ELEC-E5630 AAT Seminar

Headphones

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School of Electrical Engineering

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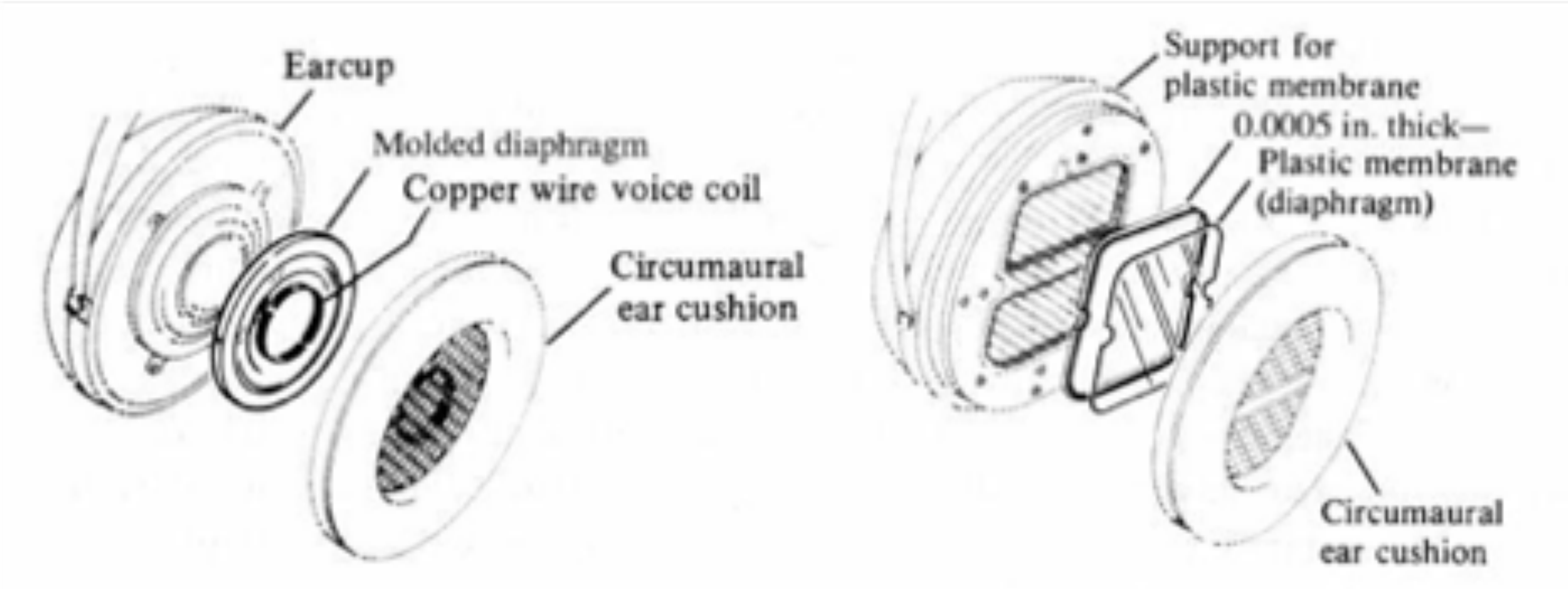
Headphones

Basic operating principles same as loudspeakers and microphones

- Dynamic, electrostatic, (and planar magnetic)



Stax SR-L700

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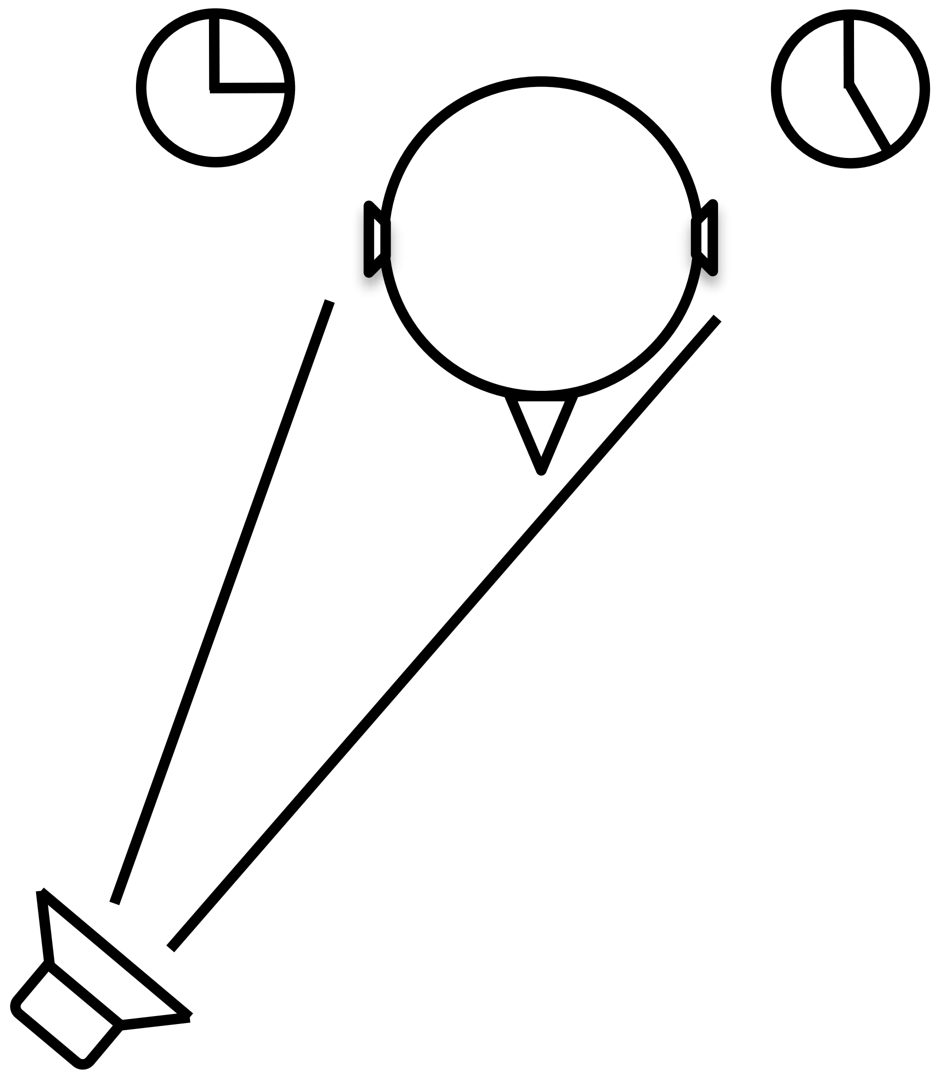
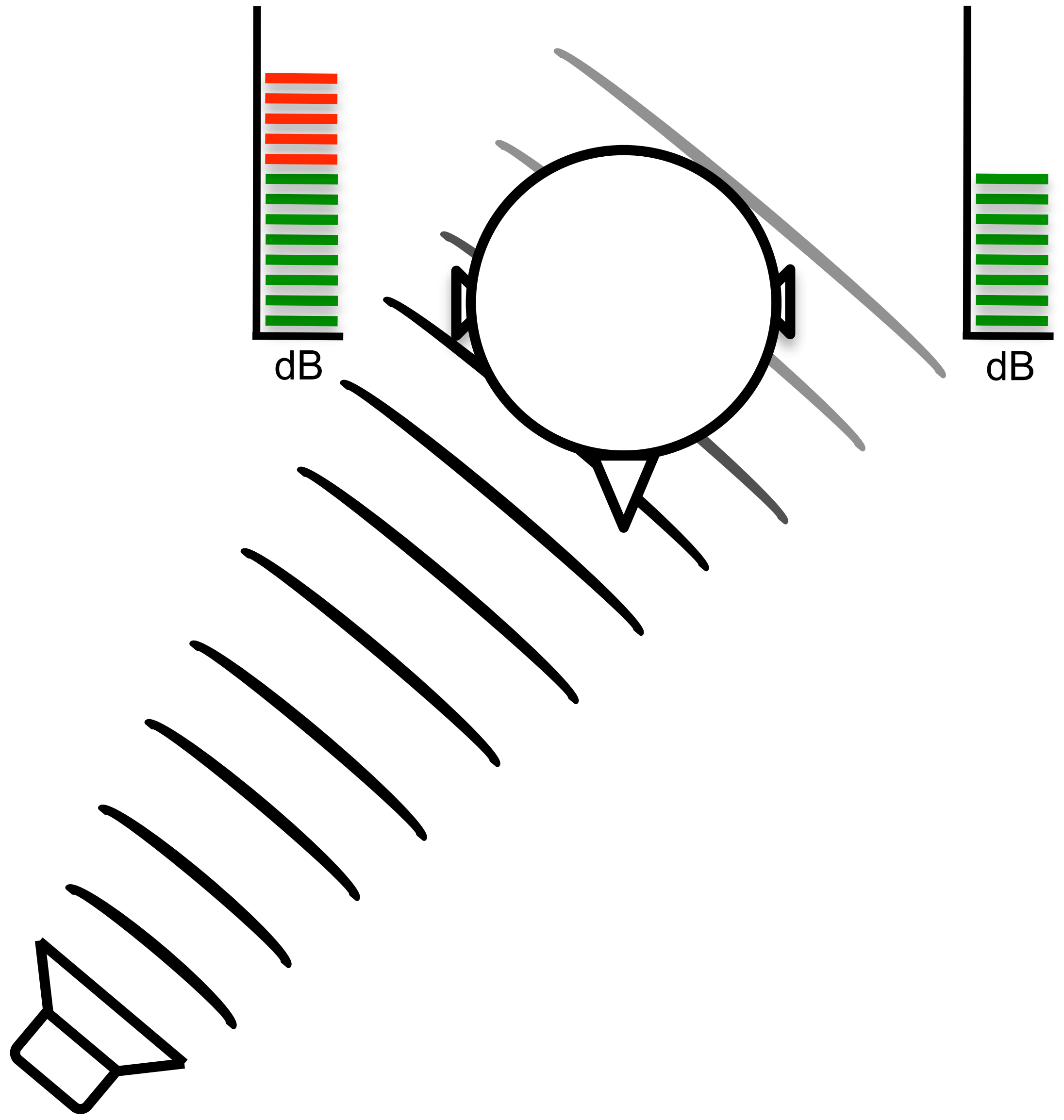
Headphones vs. Loudspeakers



