A Tube Headphone without Metallic Parts to be Used for Functional NMR

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Introduction

Functional Nuclear Magnetic Resonance (fNMR) or functional Magnetic Resonance Imaging (fMRI) over the last few years have emerged as important tools for the investigation of brain functions. The possibility to create time series of the neuronal activity enables the study of the processing of stimuli from most diverse senses.

The creation of acoustical stimuli inside of the NMR apparatus is affected by the high noise level originating from the scanning sequences of the magnetic system. The presentation of acoustical stimuli therefore requires a special headphone system fulfilling several aspects. The first aspect is to protect the subjects ears from noise. Second, the headphone may not contain any metallic that could interfere with the NMR system. Finally the acoustical quality of the headphone should provide reasonable sound quality and acceptable sound pressure level with independent channels for both ears.

Technical Concept

The Hearing Protector Tube Headphone

Different headphone systems of conventional dynamic and electrostatic type have been tested by the clinical operators and besides the problem of unacceptable hearing protection it has been found that the presence of *any* metallic or magnetic parts causes severe problems for the imaging. Hence the electro acoustical device must be placed at a remote place and the acoustical waves must be transmitted to the ears by non-metallic tubes.

To ensure that the dynamic loudspeaker unit does not interfere with the NMR scanner a position at the end of the sliding table was defined which calls for a tube length of 6 m. With respect to practical (flexibility, weight, cost) and acoustical demands (damping, frequency response) a tube with 8 mm bore and 12 mm diameter was chosen.

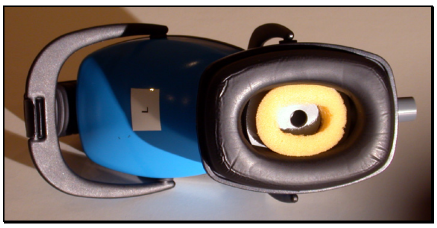

Figure 1: Picture of the right headphone shell containing a plastic piece for the interfacing of the tube. A soft foam ring is inserted to seal the pinna as close as possible to the tube without needing to plug the tube into the ear canal.

One request was that the tube should not be plugged into the subjects ear canal since the comfort and the handling of such systems were not satisfying and, moreover, a good sealing would only be achievable with an oto-plastic insert for the cavum conchae which in general would be too expensive or too time consuming to realize. Therefore a combination of a circum-aural hearing protector in combination with an integrated supra-aural foam sealing was chosen. Figure 1 shows a photo of the realisation of the 'hearing protector tube headphone' (HPTH). The actual hearing protector was selected with respect to the very limited space inside of the NMR-ring.

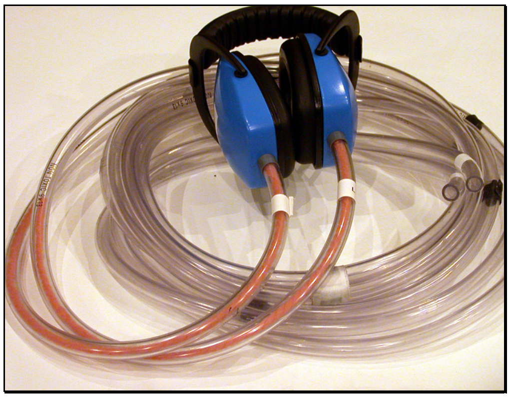

Figure 2: The HTPH with the tube attached. The short thread of wool is used to damp reflected sound energy.

The Electro-Dynamic Driver System

In a small tube the frequency dependant damping causes a rather steep roll-off at higher frequencies. Figure 3 shows the frequency response of the HPTH with the actual horn driver.

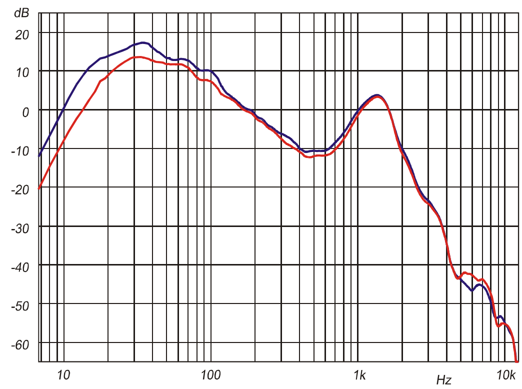

Figure 3: Frequency response of the un-equalised HPTH measured on a head-acoustics HMS3 dummy head with ear drum impedance simulator. The overall attenuation at 10 kHz rises to about 70 dB relative to 100 Hz.

