Radiofrequency Receive Coil Arrays for Large-Bore Vertical 3T MRI in Process Engineering

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Introduction: Magnetic resonance imaging (MRI) has become a powerful modality for the non-invasive characterization of dynamic processes in bio-/chemical engineering [1]. To expand the capabilities of our world-wide unique vertical 3 Tesla MRI system, we developed a modular suite of radiofrequency (RF) receive coil arrays with 1-, 5-, and 32-channel configurations, each optimized for different imaging objectives. Unlike traditional horizontal MRI systems, the vertical large-bore design supports upright experimental setups and large-scale imaging of pilot-scale reactors, enabling studies of flow, mixing, and reactions under realistic process conditions. Rather than pursuing a single highest-performance array, we implemented a purpose-driven approach balancing spatial/temporal resolution, field-of-view (FOV), and operational simplicity [2, 3].

Methods: The receive arrays were constructed using low-loss copper conductors on thin 3D-printed scaffolds, conforming to sample geometries. Geometric overlap minimized mutual inductance between adjacent coil elements. Active detuning circuits and low-input-impedance preamplifiers enhanced sensitivity and minimized noise. Finite element modeling (COMSOL Multiphysics) guided the coil layout to reduce inter-coil coupling, critical for high parallel imaging performance. RF bench testing validated tuning, matching, and decoupling, with S-parameter isolation levels of at least -20 dB at the operating frequency of 127.8 MHz.

Results and discussion: The arrays enabled imaging of liquids inside structured packings with Schwarz-Diamond triply periodic surface (TPSf) geometries. The 1-channel array delivered uniform sensitivity and high spatial resolution for fine structural imaging in small columns. The 5-channel array offered a balance between resolution and speed for larger setups. The 32-channel array leveraged parallel imaging for rapid 3D acquisition, improving signal-to-noise ratio (SNR) and reducing scan times. This configuration facilitated real-time imaging of flow dynamics in large reactor columns, demonstrating the advantage of tailoring array design to experimental goals and sample scales.

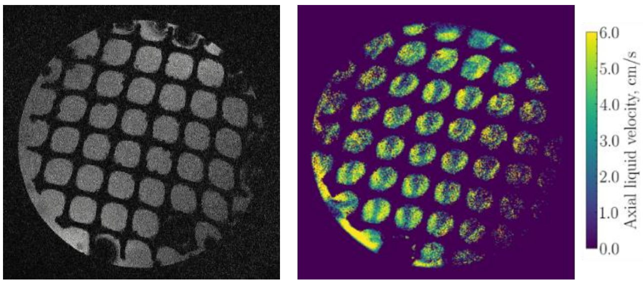

Fig. 1: (Left) MRI of DN 40 TPSf structured packing using 1-channel receive coil, with spatial resolution of 0.1 mm x 0.1 mm x 0.3 mm and temporal resolution of 60 s. (Right) MRI-based velocity mapping of the same packing at Reynolds number of 990, with spatial resolution of 0.1 mm x 0.1 mm x 1 mm and temporal resolution of 18.1 s.

Conclusion: The 1-, 5-, and 32-channel RF receive arrays significantly expand the practical utility of MRI in process engineering. By balancing resolution, FOV, and operational flexibility, this approach supports diverse applications from detailed structural imaging to real-time flow monitoring. Future work will focus on further enhancing performance, modularity, and usability of the RF receive coil arrays.

References: [1] Gladden, Annual Review of Chemical and Biomolecular Engineering. (2017). [2] Roemer, Magnetic Resonance in Medicine. (1990). [3] Wiesinger, Magnetic Resonance in Medicine. (2004).