Inter-aural time difference (ITD)



Inter-aural level difference (ILD)

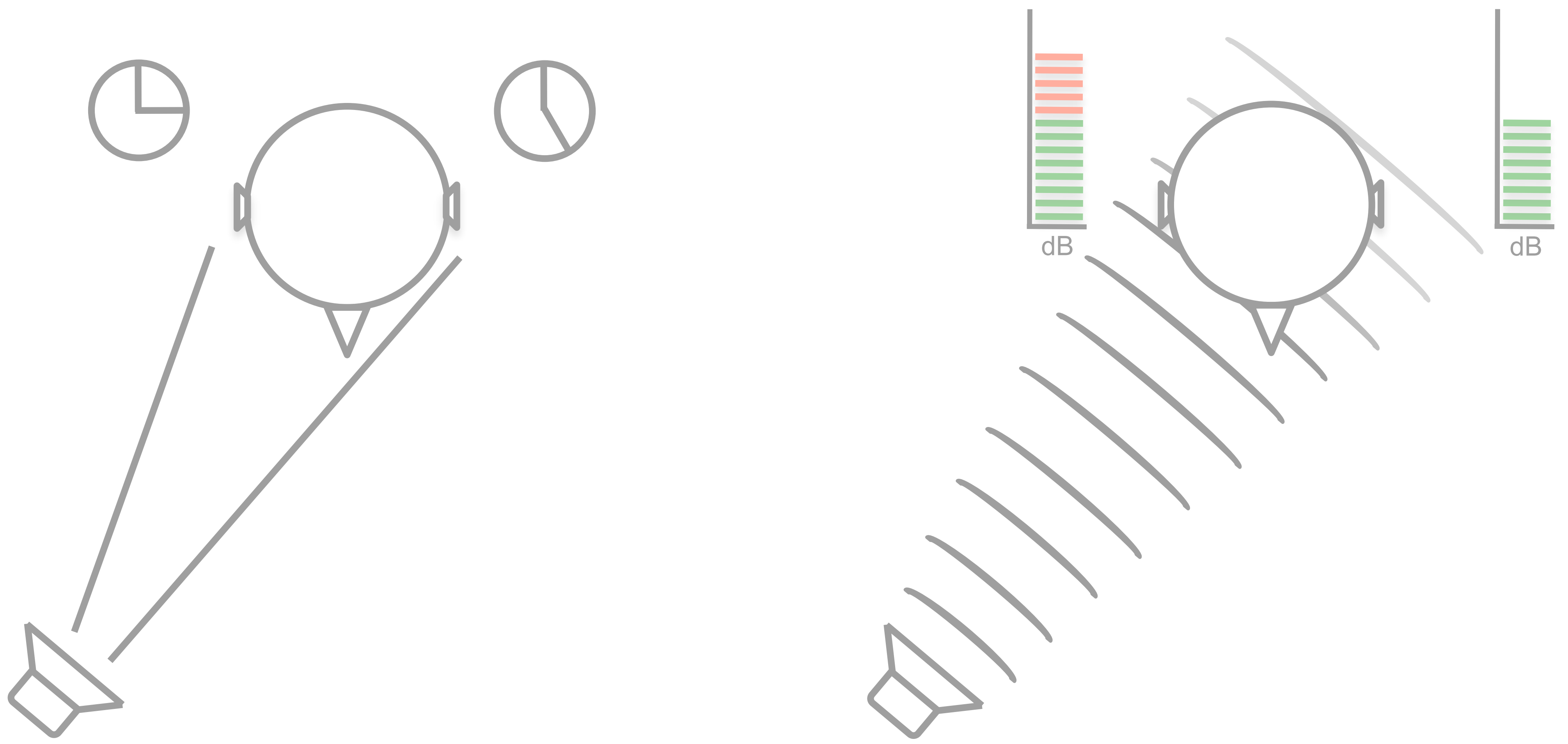
Loudspeaker listening

- Effects of the room and listeners head and body are included.
  - Binaural cues (ITD and ILD) are preserved.
- All speakers are heard with both ears.

