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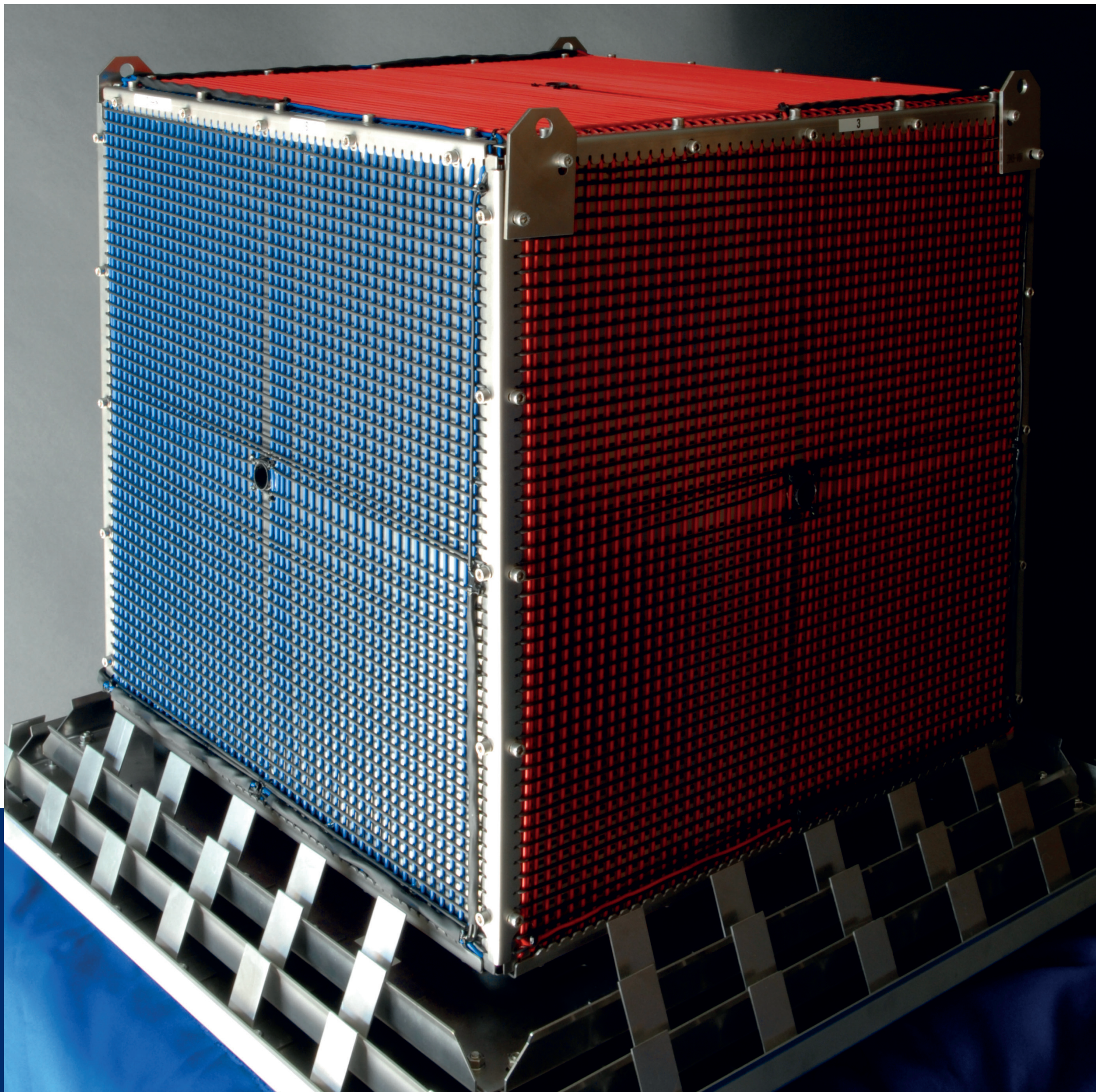
HOMIE

HOMOGENEOUS FIELDS IN EXPERIMENTS



Generate 3D magnetic fields of very high spatial homogeneity for your experiments

Several scientific experiments require magnetic fields of very high spatial homogeneity or defined field gradients. Such experimental setups are used for the characterization of high precision magnetic field sensors or in other fields of atomic or nuclear physics, neuroscience and in nanoparticle research.

