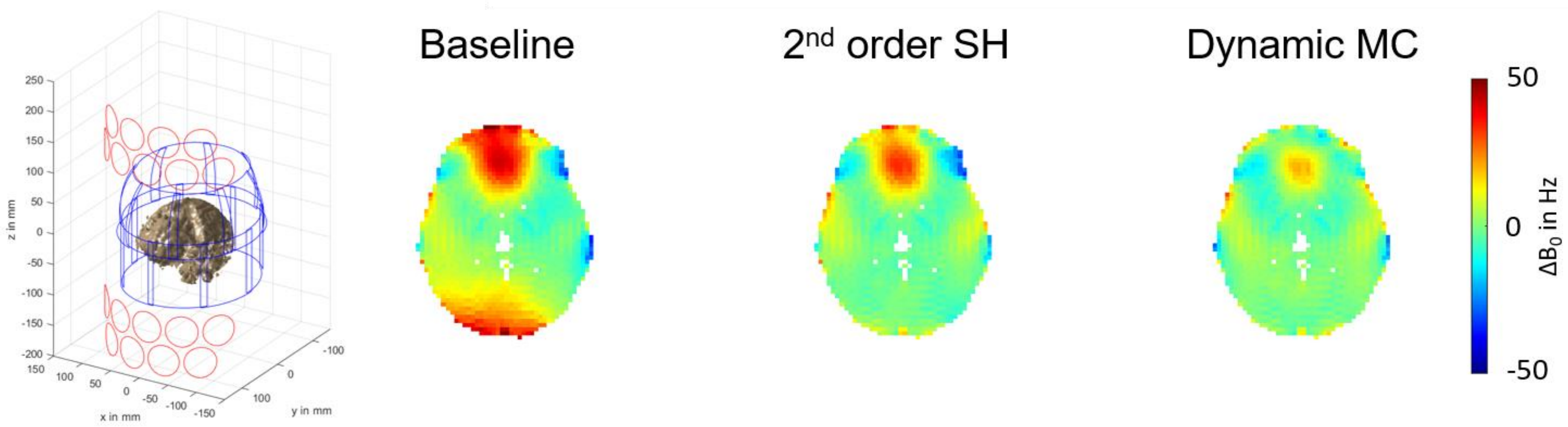

Figure 4. B_0 shimming performance of the hybrid setup. (Left) Coil setup. The RF elements, in blue, were modeled with a single turn of wire, the MC elements, in red, were modeled with 40 turns each. (Right) B_0 maps in a representative slice of the brain before shimming (baseline), after 2nd order spherical harmonics (SH) and dynamic MC shimming.