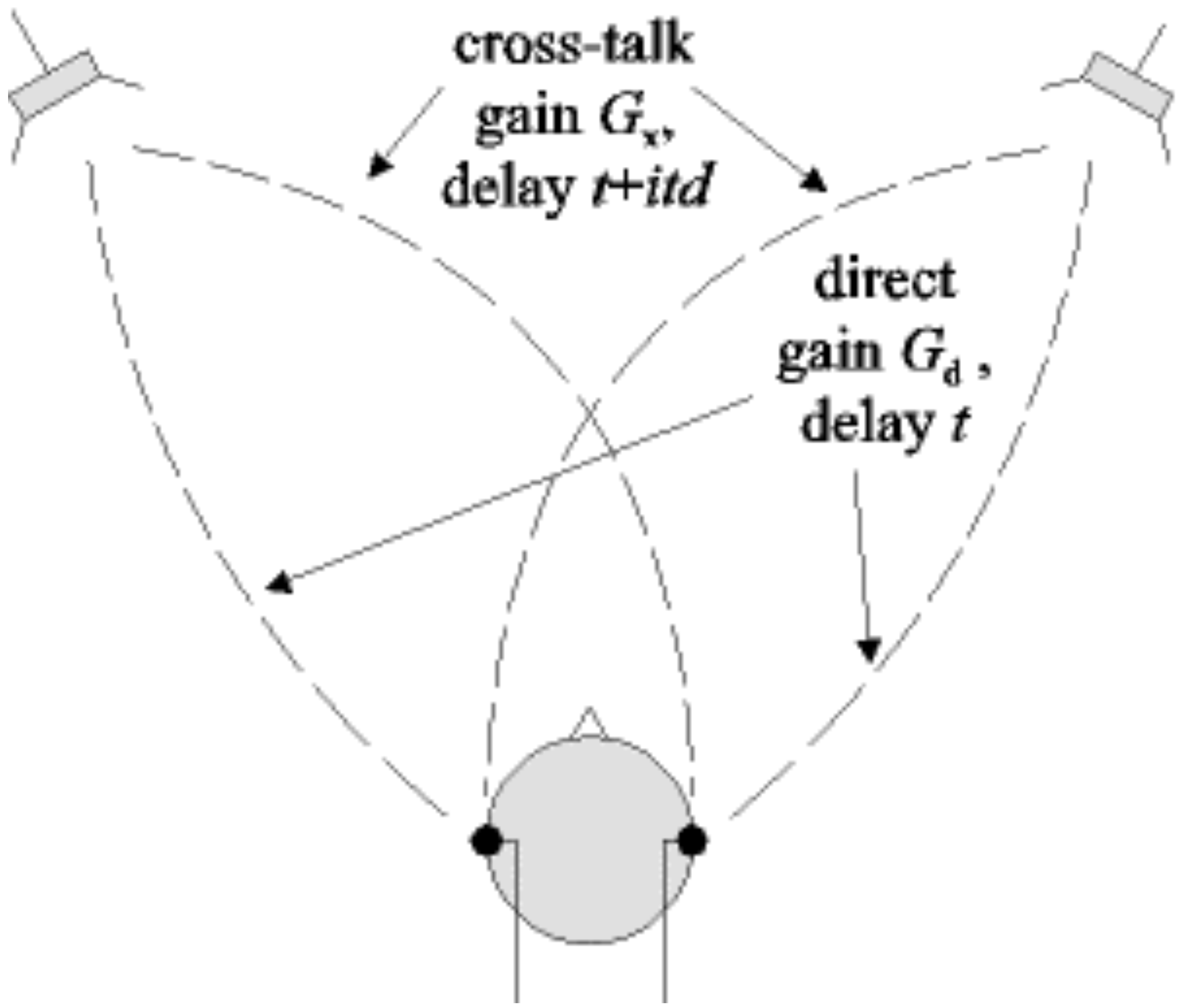
Headphones vs. Loudspeakers

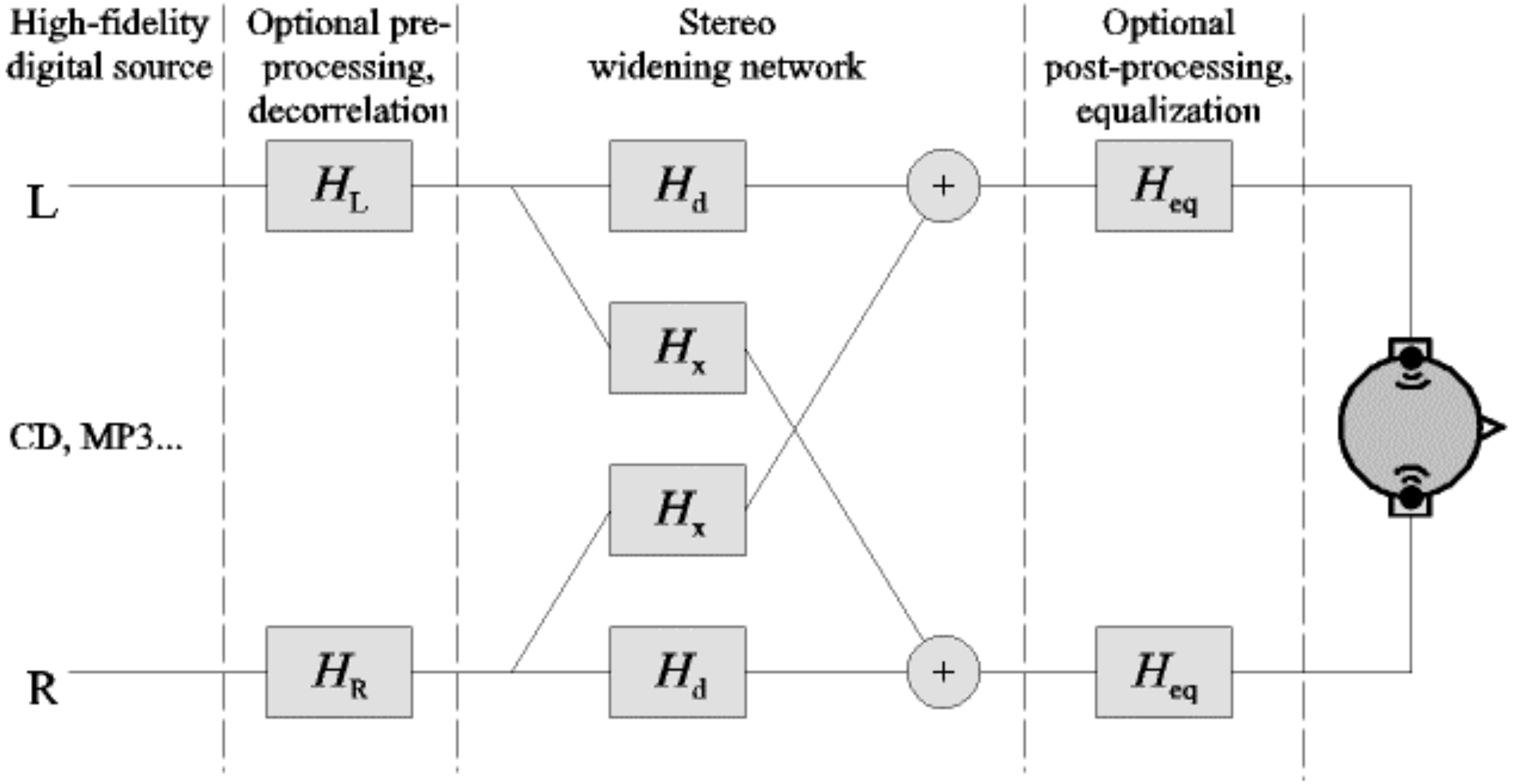
Headphone listening

- Effects of the environment and the listener's body are lost,
- Almost perfect channel separation,
  - Poor externalization—Sounds localize inside the head
- Often isolates listener from their surroundings,
  - Personal,
  - Less social,
  - Dangerous in certain situations.



