

Lab Report

“Otoacoustic Emissions”

M.Sc. BMT, Implantology

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July, 7th 2022

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Motivation

The aim of this practical was to investigate otoacoustic emissions (OAE) measured at a healthy subject. OAE are sounds which are generated in the inner ear. In the practical work, first, distortion products of OAE (DPOAE) were evaluated via continuous measurement, as it is commonly applied in clinics as an objective and non-invasive audiometric test of the cochlear amplifier. Second, pulsed stimuli were applied on the subject for time domain measurement of DPOAE of the cochlear amplifier, as it is used in research.

Preparation

Before starting the measurement, the healthy subject was prepared by placing eartips in both ears. Those eartips contained a microphone and two speakers each, with the speakers emitting acoustic stimuli in different frequencies, and the microphone serving to record sounds obtained from the inner ear. To enable a measurement without any disturbing noises, the subject was situated in a soundproofed chamber without moving too much. Two softwares were used, one for recording the data, and the other one for processing. For calibration, a background measurement was made in which no stimuli were delivered by the speakers, but the microphones recorded the signals from each of the ears. It was observed that low-frequency disturbances occurred, which were related to natural physiological movements of the body, as for example, the beating of the heart or breathing.

DPOAE - Continuous signals

First, a DPOAE measurement was performed with continuous primary sinusoidal tones. For this purpose, an automatic calibration was initially done using the previously obtained calibration data to check whether the eartips were still in the right position. Subsequently, two continuous tones with different frequencies f_1 and f_2 with the sound pressure levels $L_1 = 55$ dB and $L_2 = 65$ dB were emitted from the speakers. The respective frequencies were varied over time while the sound pressure level was fixed.

Figure 1 (left) shows the nonlinear output pressure signal of the two overlapping frequencies in the time domain. Beat occurs due to similar frequencies used for excitation. By conducting a Fourier transform a DP-gram is obtained as it is depicted

in figure 1 on the right image. Here, it can be seen that in the recorded frequency spectrum of the sound pressure levels, in addition to the two largest peaks (green and black crosses) induced by the excitation tones, another high peak (red cross) occurred in a slightly lower frequency range.

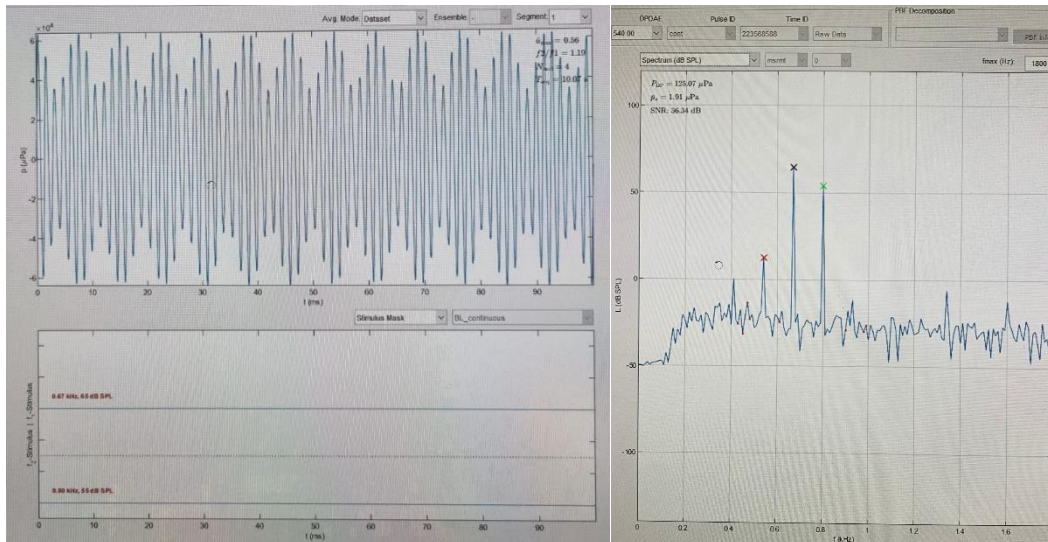


Figure 1: DPOAE output of overlapping signals with beat frequency (left) and DP-gram with distortion peak (red) and input frequencies (black and green) (right)

