Custom MEMS Switch for MR Surface Coil decoupling

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Abstract: A custom MEMS (Micro Electro Mechanical System) switch has been developed to operate in an MR environment. This new switch greatly reduces the power dissipation, both DC and RF, and simplifies the decoupling design for MR RF coils. With a standoff voltage of greater than 500V and an isolation impedance of less than 2pF, the new switch can directly replace the pin diode tank circuits conventionally used in MR surface coils. Additionally, the Q of a coil element is maintained with the switch having a closed resistance of much less than 1 ohm. The switching time is less than 10 microseconds, consistent with new ultrashort TE applications(1). Reliability of the device allows more than 5 years of life in an MR environment. The unique features of this MEMS switch will enable the simplification of surface coils as they move to higher densities. Apart from decoupling, other uses of the switch include channel routing, dynamic tuning, T/R switch, and transmit coil applications.

Introduction: The conventional technology in the MR industry for decoupling receive coils from the transmit field has been to use a LC tank circuit that is enabled by a PIN diode. However, this implementation has several disadvantages:

- During transmit; a large RF circulating current is generated in the tank circuit that can generate several watts of heat.
- A significant DC current is required to bias each PIN diode during transmit, a reverse voltage is necessary during receive
- The circuit only functions over a narrow band requiring multiple modules for multinuclear applications.
- "Passive decoupling" is necessary as a backup in case a coil does not receive bias current during a transmit

The use of a MEMS switch to mitigate these issues has been discussed previously (2, 3). In commercially available switches, some of the requirements for a surface coil are met, but not others. This is due to commercially available RF MEMS switches being design primarily for low power, 50ohm applications. No switch on the market has demonstrated a standoff voltage of greater than 110V, simultaneous high beam reliability with high conductance, or a non-magnetic design.

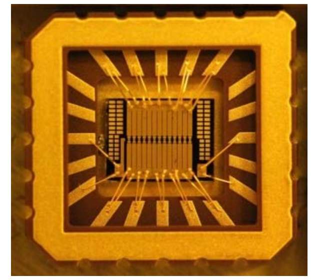

Figure 1. Custom MEMS switched designed for MRI. Package dimensions are 1cm by 1cm.

Methods and Results: In order to produce a MR MEMS switch, a custom design and production process had to be developed. Once initial switches were produced, a set of jugular experiments were devised to test the feasibility of the part for MR. These included tests for power handling, resistance, isolation, switching time, and reliability in the MR environment with both RF and gradient stresses. Next, a single channel coil using the switch was built to assess Coil Q, B1 capability (peak and RMS), noise stability, and overall performance. In order to build a coil, an MR compatible MEMS driver also had to be developed to convert the drive signals from a system into the appropriate drive voltage for the MEMS without the driver being triggered by RF or gradient pulses. Finally, once proven out with a single element, the switch and driver were used to implement a 32ch spine array. Following coil level performance testing of the array, volunteer images were acquired to measure clinical performance in clinical applications; a set of FSE images are shown in Figure 3. The switches are currently being integrated into other coil designs.

Discussion: The MEMS switch demonstrated in the 32ch spine coil enables new possibilities for coil design. The basic topology of the switch is shown in Figure 2. The switch is electrostatically controlled and draws much less than 0.1mA of current during operation as compared to ~100mA for a traditional PIN diode decoupling network. The extremely low drive current enables the use of resistors instead of RF chokes when biasing the switch. The switch also looks like small, high Q, capacitor when open. The capacitive nature of the switch, and the use of resistors, allows the decoupling circuitry to operate over a broad range of frequencies allowing commonality in 1.5T and 3T designs and potentially greatly simplifying MNS designs. Power dissipation in coils is also reduced; both at DC and RF. The extremely low "on" resistance of the switch maintains coil Q and also allows the switch the be used in other applications where low insertion loss is required; such as switching in capacitors for tuning on the fly MNS applications (4), or channel routing. Another advantage of the switch is that it is normally open and the coil would remain decoupled until it is actively enabled for receive. An unanticipated feature of the switch is its ability to handle current; an RMS current of greater than 5 amps has been demonstrated. This capability enables the use of the switch for transmit applications; either in T/R switches or direct use in transmit coils.

This switch is a first for both the MR and MEMS communities. As we continue to use the switch and improve upon its design, we expect to enable new applications and further improvements in coil design.

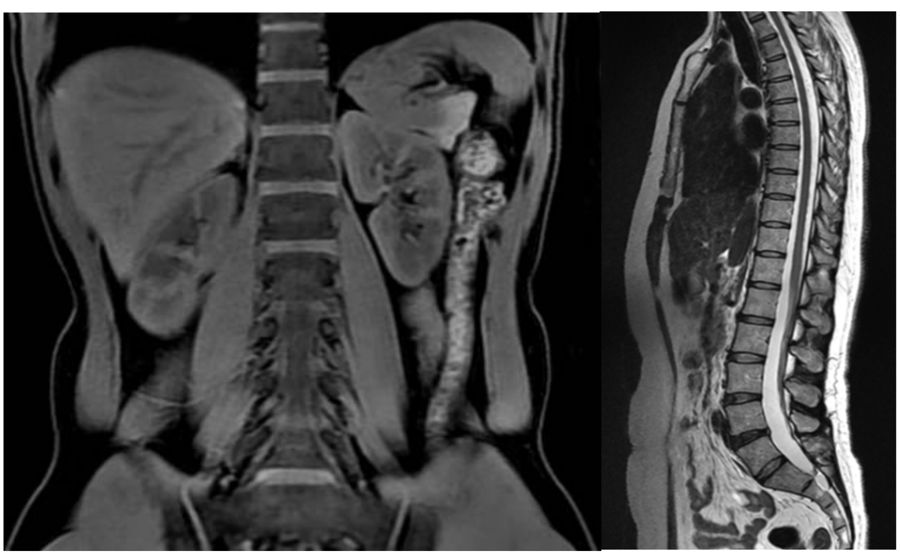

Figure 3. Coronal and Sagittal Spine images acquired with an FSE protocol using a 32ch MEMS spine array

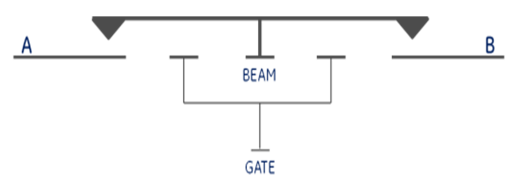

Figure 2. MR Switch Topology

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