In many cases quasi-static field vectors with magnitudes in the sub-mT-range are needed that can be adjusted in two or three dimensions within a highly spatially homogeneous volume. To generate precise field conditions in this range, an effective shielding of the earth's field and of laboratory fields is required.

Low-frequency and DC magnetic fields can only be shielded by the method of flux guidance, preferably with a closed boxlike shape and several layers of the high-permeability shielding material MUMETALL®. Defined magnetic fields inside the shielded space can either be generated by permanent magnets or by electrical currents.

HOMIE is based on electrical currents to be able to adjust the magnetic field strength without mechanical changes. As the shielding materials also interact with the generated internal fields, a concept is needed that lets the passive shielding support the generation of the homogeneous field instead of interfering with calculationally optimized air coil systems. Many conventional setups use Helmholtz coils, whose theroretical field homogeneity is limited to the 2nd order and is additionally affected by surrounding shielding material.

The HOMIE system is based on a different approach that uses the shielding material to even improve the field homogeneity. In principle (limited by the practiced constructional effort), the whole interior can be filled with an absolutely homogeneous field. It therefore offers a large utilizable volume fraction for experiments and in contrast to solenoidal coil systems e. g., it is easily accessible from the outside. Effects on the field homogeneity by customer-specific openings can be minimized by a sophisticated current diversion method. Besides, the whole interior can be kept free of electrically conductive material which is important if higher frequency experiments are to be performed under controlled quasi-static magnetic field conditions.

The Setup

The HOMIE shielding box shown in fig. 1 consists of five layers of MUMETALL®, a very high-permeability and low-coercivity material that is used for shielding applications with highest demands. This minimizes stray fields and effects of remanent magnetization to a minimum.

The homogeneous magnetic field is introduced by a sophisticated array of cables that is applied to the innermost shielding layers so the shielding works both as an external field suppressor and a field homogenizer.

The control unit is delivered externally and consists of power supplies and a control device. It is optimized to provide stable current conditions for an absolute minimum of time-dependent field fluctuations.

Fig. 1: HOMIE system with inner dimensions of $(500\ mm)^3$ and outer dimensions of $(700\ mm)^3$ together with its electronics rack.

Advantages

- 1D/2D/3D magnetic fields < mT
- typical magnetic shielding factors of 10 000 (80 dB) ... 1 000 000 (120 dB), depending on the system size
- higher field homogeneity than Helmholtz systems
- wider homogeneous volume than with active dynamic compensation
- easily accessible interior
- customer-specific adaptions possible (size, shielding requirements, openings, electronics, software...)
- optional: demagnetization of shielding material
- defined field gradients
- already in use by several research labs

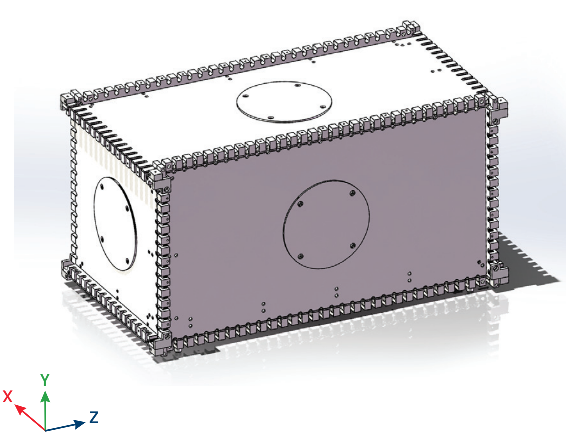


Fig. 2: Mumetall parts of a HOMIE system with inner dimensions X x Y x Z = 160 x 160 x 320 mm³ with covered feedthrough holes. Note the coordinate system in the lower left corner. The optional outer shielding layers are suppressed.