This peak represents the distortion product generated by the non-linear amplifier of the cochlea. It occurs due to the stereocilia of the outer hair cell (OHC) being bent by hydrodynamic oscillations initiated by the overlapping acoustic stimuli, opening K^+ and Ca^{2+} ion channels and causing depolarization. This process is called mechano-electrical transduction (MET). The now present action potential leads to electro-mechanical transduction (EMT), which causes conformational changes of prestin molecules located on the inner side of the plasma membrane of the OHC. This results in elongation and shortening of the OHCs, which induces oscillations of the basilar membrane. The oscillations can ultimately be measured as a distortion product. This intermodulation product has a frequency of $f_{DP} = 2f_1 - f_2$ resulting from the excitation frequencies f_1 and f_2 . This occurs due to the nonlinear processing of the overlap of these excitation frequencies on the basilar membrane in the inner ear.

Although this method is used clinically, it has an imprecise accuracy, as the measurement may be falsified by the technical equipment, interindividual sound pressure dependence of the OAE and the influence of the middle ear sound forwarding. However, the inner ear of the subject examined in this experiment showed results that indicated a normal hearing function.

DPOAE - Short-Pulsed signals

Pulsed-signal measurements are conducted to determine the optimum difference between the two applied stimulus frequencies. However, this method is so far only used for research and not applied in clinical testing.

After calibration, five pulsed thirds were generated by the speakers within 150 ms for 30 ms each. At the bottom of figure 2 the time points and durations of the applied acoustic signals are displayed. As shown in the diagram the first frequency f_1 was emitted continuously over a time period of 30 ms while the second frequency f_2 was generated in short pulses. As in the continuous measurement, DPOAE was recorded on each ear using the microphones and its sound pressure was plotted in the time domain. The graph of the time domain shows the sound pressure maximum of the primary tones, followed by the peak of the delayed generated distortion product of the inner ear.

