Multiple Exponential Sweep Method for Fast Measurement of Head Related Transfer Functions

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Head Related Transfer Functions (HRTF)

- Filtering of free field signals
- Effects of:
  - Pinna
  - Head
  - Torso
- Dependent on spatial position of sound source
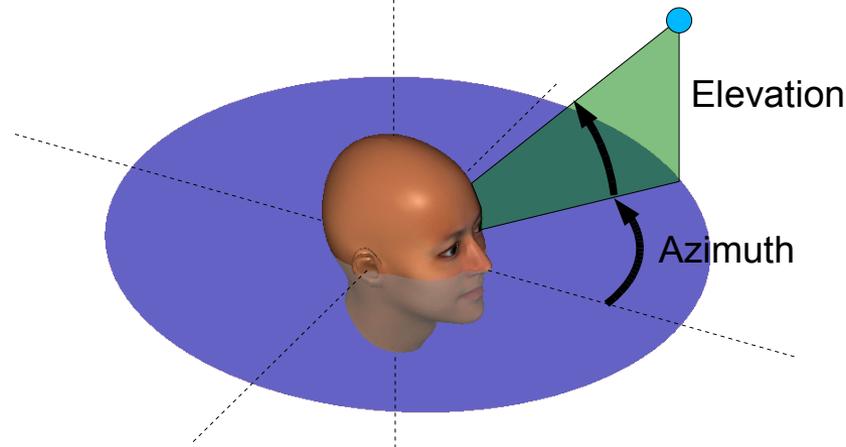
Measurement of HRTFs
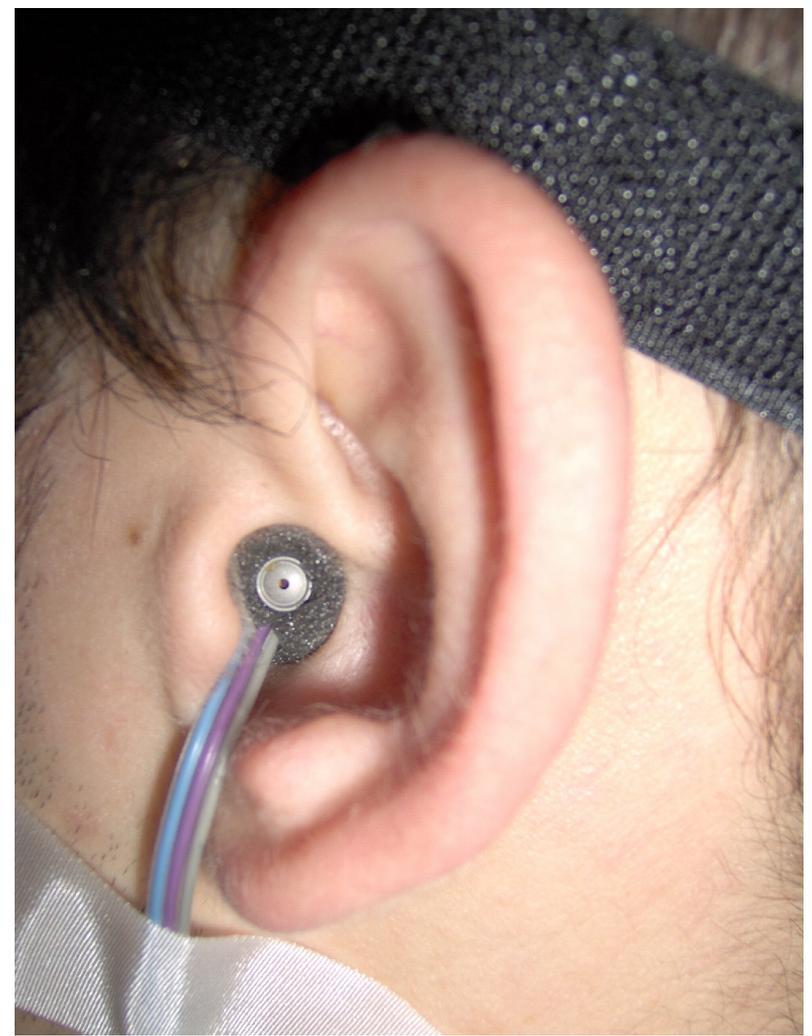
Electro-acoustic signal path

- Weakly nonlinear, time invariant systems
  - Power amplifier
  - Loudspeaker
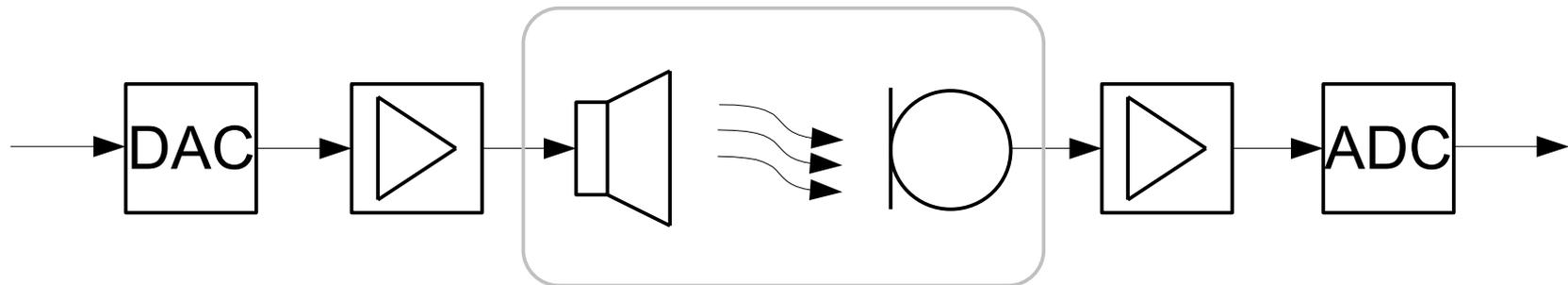
Electro-acoustic signal path

