Evaluation of Sensor Self-Noise in Binaural Rendering of Spherical Microphone Array Signals

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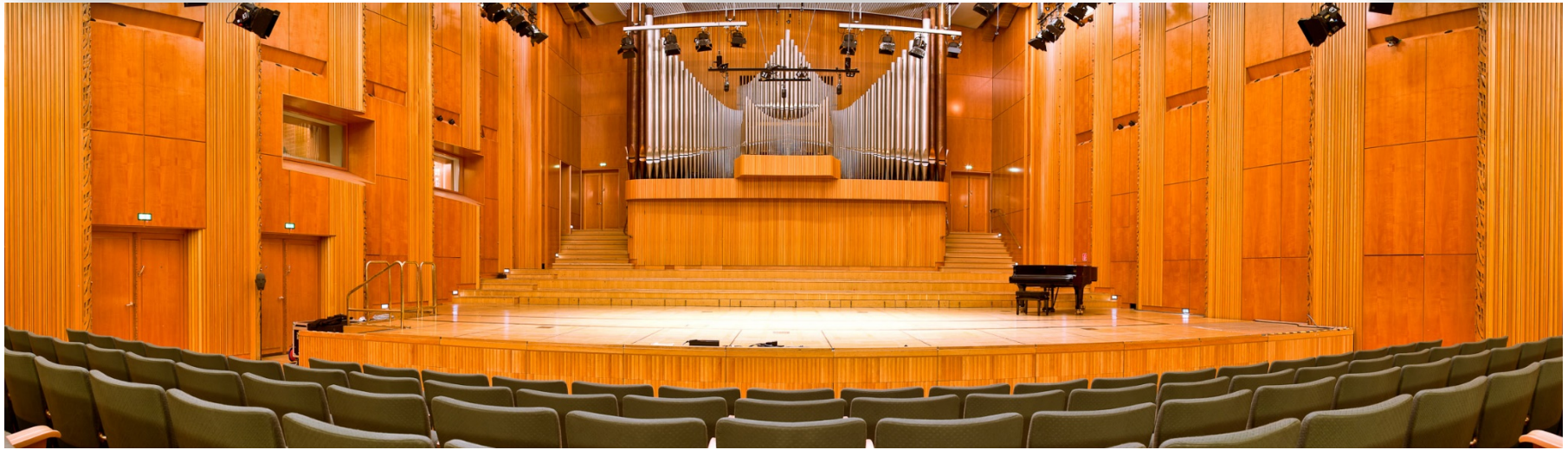
Introduction

Sound field capture

Spherical Microphone Array

Sound field reproduction

Headphones (head-tacked binaural)



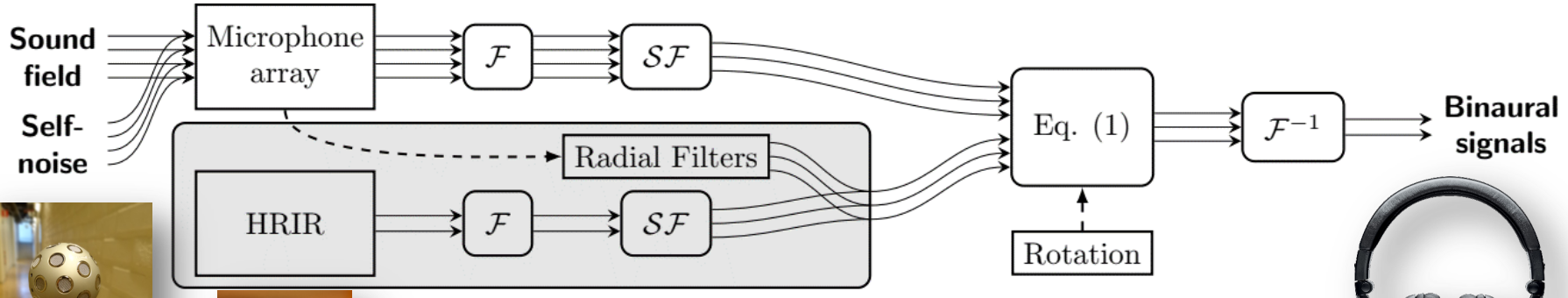
(Pictures: Audio Signal Processing Group, TH Köln)

