# Time Efficient Measurement Method for Individual HRTFs

Pascal Dietrich, Bruno Masiero, Martin Pollow, Benedikt Krechel and Michael Vorländer
*Institute of Technical Acoustics, RWTH Aachen University, Neustraße 50, 52056 Aachen, Email: pdi@akustik.rwth-aachen.de*

## Introduction

An optimized multi-channel measurement setup for the acquisition of individual HRTFs in anechoic environments has been developed as shown in Figure 1. This kind of measurement is usually time-consuming, if high spatial resolution is required. A recently introduced technique allows simultaneous playback of multiple exponential sweeps through several sound sources by even considering slightly non-linear behavior [1]. This approach directly leads to a significant reduction of the required measurement duration. A different approach uses a continuous measurement method of a rotating person with a single or several loudspeakers to speed up the HRTF measurement on horizontal rings [2]. This contribution introduces a new optimization strategy for the excitation signals, regarding measurement duration and achieved accuracy of the measurement.

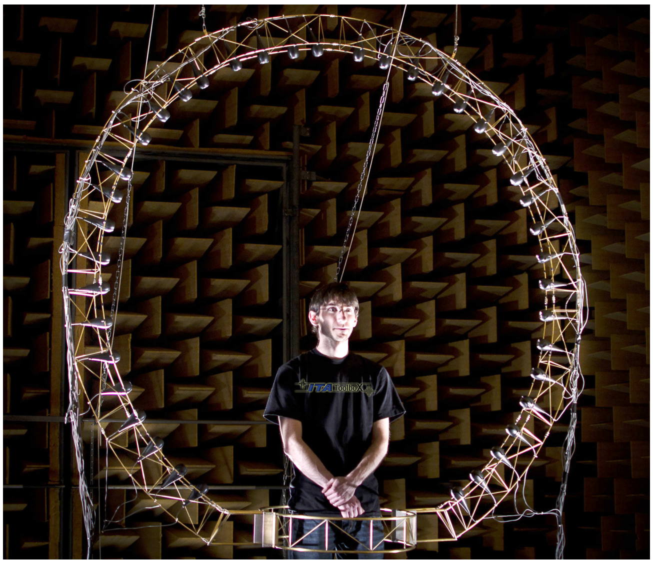

**Figure 1:** HRTF arc in the anechoic chamber at ITA.

## Multiple-exponential sweep method

Acoustic systems are usually assumed to be linear time invariant (LTI). Hence, linear system theory is applicable along with various excitation signals for correlation measurement techniques. Exponential sweeps are known to have advantages when it comes to non-linear systems [3]. Non-linear behavior of the system is observed as anti-causal impulse responses $h_{\mathrm{harm},i}$ for different harmonic orders $i$ separately. The multiple-exponential sweep method (MESM) proposed by MAJDAK is applicable for weakly non-linear systems [1]. By this method the measurement duration can be significantly reduced when the number of sound sources $L$ is high. MAJDAK introduced two different strategies. One called *overlapping*, where the harmonic impulse responses appear between the impulse responses of interest; and another strategy called *interleaving*, where the impulse responses of interest are grouped together and then a group of all non-linear impulse responses follows. A combination of both strategies is given with an optimization algorithm by MAJDAK as well. The measurement duration of $N$ multiple sweep measurements with a sweep of length $\tau_{\mathrm{sweep}}$ and a silence in the end of length $\tau_{\mathrm{stopMargin}}$ is given by

$$\tau_{\mathrm{MESM}}(L) = (L-1)\tau_{\mathrm{wait}} + \tau_{\mathrm{sweep}} + \tau_{\mathrm{stopMargin}}, \qquad (1)$$

compared to the duration of a conservative, discrete measurement

$$\tau_{\mathrm{separate}}(L) = L(\tau_{\mathrm{sweep}} + \tau_{\mathrm{stopMargin}}). \qquad (2)$$

The theoretically achievable reduction of measurement time for a large number of loudspeakers can be expressed as

$$\lim_{L\to\infty} \frac{\tau_{\mathrm{MESM}}(L)}{\tau_{\mathrm{separate}}(L)} = \frac{\tau_{\mathrm{wait}}}{\tau_{\mathrm{sweep}} + \tau_{\mathrm{stopMargin}}}. \qquad (3)$$

Usually the length of sweeps lies in the length of 0.2 s for very short and 2 s for moderately long sweeps. The constant $\tau_{\mathrm{wait}}$ depends on the sweep rate, the maximum order of non-linearities and the length of the measured impulse response. For HRTF measurements in suitable anechoic environments the range of the impulse response $h_{\mathrm{RIR}}$ is estimated as 20 ms to 100 ms.

The MESM method can yield impulse responses that have the same quality as separately and consecutively measured impulse responses. The signal to noise ratio and the temporal and spectral structure of both results remain the same if the following requirements are fulfilled: The system has to be at most weakly nonlinear, i.e. the number of harmonic impulse responses has to be small. In case non-linearities are observed, the level has to be kept constant during both measurement and calibration – note that this constrained has not been stated in the original paper. The length of the impulse response should be much smaller than the smallest time $\tau_{\mathrm{wait}}$ between two subsequent sweeps. Once the weakly non-linear loudspeakers playback the MESM signal no further weak non-linearities are allowed, i.e., the microphones and preamplifiers have to be driven in a straight linear range only.