- HRTF: linear, time invariant system
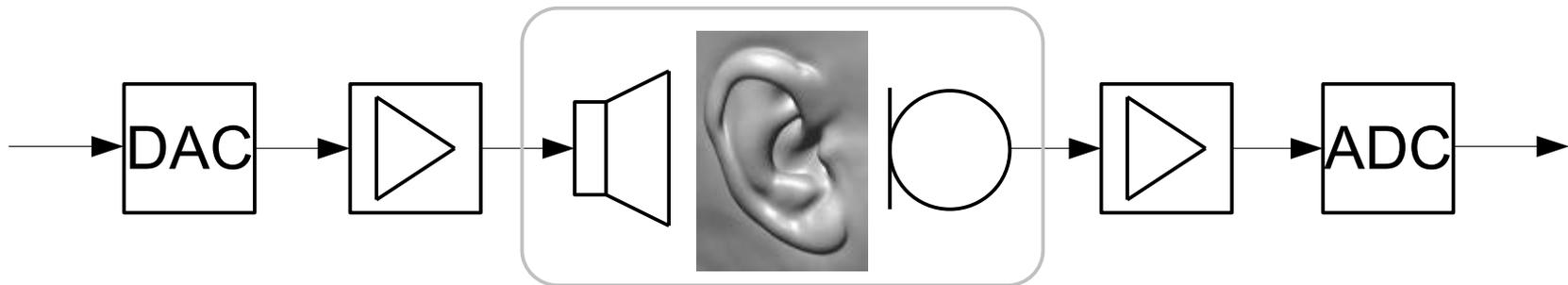
# System identification methods

- Periodic Impulse Excitation

- 2-Channel FFT

- Binary Pseudo Random Sequences
  - Maximum Length Sequences (MLS)
  - Golay Codes

