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Acoustic radiation force to generate magnetic sensing signal

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The advancements in biomedical nanotechnology have sparked the emergence of nanomedicine, a multidisciplinary field that combines physics, chemistry, biology, and medicine. Nanomedicine has revolutionized diagnostics and treatment at the cellular level, particularly in the realm of cancer[1]. In this context, nanomagnetism, which employs magnetic nanoparticles (MNPs), plays a pivotal role in various applications including biomolecule manipulation, targeted drug delivery, and hyperthermia treatment[2]. MNPs can be functionalized or loaded with additional payloads to carry out specific tasks in treatment, sensing, or imaging. This integration presents opportunities for personalized medicine to enhance patient outcomes by precise and minimally invasive procedures. To drive technological advancements and foster innovative solutions, it is essential to comprehend and regulate nanomagnetism effectively.

External sensing devices can detect the magnetic response of mobile magnetic nanoparticles (MNPs) in a stationary magnetic field. Magnetic Particle Imaging (MPI) is an emerging imaging technique that holds promise for directly visualizing MNPs within the body. However, its clinical applications are currently constrained by limited penetration depth caused by the significant electromagnetic damping effect, as well as the large and energy-intensive installations required. To address these challenges, we employ acoustic waves to excite the MNPs, aiming to overcome these limitations.

The experimental setup illustrated in the figure utilizes acoustic radiation force to dynamically displace magnetic nanoparticles (MNPs) within a static magnetic field, leading to a change in their magnetic moment and thereby generating a detectable signal through a receiver coil. For the proof-of-concept experiments, two cylindrical vials were employed: one empty and the other containing a total volume of 1.5mL of plain Synomag®-D particles (micromod Partikeltechnologie GmbH, Germany) with unmodified dextran surface and hydrodynamic diameters of 70 nm. The experimental setup comprises an excitation coil, a piezoelectric ultrasound transducer (NCE46, Noliac, Denmark) attached to the sample vial using adhesive (Turbotec 911 UV glue, Microtec GmbH, Germany), a 10W RF amplifier (210L, Electronics & Innovation, USA), and a detection probe. The excitation coil applies a DC offset-field at a frequency of 5 kHz. Each cycle of the sequence consists of four blocks: no offset, positive offset, no offset, and negative offset. The piezoelectric element introduces an acoustic square wave at a driving frequency of 100 kHz, inducing the movement of MNPs and consequently eliciting a magnetic response when situated in a DC magnetic offset-field. The driving square wave signal at the transducer is responsible for acoustic displacements of MNPs lasting for 2 ms. For signal detection, a 12 mm-diameter detection probe consisting of a gradiometric configuration of two coils was utilized. This probe was previously introduced[3] as a laparoscopic probe operating in DiffMag mode[4,5].

The obtained results, presented in a scatterplot, indicate that there is a minimal difference in the acquired signal between the vial containing magnetic nanoparticles (MNPs) and the empty vial during the portion of the DC-field cycle with zero amplitude. However, a significant distinction in the acquired signal is observed during the portion of the DC-field cycle when the DC-field is switched on. These

findings suggest that the presence of MNPs affects the detected signal, particularly when the DC-field is active. Further analysis and interpretation of these results can shed light on the behaviour and interaction of MNPs contributing to the understanding and advancement of related research in the field of nanomedicine.

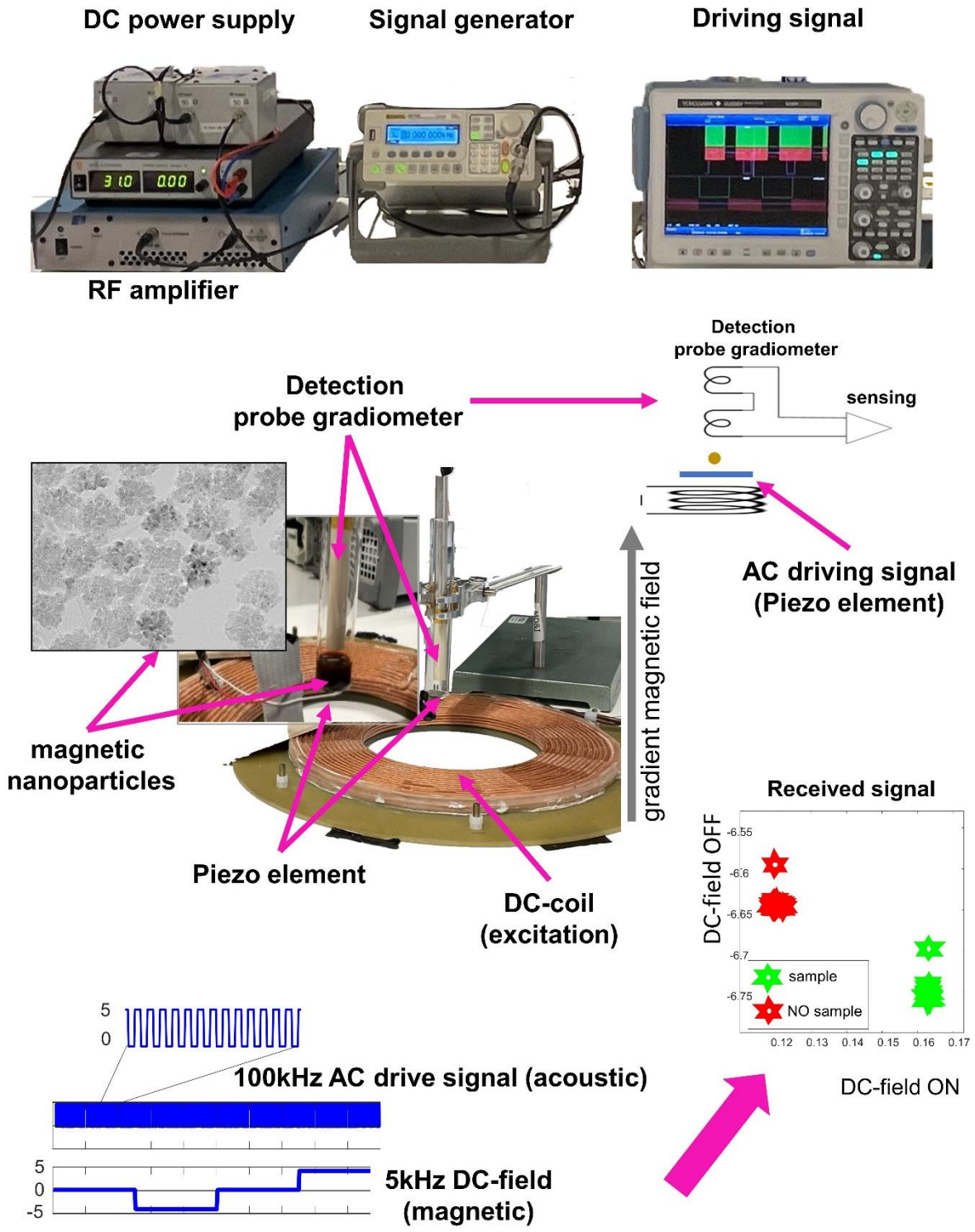

Figure 1. The experimental setup, generated signals, acquired data, and results.

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