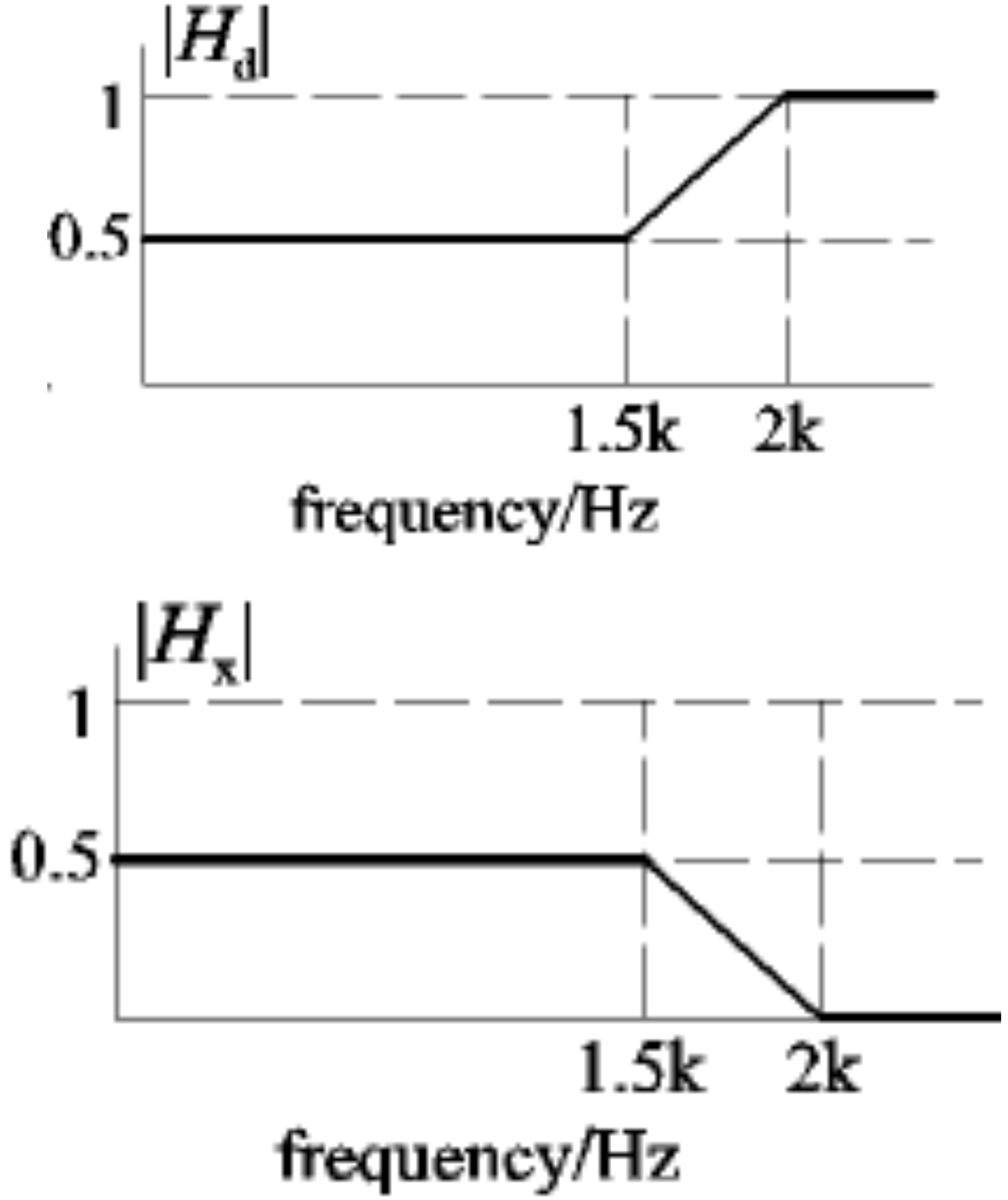
Stereo Widening for Headphones

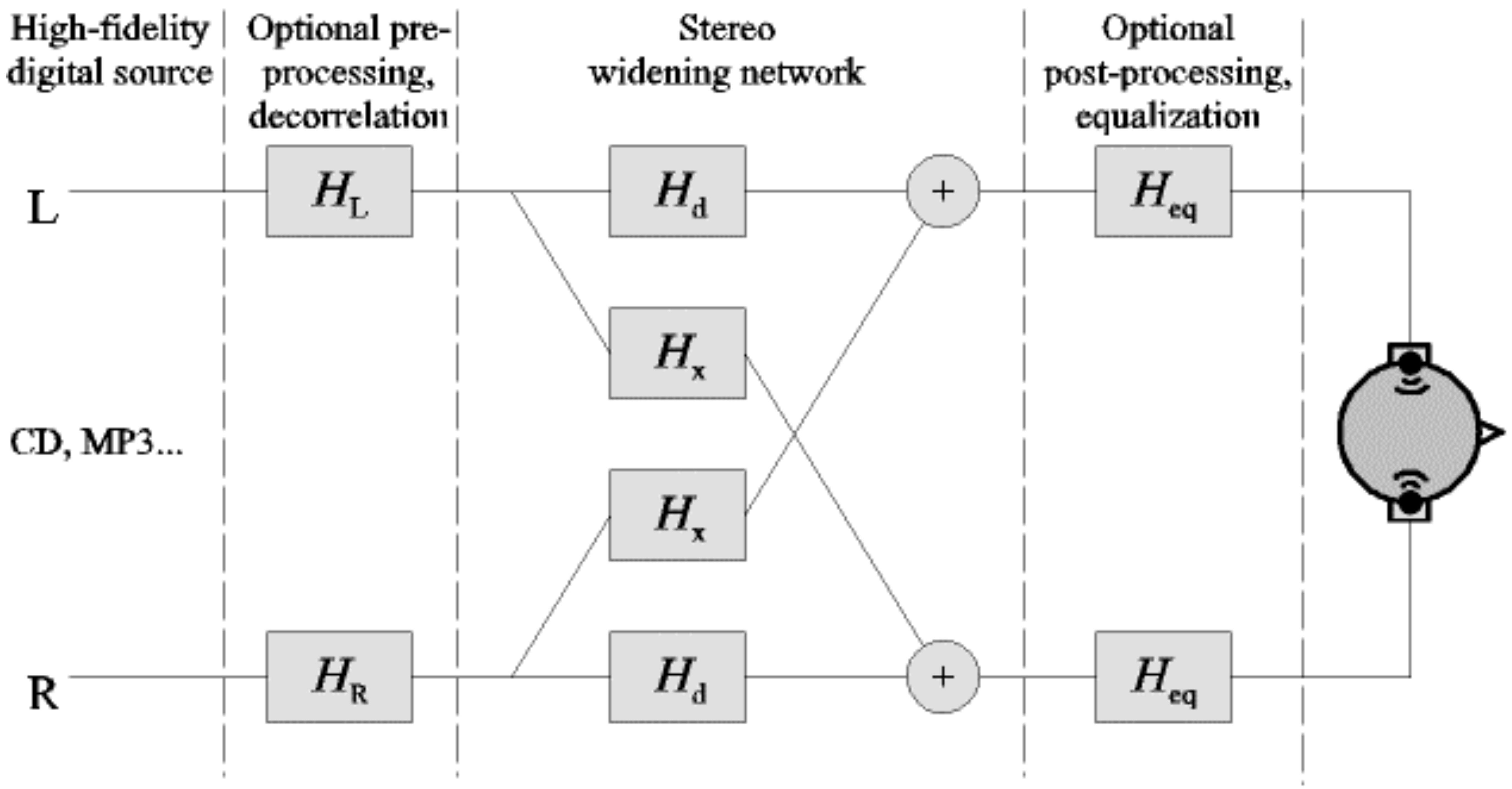




O. Kirkeby, A Balanced Stereo Widening Network for Headphones, AES 22nd Int. Conf., 2002

Stereo Widening for Headphones



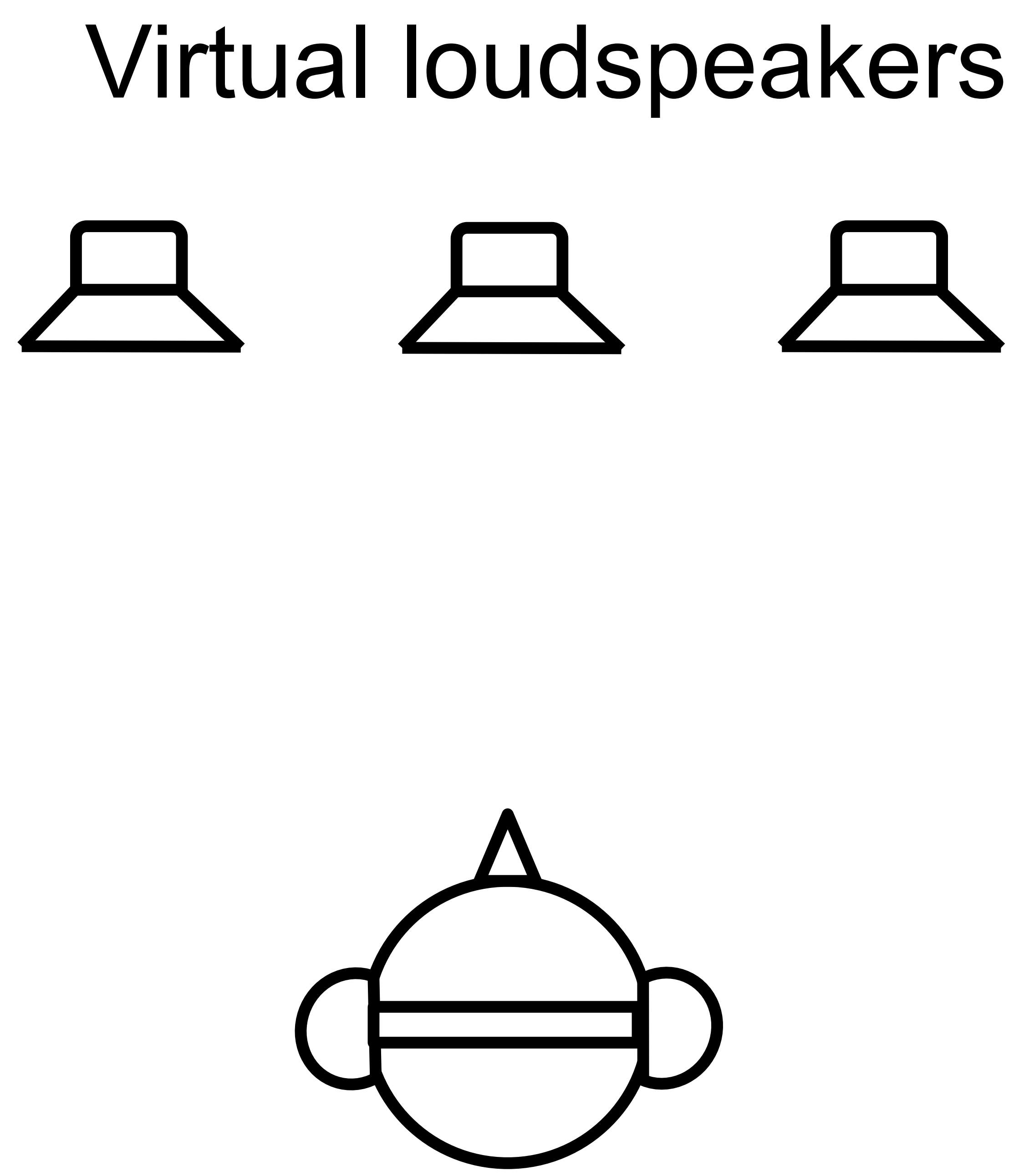


O. Kirkeby, A Balanced Stereo Widening Network for Headphones, AES 22nd Int. Conf., 2002

HRTF

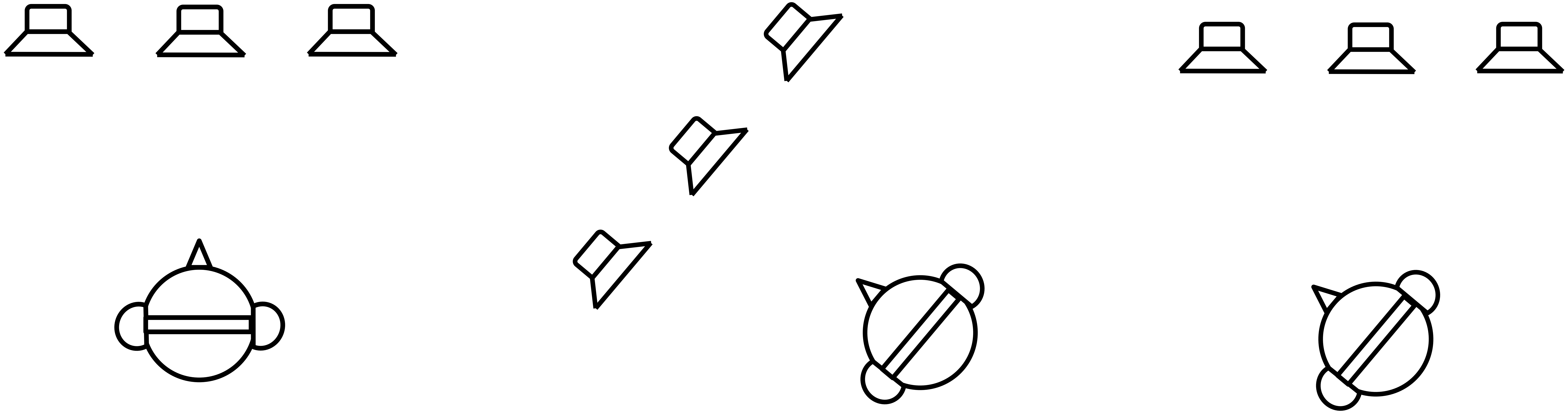
Head Related Transfer Function

- Transfer function in free field from a point source to the ear canal entrance or ear drum.
- Can be used to reproduce virtual loudspeakers over headphones
  - Multi-channel audio,
  - Measurements from loudspeaker positions,
