Sound pressure level prediction of arbitrary sequences

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Introduction:

It is a well-known problem that MRI scanners produce huge sound pressure levels (SPL) of more than 120 dB during image acquisition [1]. Calculation and Prediction of the acoustic noise generated during an arbitrary sequence is advantageous, especially in fMRI experiments, where the acoustic noise can tamper the results [2]. Hedeen and Edelstein [3] made the assumption that the MR scanner and the gradient switching form a linear system. On this basis they could predict the SPL of a fast spin echo sequence (92.7 dB) with a deviation of only 0.4 dB from the measured SPL. However the assumption of linearity for high sound pressure levels above 100 dB has not yet been verified.

In this work the linearity between gradient amplitude and sound pressure of a 3 T MR-Scanner has been examined. Additionally the predicted acoustic noise is compared to the measured values of a sinusoidal echoplanar sequence [4], which can be adapted to the scanner's acoustic resonance minima as well as to the maxima.

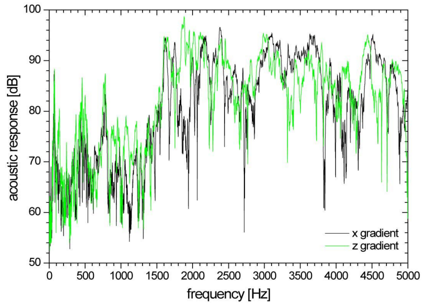

***Fig 1**: Frequency response function in decibels of the x- and the z-gradient coil.*

Methods:

If the sound pressure p(t) generated by the switching g(t) of a gradient coil can be described as

$$p(t) = g(t) * IRF, \quad (1)$$

then the gradient coils form a linear electromechanical system, where IRF is the impulse response function. In the frequency domain the convolution becomes a product of G(f) and the frequency response function (FRF), the Fourier transforms of g(t) and IRF, respectively.

In order to find out, whether the sound pressure is linear to the gradient amplitude, the FRF of all three gradient coils of a 3 Tesla scanner (Magentom Tim Trio, Siemens Medical Solutions, Erlangen, Germany) was measured first. With the help of an optical microphone (MO 2000, Sennheiser electronic, Wedemark, Germany) the FRF was determined by measuring the frequency resolved SPL, generated by a sinusoidal gradient "sweep", in steps of 1 Hz. Thus, the switching frequency is increased continuously from 0 to 5000 Hz. Next the SPL's dependence on the gradient amplitude $\hat{g}$ was measured during a sinusoidal gradient switching at three different frequencies: 543 Hz, 768 Hz and 2372 Hz with a low, median and high acoustic response (Fig 1). If equation 1 holds true, then the SPL can be calculated by

$$SPL = a\log(\hat{g}/g_0) + FRF_{dB}\ , \quad (2)$$

where the coefficient *a* must be equal to 20. Here g_0 is the amplitude of the gradient sweep which was used for determination of the FRF. FRF_{dB} is the frequency response function in decibels for an 8mT/m gradient switching. Finally the SPL of a silent and a loud sinusoidal EPI seqence was simulated and measured, using the following imaging parameters: TE = 42ms, TR=79ms (per slice), BW=1324Hz/Px, (silent sequence); TE = 31 ms, TR=59 ms (per slice), BW=1816Hz/Px, (loud EPI-Sequence). The simulated spectrum was determined by calculating

$$SPL = 20\log|FT(\hat{g}(t)/g_0)| + FRF_{dB}\ .$$

The corresponding SPL was calculated by the power integral over the simulated spectrum.