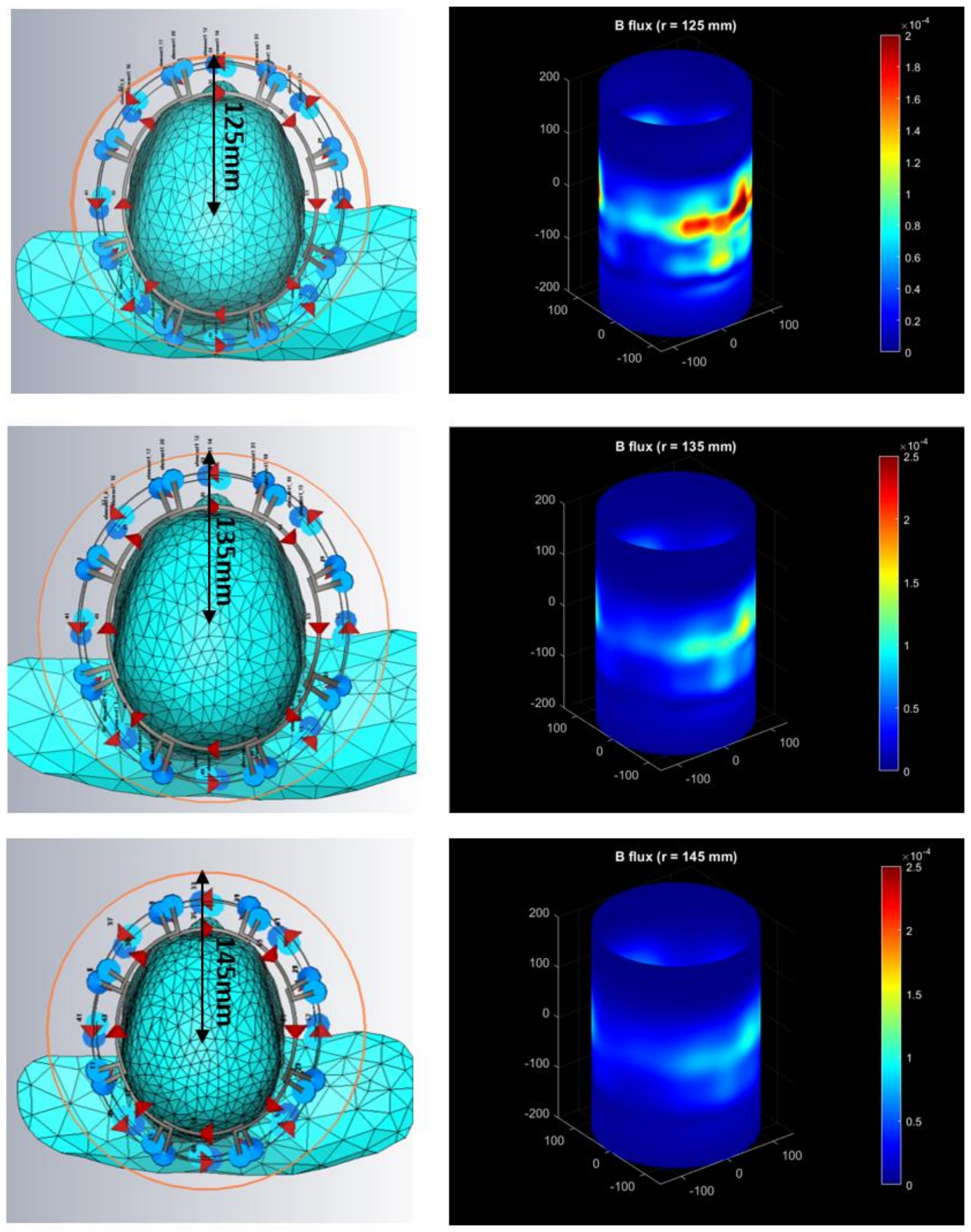

Figure 3. Magnetic flux maps obtained from sampling the array magnetic field flux through three cylindrical surfaces of radius = 125, 135, 145 mm. Each point represents the magnitude of the flux through a 40-turns 25-mm-radius MC-only element centered in that location.

Discussion

- As expected as the distance between the RF coil and the MC elements increases (in both radial, and longitudinal directions), the flux decreases.
- Quadrature-like phase combination led to magnetic flux (i.e. coupling) hotspots near the overlapping areas of neighboring coils.
- These maps can be used as guidance for the placement of MC elements to mitigate coupling arising from Faraday's law.
- The advantage of such approach is that it only requires a single simulation, as opposed to simulating all possible MC elements positions around the RF coil.
- The simulated setup dramatically improved B_0 homogeneity, especially in the prefrontal cortex which is a notoriously challenging area for B_0 shimming due to drastic changes in magnetic susceptibility.

Conclusions

In this preliminary work we have investigated the feasibility of an integrated B_0 shimming and RF receive array coil. Here we focused on mitigating the potential coupling between the RF and MC elements which could potentially decrease the RF performance. While the B_0 shimming performance of the simulated setup already outperformed the state-of-the-art, the positioning and size of the MC-only element was not optimized for shimming performance. Future work will include such optimization using the magnetic field flux maps in Fig. 3 as a penalty factor to minimize coupling.

References

[1] Juchem, C. Et al., J Magn Reson. 2011;212(2):280-288. [2] Manly, J., et al., PsyArXiv, 10 Aug. 2020. Web. [3] Juchem, C., et al., NMR Biomed, 2014. 27(8): p. 897-906.

Acknowledgments

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