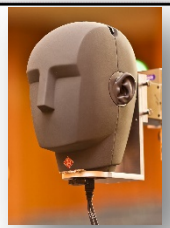
Rendering Method

ReTiSAR *(Real-Time Spherical Array Renderer)*

https://github.com/AppliedAcousticsChalmers/ReTiSAR

$$E_{\mathrm{L,R}}(\omega) = \sum_{n=0}^{N} \sum_{m=-n}^{n} \underbrace{(-1)^m \, d_n(\omega) \, \mathring{H}_n^m(\omega)}_{\mathring{B}_n^m(\omega)} \, \mathring{S}_n^{-m}(\omega) \, \mathrm{e}^{-\mathrm{j}m\alpha} \qquad (1)$$





Instrumental Evaluation (Uniform Contribution)

Sensor signal

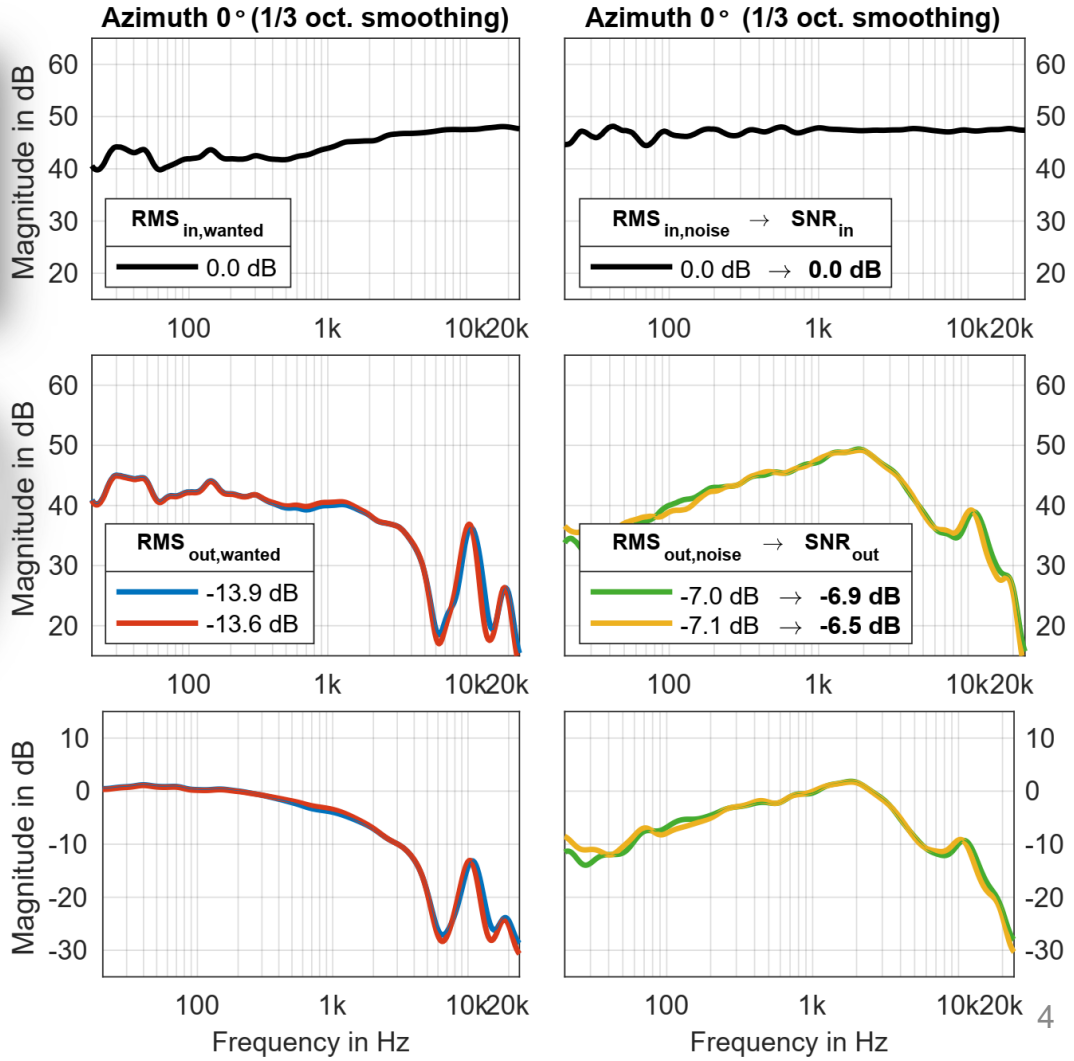
↓

Ear signal (left and right)