## Optimization Strategy

A new optimization strategy is used taking into account the expected structure of the theoretical impulse response of the system measured with an exponential sweep as shown in Figure 2. The impulse response of the loudspeaker and the HRTF is very short with an approximate duration of 4 ms. This part of the impulse response carries the important information and shall never be superposed by harmonic impulse responses. It is therefore called *avoid zone*. On the other hand, the impulse response of the hemi-anechoic chamber of the institute shows reflections from the floor, supports, mounts and doors in the order of 40 ms. The remaining impulse response of the room does not carry any useful information and can therefore be used as a place holder for the harmonic impulse response. This observation enables us to find optimized sweep parameters to fulfill the requirement by using $t_{\text{wait}}$ very close to 40 ms. As this time is usually much smaller than the measurement signal the MESM reduces the measurement time dramatically. Since the subject has to be measured under $N$ different orientation angles the measurement time of the optimized MESM method reads as $N \cdot \tau_{\text{MESM}}(L)$.

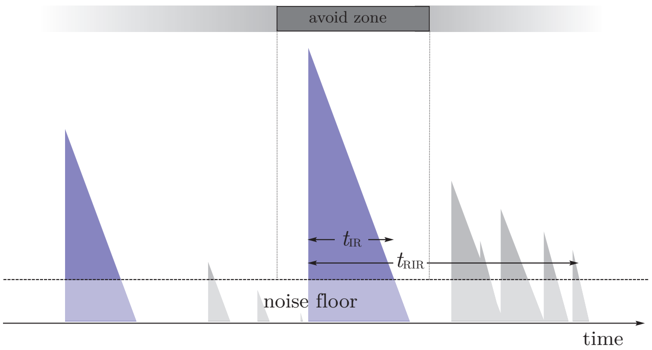


**Figure 2:** Temporal structure of an impulse response measured with an exponential sweep.

## Results

The frequency response of the transfer function from one loudspeaker to one ear of the artificial head is depicted in Figure 3. The results show no noticeable deviations and therefore the optimized MESM is considered valid. The measured HRTF using a continuous rotation of the subject is compared with the discrete rotation in Figure 4. The excitation signal remains the same but it is directly concatenated for the continuous rotation. The HRTF shows only slight deviations and a small rotation.

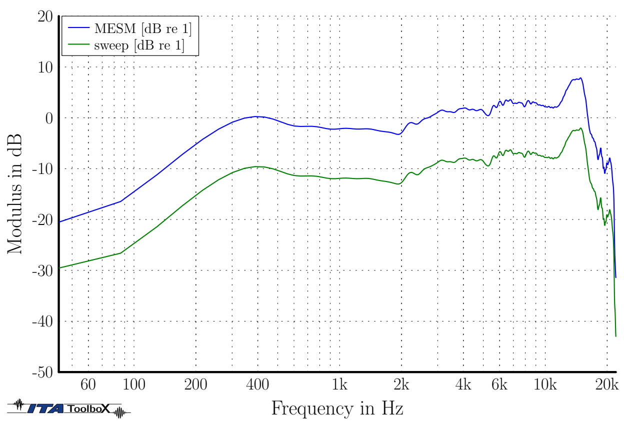


**Figure 3:** Comparison of sequential sweep measurements with MESM measurements (only one direction is plotted, MESM shifted by +10 dB).

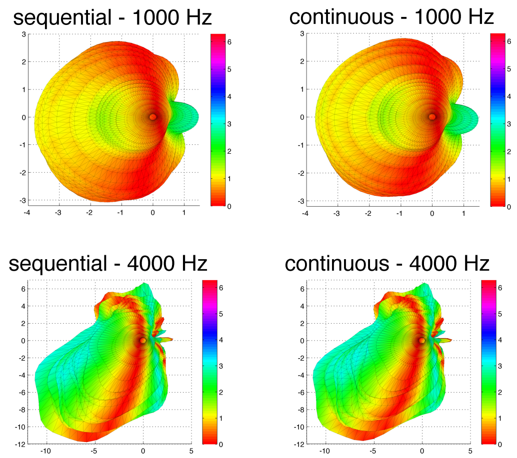


**Figure 4:** Comparison of HRTF with optimized MESM and continuous rotation (top: sequential, bottom: continuous, left: 1 kHz, right: 4 kHz).

## Conclusion

The adaptation of the MESM by using a detailed model of the impulse response and a new optimization strategy shows great potential for realistic anechoic environments. The non-linearities caused by the loudspeaker are considered. The signal to noise ratio remains the same. The required measurement duration has been reduced from 80 minutes for the conservative method to 4 minutes for the optimized MESM and sequential rotation of the subject. The spatial resolution is 7.5° in elevation and 3.75° in azimuth. No loudspeakers are available at elevation angles 150° to 180°. The combination with the continuous measurement by continuously rotating the subject yields a reduced measurement time of only 2 min with the same resolution.

## Acknowledgments

The authors would like to thank Piotr Majdak for valuable discussions and Johannes Klein for first testing of the routines and photography. The routines have been implemented in MATLAB using the ITA-Toolbox [4].

## References

[1] P. Majdak, P. Balazs, and B. Laback, "Multiple exponential sweep method for fast measurement of head-related transfer functions," *J. Audio Eng. Soc.*, vol. 55, no. 7-8, pp. 623–637, July-August 2007.

[2] G. Enzner, "3d-continuous-azimuth acquisition of head-related impulse responses using multi-channel adaptive filtering," in *IEEE Workshop on Applications of Signal Processing to Audio and Acoustics*, 2009.

[3] S. Müller and P. Massarani, "Transfer-function measurement with sweeps," *Journal of the Audio Engineering Society*, vol. 49, pp. 443–471, 2001, printed.

[4] P. Dietrich, M. Guski, M. Pollow, M. Müller-Trapet, B. Masiero, R. Scharrer, and M. Vorländer, "ITA-Toolbox – An Open Source MATLAB Toolbox for Acousticians," in *Fortschritte der Akustik – DAGA*, 2012.