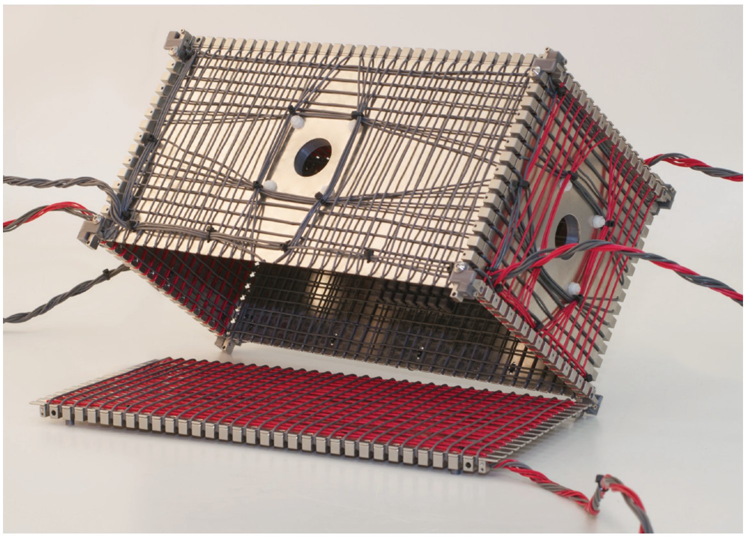
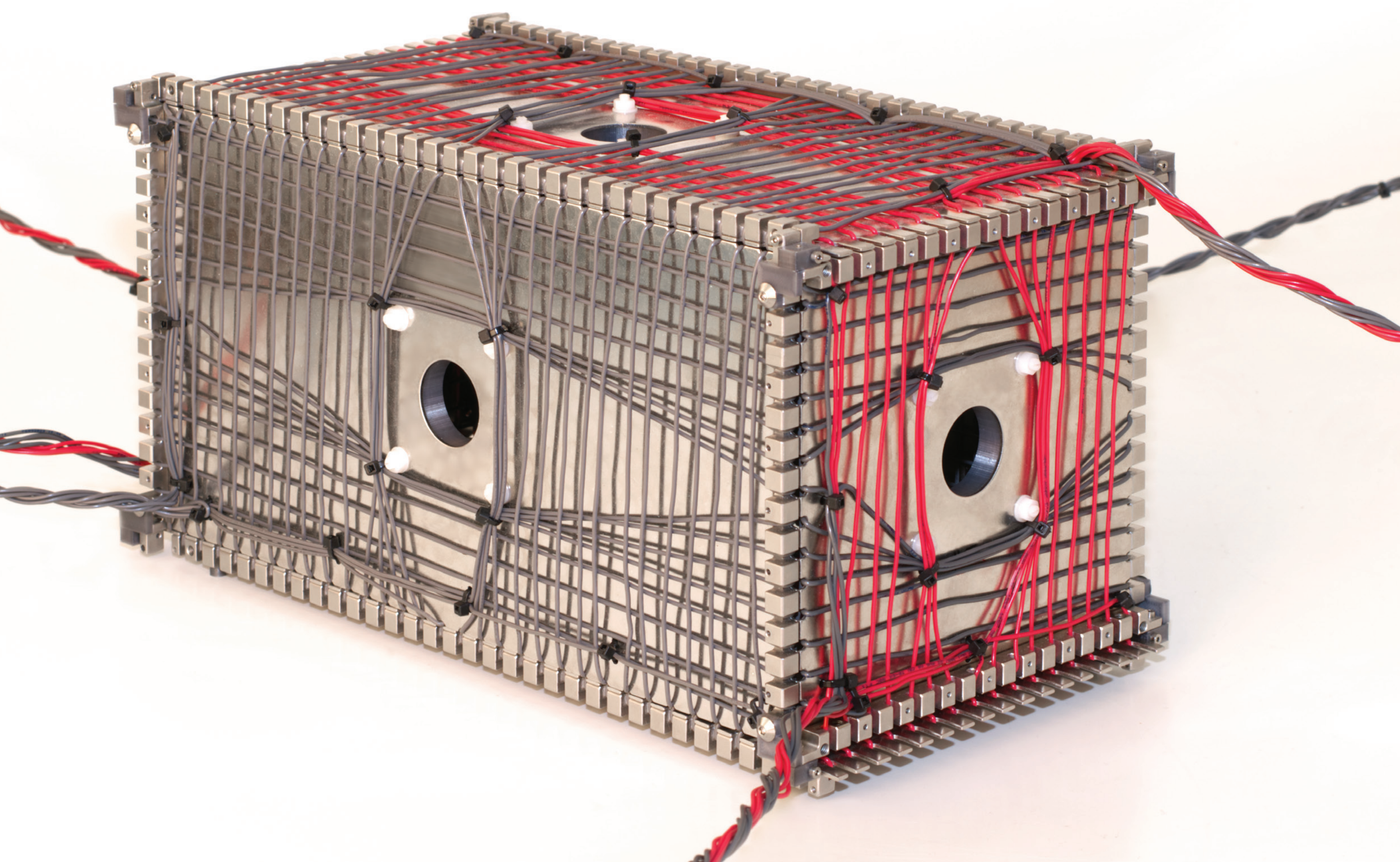


