A Q-switch system for an MRI RF coil operating at 2.5 MHz.

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Synopsis

RF coil ringing following an excitation pulse is particularly problematic at low frequency and can prevent the measurement of signals from short-T2 samples or tissues; this issue can be addressed by Q-switching. A Q-switch circuit, designed to operate at 2.5 MHz and reduce the dead-time of an RF coil following an RF pulse, is described. The resulting reduction in coil dead-time allows signal to be detected earlier and RF pulses to be spaced closer together. MOSFETs are used in our design to isolate RF from the DC control system and the circuit can be inductively coupled to any RF coil. The device was found to reduce the duration of coil ringing by a factor of five.

Introduction

RF coils are often desired to have a high Q-factor due to the related increase in SNR. However, at low frequencies there are two factors which limit the usefulness of an ever higher Q-factor; the bandwidth of the coil and the dead-time after an RF pulse. Residual energy stored in the coil circuitry following an RF pulse dissipates with a time constant

$$\tau = \frac{2Q}{\omega_0} \ln \frac{V_p}{V_n}$$

giving a dead-time that lasts on the order of twenty time constants to get from a peak voltage, V_p, to the noise floor, V_n [1] (where ω_0 is the resonant angular frequency). If it is necessary to be able to acquire signal or apply additional pulses soon after an RF pulse then techniques must be found to reduce the dead-time.

Several methods, covering a range of complexity and efficacy, have been developed to reduce ringing including over-coupling the coil to the preamplifier [2], application of a second, short RF pulse with the opposite phase [3], and using additional circuitry to vary the Q-factor of the RF coil [1, 2, 4-7]. The work presented here belongs to the last category; an active circuit, known as a Q-switch, which acts to greatly reduce the Q-factor of the RF coil for a short period following an RF pulse. This permits the RF coil to have a high Q-factor for both transmit and receive but reduces the ring-down time with a low Q-factor while the coil recovers from a pulse. Q-switching is a well-used technique in low-frequency RF coils and the circuit described here represents a very simple design which can be implemented on all forms of RF coil.

Circuit design

In order to ensure that the RF coil maintained a high Q-factor when the Q-switch was inactive the additional circuitry was inductively coupled to the main RF coil. This was achieved by co-winding the main coil with a secondary coil forming an air-core transformer with a 1:1 turns ratio, each winding comprising a 10-turn solenoid with a 11 mm radius and a 70 mm length. The main RF coil was tuned to 2.5 MHz and capacitance matched to 50 Ω.

The designed system (Fig. 1) is able to greatly reduce the Q-factor of the RF coil by selectively grounding the secondary windings of the transformer through two MOSFETs. By rectifying the induced RF voltage, using four BYT52M small-signal diodes in a diode-bridge configuration, the positive and negative sides of the cycle could be controlled by an N-channel MOSFET (STP15N95K5) and a P-channel MOSFET (IXTX32P60P) respectively.

When both MOSFETs are "closed" the Q-switch side of the circuit shunts the oscillatory circuit, efficiently removing the stored energy responsible for the coil ringing. However, when the MOSFETs are "open", no current flows through the Q-switch circuit and the Q-factor of the RF coil remains high. The Q-switch is triggered by a TTL input to a MOSFET driver (LTC1693-1IS8) which provides the gating voltages for both MOSFETs. The gating voltage seen by each MOSFET is shaped by the resistance through which its internal capacitance is charged and discharged. A diode is used to allow the MOSFET to be quickly charged through a small resistance but discharged more slowly due to the larger resistance presented. This causes the MOSFETs to "open" more slowly, reducing the secondary-ringing which can otherwise occur.

Results and conclusions

The unloaded Q-factor of the 2.5 MHz RF coil was found to have a value of 110 with the Q-switch off, which was reduced to a value of 3 when the Q-switch was activated. Figure 2 shows the impact of the Q-switch on reducing the duration of ringing. With the Q-switch in operation, the ring-down time was reduced from ~160 μs to ~30 μs. The Q-switch presented in this paper has been seen to function well at 2.5 MHz. It is hoped that this device will enable detection of samples with short T_2^* values which would have otherwise not have been possible. The Q-switch's simple design and implementation means that pre-existing RF coils will also be able to be easily converted into fast-recovery systems.

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Figures

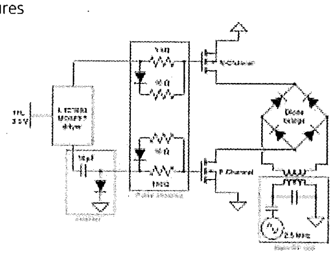

Figure 1: *Circuit diagram of the Q-switch and control lines. Elements of the circuit which perform specific roles are indicated for clarity. In order to gate the P-channel MOSFET it was necessary to invert the output from the MOSFET driver.*

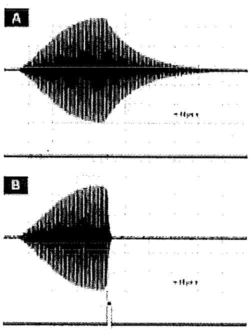

Figure 2: *Normal (A) and Q-switched (B) operation of the main RF coil. In both plots the upper trace is the voltage induced in a small pick-up loop inside the RF coil while the lower trace shows the TTL trigger.*