Magnetic Particle Imaging for Nanomedicine

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Magnetic Particle Imaging (MPI) is a promising tool for nanomedicine for cancer therapy, allowing to assess drug delivery by quantifying the Enhanced Permeability and Retention (EPR) effect. Usually MPI quantitatively determines the spatial distribution of superparamagnetic iron oxide nanoparticles (SPIONs) by exploiting their characteristic nonlinear magnetization response to a changing magnetic field. Current MPI scanners offer high temporal and spatial resolution, but are still limited in terms of sensitivity and their capability of measuring functional parameters such as temperature, pH-value, cellular uptake or tracer binding status. One promising approach to determine these parameters is particle excitation at multiple frequencies. Conventional MPI systems use resonantly powered excitation fields to stimulate SPIONs and narrow band-stop filters to cancel the drive field feed-through. However, these frequency selective components have to be replaced by other techniques to enable multi-frequency excitations.

We will present a novel proof-of-concept multi-frequency MPI device, which uses a combined passive and active drive field feed-through compensation approach. Passive compensation was realized by inductive decoupling of separate transmit (TX) and receive (RX) solenoid coils. The inner bore of RX is 33 mm, enabling imaging applications. It is placed inside the TX coil and can be moved along the longitudinal axis to reduce the inductive coupling between the TX and RX coils. The residual feed-through signal is further attenuated actively by inductively superimpose an inverse signal. A feedback loop was implemented, which allows minimizing the respective peak in the frequency spectrum. Across the bandwidth of 1 - 20 kHz an almost constant combined feed-through compensation of about 130 dB was measured, enabling imaging applications at arbitrary excitation frequencies. To prove the concept of multi-frequency excitation and first harmonic detection, particle spectra of a 200 µl Perimag® sample with a concentration of 25 mg/ml were acquired. Results will be shown at the conference.

OpenMPIData: An initiative for freely accessible magnetic particle imaging data

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Magnetic particle imaging is a tomographic imaging method capable of measuring the local concentration of magnetic nanoparticles that can be used as tracers in biomedical applications. Since MPI is still in a very early stage of development only few MPI systems exist worldwide. Consequently, it is difficult to obtain experimental MPI for researchers not having direct access to an MPI system. The purpose of the OpenMPIData initiative is to make experimental MPI data freely accessible through a dedicated web platform. Measurements performed with several phantoms and different imaging sequence ranging from 1D to 3D are provided. The data is stored in the magnetic particle imaging data format (MDF), which is an open document standard for the storage of MPI data.

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A Summing Configuration based Low Noise Amplifier for MPI and MPS

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Magnetic particle imaging (MPI) is a novel tomographic imaging modality which uses static and dynamic magnetic fields to measure the magnetic response generated by superparamagnetic iron oxide nanoparticles (SPIONs). For the characterization of the SPIONs magnetic particle spectroscopy (MPS) is used. In the current research, a low noise amplifier (LNA) suitable for MPI and MPS is presented. LNA plays a significant role in the receive chain of MPI and MPS by amplifying the signals from the nanoparticles while keeping the noise induced through its own circuitry minimal. The LNA is based on the summing configuration and fabricated on a printed circuit board (PCB). Moreover, the prototyped LNA is compared with a commercially available pre-amplifier. The input voltage noise of the prototyped LNA with a receiving coil of series resistance of 0.551 mΩ and an inductance of approx. 130 µH is approx. 561 pV/√Hz with a noise figure (NF) of 11.57 dB.