- Frequency Sweeps:
  - Linear (Time Delay Spectrometry)
 - **Exponential**

Excitation with an exponential sweep


Noise

Signal → ? → + → Output
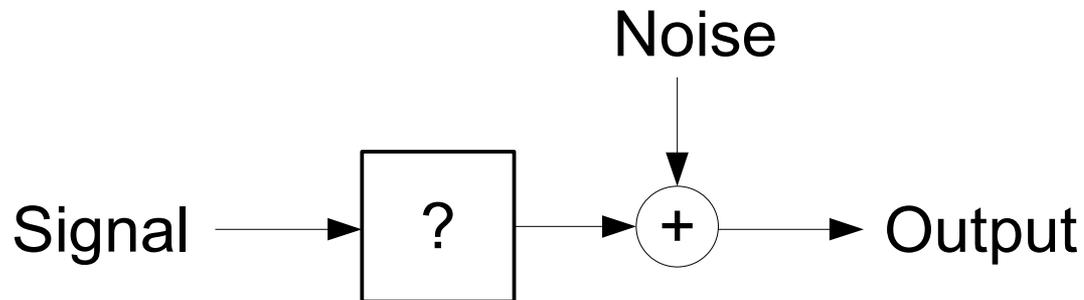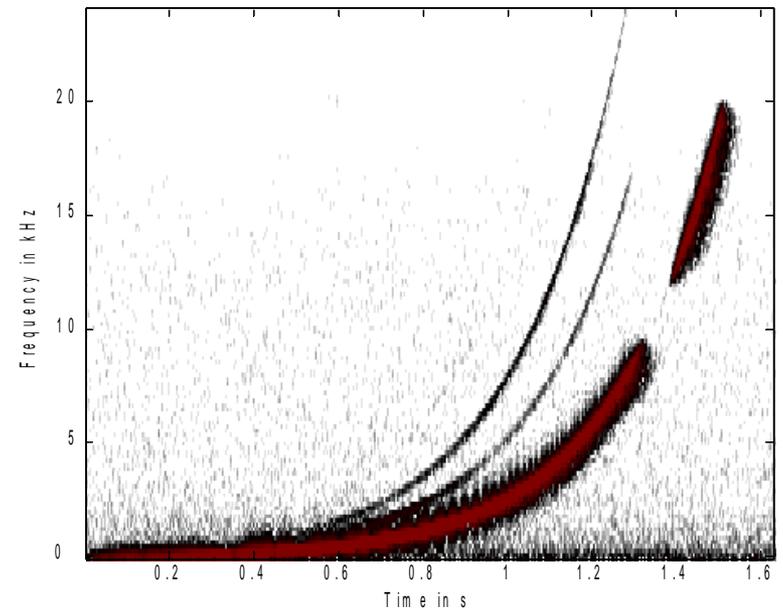