Fig. 3: Photograph of the opened system. All six plates can be connected arbitrarily.

Comparison of magnetic field profiles generated by the HOMIE system with Helmholtz-like coil fields

We compare the spatial homogeneity of an unidirectional magnetic field generated by a HOMIE system with the calculated magnetic field generated by an ideal square coil pair with infinite current density (punctiform conductors). These two current loops enclose the same cross section as the free inner space of the HOMIE system. Their distance is optimized to yield the best field homogeneity in the central plane inside the HOMIE system.

Fig. 4: Photograph of the innermost HOMIE layer as in fig. 2 with attached windings for 3D magnetic field and linear gradient generation. All feedthrough holes are open in this case. The size of the system as well as the number, size and position of the feedthroughs can be customized.



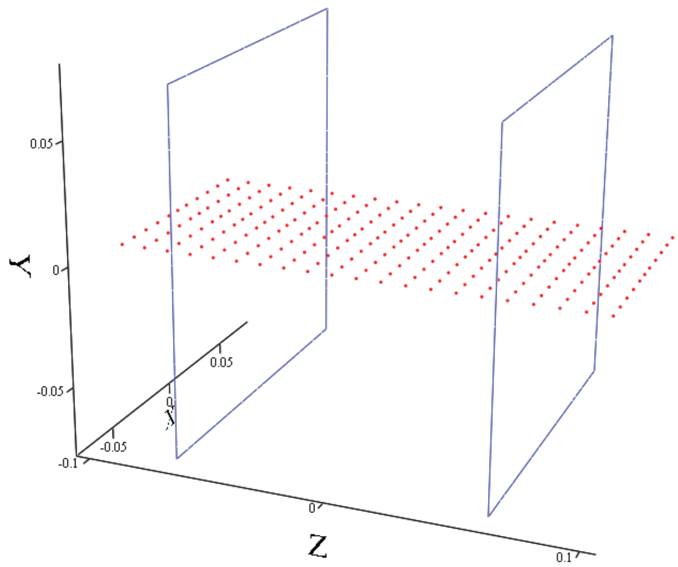


Fig. 5: Representation of idealized square field coils (blue) which have the same edge length as the inner dimensions of the HOMIE system described above (160 mm). The coil distance was optimized to achieve the best magnetic field homogeneity in the examined XZ plane (red). The dimensions are in meters [m].

