B0 SHIMMING FOR PRECLINICAL IMAGING

Preclinical magnetic resonance imaging (MRI) is essential for enhancing our understanding of biological processes and disease mechanisms. It provides in-depth anatomical and functional information about biological samples, such as small animals, prior to human testing. This technique enables researchers to explore the underlying mechanisms of diseases, assess treatment effectiveness, and examine anatomical structures at a microscopic scale. However, there are still technical challenges facing preclinical MRI, especially concerning ultra-high field (UHF) MRI.

One of the major challenges facing UHF-MRI is the presence of strong background magnetic field inhomogeneities, which if not addressed can manifest as artifacts such as geometric distortions, blurring and signal void in the acquired images. MR spectroscopy and spectroscopy imaging **(MRS, MRSI)** and fast imaging sequences such as Balanced Steady-State Free Precession **(BSSFP)** or echo planar imaging **(EPI)** used in diffusion and functional MRI are particularly sensitive in this regard. These techniques enable the exploration of neural connectivity and functional activity, providing a deeper understanding of brain function and its alterations in various conditions.

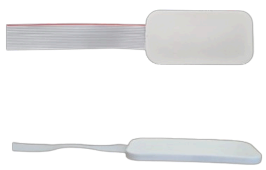
The issue of magnetic field inhomogeneity is especially pronounced in case of small animal imaging due to the small and complex anatomy of the sample, leading to very local residual inhomogeneity patterns in the magnetic field (e.g. close to the ear cavity).

Metis *Small animal cradle with* ***integrated local shim array*** *inside*

Counteracting these field inhomogeneities is essential for obtaining high-resolution images of the brain and other organs, and is particularly important in studies involving disease models, where precise imaging can reveal critical insights into pathological changes and treatment responses.

“Active shimming” refers to the process of adjusting the magnetic field using a set of shim coils to achieve a uniform field distribution across the imaging volume. This process is usually performed as part of the pre-scan adjustments using the scanner-provided spherical harmonics shim coils.

Although effective in counteracting global and slow-varying inhomogeneity patterns in the magnetic field, the physical limitations of the vendor-provided shim hardware, including the size, shape and strength of these spherical



Metis ***local shim array***
in add-on form (for use with existing cradles)

harmonic shim coils, limits their ability to achieve a perfectly uniform magnetic field. As a result, researchers may face challenges in obtaining high-quality images, potentially compromising the accuracy of their findings and the overall effectiveness of their studies.

Additionally, sometimes the shimming process turns into a time-consuming part of the overall scan protocol as researchers resort to iterative shimming to achieve a more homogenous field. This method involves repeatedly adjusting the scanner shim settings, and then assessing the results to determine whether the shimming has improved the uniformity of the magnetic field.

The iterative approach is often deemed necessary because achieving an optimal shim in small animals with intricate anatomical structures inherently leads to an ill-posed mathematical problem. Each adjustment may only yield marginal improvements, requiring multiple cycles of tuning to reach the desired level of field homogeneity. The time required for each iteration adds up, making the overall procedure lengthy.

Shimming in preclinical UHF MRI continues to pose significant challenges, necessitating tailored and advanced solutions to enhance field homogeneity and minimize scanning overhead.

This further underscores the need for more efficient and effective shimming techniques **tailored** to the unique challenges of preclinical MRI that can achieve a **reliable** and **repeatable shim** over a small volume of interest.

Innovative Technology

To tackle the critical issue of shimming in preclinical MRI, we introduce the *Metis* Local Shim System [1]—a cutting-edge local shim coil system specifically designed to enhance magnetic field homogeneity beyond traditional scanner shimming routines for small animal imaging, thereby significantly improving data quality.

