Acoustic fMRI noise:
Linear Time Invariant System model

Carlos V. Rizzo S, Hendrikus Duifhuis and Hans Hoogduin

*Carlos V. Rizzo S. is performing graduate studies at the Department of Biomedical Engineering, Faculty of Mathematics and Natural Sciences, University of Groningen, The Netherlands (e-mail:**c.rizzo@ med.umcg.nl**)*
*Hendrikus Duifhuis is with the Department of Biomedical engineering and BCN Neuroimaging Center, University of Groningen, The Netherlands (e-mail: **duifhuis@ieee.org**)*
*Hans Hoogduin is MR Physicist from the BCN Neuroimaging Center, School of Behavioral and Cognitive Neurosciences, University of Groningen, The Netherlands (e-mail:**j.m.hoogduin@med.rug.nl**)*

Abstract—Functional magnetic resonance imaging (fMRI) enables sites of brain activation to be localized in human subjects. For auditory system studies, however, the acoustic noise generated by the scanner tends to interfere with the assessments of this activation. To understand this scanner noise, the magnetic resonance imaging (MRI) scanner can be modeled as a linear electromechanical system receiving input gradient currents and generating high sound pressure signals. For one fMRI scanner, a train of impulses is used to obtain the frequency response function (FRF) which characterizes this electromechanical system. Since an fMRI sequence is made out of gradient currents, the FRF prediction ability can be validated e.g., for an echo planar imaging (EPI) sequence. The predicted sound pressure level for the EPI sequence was 104.5 dB SPL which was 1.8 dB above the measured value of 102.7 dB SPL. The predicted EPI pressure waveform shows similarity to as well as some differences with the directly measured EPI pressure waveform.

Index Terms—acoustic noise, fMRI, gradient noise, linear system, SPL.

[1] Ogawa, S., Lee, T. M., Kay, A. R., Tank, D. W. (1990). Brain magnetic resonance imaging with contrast dependent on blood oxygenation. Proceedings of the National Academy of Sciences USA, 87:9868-9872.
[2] R. Brummett, J. Talbot, and P. Charuhas, “Potential hearing loss resulting from MR imaging,” Radiology, vol. 169, pp. 539-540, 1988.
[3] P. Bandettini, A. Jesmanowicz, J. Van Kylen, R. Birn, and J. Hyde, “Functional MRI of brain activation induced by scanner acoustic noise,” Magn Reson. Med., vol. 39, pp. 410-416, 1998.
[4] Z. Cho, S. Chung, D. Lim, and E. Wong, “Effects of the acoustic noise of the gradient systems on fMRI: A study on auditory, motor, and visual cortices,” Magnetic Resonance in Medicine, vol. 39, pp. 331-335, 1998.
[5] M. Elliott, R. Bowtell, and P. Morris, “The effect of scanner sound in visual, motor, and auditory functional MRI,” Magn. Reson. Med., vol.41, pp. 1230-1235, 1999.
[6] A. Mazard, B. Mazoyer, O. Etard, N. Tzousorio-Mazoyer, S. Kosslyn, and E. Mellet, “Impact of fMRI acoustic noise on the functional anatomy of visual mental imagery,” J.Cogn Neurosci., vol 14, pp. 172-186, 2002.
[7] R. Hedeen and W. Edelstein, “Characterization and prediction of gradient acoustic noise in MR imagers,” Magn Reson. Med., vol. 37, pp. 7-10, 1997.
[8] M. E. Ravicz, J. R. Melcher and N. Y. Kiang, “Acoustic noise during functional magnetic resonance imaging,” J. Acoustic. Soc. Am. 108 (4), October 2000.

[9] M. E. Ravicz, J. R. Melcher (1998) “ Imager noise and noise reduction during fMRI ”, Neuroimage 7(4), S556.
[10] S. A. Counter et al, (1997) ” MRI acoustic noise: Sound Pressure and Frequency Analysis”, ISMRM.
[11] W. Li, C.K. Mechefske et al, “Acoustic Noise Analysis and Prediction in a 4-T MRI scanner” Concepts in Magnetic Resonance Part B (Magnetic Resonance Engineering) Vol. 21B(1): 19-25, 2004.
[12] A. Barnett, “Comments on gradient-induced acoustic and magnetic field fluctuations in a 4T whole-body MR Imager” Magnetic Resonance in Medicine 46:207 (2001).
[13] G. Hoiting, “Measuring MRI noise”. PhD Thesis, 2005. ISBN 90-367-2235-7 (Online version)
[14] M. McJury, R.W. Stewart, D. Crawford, and E. Toma. The use of active noise control (ANC) to reduce acoustic noise generated during MRI scanning: some initial results. Magn. Reson. Imaging, 15:319-322, 1997.
[15] J. Chambers, M.A. Akeroyd, A. Q. Summerfield, and A.R. Palmer. “ Active control of the volume acquisition noise in functional magnetic resonance imaging: method and psychoacoustical evaluation”. J. Acoust. Soc. Am., 110:3041-3054, 2001.
[16] W.A. Edelstein, R. A. Hedeen, R.P. Mallozzi, S.A. El Hamamsy, R.A. Ackermann, and T. J. Havens. “Making MRI quieter”. Mag. Reson. Imaging, 20:155-163, 2002.
[17] W.A. Edelstein, et al. ”Active-Passive Gradient shielding for MRI acoustic Noise Reduction. Mag. Reson. In Medicine 53:1013-1017 (2005).