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A Fast MOSFET RF Switch for TRASE MRI at Low Magnetic Field

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Synopsis

TRansmit Array Spatial Encoding (TRASE) MRI uses trains of B_1 pulses alternatively produced by distinct transmit coils. Commonly used coil switching involving PIN diodes is too slow for low-field MRI and would introduce wait times between pulses typically as long as each individual pulse (hence, significant diffusion-induced resolution loss in TRASE MRI of gas samples). A MOSFET-based RF switch is described and characterised. Up to 200 kHz, it allows for sub- μ s switching of RF currents from a single amplifier to several coils with sufficient isolation ratio and no delay between pulses.

Introduction

TRansmit Array Spatial Encoding (TRASE) is a MRI method using repeated pulses of radiofrequency (RF) B_1 fields from different phase-gradient transmit coils instead of the standard imaging gradients of B_0 to manage spatial encoding.^{1,2} An evaluation of the benefits and limitations of TRASE MRI at low field (a few mT) is under way using hyperpolarised gas samples.^{3,4} Fast switching between two or more transmit coils with sufficient isolation and negligible wait time between pulses is required to jointly reduce the total RF encoding time and the RF peak power. PIN diodes are often used for coil switching,² but bias control with RF isolation involves response times (several RF periods) which are too slow for the targeted low-frequency application.

Methods

Switching times (delays and jitter) have been inferred from datasheet or measured for different mechanical switches (MEMS, reed or standard relays). Bidirectional MOSFET switch prototypes, with floating and optically isolated gate control, have been designed and wired (Figs. 1 and 2). Electrical tests have been performed using different RF power amplifiers (a 250-W-peak, BT00250-Alpha A model, Tomco Technologies, and a 100-W-CW in-house linear amplifier), different loads (a 50- Ω resistive load or tuned and untuned transmit coils), and different frequencies (in the range DC – 200 kHz). An Apollo Tecmag console (low-frequency LF1 model), allowing for 100 ns time resolution of sequence events, was used to manage RF pulses and TTL signals to control switches. RF currents were recorded using a 4-channels digital oscilloscope by monitoring the voltage drop across a 1- Ω resistor inserted on the ground return line at the output of the RF amplifier.

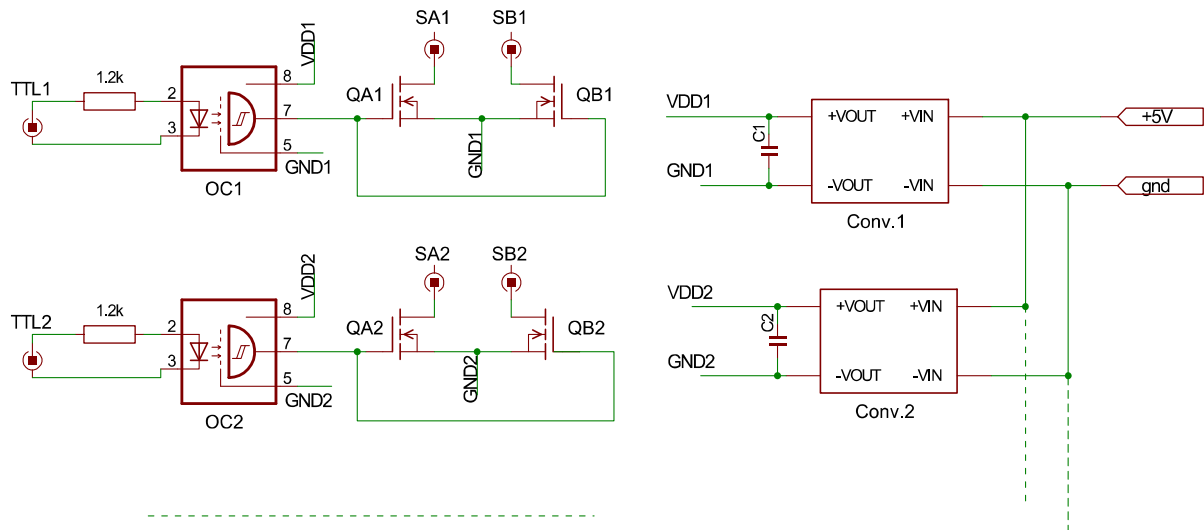


Figure 1: Schematic drawing of the MOSFET switches used for low-frequency TRASE MRI. Two of the three identical channels are displayed. On the right-hand side, independent DC-DC converters (Conv.) are used as floating 12-V power supplies of the gate control circuits. On the left-hand side, optocouplers (OC) are used to isolate the TTL control inputs from the power MOSFETS QA and QB which act as bipolar switches between terminals SA and SB.

