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Microwave Ferromagnetic Resonance Imaging of the Breast using Iron Oxide Magnetic Nanoparticles

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Contrast-enhanced microwave imaging (MWI) of the breast using magnetic nanoparticles (MNP) has been recently studied as a method of overcoming the limitations of conventional MWI arising from the inherently low dielectric contrast that may exist between cancerous and healthy fibroglandular tissues [1]. Scattered field data suitable for MWI of the MNPs' magnetic permeability can be collected through the application and withdrawal of a polarizing magnetic field (PMF) across the imaging domain, an acquisition technique that has been demonstrated experimentally in earlier work [2-3]. It has been observed that increased detection sensitivity for this weak differential signal can be attained when imaging is carried out within metallic resonant enclosures, specifically at certain geometry-dependent resonant frequencies that coincide with the inherent ferromagnetic resonance response of the MNPs themselves. The physical principles that govern this ferromagnetic resonance imaging (FRI) technique are conceptually similar to those of ferromagnetic resonance (FMR) spectroscopy, in which detection of FMR phenomena is best achieved at probing frequencies matching the structural resonant frequency of a metallic cavity. An aluminum faceted quasi-resonant chamber designed for 3D MWI of the breast has thus been populated with non-magnetic antenna elements and integrated into the bore of a large custom-made electromagnet to collect imaging data for an electromagnetic inverse scattering-based FRI system, or magnetic contrast-enhanced MWI system. Simple targets containing a low-dielectric hydrocarbon-based solvent were fabricated for the initial signal acquisition trials, with variable sizes, positions, and concentrations of iron oxide MNPs serving as a ferromagnetic contrast agent. The electromagnet is capable of sustaining a static PMF of at least 0.2 Tesla across the imaging domain at the chamber's center, modulating the MNPs' ferromagnetic resonance behavior, which effectively changes the magnetic permeability of the contrast-enhanced target. An initial four-antenna signal acquisition study was successful in characterizing a particular narrow band of suitable imaging frequencies for these simple single-layer MNP-enhanced targets within the faceted chamber [4]. These resonant characteristics will be validated through numerical models based on the discontinuous Galerkin method (DGM), and more realistic multilayer breast phantoms will be employed, to determine how high-dielectric targets affect the resonant modes within the chamber. The FRI system will also be populated with a full array of twenty-four antenna elements for follow-up experimental trials. The goal of ongoing investigations is to ultimately achieve full-scale 3D reconstructions of breast phantoms' magnetic permeability, accomplished using a DGM 3D formulation of the Contrast Source Inversion algorithm (DGM-CSI), which has been modified to employ a previously-described two-stage reconstruction technique of both the complex dielectric permittivity and magnetic permeability of imaging targets [5].

References

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