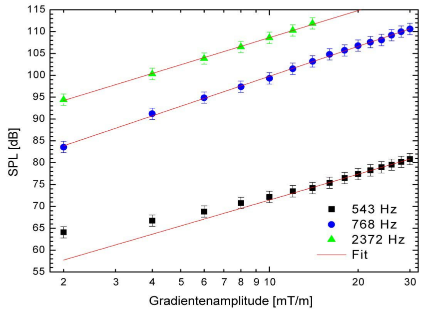

***Fig 2**: Dependency of the SPL on the amplitude of a sinusoidal gradient switching.*

frequency	param. *a*	σ(*a*)	param. *b*	σ(*b*)
543 Hz	19.7	5.2	51.8	7.0
768 Hz	22.5	1.4	77.3	1.6
2372 Hz	20.6	1.8	88.0	1.6

***Tab. 1**: Values of the parameters resulting from the logarithmic fit in Fig. 2.*

Results:

Fig. 1 shows the frequency response function in decibels for the x- and the z-gradient coil. As the x- and y-gradient coils is identically constructed, their FRF's are similar. Fig. 2 shows the SPL's dependence on the gradient amplitude for three different sinusoidal gradient switching frequencies. All the three curves are approximated by a fitting function y = *a* log(x) +*b*. As the black curve (543 Hz) is elevated due to the background noise with an SPL of about 61.2 dB for lower sound pressures, only values above 8 mT/m contributed to the fit. Table 1 shows the determined fitting parameter values and their errors.

Fig. 3a and 3b shows the simulated and the measured spectrum for the silent sequence. The corresponding SPL amounts to 67.8 dB (measured) and 68.0 dB (simulated). The values for the loud EPI sequence add up to 101.4 dB (measured) and 103.2 dB (simulated), their spectra are displayed in Fig 3c and 3d. Apart from higher orders of the main frequency component, which are reduced in the simulation of the loud sequence compared to the measured spectrum, the comparison of simulation and measurement reveals high similarities in both sequences.

Discussion

As Fig. 1 shows, a linear dependence between sound pressure p and gradient amplitude is observable even at high sound pressure levels above 100 dB. The values of the fitting parameter *a* agree with the expected value of 20 within their errors for the 2372 Hz curve and the 543 Hz curve. For the 768 Hz curve the deviation is within 2σ. These observations are confirmed by the SPL simulation which predict the measured SPL with a deviation of 0.3 dB (silent) and 1.8 dB (loud), respectively.

These results show that the assumption made by Hadeen and Edelstein [3] are reasonable, even for high sound pressure levels. On this basis the generated acoustic noise of a sequence with arbitrary gradient switching can be predicted with a precision of only a few decibels.

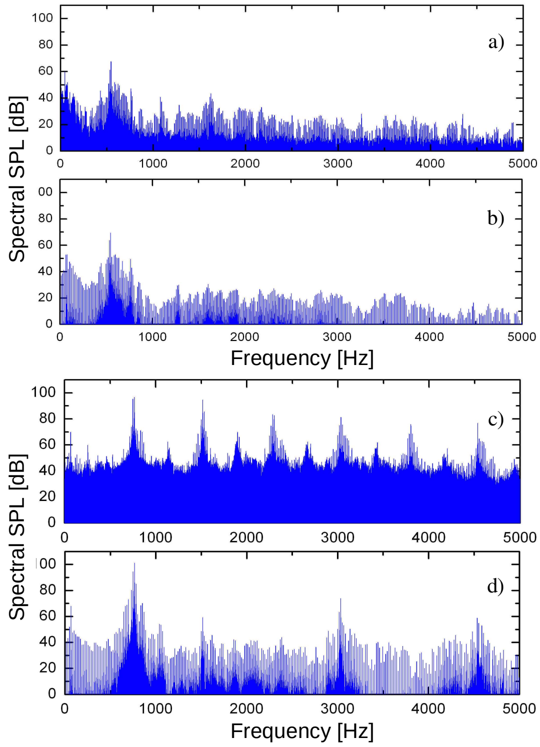

***Fig. 3**: Measurement (a) and simulation (b) of the silent sequence's spectrum. Loud sequence's spectrum: measurement (c) and simulation (d).*

References:

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[2] Bandettini PA et al. [1998] Magn. Reson. Med. 39:410-6.
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[4] Schmitter S. et al. [2006] Proc. ISMRM, 2814.