Wireless Magnetic Field Monitoring

Matthew J. Riffe[1], Daniel Neumann[2], Colin Blumenthal[3], Gregory Lee[4], Nicole Seiberlich[1], and Mark A. Griswold[1,4]
[1]*Biomedical Engineering, Case Western Reserve University, Cleveland, Ohio, United States,* [2]*Research Center for Magnetic Resonance Bavaria (MRB), Wuerzburg, Germany,* [3]*Electrical and Computer Engineering, Ohio State University, Columbus, Ohio, United States,* [4]*Radiology, Case Western Reserve University, Cleveland, Ohio, United States*

Introduction: Magnetic field monitoring (MFM) with an array of NMR probes precisely measures the field dynamics during an MRI acquisition [1,2], which can be used for applications such as trajectory mapping. Using a receive-only array for MFM can only measure acquisitions with a fixed slice orientation, and coupling to the patient's signal may interfere with the measurement. An MFM array of hetero-nuclear transceiver probes addresses these limitations [3,4], but a separate specialized multi-frequency transceiver system is required to acquire the signals. To eliminate the need for this extra receiver, frequency-division multiplexing (FDM) has been used to combine both the signals from the standard MRI coils and the MFM probes onto a single MRI receiver channel [5]. The two signals were combined to minimize the usage of MRI receivers, but the small spectral separation (~300 kHz) of the two signals caused a 30% reduction in signal quality [5]. Our previous work with FDM-based MRI has revealed that a substantially larger spectral spacing (>5 MHz) is necessary to avoid this loss [6], but a spacing that large would prohibit the MRI receiver to acquire both signals. To address this, a FDM-based wireless MFM (wMFM) system is proposed. wMFM signals can be encoded with large spectral spacing to avoid signal loss. A simple demodulator would allow wMFM signals of any nucleus to be collected with normal MRI receivers. Additionally, in order to minimize the usage of available MRI receivers, the wireless signals would be received only as necessary, as the wMFM system could transmit during every MRI acquisition and be ignored if not needed. To demonstrate feasibility, initial results from a four-probe receive-only wMFM system are presented.

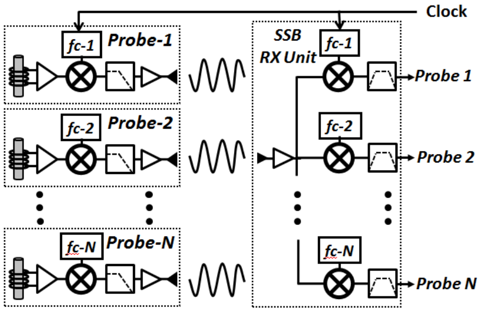

Figure 1: Schematic for the SSB-based receive-only wMFM system. In this prototype, each probe has a direct connection with a clock. This ensures the up-converting & down-converting carrier frequencies are exactly the same, which prevents additional phase noise added to the wMFM signals.

Materials & Methods: wMFM Design: Figure 1 illustrates the schematic of a receive-only wMFM system using single-sideband amplitude modulation (SSB). The SSB system is a simple adaptation from previous work in wireless MRI detector arrays [6]. The NMR probe is a simple three-turn solenoid (inner diameter = 1 mm, height = 1 mm) around a glass capillary tube filled with water and copper sulfate pentahydrate, similar to the design used in [3]. The wMFM system consists of four probes with carrier frequencies spaced 10 MHz apart: 915 MHz, 925 MHz, 935 MHz & 945 MHz. After wireless demodulation, the recovered probe signals are collected by the MRI system as if they were normal coil signals.

MRI Experiments: Experiments were performed on an 1.5 T Siemens Espree system. The four wMFM probes were positioned in a rectangle (31 x 17 cm) around a water phantom in the plane orthogonal to the magnet bore. The wMFM system was used to measure a TrueFISP spiral trajectory (TE=2.5ms, TR=5ms, FA=70) designed to cover a 128^2 acquisition matrix with a FOV of 400 mm^2 in 48 spiral arms, as described fully in [7]. An element from the spinal array was used to collect signal from the phantom for image reconstruction. In addition, the same spiral trajectory was measured with the technique described by Duyn et al [8] for comparison. Phantom images were generated by gridding the acquired signal with the trajectories derived from both trajectory measurements using NUFFT [9].

