Micro-Electromechanical Systems (MEMS) based RF-switches in MRI – a performance study

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ABSTRACT: Modern Magnetic Resonance Imaging (MRI) systems permit parallel, spatial-encoded MRI (pMRI) and as such it is now possible to have up to 128 adjacent coil elements in a coil array [1]. Together with reduced imaging times, pMRI can significantly help to enhance the signal to noise ratio (SNR) over extended fields of view (FOV) [2]. However, a large number of channels subsequently create new technical challenges, i.e. switching and cabling complexity as well as space constraints. This paper relates to a method of controlling and switching multiple receiver coil arrays in a manner that will reduce power consumption, cabling requirements, and increase overall SNR through the use of micro-electromechanical systems (MEMS) RF switches. The relevant performance parameters of MEMS devices are found to be acceptable for use in multi-element coil switching roles.

INTRODUCTION: Single receive coils are designed to yield the highest possible SNR for a fixed, finite, predetermined volume, but to image larger volumes with uniform sensitivity and high SNR, a number of mutually decoupled receive coils arranged into a large coil-array can be used [3]. Parallel imaging techniques can be used with these coils to shorten imaging time. If pMRI is to continue to shorten MR scan times, larger arrays will be needed to preserve SNR with such acceleration. Consequently, interfacing, control and acquisition cabling increases. MR compatible RF switching technology requiring minimal interfacing and allowing switching of RF signals with low power consumption and insertion loss are of benefit in the construction of practical, high density receive coil arrays for clinical MRI scanners.

PIN diodes or MOSFETs are the conventional approaches to T/R switching. PIN diodes at MR operating frequencies would contribute 1-2 dB in insertion loss and offer isolation of 20-25 dB with the drawback of inter-modulation distortion due to their nonlinearity. Switching time can approximate 0.5 µs largely due to the nature of the driver circuitry and, in large arrays, PIN diodes become cumbersome because each switched element requires 50 to 200mA of drive current.

Recent Advances in MEMs technology and nanofabrication processes [4] has made possible the introduction of affordable switches that have ultra low insertion loss (0.05-0.3dB), low power consumption (0.05-0.1W), extremely high linearity and excellent isolation (40-70dB). MEMs switches also provide reduced fabrication costs and significant system cost impact because there is no need for RF chokes, inductors and capacitors unlike PIN diode switches. Although MEMS switches have relatively low switching speeds, they can be manufactured to be as fast as 1–10µs, which, for the intended application, even with the fastest imaging sequences, is still acceptable. The insertion loss, isolation and switching times of an RF MEMS switch (TT712, TeraVicta, Austin) are measured here both in a laboratory environment and in MR systems with field strengths of 2T, 4.7T, 7T and 17.6T.

METHODS AND RESULTS: The insertion loss and isolation of the TT712 switch was measured on the bench using Vector Network Analyser (Agilent 8712ET). The measured isolation was 40dB and the insertion loss was 0.14dB for source frequencies between 20MHz and 500MHz. The insertion loss and isolation were also measured inside of the MR environment at field strengths of 2T, 4.5T, 7T, and 17.6T, with and without presence of switching gradients. An MR compatible VNA was used in this set of measurements and no difference was found in either insertion loss or isolation in the presence of static and switched gradient fields.

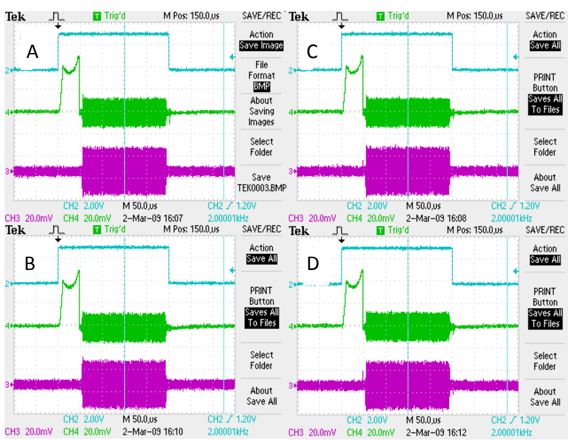

Figure 1. Oscilloscope traces showing; Switch drive (blue), input (purple) and output (green) at A)2T B)4.5T C) 7T D) 17.6T

