Insert Gradient Subsystem Tuning by Direct Impedance Measurements

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Introduction: MRI systems and pulse sequences continue to push the capabilities of gradient subsystems, demanding ever-increasing capabilities in slew rate, gradient strength, and waveform fidelity. Most current MRI systems utilize switching gradient amplifier architectures, leading to complicated control circuits to maintain a high-level of waveform fidelity [1-2]. The gradient capabilities of a clinical whole-body MRI system may be further enhanced with an insert or specialty gradient coil. Introduction of an insert gradient coil on a whole-body system requires modification or a different gradient driver as demonstrated in [3] to achieve superior performance or even basic operation. This paper demonstrates an improved method for gradient coil tuning using direct coil impedance measurements in place of iterative tuning value adjustments.

Methods: Impedance measurements of gradient coils were made with two different test setups, one using an impedance analyzer (Agilent 4284A) and a second using a dynamic signal analyzer (Agilent 35670A) in combination with a current sense resistor. Careful isolation from ground currents in the measurements was necessary, and both methods proved functional. The measured impedance data was processed by Matlab to form a high-order s-domain fit; the results for a whole-body and insert gradient coil are shown as inductance in Figure 1 and resistance in Figure 2. The complex impedance fit was converted to a z-domain equivalent and loaded as a set of digital tuning parameters to the gradient amplifier digital controller. The impedance fit and resulting model are shown for the insert coil in Figure 3.

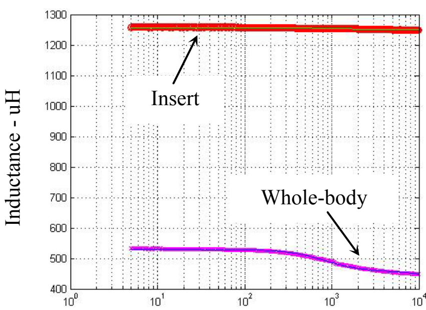

Figure 1 – Inductance vs. Frequency
Red – Insert coil, Magenta – Clinic coil

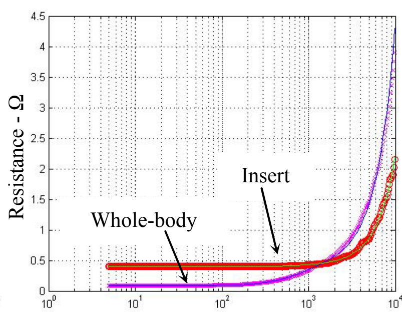

Figure 2 – Resistance vs. Frequency
Red – Insert coil, Magenta – Clinic coil

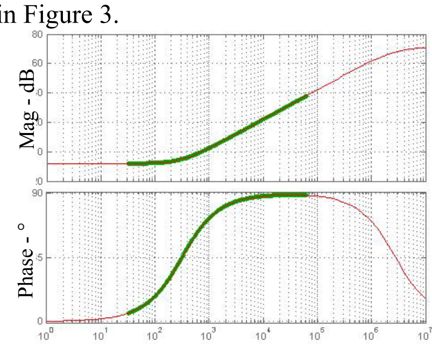

Figure 3 – Insert coil impedance Bode plot
Red – Raw data, Green – Fitted data

Results: The oscilloscope captures of Figure 4 demonstrate the benefit of an accurate coil model in the controller, comparing amplifier response for the same 112mT/m, 1150mT/m/ms waveform command on the insert coil. In the measurement with default parameters the coil current is warped resulting in current error of 14A, with matched parameters error is reduced to 1A. The reduction of current error by 93% improved the fidelity and overall capability of the insert gradient system, allowing for play-out of more stressful pulse sequences. Figure 5 shows the differences in image quality for a 3D balanced SSFP (FIESTA) scan, changing only the amplifier tuning parameters between acquisitions.

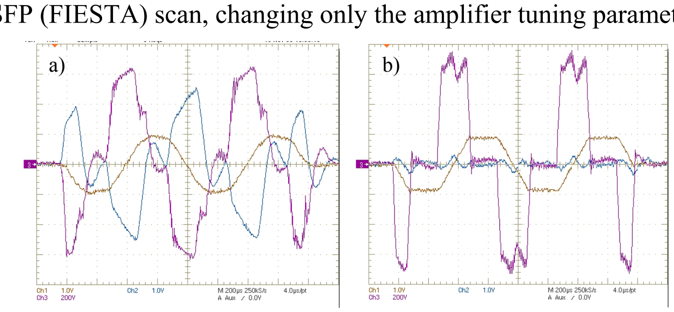

Figure 4 – Amplifier performance, a) Default b) Matched
Yellow – Coil current, Blue – Error, Pink – Coil voltage

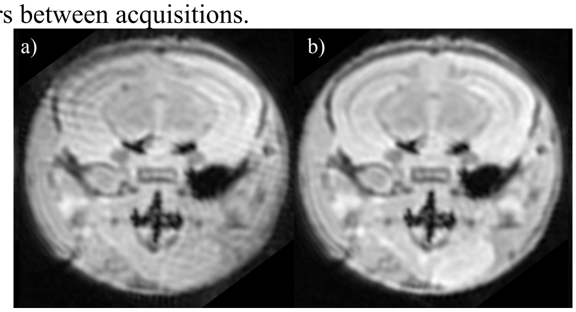

Figure 5 – 3T mouse head image acquired with insert coil
a) Default parameters b) Matched parameters

Discussion: Poor gradient waveform fidelity can cause inaccuracies in the desired MR pulse sequence and ultimately as reduced image quality. As researchers and clinics continue to develop insert and other specialty gradient coils for MRI scanners, it is desirable to have an amplifier capable of accurately driving the range of coils. Our method and results demonstrated the flexibility and robustness of a directly measured gradient coil model, implemented in a fully digitally controlled gradient amplifier, for loads ranging from 400µH to 1200µH. While this paper outlines only one example of an insert coil being driven by a clinical scanner gradient driver system, the same system has been tested with other specialty coils, including coils with inductance as low as 100µH. Research continues in using this same technique and amplifier for driving gradient coil inductances below 100µH.

References: **[1]** Sabate J, et al. Proceedings of the 20th IEEE APEC 2005, pp1087-1091. **[2]** Sabate J, et al. Proceedings of the 35th IEEE PESC 2004, pp261-266. **[3]** Martinez-Santiesteban, FM, et al. Proceedings ISMRM 2009, p780.