Results & Discussion: Figure 2 shows one shot of the spiral trajectory measured with the wMFM system (left) and a close up of the center measured with both techniques (right). This demonstrates that the spiral trajectory can be measured accurately with the wMFM system. Figure 3 reveals a sharper edge in the image reconstructed with the wMFM trajectory. This is likely due to a slight timing difference between the Duyn measurement and the actual scan. This timing difference is also visualized as the slight rotational offset produced when the two reconstructions are subtracted.

Conclusions: Wireless SSB technology is capable of transmitting and preserving the multiple signals from a MFM system. The results here show the system accurately measures a spiral trajectory with a 256kHz bandwidth. While only a receive-only wMFM system is presented here, SSB-technology can be used with any hetero-nuclear MFM transceiver system. With a simple adjustment to the upconverting and downcoverting carriers, hetero-nuclear wMFM signals can be collected with the narrow-band MRI receivers and integrated into the system, allowing simultaneous acquisition of a non-Cartesian trajectory and k-space data.

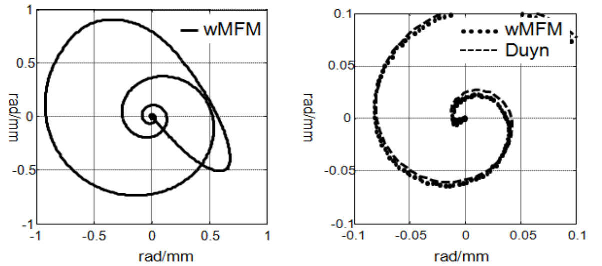

Figure 2: (Left) A single shot measured by the wMFM system. **(Right)** A 10x zoomed plot of both measured trajectories reveal good agreement between the two techniques.

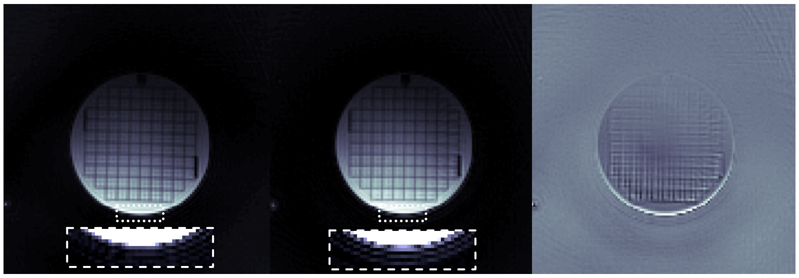

Figure 3: Phantoms image reconstructed using the trajectory measured by **(Left)** the wMFM system and **(Middle)** the Duyn method. The wMFM trajectory produces sharper edge than Duyn trajectory. **(Right)** The difference between the two images show slight rotational offset in the two measurements.

References: **[1]** De Zanche N et al. Magn Reson Med. 2008 Jul; 60(1):176-86. **[2]** Barmet C et al. Magn Reson Med. 2008 Jul; 60(1):187-97. **[3]** Barmet C et al. Magn Reson Med. 2009 Jul; 62(1):269-76. **[4]** Sipilä P et al. Magn Reson Med. 2011 May; 65(5):1498-506. **[5]** Pavan et al. Proc. 18th ISMRM. 2011; #1538. **[6]** Riffe M et al. Proc. 17th ISMRM. 2010; #2936. **[7]** Seiberlich N et al. Magn Reson Med. 2011 Apr 26. doi: 10.1002/mrm.22952. **[8]** Duyn J et al. J Magn Reson. 1998 May; 132(1):150-3. **[9]** http://www.eecs.umich.edu/~fessler/code/

Acknowledgements: The authors would like to acknowledge funding from Siemens Medical Solutions and NIH grants 1RO1HL094557 and 5K99EB011527. Thanks to Candice Bookwalter, MD PhD and Hiroyuki Fujita from Quality Electrodynamics.