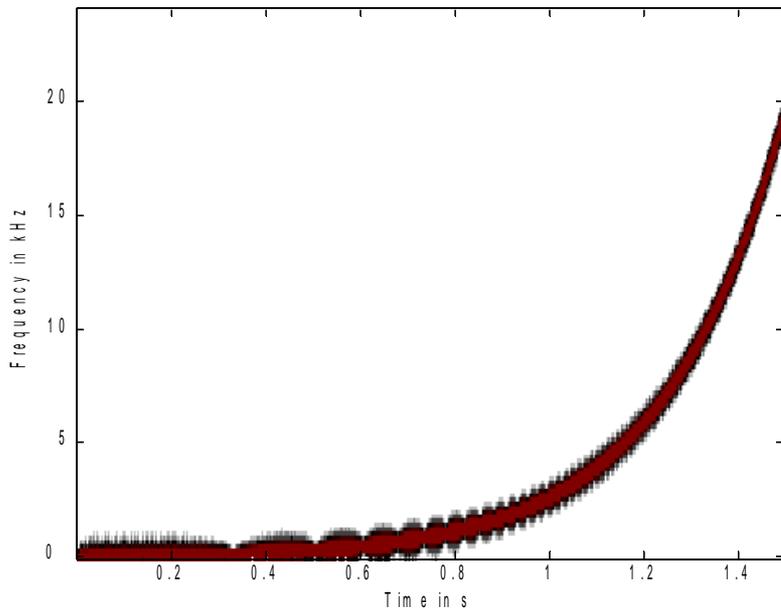
Deconvolution process
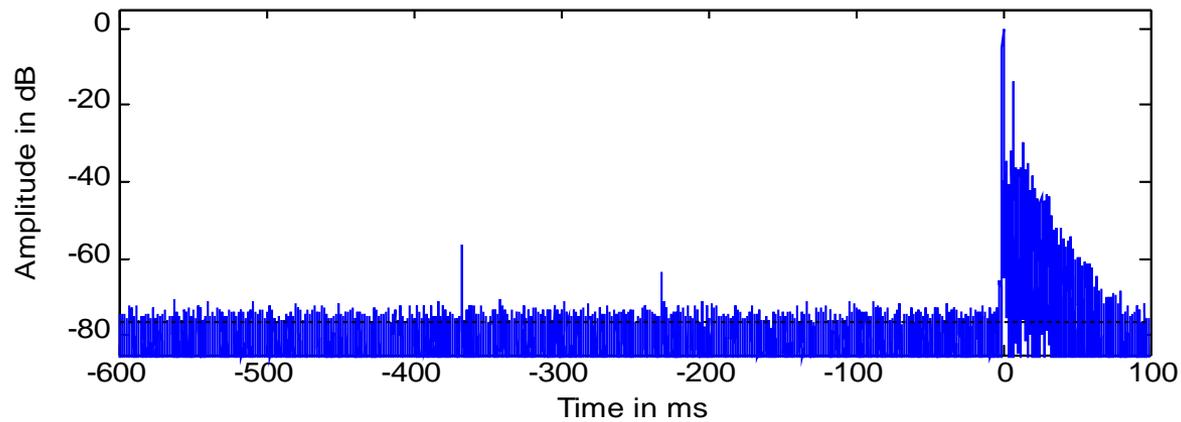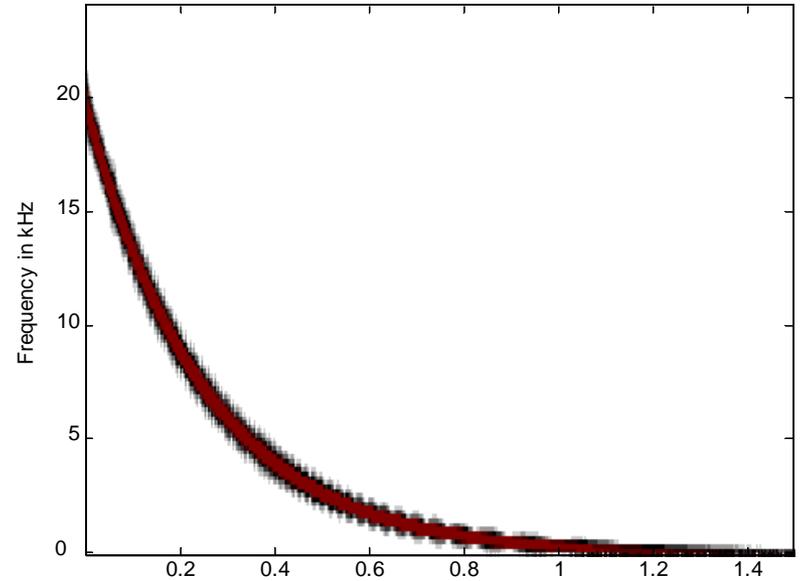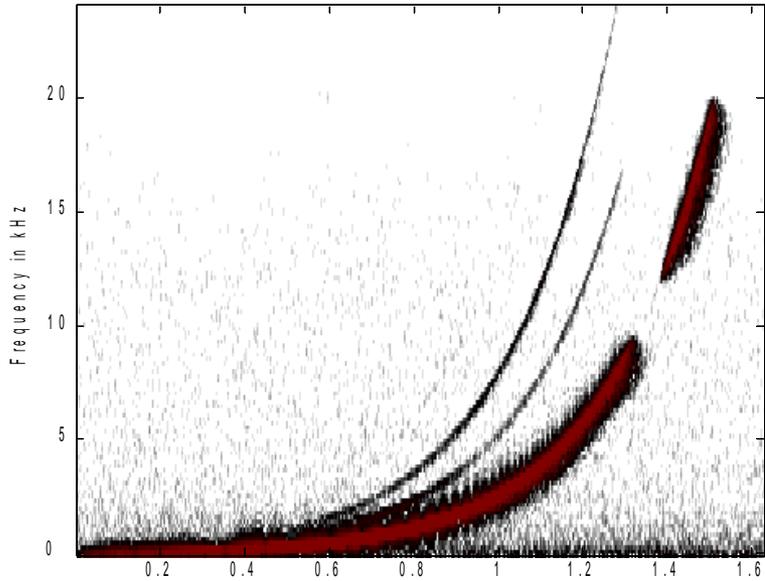
