Rapid Field Pulsing Circuit with Leakage Current Bypass for Pulsed Magnetic Coils in MR

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Introduction

Pulsed magnetic fields are used in NMR and MRI for a variety of experiments, including relaxation dispersion, zero-field NMR, FC-PEDRI, and Prepolarized MRI [1,2,3,4]. Most of these pulsed-field systems use variants of Redfield's energy storage principle, which uses an energy storage capacitor to rapidly ramp a single coil between two current levels [5]. Unlike these single coil systems, our Prepolarized MRI system uses two independent coils inside the bore for prepolarization (0.5 T) and readout (1 MHz) of the sample. As a result, leakage current in the prepolarizing coil during the off state can introduce errors in the readout, which is not a concern in single coil systems since the coil is on during the readout.

Design

The circuit in Fig. 1 is an adaptation of the energy storage technique used in pulsed NMR systems that we redesigned for pulsing the prepolarizing coil in our Prepolarized MRI system. The pulsing module is placed between the coil and its DC power supply. During steady state, the power supply directly drives the coil. During ramping, C_{store} creates a series resonant circuit with the coil that rapidly transfers stored energy between C_{store} and the coil. In the off state, the IGBTs are off, the diodes are reversed biased, and ideally no current flows through the coil. However, the IGBTs and diodes in the circuit have time varying leakage currents in the off state that depend on the junction voltages and temperatures. Since these devices are large, the leakage can be as much as 10 mA, which produces a measurable phase error in the MR signal. We bypass this leakage current around the coil with D_L and R_{leak}. The addition of D_L in series with the coil gives the coil a high impedance close to zero current, allowing the leakage current to be bypassed around the coil with the parallel R_{leak}, where R_{leak} can have 100 times larger impedance than the coil so that R_{leak} has little effect on the circuit during the on state. D_L also serves the dual purpose of isolating the coil from external capacitances that may adversely affect the damping of the coil, which is critically damped using R_{damp}.

Results and Discussion

We configured the pulsing circuit to pulse our 63 mH, 0.5 T (100 A), 12 cm bore polarizing coil with 13 ms ramp times. This used a peak ramping voltage of 750 V, which would not have been possible with our 130 V steady state power supply alone. With the coil in the bore of our 1 MHz MRI system, the off-state leakage currents from the pulsing circuit dominate the phase error in an FID (Fig. 3). With the leakage bypass components in place, the phase error is greatly reduced, and probably dominated instead by error in the readout coil as a result of the transient disturbance. With the availability of high power electrical components, this circuit can be easily scaled for almost any transient time with any coil. These results demonstrate that an inhomogeneous polarizing coil can be rapidly pulsed in the bore of an MRI system without adversely affecting the quality of the B_0 field during readout.

References

[1] Rommel, et. al., *JMR* 70:219 (1986).
[2] Zax, et. al., *J. Chem. Phys*. 83 (10):4877 (1985).
[3] Lurie, et. al., *Phys. Med. Biol*. 43:1877 (1998).
[4] Macovski, Conolly, *MRM* 30:221 (1993).
[5] Redfield, et. al., *Rev. Sci. Instr*., 39:710 (1968).

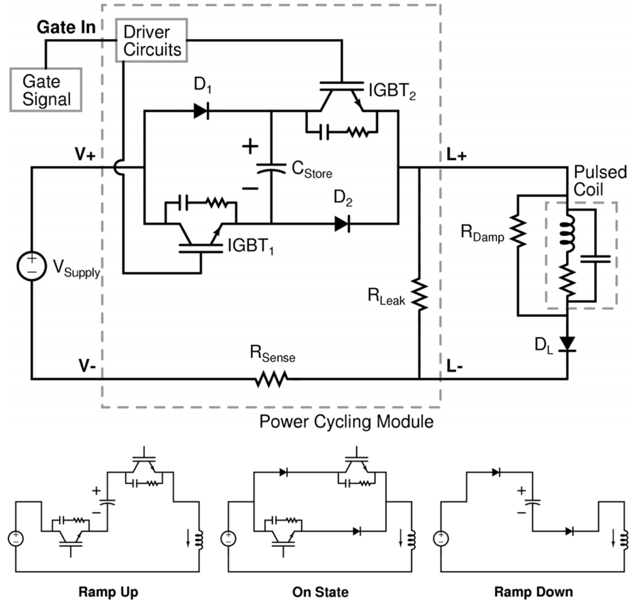

Figure 1: Schematics of coil pulsing system (top) and current path diagrams (bottom).

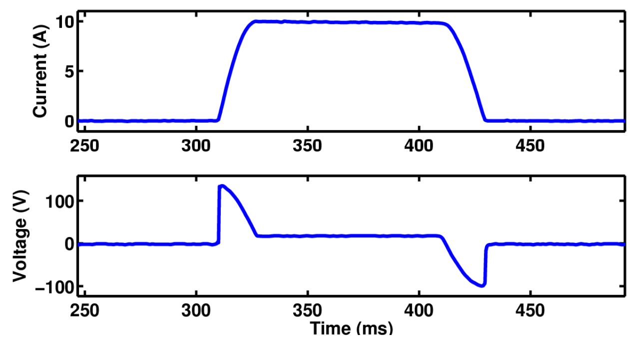

Figure 2: Coil waveforms for a 10 A pulse. We routinely pulse at 100 A.

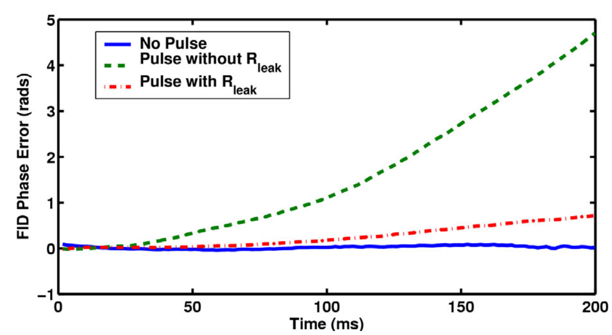

Figure 3: Phase error of an FID at 1.09 MHz with and without a 0.5 T prepolarizing pulse. The leakage current bypass decreases phase error due to the pulse by a factor of 6. The prepolarizing pulse boosts magnetization by a factor of 20.