  - Often some artificial reverb is added.



HRTF - Head Tracking

When the user turns their head when wearing headphones



Typical listening situation | No head tracking | With head tracking

HRTF - Example Measurements

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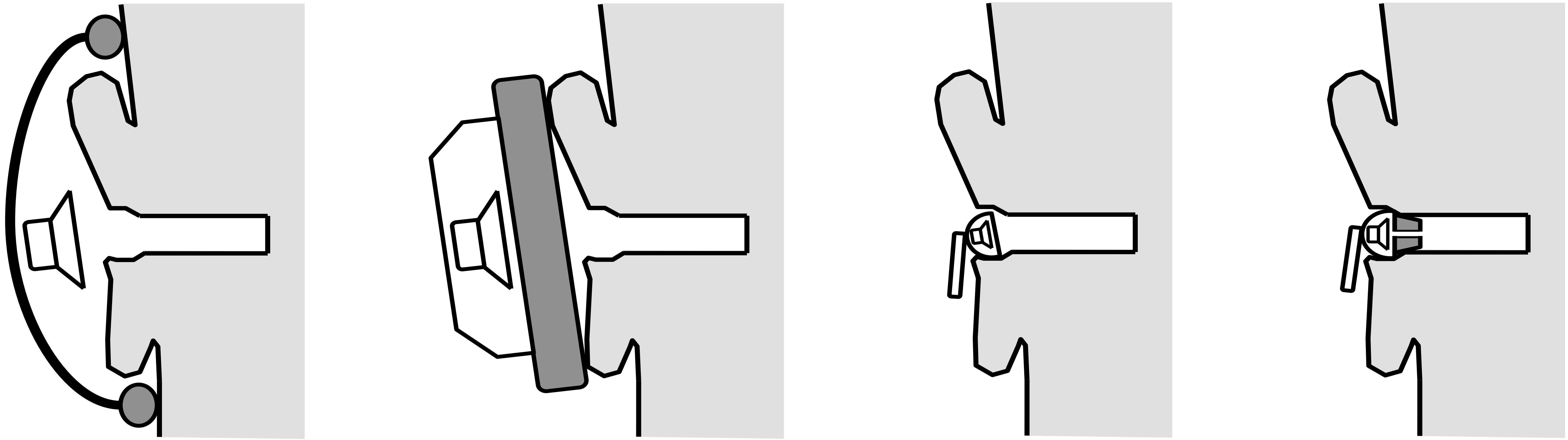
Headphone Types



Circum-aural   Supra-aural   Intra-concha   In-ear

Additional types/features

- Active noise control (ANC),
- Wireless or truly wireless

Headphone Types

Supra-aural

Circum-aural

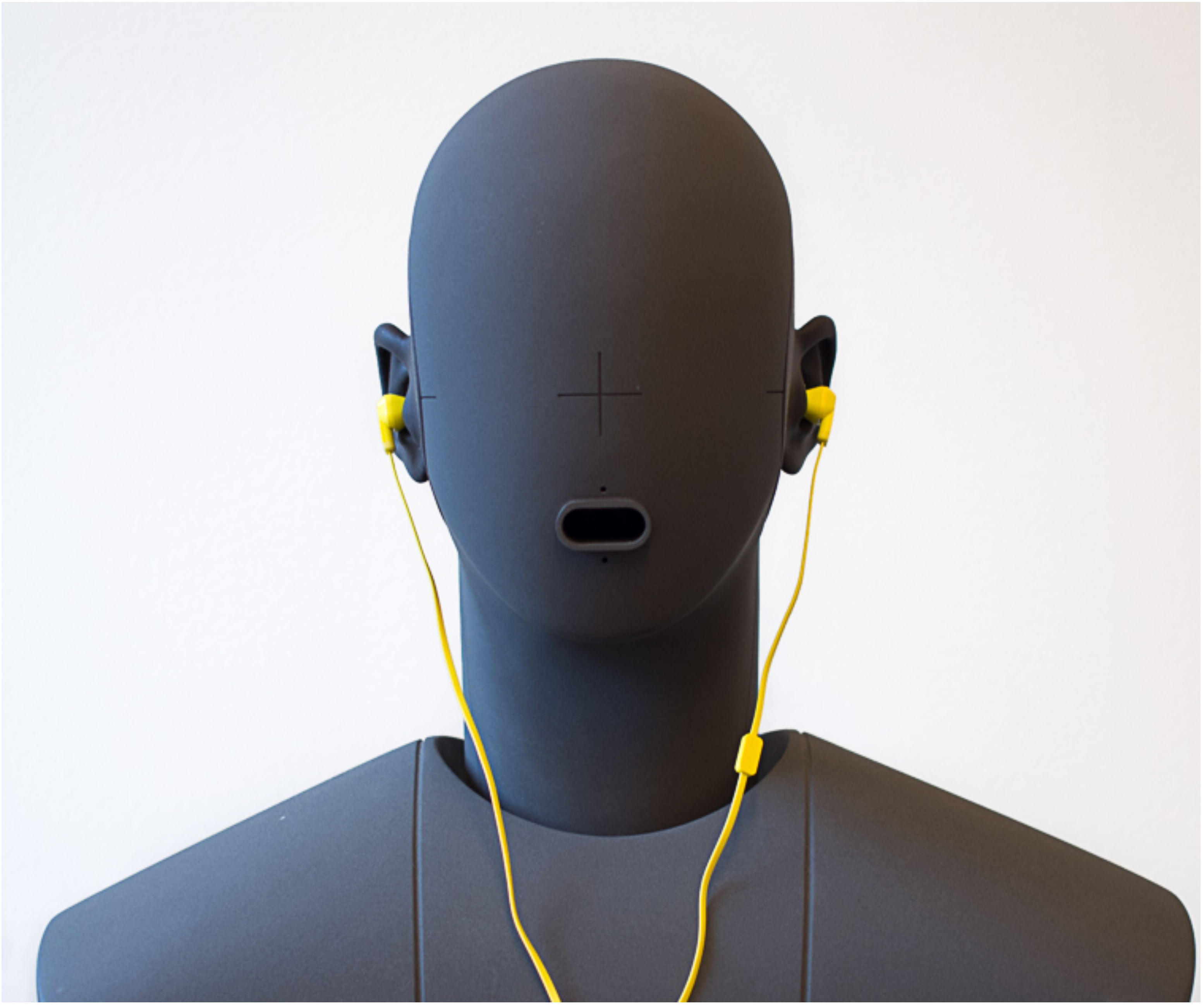
Intra-concha

In-ear

Measuring Headphones

Headphones are measured using a coupler, such as a dummy head or an ear canal simulator