Series of Harmonic Impulse Responses (HIR)
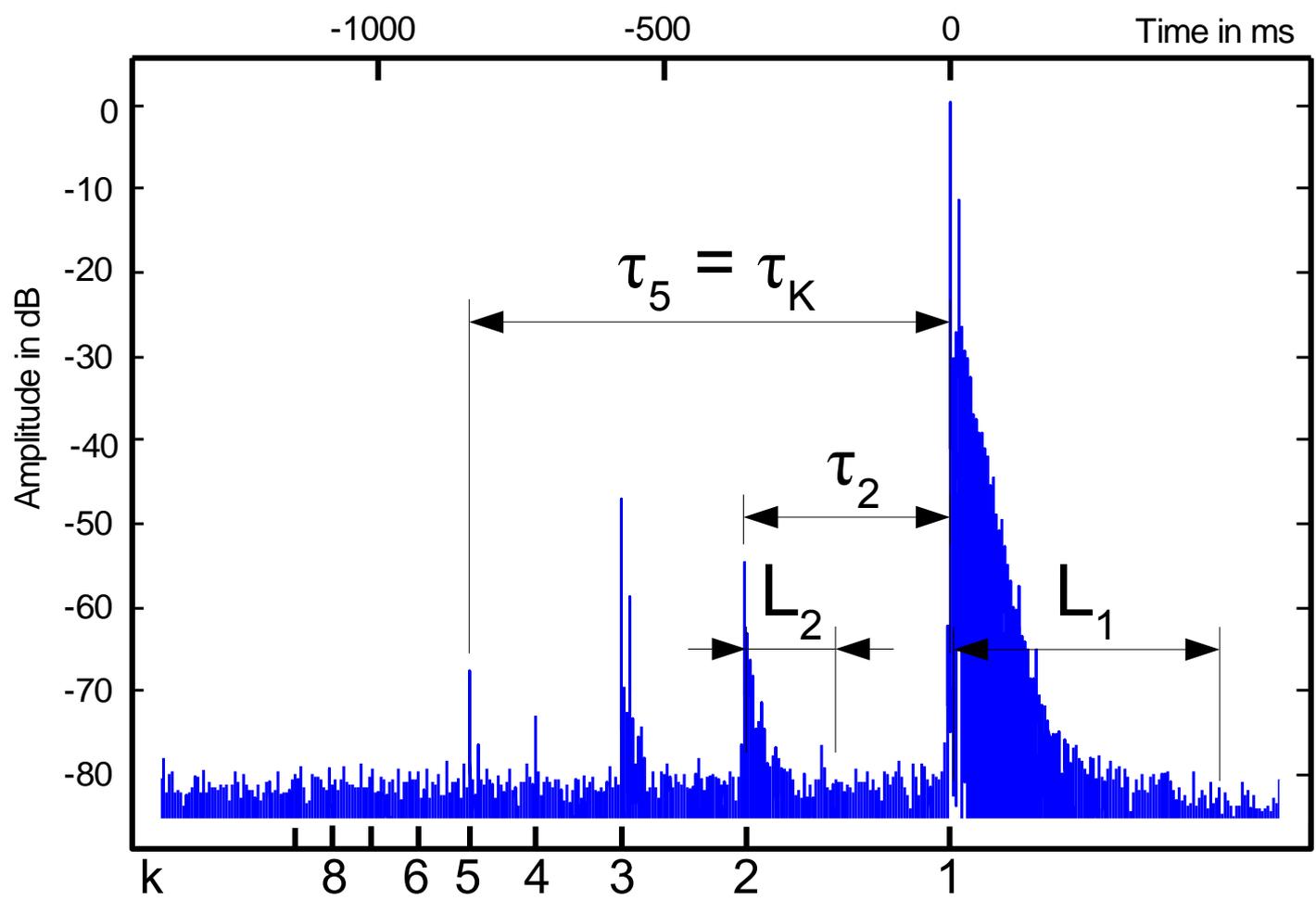
HRTF-Measurement: Positions
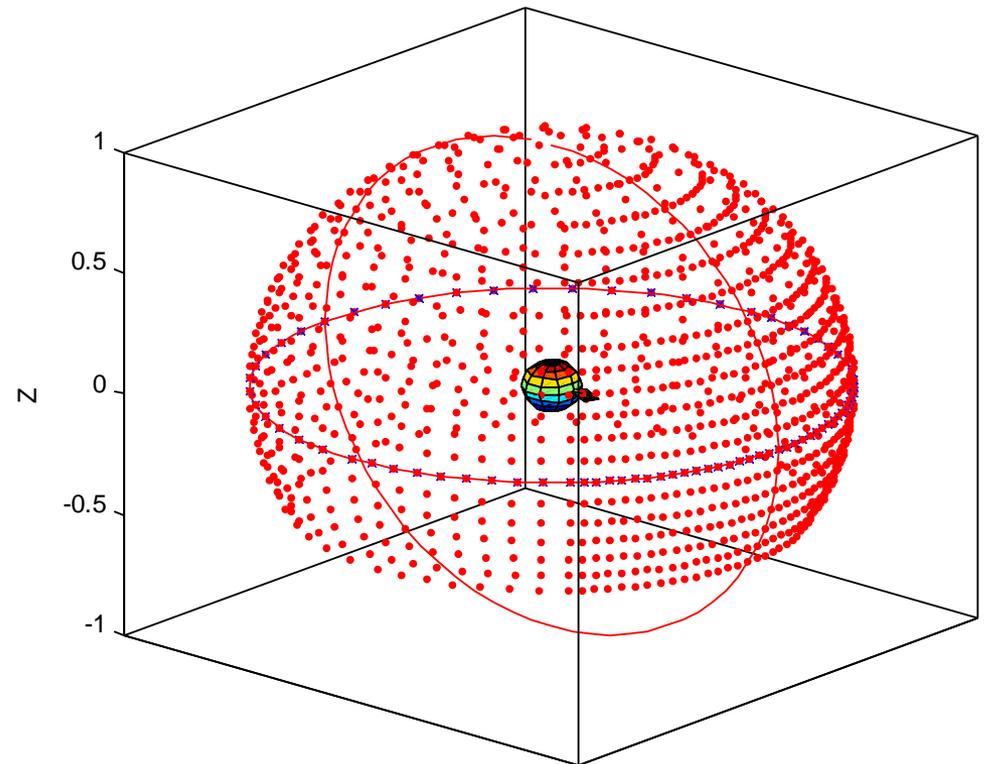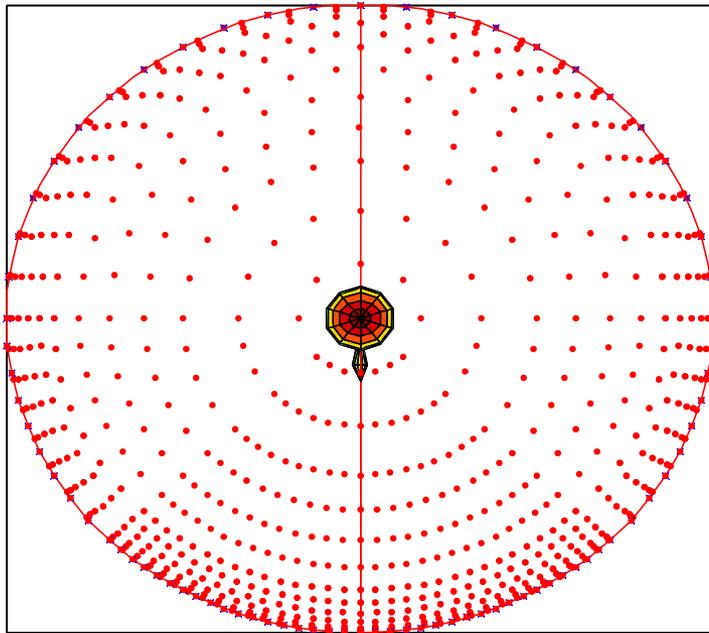
1550 Positions á 1.5 seconds: 41 minutes