In consequence, the sound pressure level (SPL) of the feeding horn driver (to achieve a reproduction level of more than 90 dB) has to deliver up to 160 dB into the tube input. Though a level of this intensity does not cause a problem for the horn driver, it will produce strong harmonic distortion due to the non-linear characteristic of the adiabatic equation. A second challenge is the quite high dynamic of about 70 dB, that has to be equalised by passive or active means. In connection with the aimed low cut-off frequency of about

80 Hz the selection of an appropriate driver was rather difficult. The used BMS4592 2-way coaxial driver provides both, a low cut-off of about 100 Hz and a smooth frequency response up to 15 kHz. A conical impedance transformer is used for the adaptation of the 2" bore of the horn driver to fit into the tube bore of (see Figure 4):

Figure 4: The driver cabinet forming a rigid and secure

Equalisation System

To maintain a proper frequency response a digital equaliser was used with FIR filter implementation of the inverse frequency response. The frequency band was split into 3 FIR bands at full (100 Hz – 1 kHz / 44.1 kHz / 243 taps), quarter (1 kHz – 3.9 kHz / 11.025 kHz / 389 taps) and 1/16th (3.9 kHz – upper cut-off frequency / 2756.25 Hz / 701 taps) of the sampling frequency. Figure 5 shows the result for different upper cut-off frequencies. Unfortunately the equalisation up to higher frequencies must be paid with a loss of maximum output level. Therefore three different cut-off frequencies are user selectable. The shortening of the tube would provide larger bandwidth in combination with higher level and less distortion.

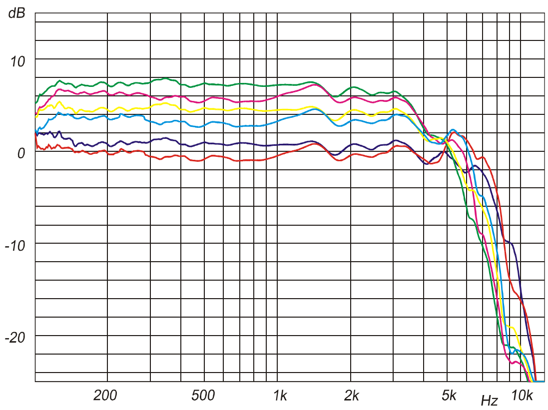

Figure 5: Frequency response curves of the equalised tube headphone, measured on HMS3 dummy head. Three different upper cut-off frequencies (5 kHz, 6 kHz, 8 kHz) can be used to provide either large bandwidth or high level.

The Hearing Protector Attenuation

The modification of the capsule protector (insertion of the pinna adapter, tube connection) requires a new determination of the sound insulation. Measurements in accordance to the ISO standard (ISO8469) have been performed in an artificial diffuse sound field using four independent channels and narrow band noise excitation. The tests have been performed by 17 subjects. The results for the open and protected thresholds are given in Figure 6.

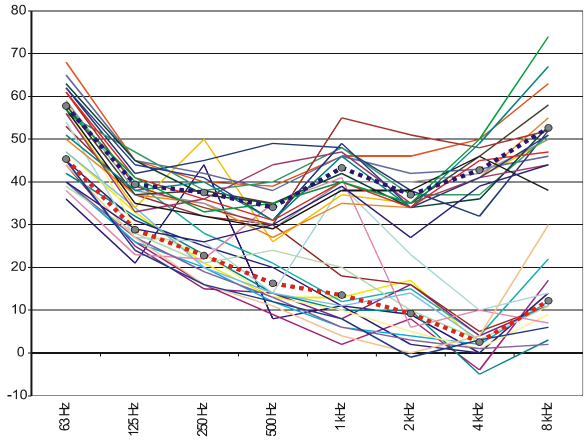

Figure 6: Threshold of hearing measurements for 17 subjects with and without hearing protector in place. The dotted lines are the average values.

From these measurements the hearing protector attenuation was calculated. In Figure 7 the overall result from 16 subjects (the subject with the odd results at 500 Hz and 1 kHz was taken out) is calculated as an average. The overall attenuation is fairly good and fulfils the requirements.

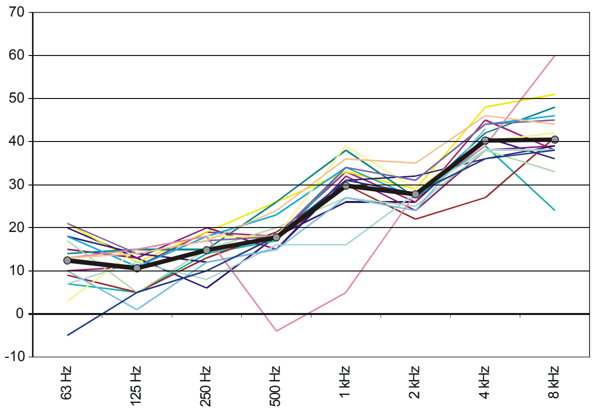

Figure 7: Attenuation of the HPTH. The tube was inserted and the ends of the tube have been closed by plugs.

Conclusion

A tube headphone to be used in functional nuclear magnetic resonance tomography has been realised, that provides rather good insulation from the noisy environment in combination with satisfying audio quality. The demand to provide a 6 m tube led to a very high attenuation and therefore a high power compression driver was used to achieve adequate sound pressure level up to 8 kHz. However, both bandwidth and achievable sound pressure level would benefit from shortening the tube.

The HPTH is in use at the University Hospital Aachen since about two years. The first impression was quite affirmative and since that time the system has been used successfully for many times without problems.