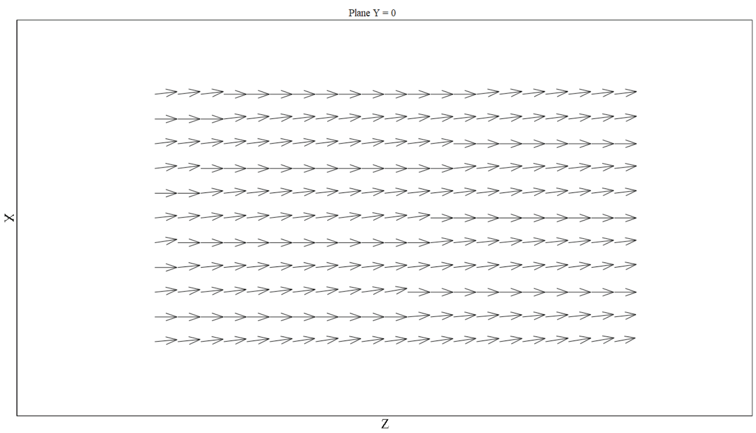


Fig. 6: Representation of the measured magnetic field in the XZ plane, generated by the HOMIE system set to field generation in the Z direction only.

The (X; Z) components of the arrows are calculated as:

$$\begin{pmatrix} B_z \\ \operatorname{sign}(B_x)\cdot\sqrt{B_x^2+B_y^2} \end{pmatrix}$$

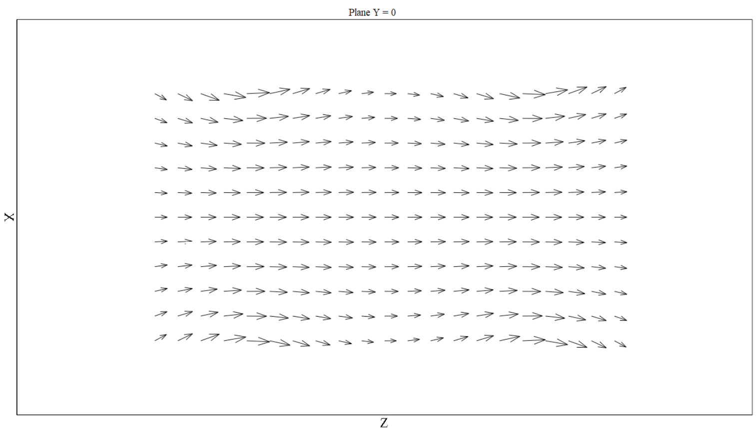


Fig. 7: Calculated magnetic field in the XZ plane, generated by an idealized Helmholtz-like coil pair with optimized coil distance.