Optimization of the measurement duration

Interleaving

+

Overlapping

=

Multiple Exponential Sweep Method

(MESM)
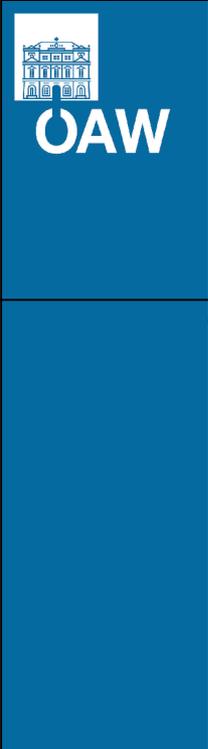
Interleaving
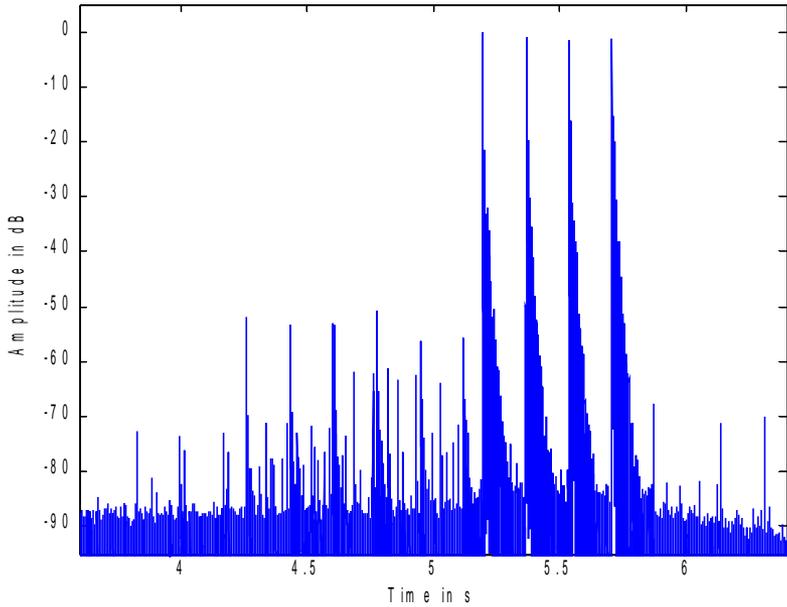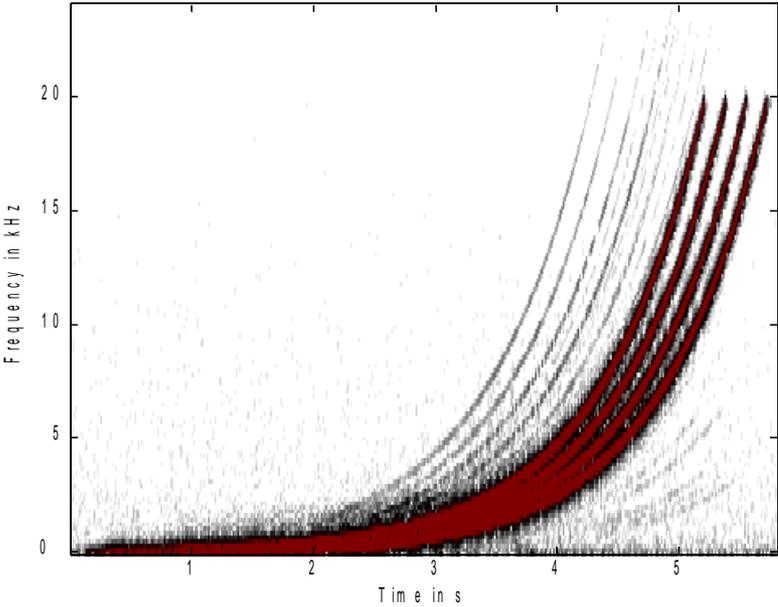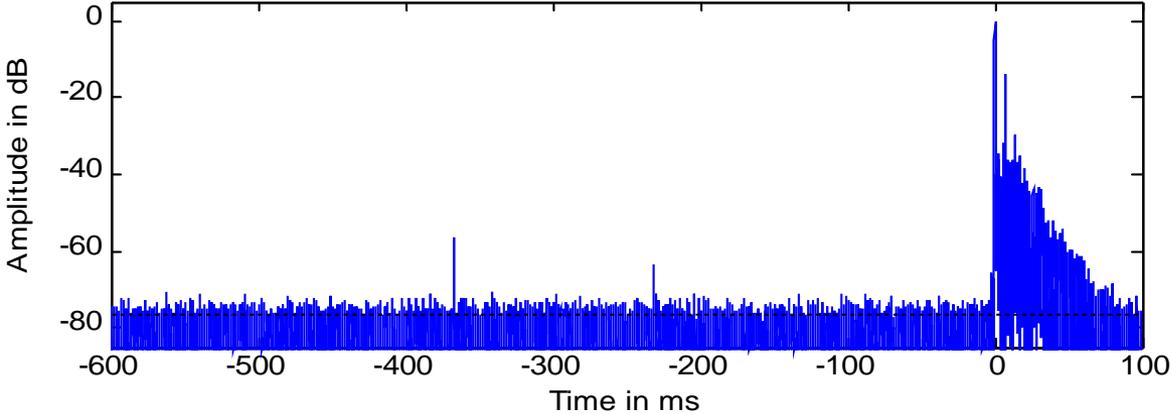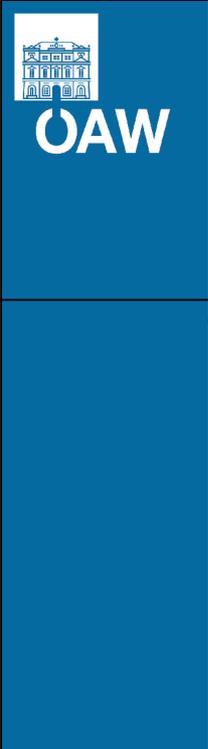
Overlapping
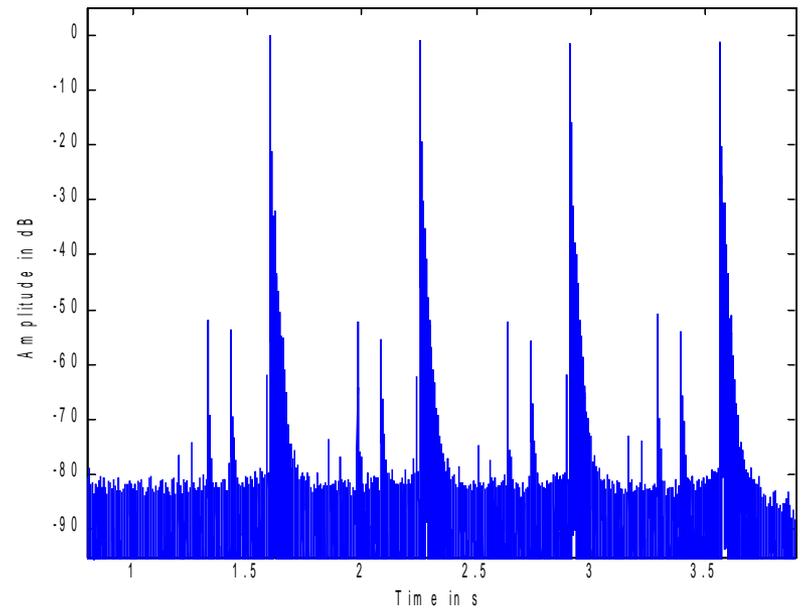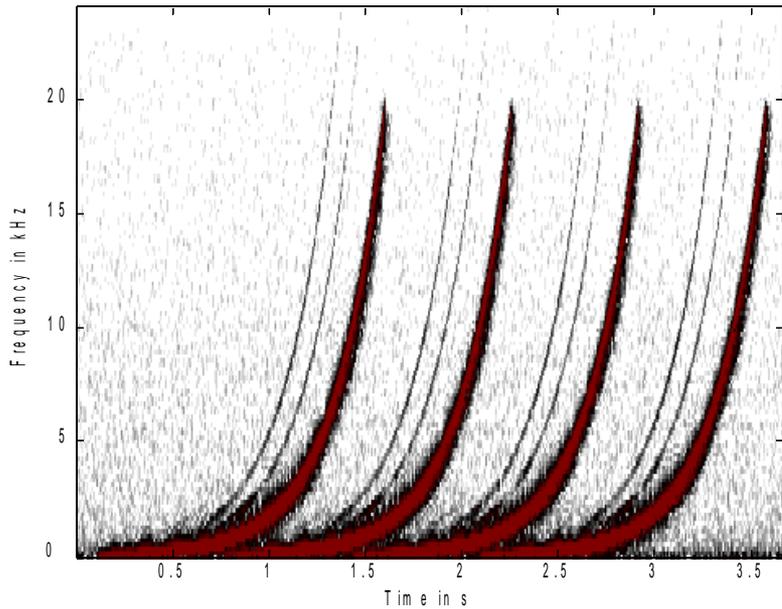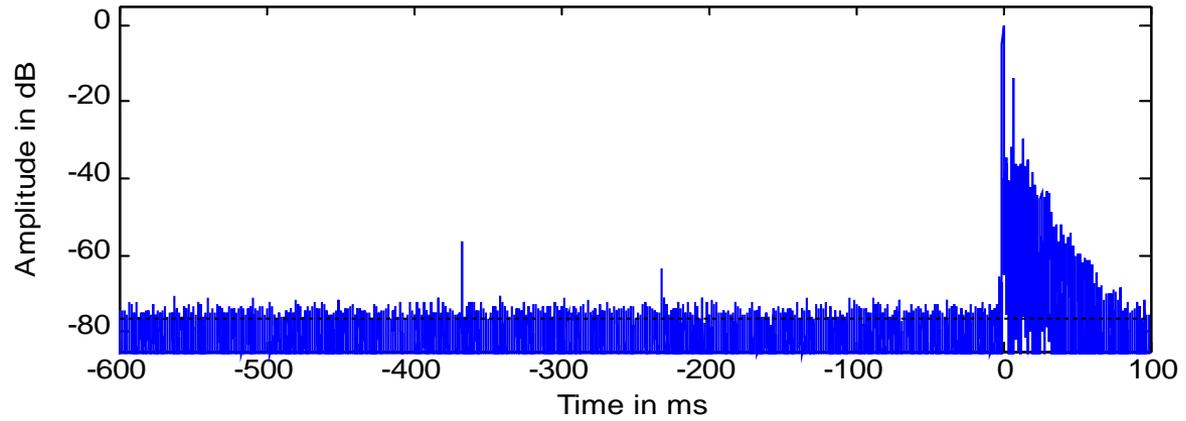
MESM