To measure the switching speed and transients, a programmable RF signal synthesiser (Hameg AFG8134-3) in conjunction with an arbitrary function generator (Tektronics AFG3021) and a digital oscilloscope (Tektronics TDS 2024B) was used in both a laboratory environment and in MR field strengths of 2T, 4.5T, 7T, and 17.6T. The switch delay was measured to be 50 µseconds for RF frequencies between 20 MHz and 700MHz, and was unchanged by the static and gradient magnetic fields of the MR systems (figure 1). Finally, the MEMs switch was integrated into one of the 3 channels of a tri-channel receive only knee coil [5], the other 2 channels were connected directly to the scanner. Images of a phantom were acquired using RARE and EPI sequences in a 2T MR system (figure 2).

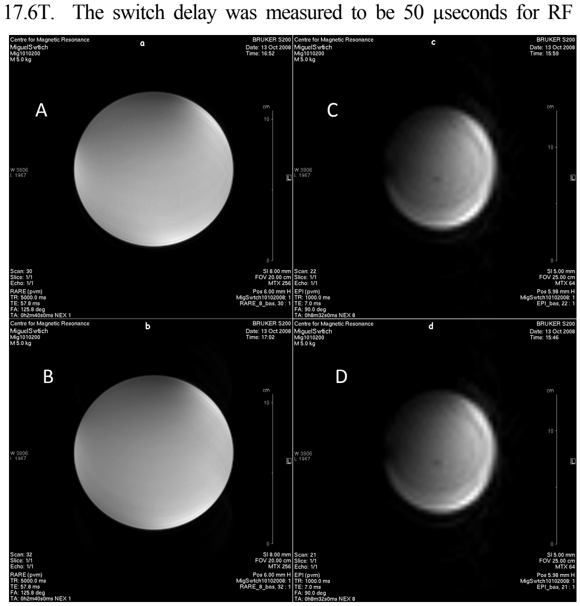

Figure 2. RARE and EPI images of a phantom acquired with a tri-phase knee coil A) RARE without switch B) RARE using MEMS C) EPI without switch D) EPI using MEMS

DISCUSSION: We have focused on parameters relevant to T/R switching applications in MR coil arrays that could be adversely affected in the MR environment due to the inherent mechanical nature of this switch. These parameters are insertion loss, isolation, and switching speed. Although the TT712 is not the fastest of MEMs switches available, 50 µsecond switching time is still acceptable for most T/R switching applications and as a fixed delay, which could be compensated through the pulse sequence. However, if the switching speed were to be reduced under the influence of the static or gradient magnetic fields it could become unusable. The static and gradient magnetic fields do not influence the switching speed or transients, even in MR scanners with field strengths beyond current clinical applications.

The insertion loss and isolation of the switch were unaffected by the static and gradient magnetic fields. There was no measureable difference in these switching parameters at static field exposures up to 17.6T. Figure 1 indicates that there is some insertion loss at the switch due to the amplitude of the switch output is less than the switch input. This is due to difference in cable length used during the experiment rather than inherent insertion loss in the switch. These results where verified by compensating and calibrating the network analyser with the cable used during the experiment.

The MEMS switch evaluated here shows favourable quantifiable performance on the bench and in MR environment testing. Qualitatively, phantom images show no deleterious effects compared to directly connecting the coils to the receiver of the MRI system. Future investigation will encompass the integration of MEMS switches as active decoupling elements in 16 and 32 channel receive only phased array coils and multichannel RF matrix switches.

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