32ch sh4 4.2cm 0dB

Sound field (wanted / target) ∓ **Self-noise (unwanted)**

- Based on simulated plane wave array IRs
- Referenced sensor in direction of source
- Rendered head orientation 0° (facing source)



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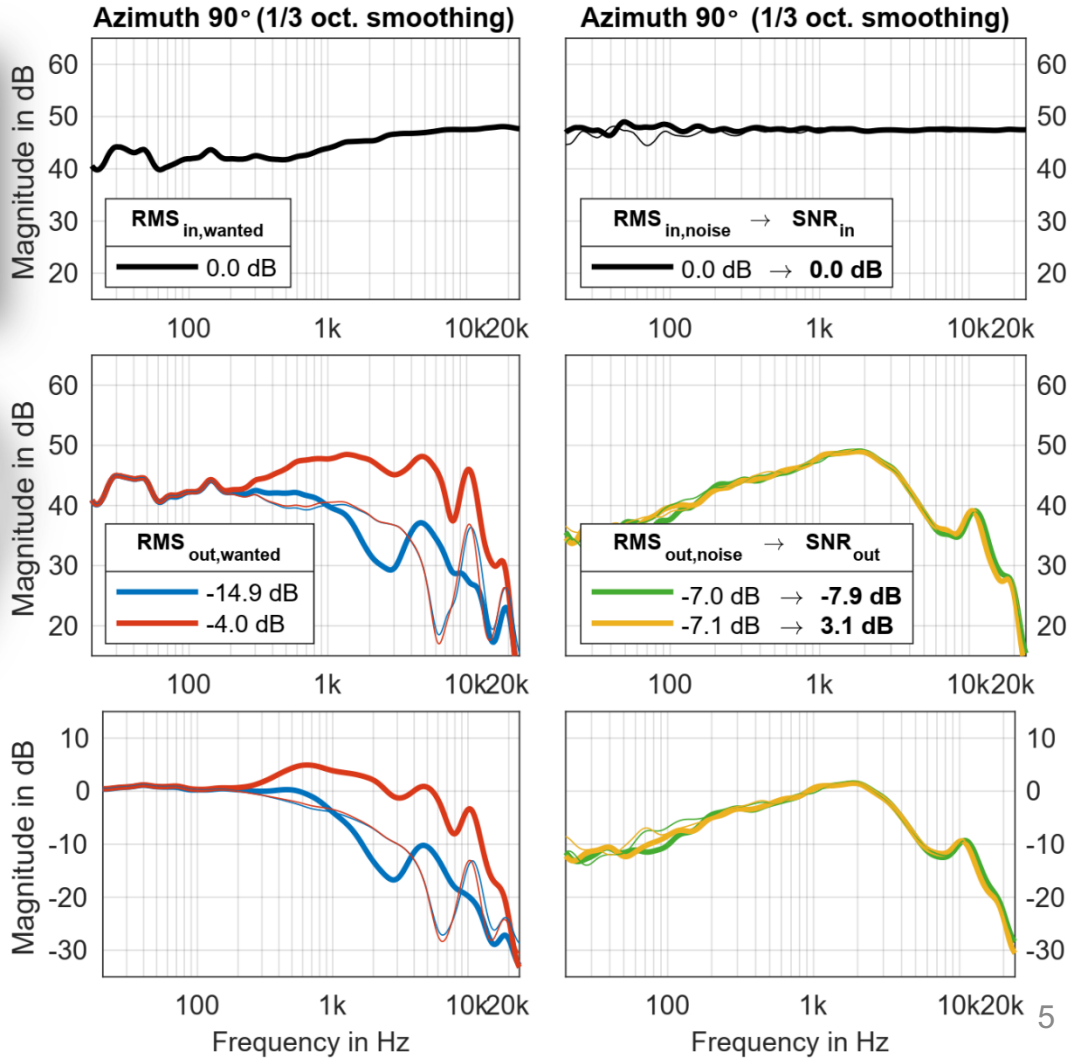