- Exact time of the excitation

- Basing on system parameters from a previous reference measurement

- Correct results for the linear parts only
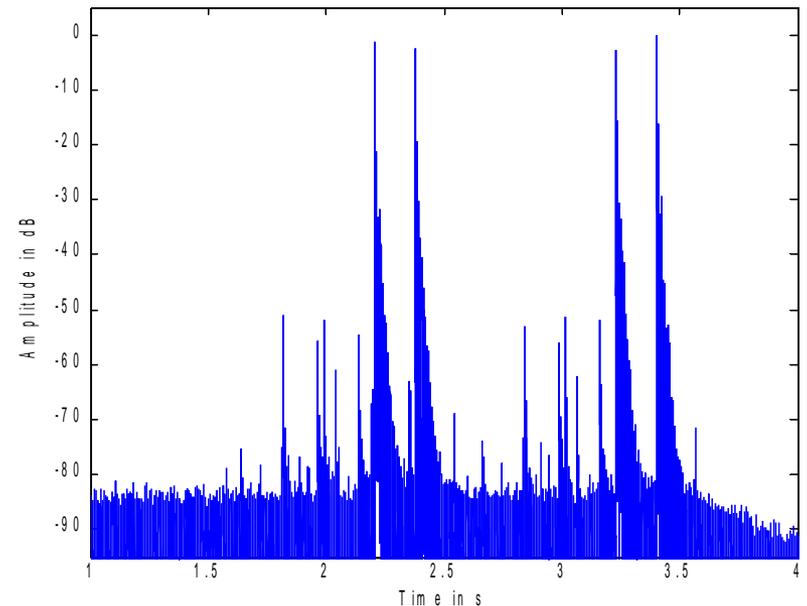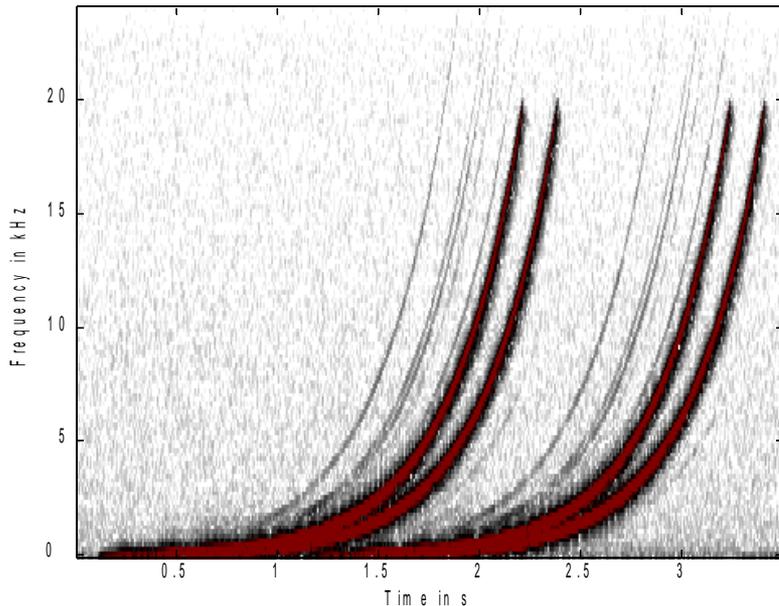
MESM and HRTF-Measurement

- 22 elevations
- 7 groups á 3 interleaved sweeps + 1 sweep
- Duration: **7.1 s** *(unoptimized: 35.2 s)*
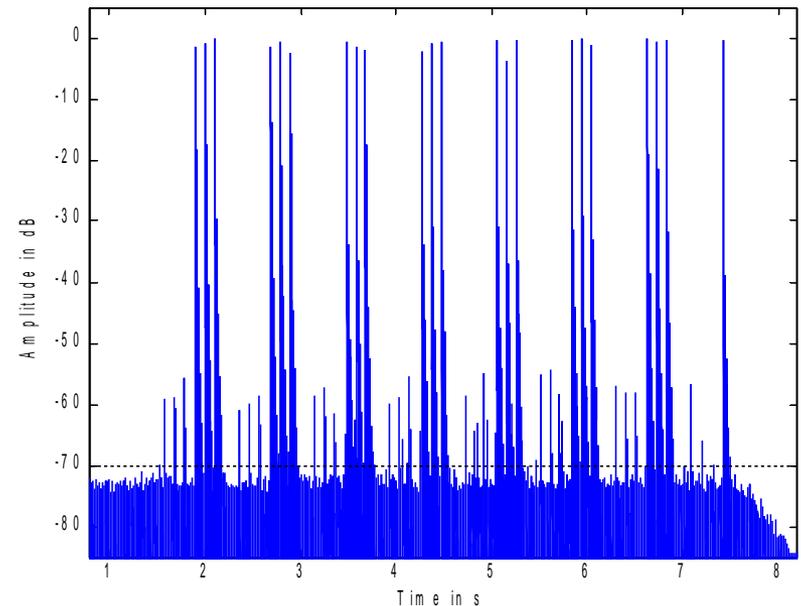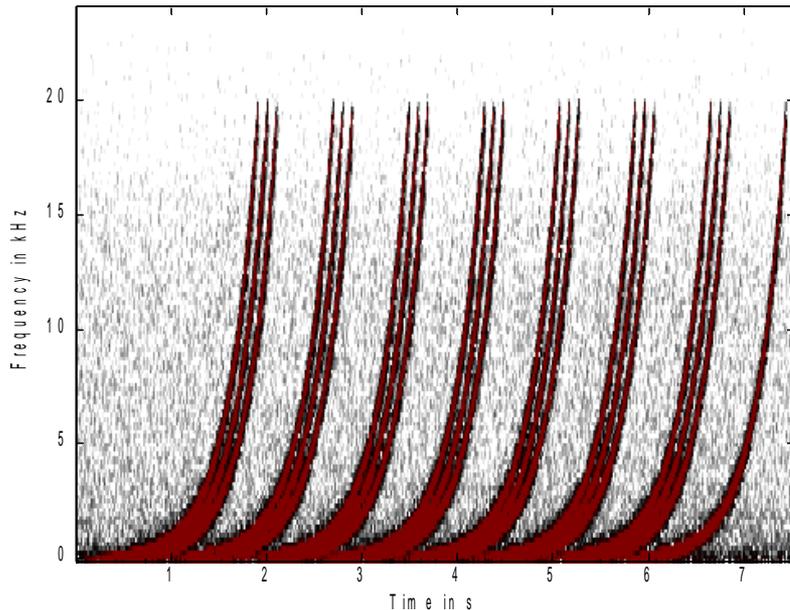
HRTF-Measurement

