Passive acoustic noise reduction – a first step towards an active noise cancellation on MRI scanners

V. Senaj[1,2], A. Amadon[1,3], D. Le Bihan[1], F. Lethimonnier[1]
[1]SHFJ/UNAF, CEA, Orsay, France, [2]Odd. Tom. Metod, Ustav Merania SAV, Bratislava, Slovakia, [3]DAPNIA, CEA, Gif sur Yvette, France

Introduction

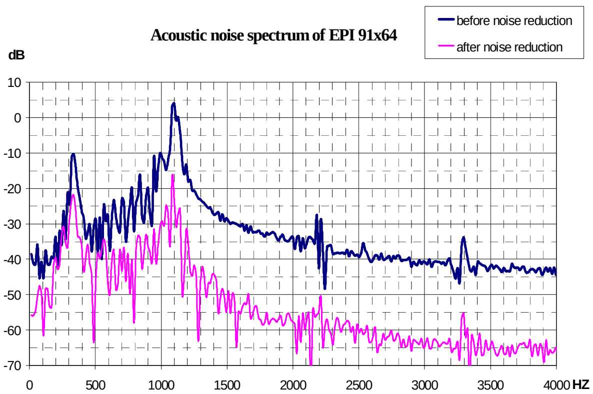
Functional magnetic resonance imaging (fMRI) requires fast imaging techniques and thereby high magnetic field gradient magnitude and slew rate (SR). However, mechanical vibrations of the gradient system due to Lorenz forces generate intense acoustic noise that can expose the imager staff and patient to discomfort and stress, especially at high magnetic field. A traditional approach consists of using earplugs and earmuffs with attenuation limited to about 40dB due to bone conduction [1]. The same is valid for an active noise cancellation (ANC) system applied only to ear-phones [2].

Materials and Methods

The measurements were made on a 3T whole body Bruker scanner equipped with a BGA55 gradient coil set (Gmax=45mT/m, SR=144T/m/s). For acoustic measurements, we used a B&K sound meter of type 2238 Mediator, with a prepolarised condenser microphone of type B&K 4188. The analogue output of the sound meter was stored and analyzed by a Le Croy Wave Runner 6050 digital scope. The window duration of the investigated sound signal was 200ms and the signal was sampled at 500 kHz. The sound meter used the C filtering curve (corresponding to human hearing) and the sound pressure level (SPL) was averaged over at least 10s. The measurements were made with the microphone placed at the patient ear position, but the influence of different microphone directions and placements were studied as well. Five sequences used in fMRI protocols were studied: three EPI sequences (128x80, FOV 240mm; 91x64, FOV 220 mm; 64x64, FOV 192 mm), a T1 weighted MP-RAGE anatomy sequence (Anat_T1) and a double gradient echo sequence Fieldmap_3D used for image post-processing. Our first aim is SPL reduction by passive noise shielding (especially for high frequency components where ANC does not work well) and to prepare installation of ANC external to the RF coil.

Results

We found that SPL of all sequences of interest is around 130dB with the highest value of 135 dB for EPI 91x64. The acoustic power distribution was very different between the three EPI sequences and the two others, but in all cases practically all acoustic energy was concentrated below 3 kHz. We further found that our gradient system presents a mechanical resonance frequency at 335 Hz. As a principal isolation material we used a high mass noise barrier material (3 mm-thick PVC). We stuck a first layer of this material on the entire length of the gradient tunnel and a second 60 cm-long layer in the tunnel centre. To reduce internal noise reflections, the back part of the tunnel was covered by egg-box shaped polyurethane foam. Further we filled the space between the cryostat and the gradient coil system by a polyester fiber material. These modifications resulted in a noise reduction



SPL [dB]	EPI 64x64	EPI 91x64	EPI 128x80	Anat_T1	Fieldmap_3D
before noise reduction	128	135	132	130	132
after noise reduction	115	115	118	109	115

between 13 and 20dB for three EPI sequences with the highest noise attenuation for EPI 91x64 (see figure). As expected, passive acoustic shielding was much less efficient at low frequencies resulting in lower noise reduction for Anat_T1 and Fieldmap_3D. We found that one of the harmonics generated by Anat_T1 was close to a mechanical resonance of the gradient system, and by a slight adaptation of the FLASH repetition time, it was possible to reduce its noise by 8dB. Another 6dB was achieved by reducing of the read axis spoiler gradient by a factor of two without degrading the image quality. Similar modification of the Fieldmap_3D sequence together with the isolation led to comparable results. A summary of the SPL measured before and after noise reduction are presented in the table above. We succeeded in reducing the SPL for all sequences of interest to below 118dB.

Discussion

As an ANC loudspeaker, we chose an MRI-compatible piezoelectric transducer (PT) (SPL80010-02 by Sonitron) that is able to generate above 100dB SPL (at a distance of 15 cm) over a sufficiently large frequency range and with a relatively smooth frequency response curve. Since the SPL generated by our scanner is still above that of a single PT, we will use multiple PT elements - at least 8 PT per ear to increase SPL by 18 dB. Further efforts to reduce noise passively will also be explored: the second layer of mass barrier and sound deflecting foam will be extended to the entire length of the tunnel, taking into account the space necessary for the patient shoulders.

References

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