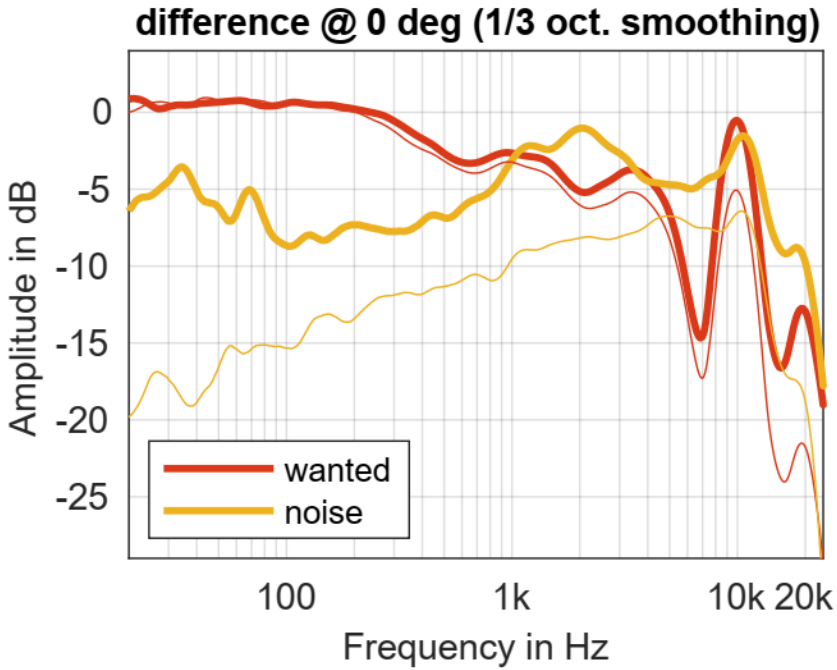
- Referenced sensor unchanged
- Rendered head orientation 90° (lateral source)

Instrumental Evaluation (Uniform Contribution)

- Influence of radial filter soft-limiting

110ch sh8 18dB **(thick)**

110ch sh8 0dB *(thin)*

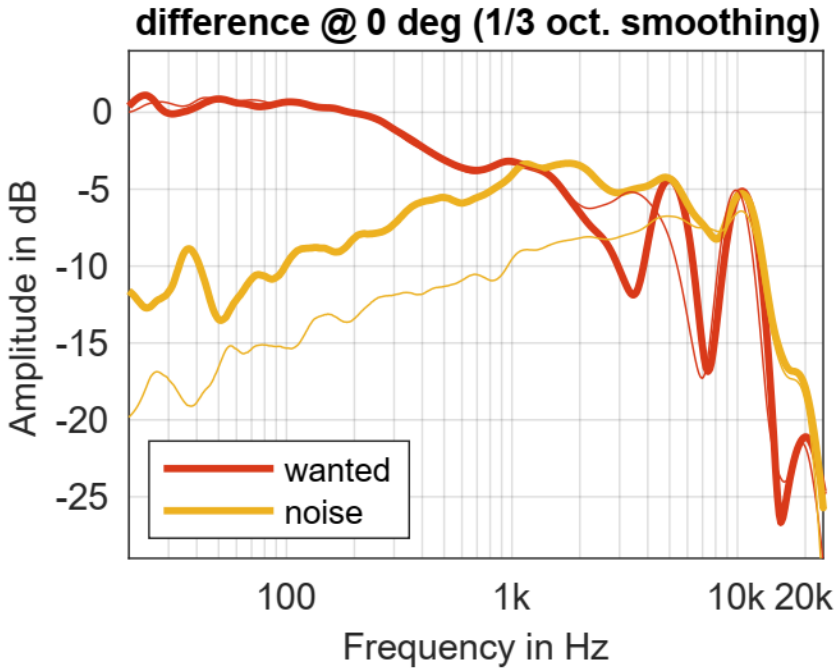


Instrumental Evaluation (Uniform Contribution)

- Influence of matched rendering order (identical array radius)

32ch sh4 8.75cm (thick)

