Single-Sided Spectrometer for Magnetic Nanoparticle Detection

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Introduction: Magnetic Particle Imaging (MPI) is a new imaging modality that relies on the nonlinear magnetization curve of superparamagnetic iron oxide nanoparticles (SPIOs).[1] When SPIOs are subjected to an external oscillating magnetic field (the "drive field,"), their time-dependent magnetization response includes higher harmonics of the drive field frequency. The harmonic signal may then be exploited for imaging, using DC gradients for spatial localization, and the result is a map of nanoparticle concentration.[1] SPIO tracers can be characterized and evaluated for suitability for MPI by measuring their harmonic dependence on field strength, frequency and local environment (MPI Spectroscopy).[2] The conventional MPI spectrometer places a nanoparticle sample inside a cylindrical bore, but the bore size limits the size and shape of the sample holder and prevents detection of the nanoparticle signal *in vivo*. Conventional bore-type MPI scanners face the same constraints, but single-sided scanners have been developed for MPI imaging in up to two dimensions, such that the concern of subjects fitting into the scanner bore has been eliminated.[3][4] A single-sided MPI spectrometer would similarly remove dependence on the nanoparticle sample holder size and shape. This abstract describes a compact, single-sided spectrometer for nanoparticle detection without the bore constraints of conventional spectrometers.

Materials and Methods: The single-sided device is shown in Figure 1. The transmit coil was a short solenoid (diameter = 4cm, length = 1.5cm) with N=105 turns and tuned using a series capacitor (Q=9). The 10kHz resonant drive signal was produced by a signal generator fed to a commercial audio amplifier, and the result was a 12mT drive field, measured at the sample position using a LakeShore Gaussmeter (455 DSP). For measurements with a DC bias field, a small permanent magnet was placed next to the sample. The receive system consisted of two planar, spiral coils (inner diameter = 0.7cm, outer diameter = 1.5cm) with N=20 turns, attached to each face of the transmit coil. The signals from the receive coils were fed to the inputs of a differential amplifier to eliminate the fundamental drive signal; the gain of one input was adjusted so that in the absence of a sample, the received drive signal was minimized. The remaining fundamental component from the drive signal was further attenuated by a third-order high pass filter (f_c=25kHz). The filtered signal was then further amplified and then fed to a signal analyzer. Before each series of measurements, the differential amplifier was adjusted to cancel the drive signal and the amplitude of the drive field was measured. The nanoparticle sample used for this experiment had a 5nm magnetite core with 2nm oleic acid surfactant layer (for a total diameter of 9nm), and was suspended in toluene at a concentration of 20mg/ml and contained in a small glass vial (1.5cm diameter, 4.5cm long).

Fig 1: Transmit coil and one planar receive coil (the second receive coil is mounted on the bottom face of the transmit coil.).

Results: The nanoparticles' signal is shown in Figure 2. The signal was measured with and without a DC bias field. The background signal (left figure), measured in the absence of a sample, contains the remnants of the drive signal; the background signal is present in the harmonic signals that follow. Without the DC bias field (middle figure), the nanoparticles' harmonic response contains only odd harmonics, as predicted by an anti-symmetric M-H curve with negligible hysteresis. Once a DC bias field was added, it shifted the nanoparticles toward saturation and the harmonic response contained both even and odd harmonics (right figure). The extent of nanoparticle aggregation is still being studied, and its effect on the signal is not yet fully understood.

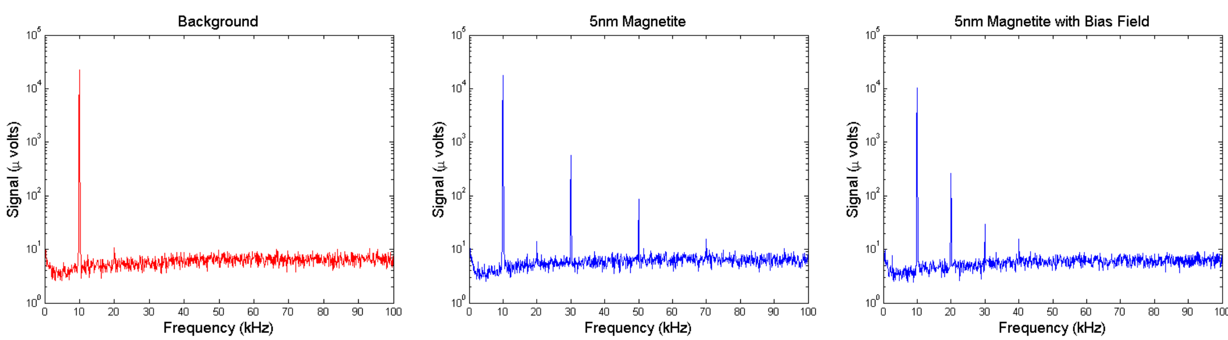

Fig 2: The harmonic signal from 5nm magnetite particles without a DC bias field (middle) and with a 0.2T DC bias field (right). The 12mT, 10kHz drive field contaminated the fundamental signal from the particles, and is shown as a background signal (left). The data was acquired without averaging using an Agilent CXA N9000A Signal Analyzer (resolution bandwidth = 56Hz).

Discussion: We have built a spectrometer for single-sided magnetic nanoparticle detection and successfully measured the harmonic signal from particles with and without a DC bias field. This spectrometer will facilitate detection of nanoparticles in different environments, including *in vivo*. The spectrometer already has localized sensitivity due to transmit and receive coil size, but the addition of DC gradients would further improve spatial localization. The ability to generate a localized magnetic field suggests that the system may also be useful for therapeutic applications such as hyperthermia, for which it would be desirable to simultaneously transmit an oscillating magnetic field and detect the presence of therapeutic agents.

References: [1]Gleich B., Weizenecker J. Nature. 2005 Jun 30; 435(7046):1214-7. [2] Rauwerdink AM, Weaver JB. Med Phys. 2011 Mar; 38(3):1136-40. [3] Sattel, T.F. et al. J. Phys. D: Appl. Phys. 2009 Jan; 42(2). [4] Sattel, T.F. et al. Proc. 18th ISMRM, p3297, 2010.

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