Magnetic Field Modeling With A Set Of Electrical Coils

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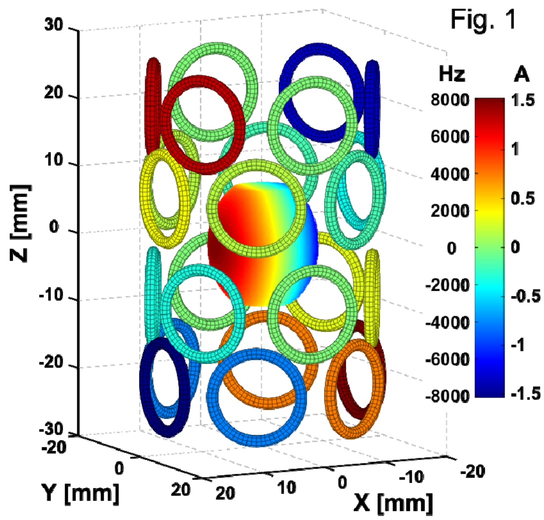
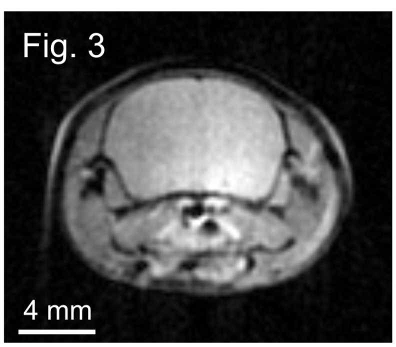
INTRODUCTION: Conventional gradient and shim coils provide one magnetic field term per coil. The sensitive volume of the coils is defined before the coils are designed and has to be chosen sufficiently large to cover all kinds of objects and MR applications.

After the theoretical introduction of the multi-coil approach for the generation of all first- to forth-order spherical harmonic field terms in the human brain one year ago [1], here we present the first experimental realization of the multi-coil concept in a miniaturized setup. We show that gradient and higher order field terms can be generated at high amplitude and high accuracy with a set of circular, localized coils. With the multi-coil approach, the choice of the sensitive volume remains temporally and spatially flexible at all times. Furthermore, the strength and accuracy of the fields are readily traded.



METHODS: The multi-coil setup consisted of 24 coils (15 turns, diameter 13 mm) that were distributed in 4 rings of 6 coils each over a cylindrical surface with an outer diameter of 30 mm. Field simulations and experiments considered a centered, 2.6 mL barrel-shaped volume large enough to cover the head of a mouse as well as single slices of that volume. Figure 1 shows an example current distribution of the multi-coil array (Ampere scale) that generates a 10 kHz/cm X gradient inside the volume-of-interest (Hertz scale). In its experimental realization, coils were made of copper wire and mounted on the surface of an acrylic former. A home-built Bolinger RF coil surrounded the multi-coil setup and was used for RF transmission and signal reception. The inner two rings of coils, i.e. 12 coils, were driven in the ±1 A range; the outer two rings were driven with a maximum of ±1.9 A. Field maps were calculated from seven single-echo GE images (field-of-view 24 x 24 x 20 mm^3, matrix 80 x 80 x 40) that were acquired with the conventional gradient system. To achieve radial MR images of the mouse brain, oblique linear field gradients were generated with the multi-coil setup at 20 kHz/cm (47 mT/m) amplitude and 192 equiangular steps with an 1.4 A maximum current. All experiments were carried out on a 9.4 Tesla animal system. Field simulations, data analysis and hardware handling were done with customized software.



RESULTS: The established multi-coil approach and setup allowed among others the reliable generation of XY, X2-Y2, Z2 and Z2X field shapes at average deviations ≤1% of the maximum amplitude, deviations from the targeted amplitude <1% and 1-R^2 values $\leq 5\cdot10^{-3}$ [2]. The example field maps shown in figure 2 were generated at 2 kHz/cm, 1 kHz/cm^2, 1 kHz/cm^2 and 1 kHz/cm^3, with maximum currents of 324 mA, 980 mA, 434 mA and 783 mA, respectively. The limitation of the sensitive volume to single slices allowed efficiency improvements, i.e. the reduction of maximum currents, of factors up to 14 (for the Z2 term) with no accuracy penalty. An additional trade of accuracy for efficiency was always possible. Furthermore, linear gradients generated with the multi-coil approach allowed artifact-free imaging of a mouse head (Fig. 3).

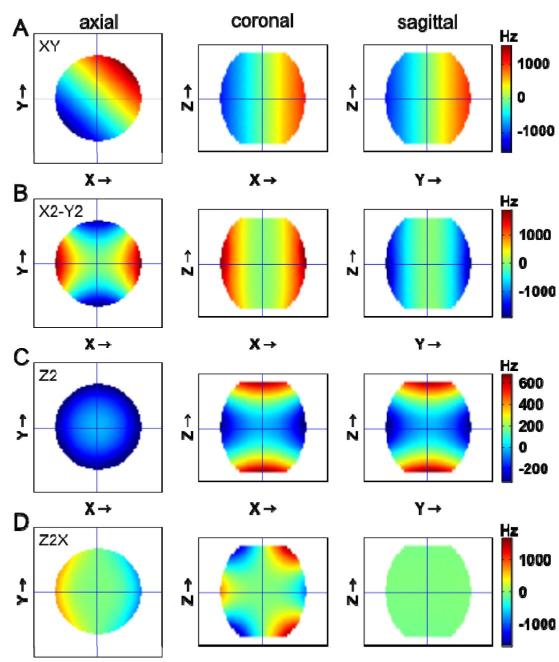


Fig. 2

DISCUSSION: A multitude of complex field shapes can be generated at high amplitude and high accuracy with a set of circular, localized coils. Lorentz forces, heat and noise generation did not pose any problem due to the applied low currents. Additional efficiency gains and modeling capabilities are expected from an expansion of the coil matrix. The new multi-coil approach provides the framework for the integration of conventional imaging and shim coils into a single multi-coil system and its further development towards a system capable of generating arbitrarily shaped magnetic fields for MR applications in animal and human setups.

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