Towards Truly Quiet MRI: Animal Scale Gradient as a Test Platform for Acoustic Noise Reduction

AbdEl-Monem M El-Sharkawy[1], and William A. Edelstein[1]
[1]*Division of MR Research, Department of Radiology, Johns Hopkins University, Baltimore, MD, United States*

Introduction. MRI acoustic noise intensity has grown substantially to levels beyond 100 dB as gradient amplifier power has increased and applied gradient pulse trains have become denser with modern multiplanar, multiecho pulse sequences. MRI acoustic noise causes patient anxiety, discomfort and potential damage to patient hearing, and interferes with fMRI and interventional MRI applications. Acoustic noise reduction through earplugs or earmuffs is limited to 30 dB because of bone conduction. Further, imperfect implementation of hearing protection measures can produce noise reduction of only 15 dB. There is usually little or no hearing protection for experimental or companion animals undergoing MRI. What is needed is a radical noise reduction to what we term Truly Quiet levels < 70 dB while maintaining full scanner functionality.

Testing hardware noise reduction measures on clinical scanners is difficult and expensive because of the large scale and weight of clinical scanner components (gradient windings ~ 1000 kg) that require special handling equipment in large engineering test facilities (1).

Here we decrease acoustic noise produced by a small gradient in an animal imaging system. Animal scale gradient noise reduction is a test platform for clinical noise reduction measures.

Our preliminary work has reduced gradient noise in an animal-scale 4.7 T magnet for a True-FISP sequence by 27 dB, from 108 dB to 81 dB.

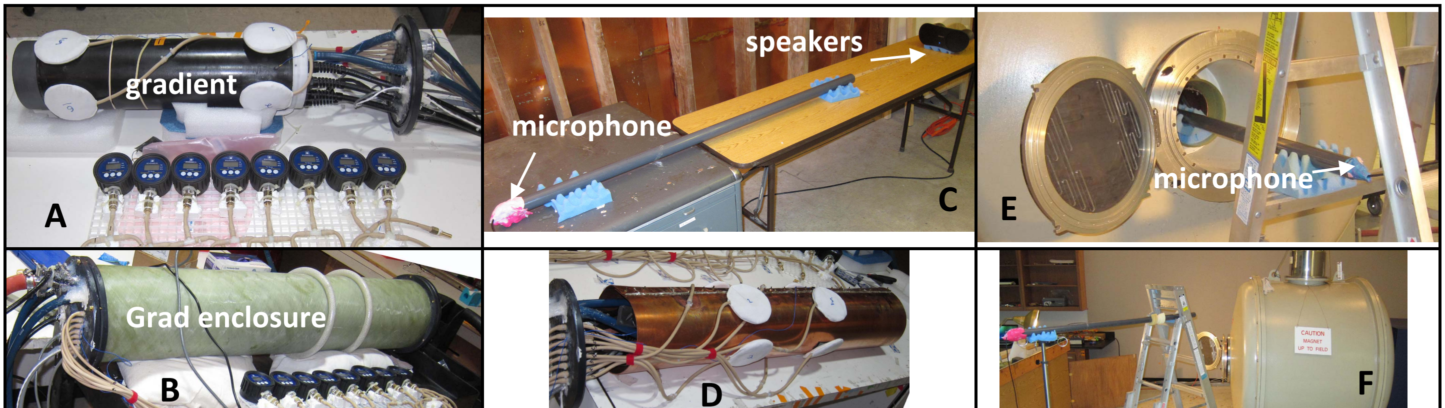

Fig. 1. A) Gradient insert, inflatable support pads & pressure gauges. B) Gradient insert in enclosure. C) Tube microphone calibration. D) Gradient insert with Cu passive shield. E) Tube microphone measuring gradient noise in magnet. F) Tube microphone measuring noise at observer position.

Materials and Methods. A small gradient insert, 150 mm OD, 90 mm ID, 750 mT/m maximum gradient (BFG-150/90-S7, Resonance Research Inc, Billerica, MA) is used in a Bruker Biospec 4.7 T animal MRI system (Bruker BioSpin, Billerica, MA) to test acoustic noise reduction measures. The gradient is supported by inflatable air pads—4 at each end—in a 203 mm ID, 6 mm thick outer fiberglass cylinder (Fig. 1A). The air pads enable control of both gradient position and spring constant to control mechanical vibration transmission. Pressures of 2-10 psi (sufficient to position the 30 kg gradient) are applied individually to the pads by a bicycle pump.