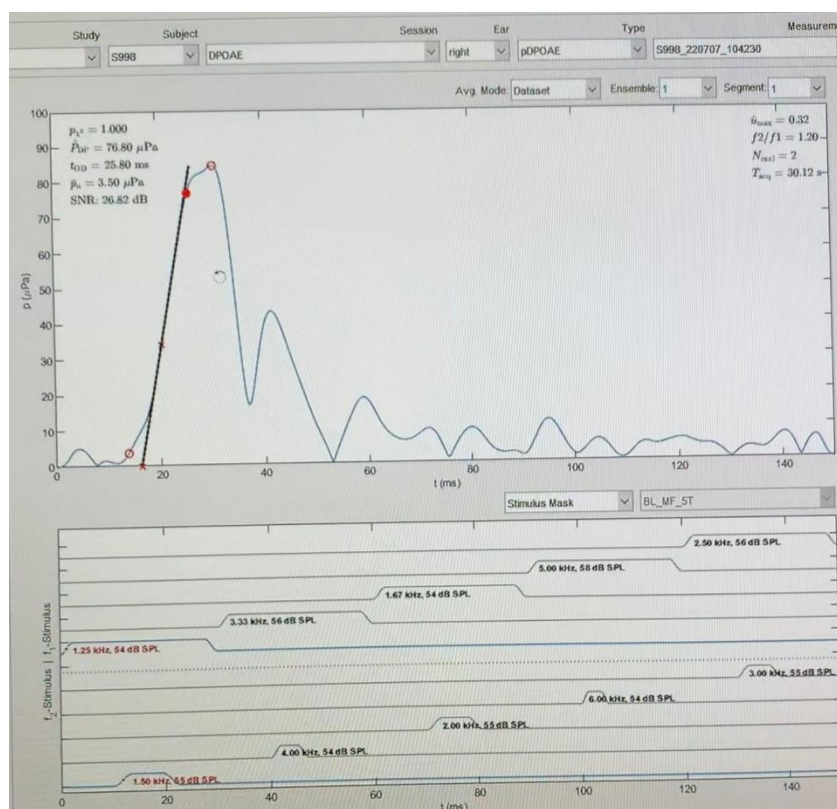


Figure 2: Pulsed DPOAE time domain

In addition, a three-dimensional level map (see figure 3, left) was created from the data, where the x- and y-axis display the sound pressure levels of the two excitation signals f_1 and f_2 , and the z-axis represents the resulting pressure. To generate this level map, a filter was applied to remove the excitation signals from the analysis. It

shows that it is beneficial to have a difference of 10 dB in the sound pressure level of the two frequencies, since then a higher distortion product is generated. However, this value is specific for every subject. Furthermore, it can be seen on the right side of figure 3 that the sound pressure level increases linearly with an increasing logarithmic stimulus. This also indicates a normal inner ear function of the subject.

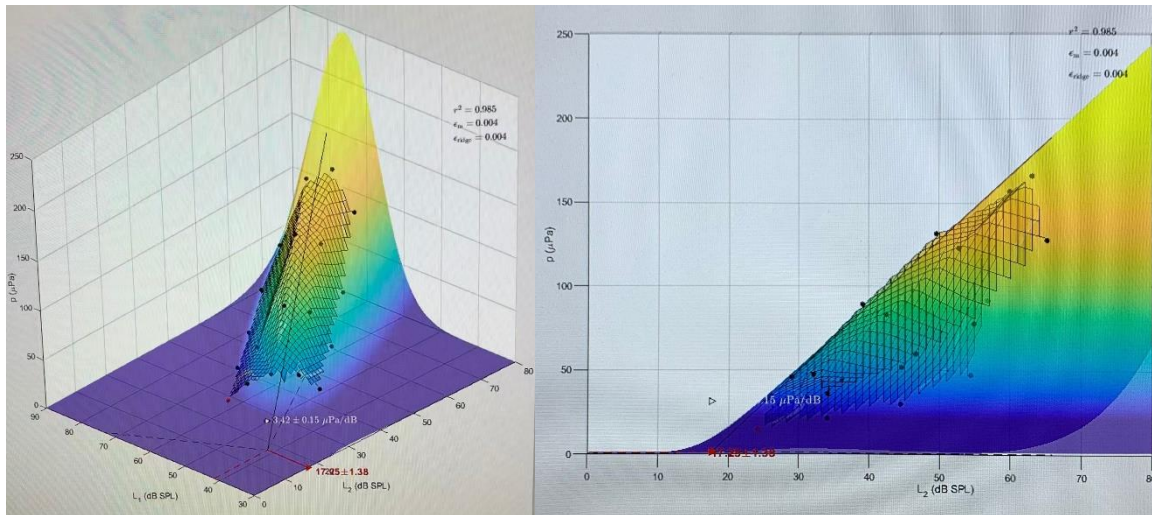


Figure 3: Level map of pulsed DPOAE measurement (left) and 2D view of the slope (right)

Conclusion

Different tests were performed to measure the otoacoustic emissions. In order to check the functionality of the inner ear, a continuous DPOAE was carried out, as it is also applied in clinical testing. Different frequencies were emitted from the speakers and the resulting distortion product of the ear was measured. Based on the frequency spectrum, it was found that the inner ear function of the subject worked well as far as it can be concluded from DPOAE measurements. Finally, a measurement relevant for research was performed in which different sound pressure level combinations were applied as pulsed stimuli. Based on the measurement of the corresponding distortion products, a sound pressure level map could be obtained, which showed that a difference of 10 dB in the two acoustic signals is optimal to generate the maximum distortion product. However, this value is specific for every subject. Possibly, the pulsed DPOAE measurements gain clinical relevance in the future since more precise results can be obtained by using that technique. Furthermore, the filtering and analysis process could be improved to obtain more accurate results.