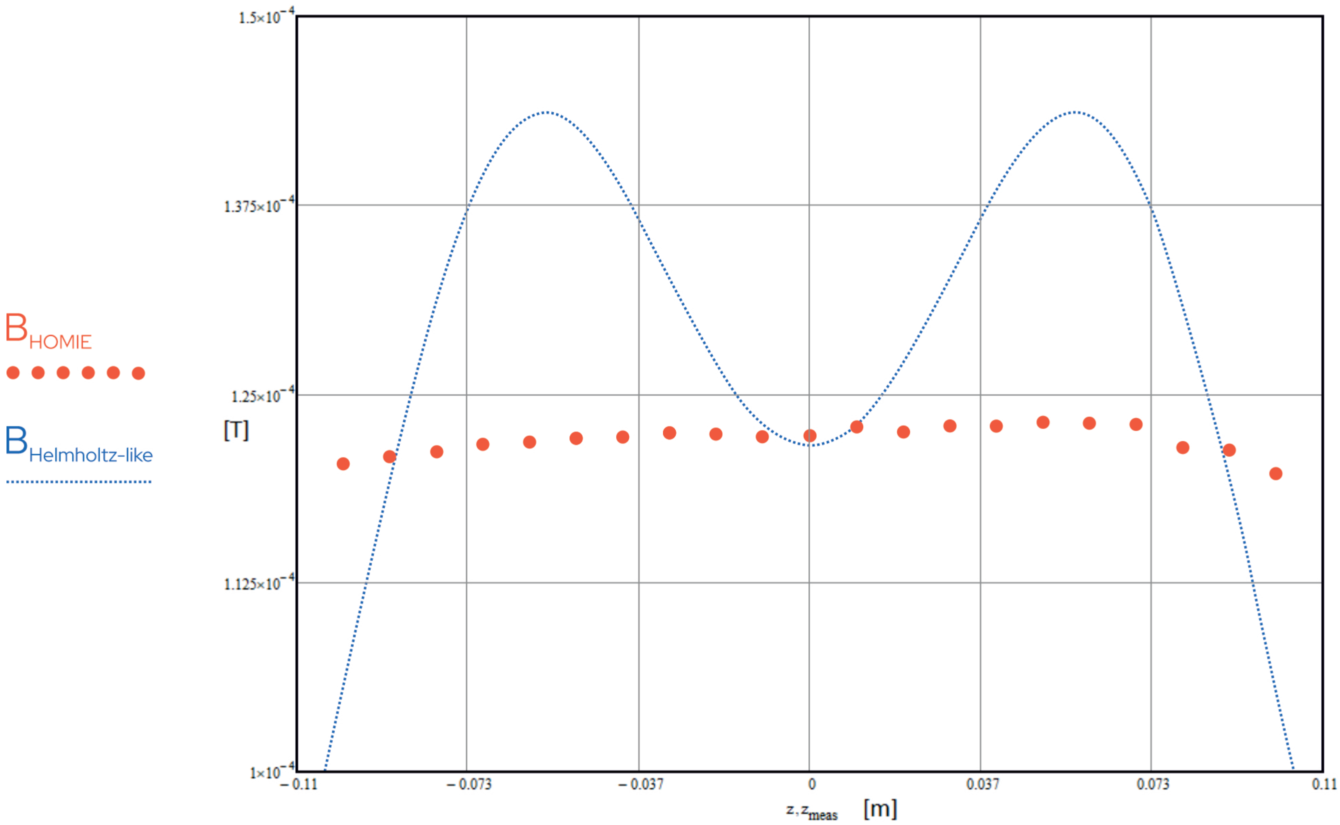


Fig. 8: Comparison of both field profiles for the dominating Bz magnetic field component along the Z axis. The measured HOMIE field (red dots, set to 1 A/cm) is much more homogeneous than the calculated coil field (blue line) based on large scales in consideration.

The measured relative field range of the HOMIE system regarding the whole line of interest (red dots) is ±4.2 % compared to ±32.3 % for the calculated optimized coil system. The relative standard deviation of the HOMIE field is below 0.8 % compared to more than 16 % for the coil system.

It should be mentioned that coil fields can be optimized for better field homogeneities than a HOMIE system of comparable size can generate, if one restricts to small volumes of consideration. This can already be recognized comparing the centers of Figs. 6 and 7, neglecting the influence of finite current densities and supposing that a real coil system could be manufactured with sufficient accuracy to reproduce the calcualated field values. But to achieve a homogeneous volume fraction comparable with a HOMIE system, Helmholtz-like coil systems would require several correction coils. With increasing requirements for the field homogeneity their layout becomes more and more complicated due to limited accuracy of FEM calculations under the influence of adjacent magnetic shielding material.

In contrast to this, the magnetic field homogeneity of the HOMIE system is not influenced by additional outer magnetic shielding layers which can be arbitrarily added to improve the magnetic shielding performance without adapting the windings.

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