110ch sh8 8.75cm *(thin)*



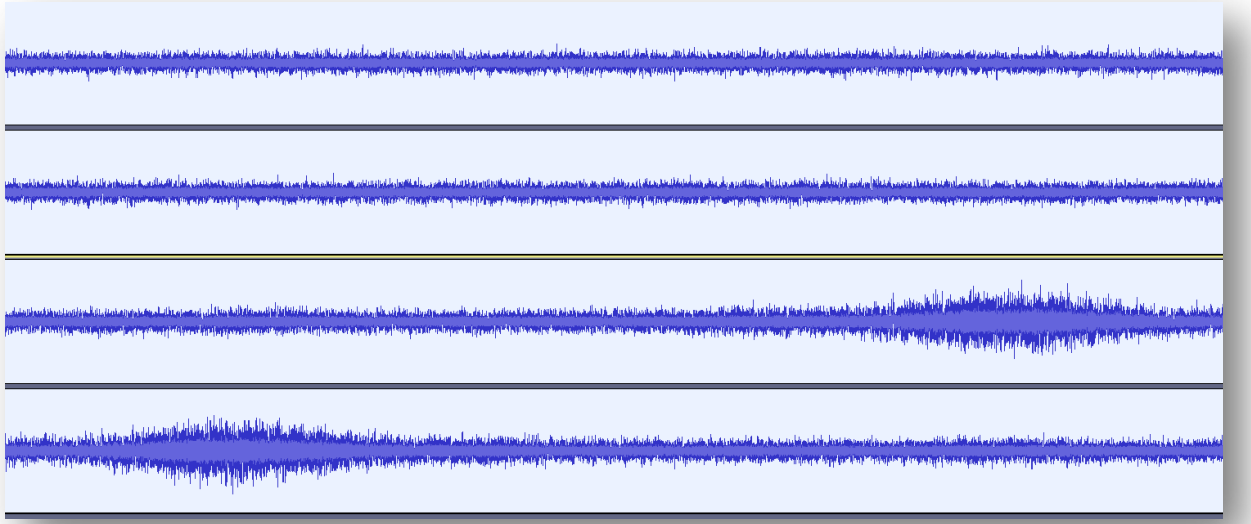
Instrumental Evaluation (Non-Uniform Contribution)

- Influence of boost level from single channel

32ch sh4 +0dB

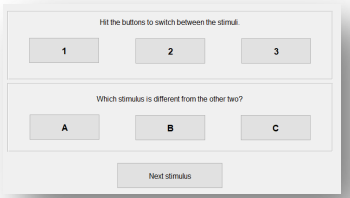
32ch sh4 +12dB

Rendered self-noise in ear signals: **full 360° head rotation over ≈3.5s**



Perceptual Evaluation (Non-Uniform Contribution)

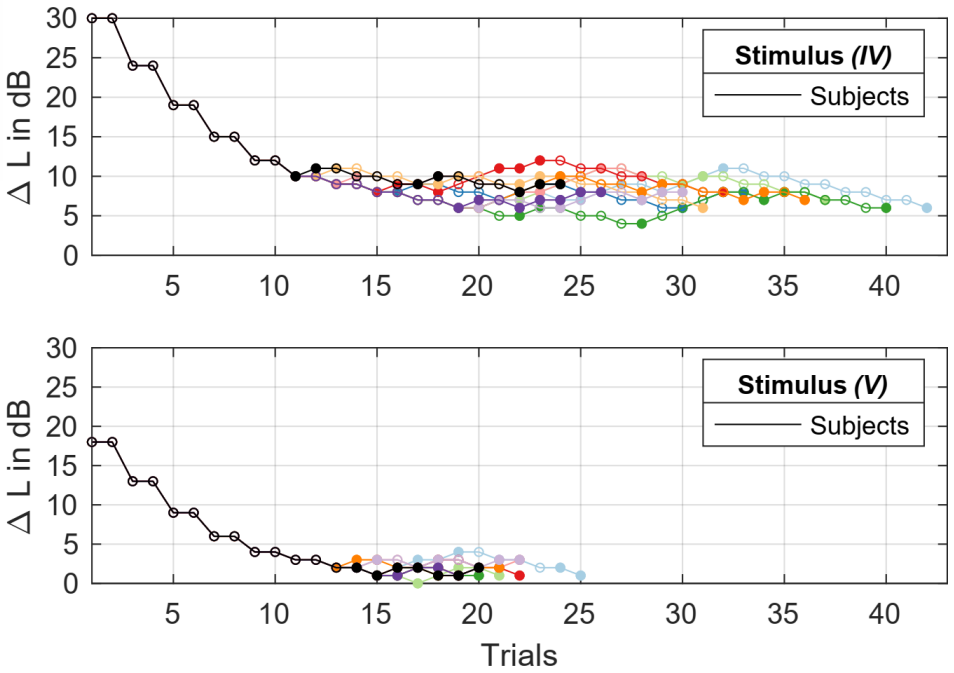
- 3AFC paradigm
- 2-down-1-up staircase (adaptive step size)