- Total: 1550 positions
- Horizontal: 144 positions
  - Maximum: 22 elevations
  - On average: 11 elevations
- Duration: 10 minutes
  - without MESM: 41 minutes
- Time savings by factor **four**

Optimization modes with MESM

- Measurement duration:
  - Improvement of the total measurement duration for unchanged SNR
  - Use sweep duration as for the unoptimized case
  - Apply MESM
  - Save time
- Signal-to-noise ratio (SNR):
  - Use longest possible sweeps, but
  - Do not change the measurement duration
  - Increase of SNR by having more energy

SNR optimization with MESM

- Unoptimized:

  – 22 sweeps á 1.5 s: Duration of 35.2 seconds

- MESM:

  – 22 sweeps á 33 s: Duration of 35.2 seconds

- SNR-Gain: **13.4 dB**
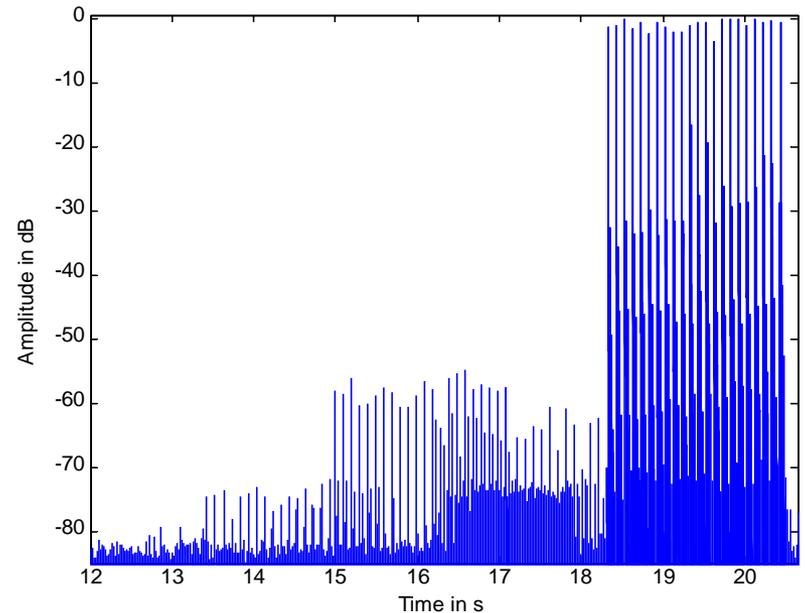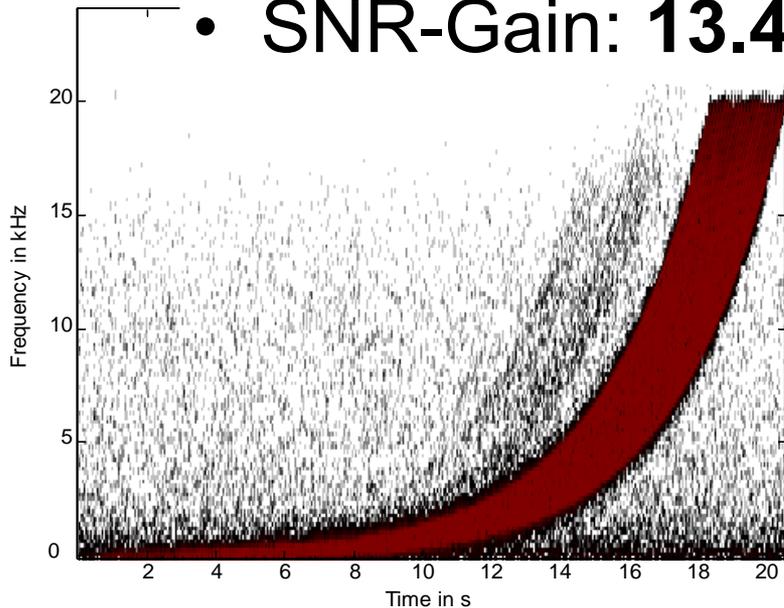
Multiple Exponential Sweep Method

- Identification of multiple weakly nonlinear systems

- Quasi simultaneous excitation of the systems

- Two optimization modes:

  – Shortest total measurement duration

  – Highest signal-to-noise ratio

- Identification of the linear parts of weakly nonlinear systems only

- Reference measurement required for parameters estimation

Applications of MESM

- HRTF-Measurement:
  - Optimization of the measurement duration
  - 1550 pos.: 41 min. (unoptimized): **10 min**. (MESM)
- System identification of speaker arrays:
  - Wavefield synthesis
  - Spatial sound reproduction (Ambisonic systems)
- In-situ absorption and reflexion measurements
- Spatial characteristics of microphones
- Optimizations in the future:
  - Higher SNR applying Gabor multiplier

Thank you very much!