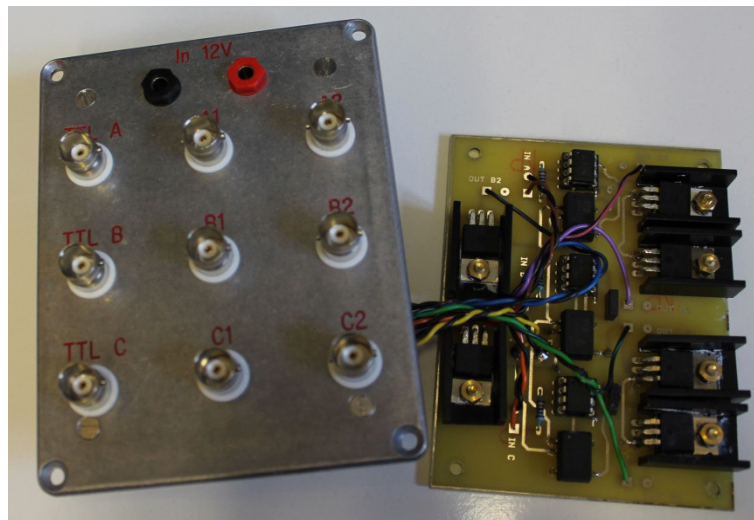
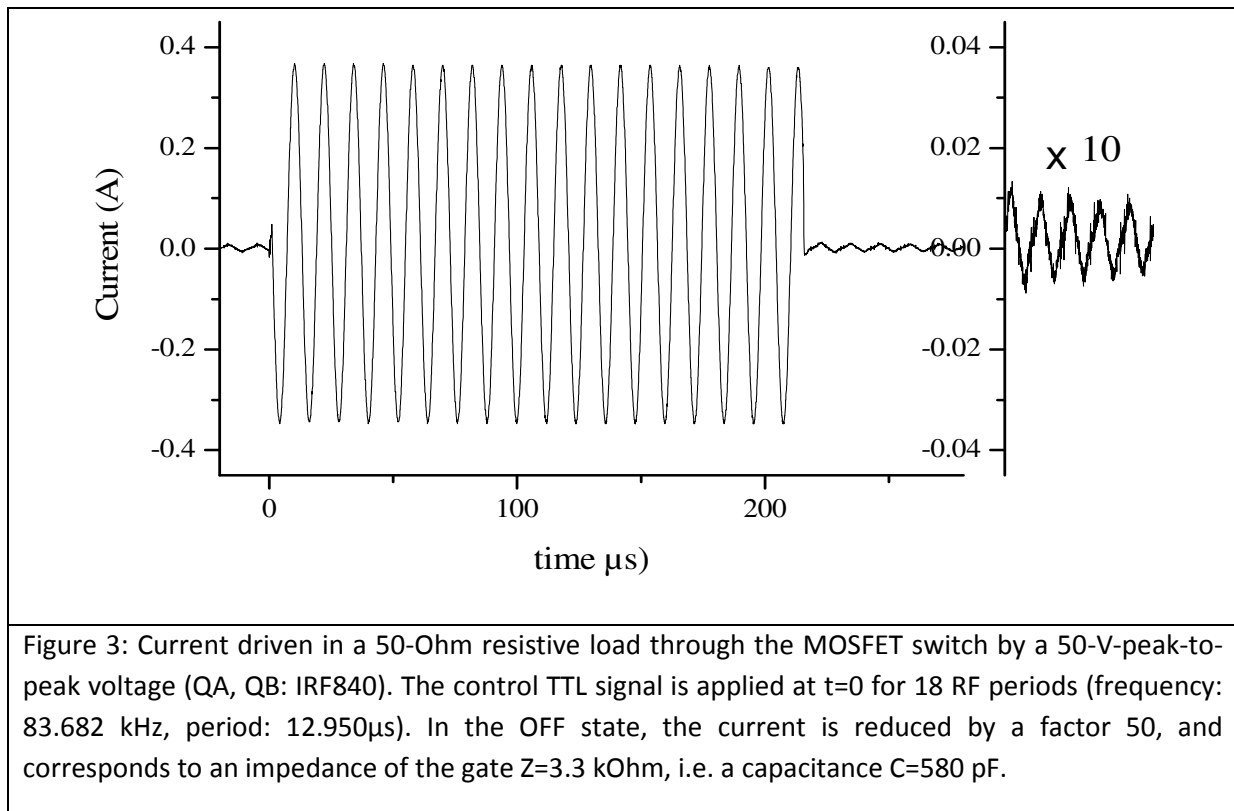


Figure 2: Photograph of a prototype MOSFET switch with 3 independent channels (see Fig. 1). The tested components are: IK0512SA or ISE1212A (Conv.), HCPL2201 (OC), and IRF840 or IRF730 (QA, QB).

Results

Switching times of mechanical relays range from $10 \mu\text{s}$ (for MR-compatible MEMS [5]) to several ms. Fast reed relays are widely available and economical, can be operated in the vicinity of low-field MR systems, and have close/release times of 0.15/0.1 ms for typical carry currents of 1 A, while miniature relays with 4-A carry currents have typical switching times of 1 ms. The MOSFET switch of Fig. 2 (with IRF 840, up to 32 A) has switching times below $1 \mu\text{s}$. It has a low ON impedance (about 1 Ohm) and a frequency-dependent OFF impedance, consistent with a 500 pF capacitance. This usually provides efficient RF current switching, both on a resistive load (Fig. 3) and on transmit coils (various situations have been evaluated and will be reported). A small RF interference due to the operation of

DC-DC converters is sometimes observed, but a suitable choice of the component eliminates the problem (different components operate at different switching frequencies).



Discussion/Conclusion

Although magnetically actuated relays provide an excellent switching efficiency and can be operated in low-field MR systems, their slow response times, on the same order as the duration of individual B1 pulses in TRASE sequences (typically 10-20 RF periods around 100 kHz [3]), introduce significant wait times during encoding pulse trains. This may result in prohibitive diffusion-induced resolution loss in gas samples, and acceleration through the use of shorter RF pulses is impractical due to Bloch-Siegert shifts and to the influence of concomitant RF fields [6]. MOSFET-based switches eliminate wait times and RF pulse currents can be switched to different transmit coils with sufficient isolation ratio and no delay between pulses. A choice of the MOSFET components can be made to achieve a suitable compromise between reducing the OFF-state capacitance and managing the required RF voltage and current.

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