

A field probe transceiver system with controllable RF coupling and decoupling

Ying-Hua Chu¹, Yi-Cheng Hsu¹, Shang-Yueh Tsai², and Fa-Hsuan Lin^{1,3}

¹Institute of Biomedical Engineering, National Taiwan University, Taipei, Taiwan, ²Institute of Applied Physics, National Chengchi University, Taipei, Taiwan,

³Department of Biomedical Engineering and Computational Science, Aalto University, Espoo, Finland

TARGET AUDIENCE: Scientists interested in the technical development of field probes to dynamically monitor the spatiotemporal distribution of magnetic field during data acquisition when the imaging object is present **without** using an independent RF transmitter.

PURPOSE: Magnetic field probes have been designed to dynamically detect the frequency shift in MRI¹, which is possibly caused by the subject, eddy currents, or systematic changes during the scan. One challenge in field probe design is that the signal originating from field probe can be overwhelmed by the signal from the imaging object. Consequently a field probe loses the ability to monitor local magnetic field disturbances. This difficulty can be mitigated by designing independent transceivers for field monitoring, such that the sample within the field probe and the imaging object have the same Larmor frequency² or different Larmor frequencies³.

Here we propose a new approach to improve the isolation of NMR signals originating from the sample within the field probe and from the imaging object **without** using an independent transceiver. The core idea of this approach is to design an RF coil (Tx loop) to pick up the RF energy from the body coil during RF transmission in order to excite the magnetization in the sample within the field probe inside an RF shield (Figure (a)). Importantly, during RF reception, the Tx loop will be detuned such that the NMR signal from the imaging object will **not** be picked up by the Tx loop. When the field probe is well shielded, the field probe can pick up no NMR signal from the imaging object. Consequently, a field probe can maintain good sensitivity to local magnetization dynamics without being overwhelmed by the NMR signal from the imaging object (Figure (b)). We constructed a one-channel prototype system to empirically demonstrate the feasibility of this design.

METHOD: Our system consists of an optimized field probe connected to the low-noise pre-amplifier inside an RF shielding box and a tuned coil (Tx loop), which causes RF power transduction across the shielding box (Figure (c)). A floating balun was used outside the RF shield to reduce common-mode current. The tuned Tx loop had an exterior part exposed outside the shielding box to pick up the RF power during body coil transmission. The Tx loop also had an interior part inside the shielding box wrapping around the field probe such that the captured RF power by the exterior part can be used to excite the magnetization in the sample within the field probe (Figures (d) and (e)). During RF reception, two diodes on the Tx loop were reverse biased in order to make it off-resonant (Figure (b)). Therefore no NMR signal can be picked up by the Tx loop. This design allows for automatic picking up the necessary RF power to excite only the magnetization for local field monitoring without receiving the strong NMR signals from the imaging object.

To further improve the performance of our system, we used the optimized field probe, which was a 4-turn solenoid constructed using the 26 AWG copper wire with a cylindrical glass capillary tube in the center (outer diameter: 0.9-1.1mm) in order to hold a water sample of 3 mm in length. This water sample was meant to provide the NMR signal. To match the susceptibility between air and the water sample, the FC-40 (3M, St. Paul, MN, USA) filled both ends of the water sample. The whole field probe was immersed in another acrylic capillary tube (3 cm long; 0.8 cm inner dia.; 1.0 cm outer dia.) filled with FC-40. The field probe was tuned to 123.2 MHz and connected to a low noise pre-amplifier integrated with a mixer (Siemens, Erlangen, Germany) through a 3-cm coaxial cable and a matching network (Figure (d)), which was a balanced circuit design and transformed the impedance to 50 Ω in order to obtain the lowest noise figure. The field probe was actively detuned by a PIN diode during RF transmission. The integrated field probe and pre-amplifier was placed inside an RF shield (Figure (c)) followed by a balun to reduce common-mode current. Free induction decay (FID) was measured with 1500 ms TR, 0.35 ms TE, 512 ms acquisition duration, 1000 Hz bandwidth, and 90° flip angle.

RESULTS: Figure (f) shows the spectra of the FID measurements with the Tx loop (red) and without the Tx loop (green). Clearly the magnetization within the water sample inside the field probe can be effectively excited by the RF power brought by the Tx loop. While theoretically the FID of the field probe measurements should have no spectral peak without the Tx loop and inside a perfect RF shield, in practice, we found that there was minor RF power exciting the water sample in the field probe (green). We found that this Tx loop worked effectively, because the spectral peak height with a Tx loop was about 4-fold higher than that without an Tx-loop.

DISCUSSION: We successfully demonstrate the feasibility of a field probe system that can work when the imaging object is present during data acquisition without using an independent RF transmitter. Similar to earlier approaches^{2,3}, we used an RF shield to reduce the field probe's sensitivity to the contaminating NMR signal from the imaging object. Importantly, a Tx loop was used to transfer the RF power generated by the body coil during RF transmission to the field probe inside the shielding box efficiently. During RF reception, the Tx loop is detuned such that the RF signal from the imaging object can no longer be transferred to the field probe. One limit of this approach is that the RF power optimized for the imaging object may not be the optimal value to excite the field probe. In the near future, we plan to develop a multi-channel system in order to capture the spatiotemporal variation of the field disturbance dynamically.

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