A central 71 mm ID, 3.5 mm thick fiberglass tube connects with end flanges to complete an annular vacuum space—containing the gradient—between the inner and outer fiberglass tubes (Fig. 1B). Four accelerometers (PCB 352C33, PCB Piezotronics Inc, Depew, NY) are attached, respectively, to the inner and outer gradient surfaces and to the inner and outer enclosure surfaces. A Varian IDP-3 scroll pump (Agilent Technologies, Santa Clara, CA) was able to reach a pressure of 35 Torr in this test fixture as monitored by a Granville Phillips 275 Convection gauge (Helix Technologies, Longmont, CO). The gradient enclosure is held within a larger gradient by surrounding flexible tubing.

A Larson-Davis LxT digital sound level meter ((PCB Piezotronics Inc, Depew, NY) with a 1 cm electret microphone is used to monitor sound levels. We found that the microphone was directly excited by the intense electromagnetic fields in the gradient, so we placed the microphone at the end of a PVC tube (142 cm long, OD 4.2 cm and wall 6 mm) and calibrated the sound detected via the tube vs. the sound directly sensed by the microphone at the same position as the open tube end using pink noise (Fig. 1C). Third octave band sound level spectra are stored by the meter and downloaded to a computer.

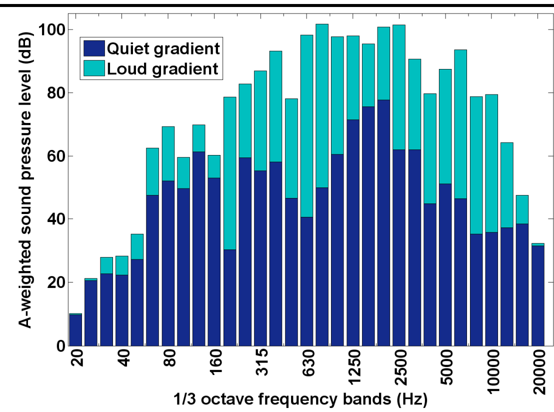

Figure 2. SPL_A spectrum of FISP acoustic noise for enclosed "Quiet" gradient and open "Loud" gradient. Total SPL_A values are 108 dB and 81 dB respectively.

A 2 mm thick, 122 cm long Cu cylinder to reduce noise produced by eddy current generation in external metal structures by leaked gradient fields (2) is positioned over the gradient insert (Fig 1D) inside the gradient enclosure in order to form the passive part of active-passive gradient shielding.

A True FISP MRI sequence, including gradients at up to 97% of their maximum value, is used for testing 1) the bare gradient with the central enclosure tube removed ("Loud gradient"), thus picking up noise direct from the inside of the gradient coil (Fig. 1E) and 2) the enclosed gradient ("Quiet gradient").

Results. The accelerometers detected levels on the gradient surfaces on the order off 15-30g and on the inside or outside of the enclosure < 2g, indicating good vibration isolation.

Figure 2 shows the A-weighted SPL (SPL_A) for a range of 1/3 octave frequency bands recorded for both the Loud and Quiet gradients. The total SPL_A levels were 108.5 dB and 81dB respectively. Noise was also measured at an observation point (Fig. 1F) 1.55 m high, just outside the magnet, where the total sound levels were 74.5 dB and 64.5 dB respectively. The room background level was 59.5 dB.

Discussion and conclusions. We have thus far reduced the sound level in this animal imaging system by 27 dB. This can be attributed to 1) the gradient enclosure and 2) the vibration isolating inflatable supports. The next step will be to decrease vibrations mechanically conveyed from gradient to enclosure via wires and other connections. We will then study the reduction possible by vacuum and the added passive isolation.

Refs: 1. Edelstein WA *et al.* Mag. Res. Imag. 2002; 20: 153-163. **2.** Edelstein WA *et al*. Mag. Res. Med. 2005; 53: 1013-1017.