- Headphones are designed to sound good when worn properly.
- A coupler simulates the acoustic properties of a human ear—Acoustic load.
- ITU-T Recommendation P.57: Artificial Ears
  - Type 3.3. simulator often used
    - Works with all headphone types
- Microphone (often) at the ear drum position.
  - Drum Reference Point (DRP)

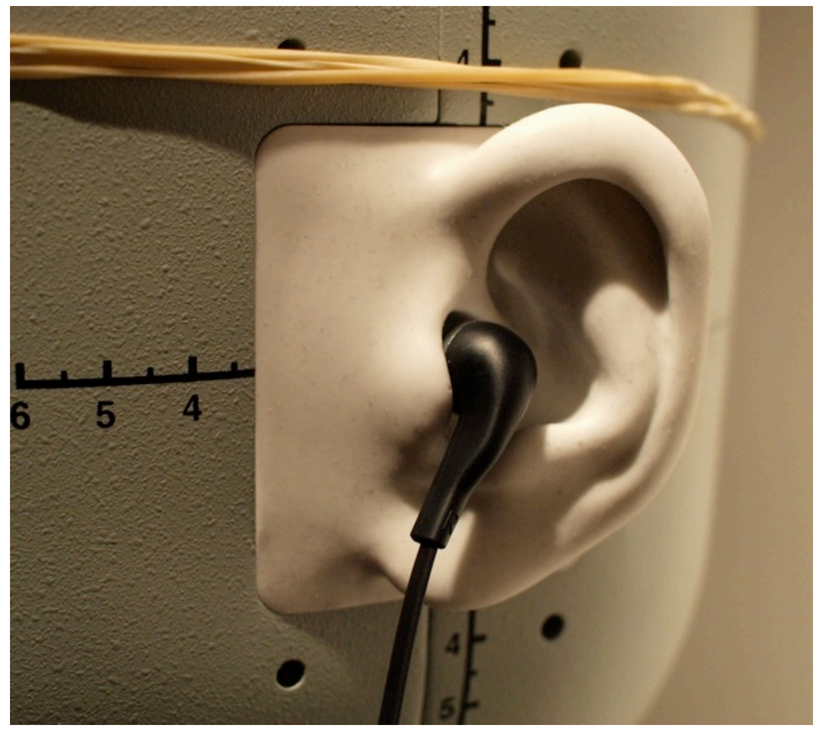


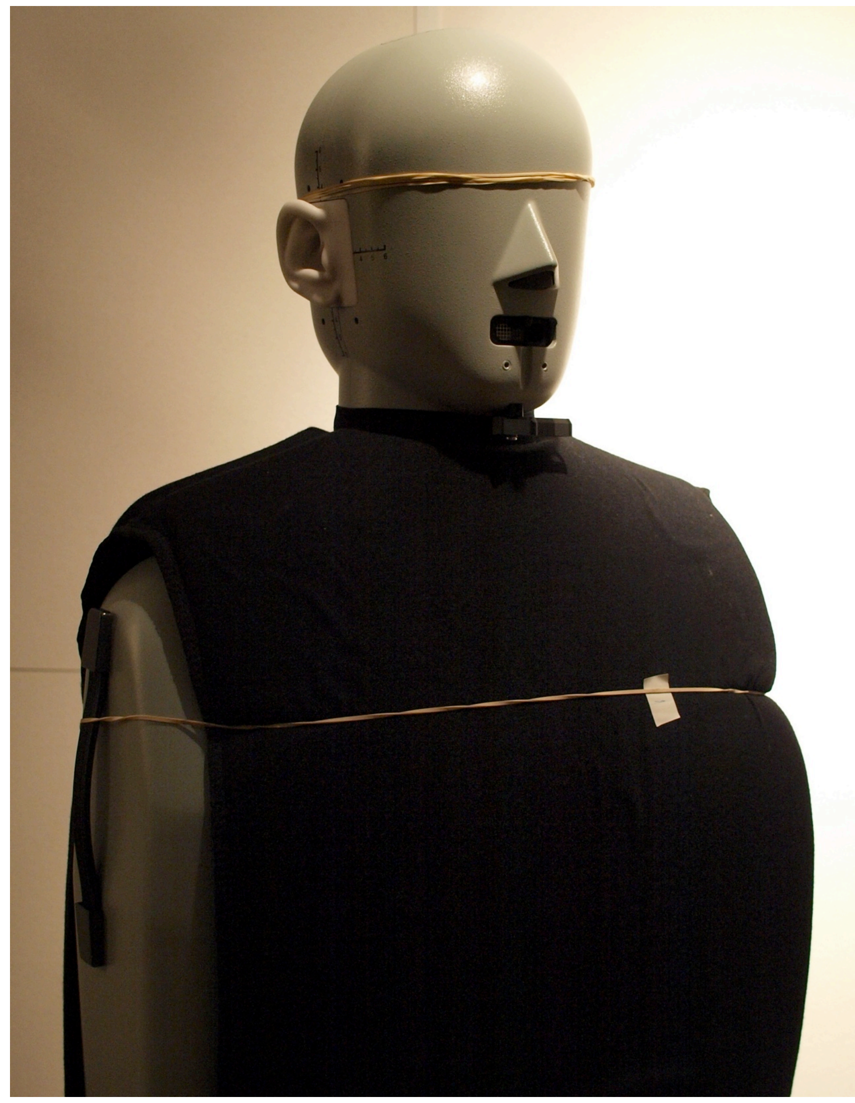
Measuring Headphones

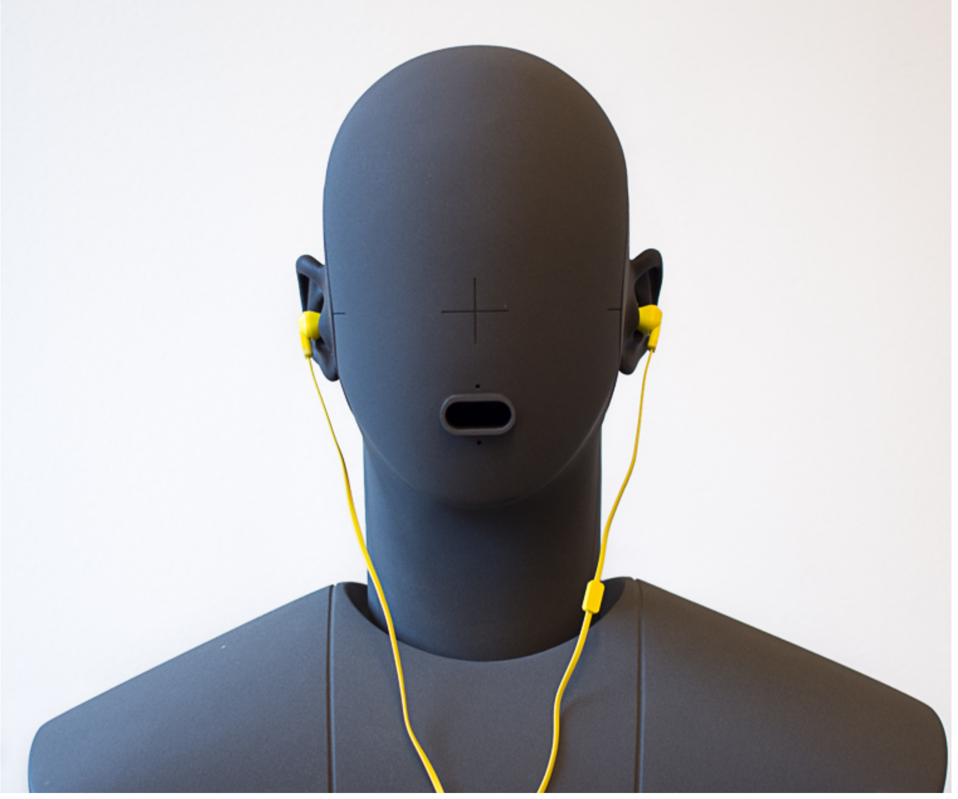
The ear canal simulator standardized in IEC 60318-4

- Cylindrical central volume with the length and diameter similar to an average human ear canal.
- Different resonators connected to the central volume.
- Microphone at the end of the cylindrical volume.
  - DRP
- Measurements and calibration according to the ITU-T Recommendation P.57

