Maximum dB/dt and Switching Noise in 1.5T MRI Scanners for Safety Evaluation of Active Implantable Medical Device

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Introduction: In Magnetic Resonance Imaging (MRI), the rapid switching of time-varying magnetic gradient induces electric fields in patients as a result of magnetic induction. Unintended stimulation of biological tissue due to magnetic induction is a known safety hazard in MRI[1, 2]. The MRI safety standards impose gradient limits to protect patients against direct tissue stimulation[3]. However, an active implantable medical device (AIMD) such as a cardiac pacemaker or a neurostimulator system implanted in a patient provides a conductive path for voltage induction resulting in tissue stimulation at gradient switching rates (dB/dt), lower than the limits set in the standards. Since the magnitude of induced voltage in a conductive loop depends on dB/dt, the dB/dt_{max} found in commercial MRI scanners becomes important to evaluate safety. The dB/dt_{max} is generally not reported by MRI manufacturers. Another effect of the time-varying gradients is the high frequency noise associated with the high power gradient coil amplifiers. This noise referred to as "switch-mode ripple" may be a safety concern due to possible interference with internal device circuitry, depending on its magnitude and frequency. To date, there is little known about dB/dt_{max} and its associated ripple in commercially available 1.5T MRI scanners. This information is of particular importance for the safety assessment of AIMD in MRI. The current study determined the magnitude and location of dB/dt_{max} and maximum ripple during application of various clinical sequences in 1.5T MRI scanners.

Methods: A total of 126 measurements were performed at three bore locations in 1.5T MRI scanners, namely, Philips Intera, Siemens Avanto and Siemens Symphony during application of seven common clinical sequences known to employ fast gradient switching rates. The measurements were made using a custom-built Faraday induction coil. The time-varying magnetic flux penetrating a coil induces a voltage proportional to the area of the coil. Two induction coils of different loop areas were prepared from a solid core copper wire with ends terminated in a custom-made twisted pair cable for electromagnetic interference protection. The loop areas used for current investigation represent the conductive loops formed by a pulse-generator device and lead, respectively. The present study investigated the worst-case induced voltage due to the G_y gradient by placing the Faraday coils in close proximity to the bore wall such that the G_y gradient was perpendicularly incident to the loop, yielding maximum induction (Fig. 1). Measurements were made at three equidistant locations on one side of the bore isocenter due to gradient coil symmetry, with the outermost position located at the bore entry. Each sequence was applied for 30 seconds for continuous acquisition and digitization at 1.25 MHz sampling frequency using the USB-6259 data acquisition (DAQ) board (National Instruments, Austin, TX) with a custom designed Labview application (National Instruments, Austin, TX). The radio frequency signals were filtered by a 1 MHz low pass filter (LPF) in series with 500 kHz anti-aliasing LPF. Post-processing of measured data was performed with Matlab (The MathWorks, Inc., Natick, MA).

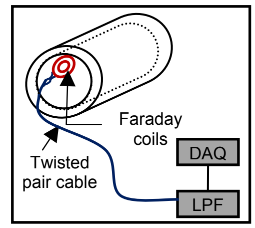

Fig 1. Test setup

Results: The measured voltage induced by the pulsed gradient field in each coil was transformed to the corresponding dB/dt values after digitally filtering the data between 1 Hz and 10 kHz to eliminate noise. The dB/dt_{max} across all tested scanners was found to be 56.5 T/s, and occurred at a distance of 25 cm from the isocenter in Siemens Avanto during Fast Imaging with Steady Precession (TRUFI) scan (Fig. 2). The high frequency ripple (Fig. 3) was determined after high pass filtering the measured signals at $\geq$ 20 kHz. The maximum ripple voltage of 155 mV at peak ripple frequency of 46 kHz was induced in 200 cm^2 coil in Siemens Symphony during Magnetization Prepared Rapid Gradient Echo (MPRAGE) scan at a distance of 31 cm from the isocenter (Fig. 4). The maximum ripple voltage evaluated at all frequencies above 20 kHz was found to be 623 mV, induced in 200 cm^2 coil in Siemens Avanto scanner at a distance of 50 cm from the isocenter during TRUFI scan.

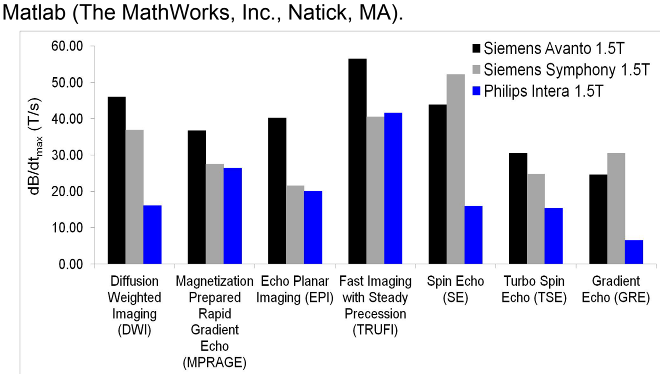

Fig 2. The dB/dt_{max} in 1.5T MRI scanners

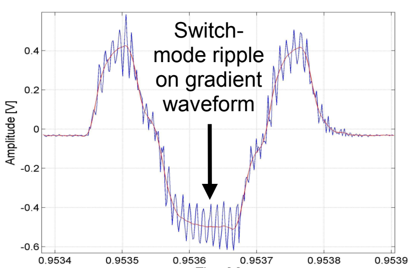

Fig 3. The switch-mode ripple

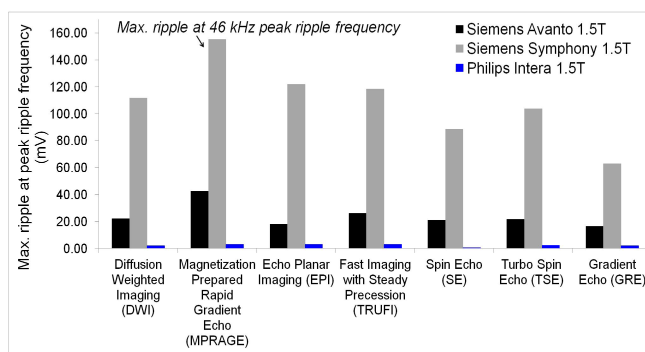

Fig 4. The maximum ripple voltage at peak ripple frequency

Conclusion: In the tested scanners, the location of dB/dt_{max} and maximum ripple was found to be at an intermediate position between the bore isocenter and bore entrance at approximately 25 to 66 cm out from the isocenter. Present study identified the magnitude and location of dB/dt_{max} and maximum ripple in commercially available 1.5T MRI scanners for maximum inducible voltage determination in AIMD. This information may be valuable for safety evaluation of the gradient induced stimulation hazard that may occur upon scanning patients with AIMD in MRI.

References: 1) Reilly JP. Ann N Y Acad Sci. 1992 Mar 31; 649:96-117. 2) Schaefer, DJ. MRI Clinics of North America 1998 Nov; 6(4): 731-748. 3) IEC 60601-2-33 Ed. 2.2 b: 2008.