Enhancements for Traveling Wave Magnetic Particle Imaging

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Since the first publication of Magnetic Particle Imaging (MPI) in 2005 several different scanner concepts have been presented each providing specific features and advantages. MPI basically relies on the non-linear response of superparamagnetic iron-oxide nanoparticles (SPIONs) on time-varying magnetic fields. For imaging a strong magnetic field gradient represented by a so-called field-free-point (FFP) is moved rapidly on a specific trajectory through the field-of-view (FOV) acquiring the non-linear response of the distributed SPIONs over time 'point-by-point'. In that way the FOV can be scanned in a fast way with a high sensitivity and good resolution sufficient for real-time in-vivo imaging of intravenious injected SPIONs in a beating mouse heart.
Traveling Wave Magnetic Particle Imaging (TWMPI) uses a highly dynamic and flexible hardware approach for generating the required magnetic fields. The TWMPI approach offers e.g. the possibility of a direct combination with low field magnetic resonance imaging (first hybrid MPI-MRI scanner) or imaging in superspeed mode with up to 1900 frames per second.
Further developments include parallel imaging with multiple FFPs and a hardware lense effect offering a local enhancement in resolution with up to 30%. These advance features will be the focus of this presentation displaying the versatility of TWMPI and outlining potential applications.

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Lateral Movement of Helical Swimmers Visualized with Magnetic Particle Imaging

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The magnetic manipulation of medical devices such as catheters, small cameras or drug filled capsules enables to improve the precision of minimally invasive surgery. Catheters can be steered towards tissue regions difficult to access. Drugs can be delivered directly to cancerous tissue or inflammatory regions, which allows lower dosages and healthy tissue is less affected.

In-vitro experiments can be easily visualized with video and microscopy methods, but in-vivo the manipulation process needs to be imaged with a tomographic real time imaging technique to facilitate image guided interventions. Here, Magnetic Particle Imaging (MPI) is a promising method.

MPI images the spatial distribution of superparamagnetic nanoparticles. It is highly sensitive and enables real time imaging with a resolution in the submillimeter range. It is based on the nonlinear response of the particles to alternating magnetic fields. A gradient field forming a field free point encodes the signal spatially. A commercially available MPI scanner (Bruker Biospin MPI 25/20 FF) features homogeneous offset fields, called focus fields, applicable in three dimensions to enlarge the field of view. By applying an alternating current to the focus field coils, a rotating magnetic field of up to 10Hz can be generated. These rotating focus fields can be used to manipulate magnetic material inside the MPI scanner, since the materials' magnetization and the rotating fields induce a torque. This enables dual use of existing MPI scanners for imaging and manipulation.

Helical swimmers are being presented, which perform a lateral movement induced by the rotating focus fields inside the preclinical MPI scanner. The swimmers are 3D printed. The material is further investigated in terms of suitability for MPI as well as the geometry of the swimmers aiming at a stable rotation and large propulsion in a water filled phantom.

MPS-mouse: first mobile Magnetic Particle Spectrometer

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Magnetic Particle Imaging (MPI) is a new imaging modality for the three-dimensional determination of superparamagnetic iron oxide nanoparticles (SPIOs). In addition to further developments in hardware and reconstruction methods for MPI the understanding of the tracer itself is essential. Magnetic particle spectroscopy (MPS) can be used to study the dynamic and behavior of SPIOs to enhance the imaging.
The MPS mouse is a mobile device that provides access to MPS to many research facilities through its ease of use, robust design and mobility.
MPS devices consist of a transmit coil for generating a strong alternating magnetic field, a receiving coil, an amplifier and an evaluation unit. Prevently available MPS devices provide high sensitivity, but are very costly, not mobile and require special training to handle. For many applications there are only lower requirements for MPS devices:
1. Simple and intuitive handling
2. Robust and application-oriented design
3. Mobility and inexpensive hardware
For the magnetic field generation a transmitting and receiving system is used, which can be adapted to the desired application. A pulse design is used producing a short-term strong magnetic field, which is manageable with only a few electrical components. This save space, energy and reduce the costs of the system. For control and data acquisition, a microcontroller is used, which can be controlled via Bluetooth with a mobile computer.
The first prototype of the MPS mouse serves as a reference model to validate functionality (pulse operation for magnetic field generation, data acquisition, data transfer, evaluation routines, etc.), robustness and stability. The material cost of the device is far below commercially available MPS devices, granting many research facilities access to this technology.