Measuring Headphones



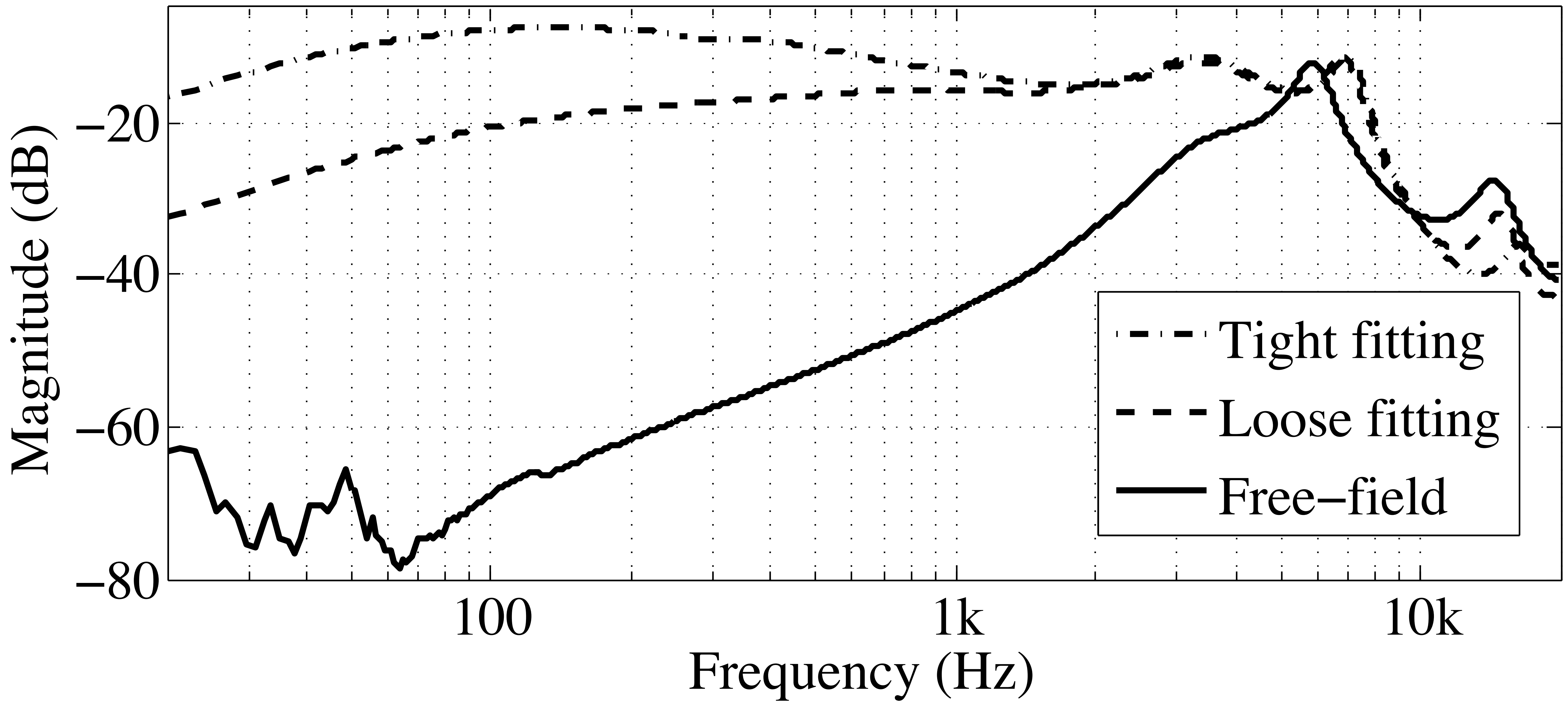




Positioning of the Headphones

Correct fitting is extremely important

An in-ear headphone fit different fitting



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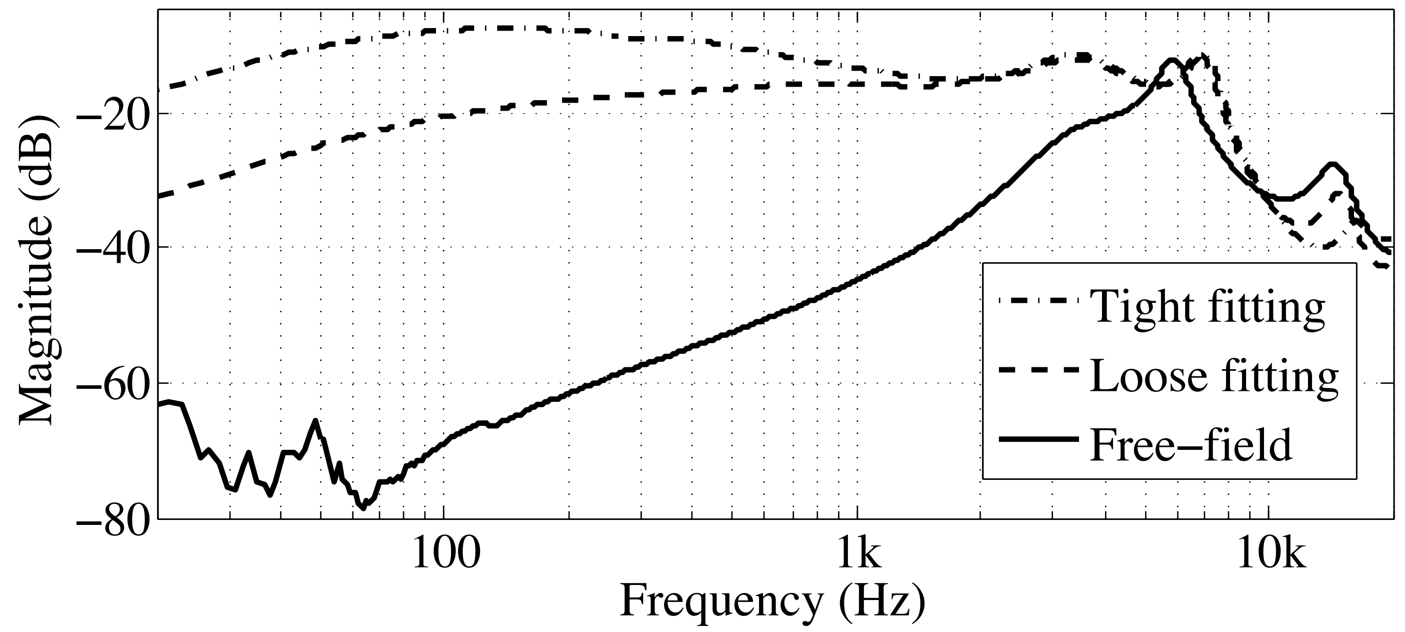
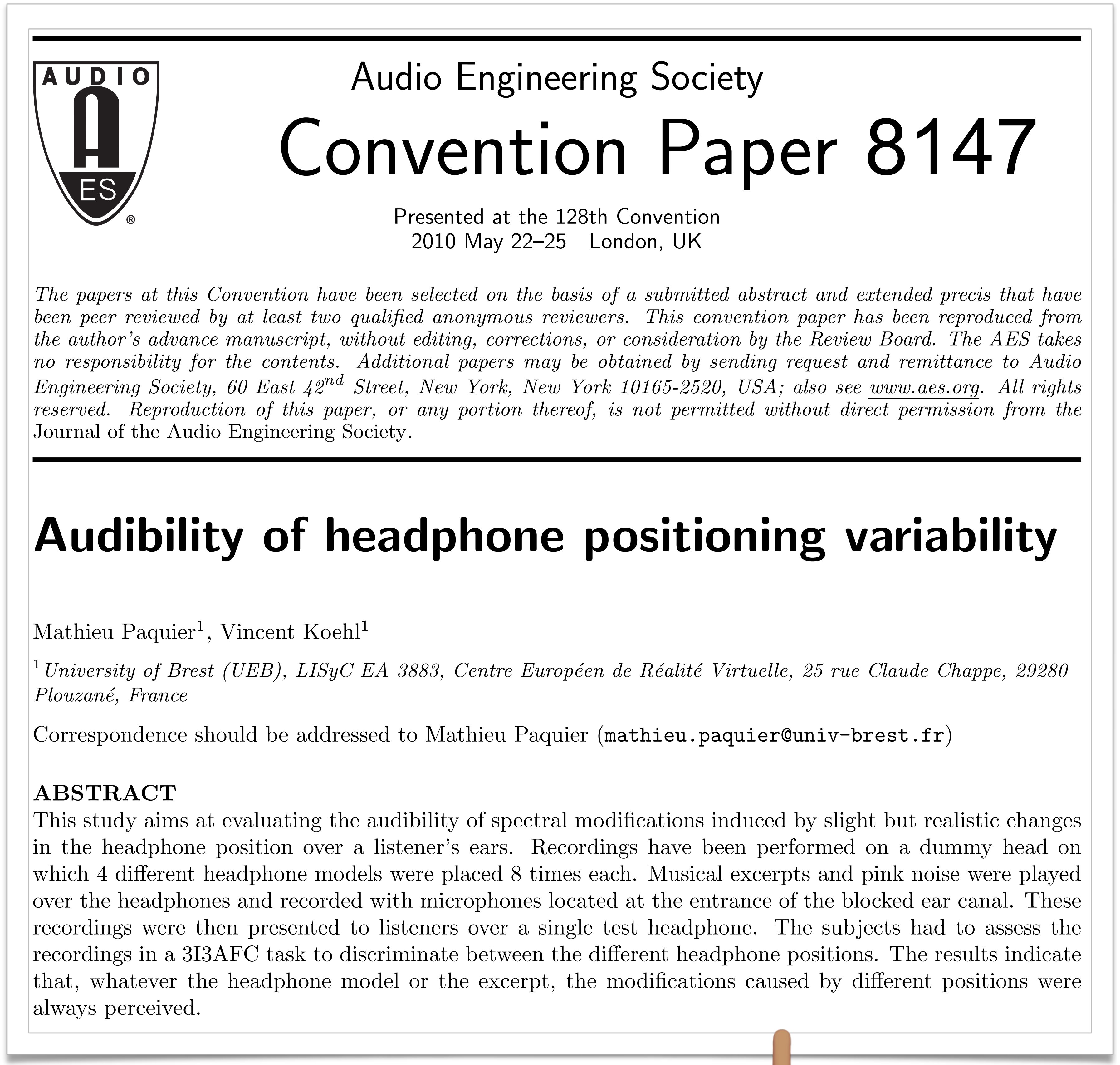
Positioning of the Headphones