110ch sh4 8.75cm

32ch sh4 8.75cm

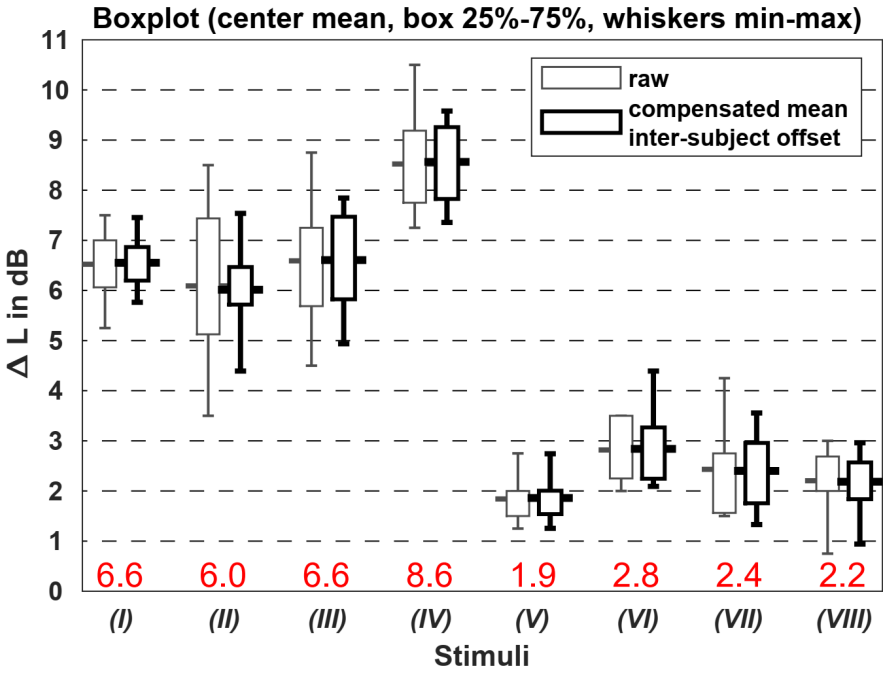
- Loudness differences equalized (based uniform contribution levels)
- Initial conditions tuned according to pre-test



Perceptual Evaluation (Non-Uniform Contribution)

- Grouping for 110 channel ***(I-IV)*** and 32 channel ***(V-VIII)*** configurations

- Extensive breaks between 8 conditions
- 11 expert listeners with thorough instructions



Conclusions

- Uniform self-noise contributions are perceived diffuse and externalized identical for all head orientations.
- Rendered self-noise level and coloration is strongly influenced by
  - **Array configuration** – radius, number of sensors, spherical sampling grid
  - **Rendering configuration** – radial filter limitation, (un)matched SH rendering order
- Non-uniform self-noise causes changes in the noise timbre with head orientation.
- For large arrays, a single sensor may have a 6 dB higher noise floor before a timbre change with head orientation is perceived. With small arrays, it is 2 dB.
  (No target sound field present; channel positioned on equator with virtual head movement restricted to rotation around vertical axis)

Adjacent materials: https://doi.org/10.5281/zenodo.3661422

- Future work
  - Instrumental evaluation of emerging SNR in ear signals (**Forum Acusticum 2020**).
  - Instrumental evaluation for large variety of SMA sampling grids and non-uniform noise contributions (**IEEE TASLP**).

Thank you for your attention!

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