Dynamic Correction of RF Transmit and Receive Phase in Electromagnet MR Systems

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INTRODUCTION

Electromagnet MR systems (low-field implementations of Hyperpolarized Gas, PHIP, ^{13}C, and Prepolarized MRI), promise new imaging modalities, reduced susceptibility artifacts, and safer, cheaper, quieter MRI systems. However, they are prone to phase error in both the transmit and receive RF signals due to B_0 field errors resulting from coil current errors, coil interactions, and fundamental limits on coil dynamics and feedback control.

Phase errors in the received MR signal cause sequence dependent imaging artifacts, especially in FSE based techniques. Phase errors in the transmit RF signal can disrupt phase sensitive RF pulses, such as CPMG echo trains or RF current density imaging [1], and degrade the performance of remote polarization methods that rely on long echo trains for imaging.

We aim to build a dynamic phase shifting module that can correct for the many sources of phase error, both repeatable and non-repeatable, in an electromagnet MR system by modulating the transmit/receive phase. A different method of phase modulating MR signals was previously invented to correct for eddy currents using pre-calculated corrections [2].

DESIGN

The polyphase filter [1] in Fig. 1 splits the RF signal into quadrature components with precise amplitude and phase over a wide frequency range (1%, 500kHz-4MHz). The quadrature channels are each multiplied and then recombined to implement an arbitrary phase shift, $\phi(t)$, according to the trig identity, $\sin(\omega t+\phi) = \sin\phi\cos\omega t + \cos\phi\sin\omega t$. The $\sin\phi$ and $\cos\phi$ signals are generated by two 16-bit DACs controlled by a 16 MHz microcontroller.

In our initial demonstration of the module, we correct for the repeatable phase errors in the system by averaging the phase error in several FIDs and programming the module to correct for this error.

RESULTS AND DISCUSSION

Using the Prepolarized MRI pulse sequence in Fig. 2, we characterized the repeatable phase errors in our system and tested the use of the module to correct for these errors on the receive channel. As shown in Fig. 3, our module successfully removes the repeatable error. The small residual errors of ±6 degrees will not cause artifacts in most 2DFT imaging.

These results demonstrate the feasibility of our method for correcting phase in an electromagnet MR system. Although the repeatable phase errors can also be corrected by preemphasis of the transmit RF and post-processing of the received MR signal, these methods cannot be used to correct for non-repeatable errors in transmit phase. Post-processing correction of non-repeatable errors in the receive phase is possible, but requires the parallel acquisition of additional data. Additionally, the difficulty of interfacing with commercial MR consoles makes a modular solution to this problem desirable.

If the phase correction is instead determined by a real-time measurement of the B_0 coil current, we expect our module to be able to maintain phase coherence between the sample spins and the MR console despite field errors due to electronic thermal drift, finite loop gain, finite loop bandwidth, noise, and interference in the B_0 control system, or even ramping of the B_0 field.

By combining the pre-calculated correction with real-time correction, our phase module has the potential to turn an error prone electromagnet MR system into a "smart" magnet system that appears to have precise phase behavior despite the existence of many sources of phase error. This could greatly relax the design specifications for an electromagnet MR system, thereby increasing the feasibility of inexpensive clinical use of such systems.

REFERENCES

[1] G SCOTT, ET. AL., PROC. 11TH ISMRM, P. 710, 2003.
[2] U.S. PATENT 5,289,197, 1994.

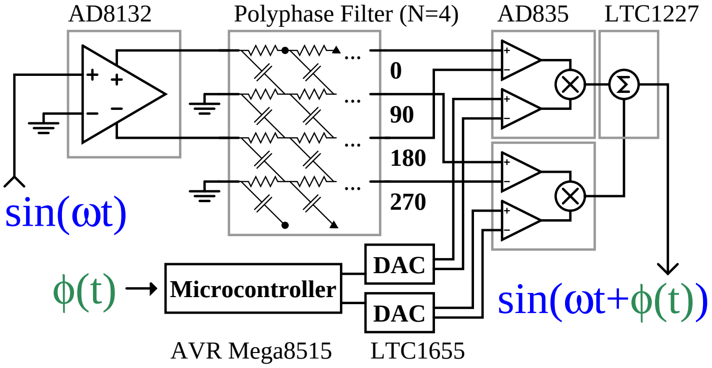

Figure 1: Schematic of our phase shifting module. The wide bandwidth of the polyphase filter enables this module to arbitrarily modulate the phase of any receive or transmit RF signal.

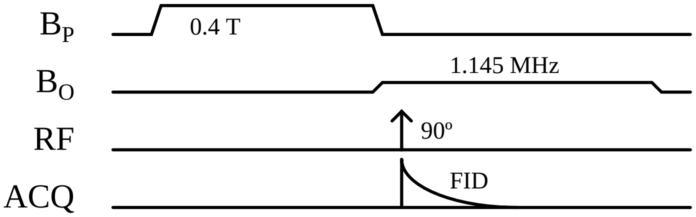

Figure 2: We recorded Free Induction Decay (FID) signals of distilled water at 1.145 MHz to characterize the phase stability of our PMRI system and test the performance of the phasing module.

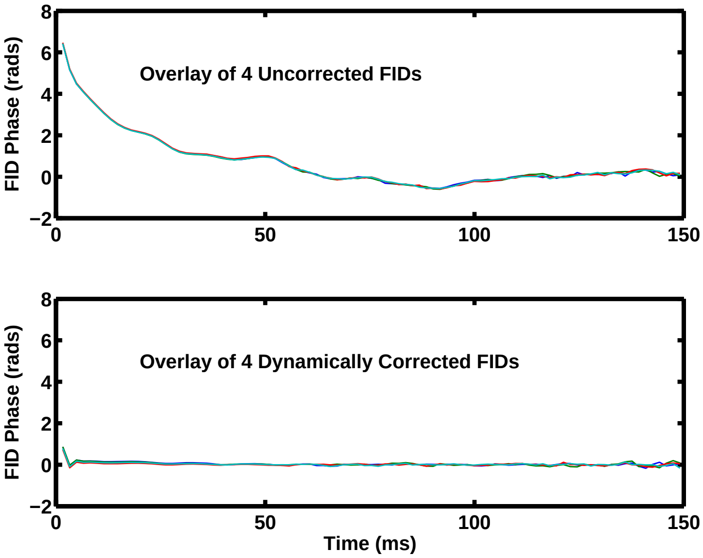

Figure 3: (Top) The unwrapped phase of four FIDs shows a very repeatable short-term phase error in our system. (Bottom) Our phase module corrects for this phase error by modulating the received signal, limiting the phase drift to ± 0.1 radians (6 degrees) over 150 ms. In these plots, the linear phase due to non-repeatable long term drift has been subtracted off with post-processing.