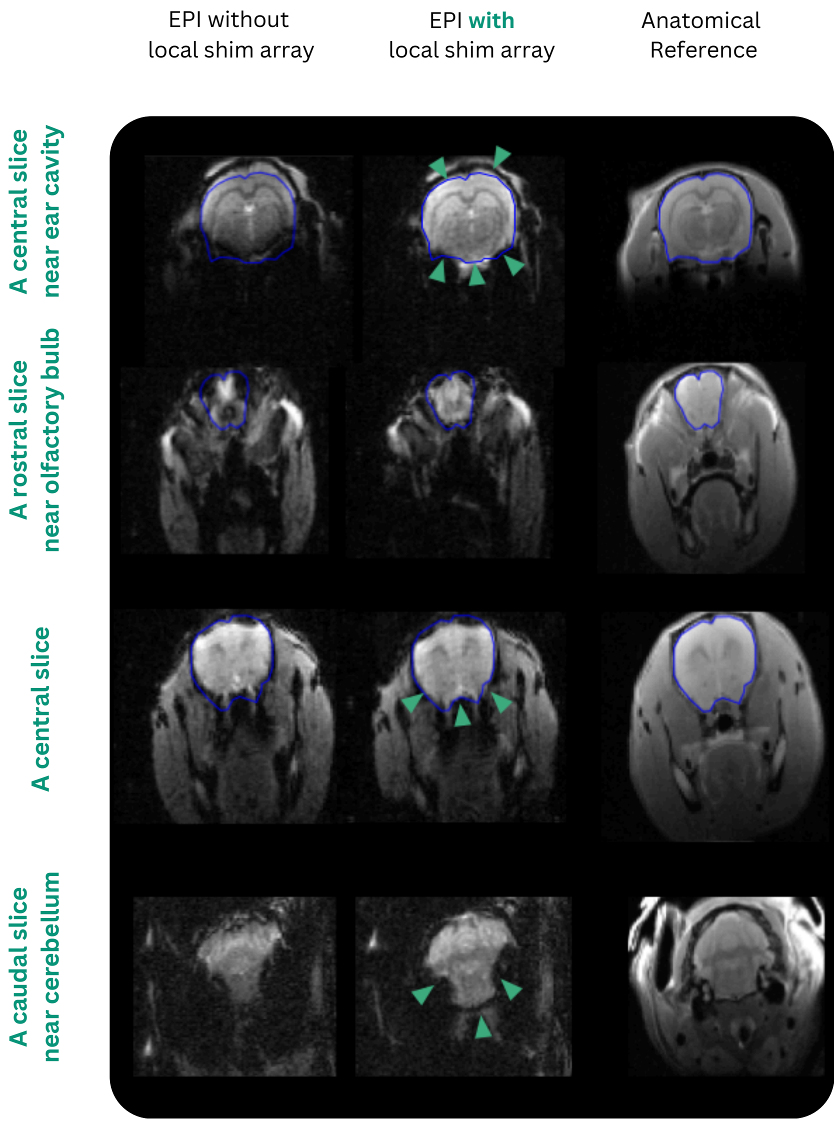
The *Metis* Local Shim System is designed with seamless integration into the animal examination bed without competing for space with RF coils and other equipment. Users simply plug the system in at the back of the examination bed, allowing for immediate use without the complications of additional setup.

Equipped with amplifiers and all necessary peripherals, the *Metis* system is an end-to-end shimming solution. Additionally, it incorporates advanced algorithms designed to optimize the magnetic field, enabling precise and tailored adjustments to address inhomogeneity challenges specific to small animal imaging. Notably, the system utilizes a non-iterative algorithm, streamlining the process and eliminating the need for lengthy iterative shimming procedures.

By providing additional degrees of freedom for local shimming, the *Metis* Local Shim System stands out as the first shim system capable of completely recovering signal loss in images, thereby enhancing the reliability of data and offering substantial value to preclinical research.
In this white paper, we present a case study aimed at improving MRI data quality acquired from the rat brain at 9.4T leveraging the advanced capabilities of the Metis local shim system.

Case Study

To evaluate the effectiveness of the *Metis* Local Shim System, a study on a 9.4T small animal scanner is presented.



9.4T EPI images of the rat brain showcasing significantly less signal dropout and distortion after local shimming

The case study [2] was conducted in-vivo on the rat brain using a 9.4T Bruker BioSpec MRI scanner [3] with a 4-ch RF receive array [3]. The specific objective of the study was to **reduce substantial distortion** (specially in the olfactory bulb and cerebellum regions) and **recover the complete lack of signal** observed near the ear cavities in EPI imaging of the rat brain.

For field mapping, a dual-echo gradient echo (GRE) field mapping sequence with the following parameters was utilized:

FOV = 28.8 mm x 28.8 mm x 28.8 mm, TR = 20ms, deltaTE = 1.427 ms, 0.4 mm isotropic resolution.

A *Metis* add-on local shim array with optimized design for brain imaging positioned at the base of the animal cradle was used to enhance the magnetic field homogeneity.

To compare the effectiveness of the local shim array, EPI images from the entire brain were acquired once with and once without the use of the local shim coils (2D multi-slice EPI sequence, with 0.25 mm x 0.35 mm in-plane resolution and

33.6 mm x 24 mm in-plane FOV, TE of 14.5ms, and TR of 1.5 seconds, slice thickness of 0.8mm and a total of 34 slices).

The process of shimming was as follows: First, standard shimming using the vendor-provided shimming routine with up to 2nd order spherical harmonics plus the Z3 and Z4 terms was performed on an elliptical shim volume covering the entire brain. EPI images with this shim setting were acquired and used as reference for comparison. Next, slice-wise shim updating was calculated through the *Arche* [1] shim software and applied before the acquisition of a set of images for each slice.

The resulting images confirmed that the application of enhanced shimming using the *Metis* shim array resulted in remarkable improvements in signal recovery and image quality across various anatomical slices (see Figure, page 3).

The quality difference between the two sets of EPI images were evaluated using ratio images of signal intensity. This approach allowed for a direct visualization of the enhancements in signal strength attributable to the new system. Additionally, anatomical outlines were drawn on the reference T2-weighted anatomical images and overlaid on each set of EPI images to help assess geometric distortions.

Comparing the two sets of EPI images across different anatomical slices revealed the following results:

Rostral Slice:
- Achieved a 50% increase in signal intensity.
- Demonstrated a significant reduction in geometric distortion, enhancing the accuracy of anatomical representations.

Central Slice:
- Observed a remarkable 300% increase in signal intensity near the ear cavity, resulting in complete recovery of signal loss.
- Achieved a 40% increase in signal intensity in cortical areas.

Caudal Slice:
- Achieved a 40% increase in signal intensity in the cerebellum.
- Also exhibited a significant reduction in geometric distortion, further contributing to the reliability of the imaging data.

Overall, these results underscore the effectiveness of the *Metis* Local Shim System in enhancing signal quality and reducing distortions, providing substantial improvements in the reliability and accuracy of preclinical MRI imaging.

Common artifacts such as signal void and geometric distortion in pre-clinical imaging can be significantly reduced (e.g. +300% increase in signal near ear cavity and +40% signal intensity increase in other challenging areas).

Conclusion

The *Metis* Local Shim System proved to be effective in improving signal quality and reducing geometric distortions in preclinical MRI imaging. The system's ability to achieve notable increases in signal intensity across different anatomical regions enhances the accuracy and reliability of research findings.

Usability is a key strength of the *Metis* system. The shim arrays are directly integrated in the examination bed, allowing for use with any preferred RF coil and examination setup.

Beyond EPI imaging application, the ability of the local shim system to significantly reduce susceptibility artifact in challenging anatomical regions can benefit other MRI applications that are susceptible to field inhomogeneity.

[1] MR Shim GmbH, Reutlingen, German
[2] Experiments conducted with Mainz Animal Imaging Centre (MAIC), AG Stroh

[3] All product and company names are the registered trademarks of their original owners. The use of any trade name or trademark is for identification and reference purposes only.

The local shim systems offered by MR Shim are customizable to any MRI setup or anatomical region.

Integrated shim cradles are available for both rat and mouse imaging and both brain and body applications.

Dynamic and real-time shimming kits available. Learn more by visiting our website or contact us today to schedule a meeting

VISIT US ONLINE
MR Shim GmbH
Ferd. Lassalle Str. 36
72770 Reutlingen, Germany
info@mrshim.de