- ITU-T Recommendation P.380: Electro-acoustic measurements on headsets
  - "Due to the sensitivity of the test results to the headset positioning, the tests shall be repeated at least 5 times by completely repositioning the headset…"





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Audibility of headphone positioning variability

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ABSTRACT
This study aims at evaluating the audibility of spectral modifications induced by slight but realistic changes in the headphone position over a listener's ears. Recordings have been performed on a dummy head on which 4 different headphone models were placed 8 times each. Musical excerpts and pink noise were played over the headphones and recorded with microphones located at the entrance of the blocked ear canal. These recordings were then presented to listeners over a single test headphone. The subjects had to assess the recordings in a 3I3AFC task to discriminate between the different headphone positions. The results indicate that, whatever the headphone model or the excerpt, the modifications caused by different positions were always perceived.

"…the modifications caused by different positions were always perceived."

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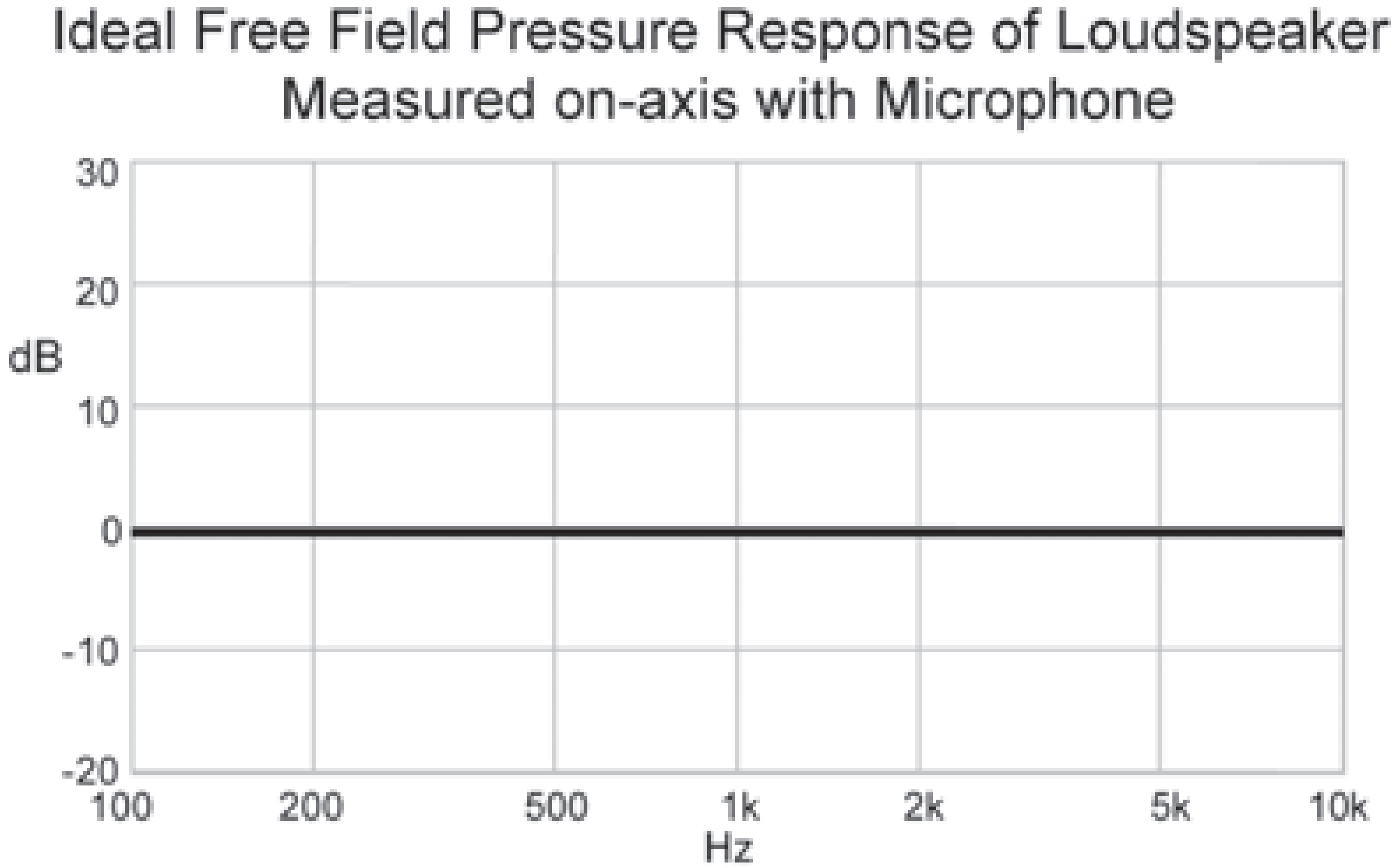
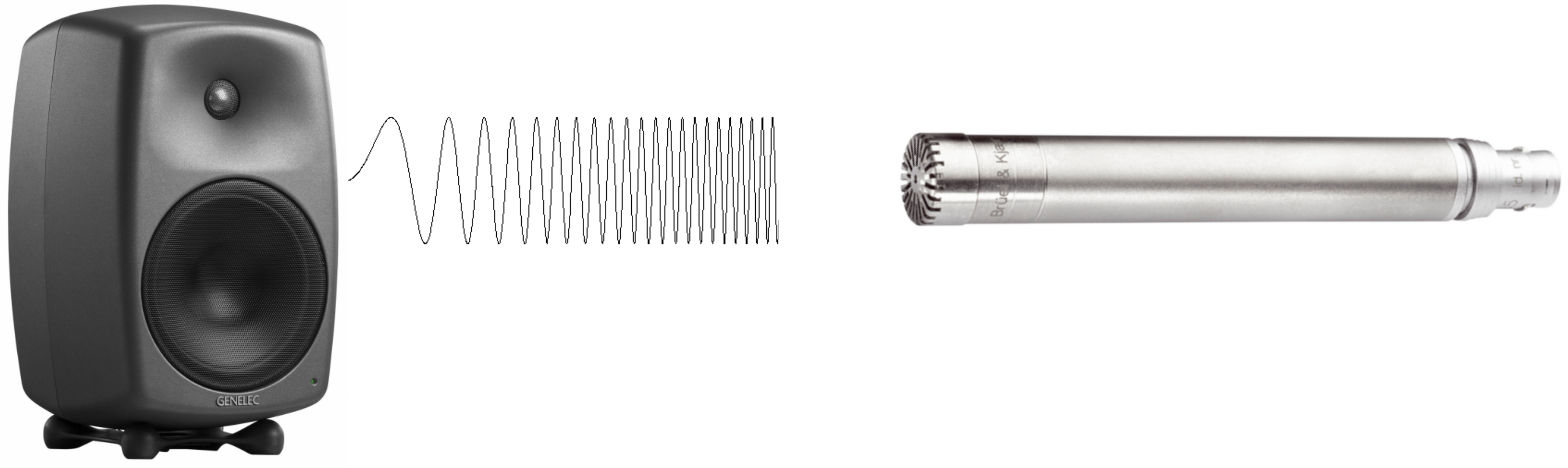
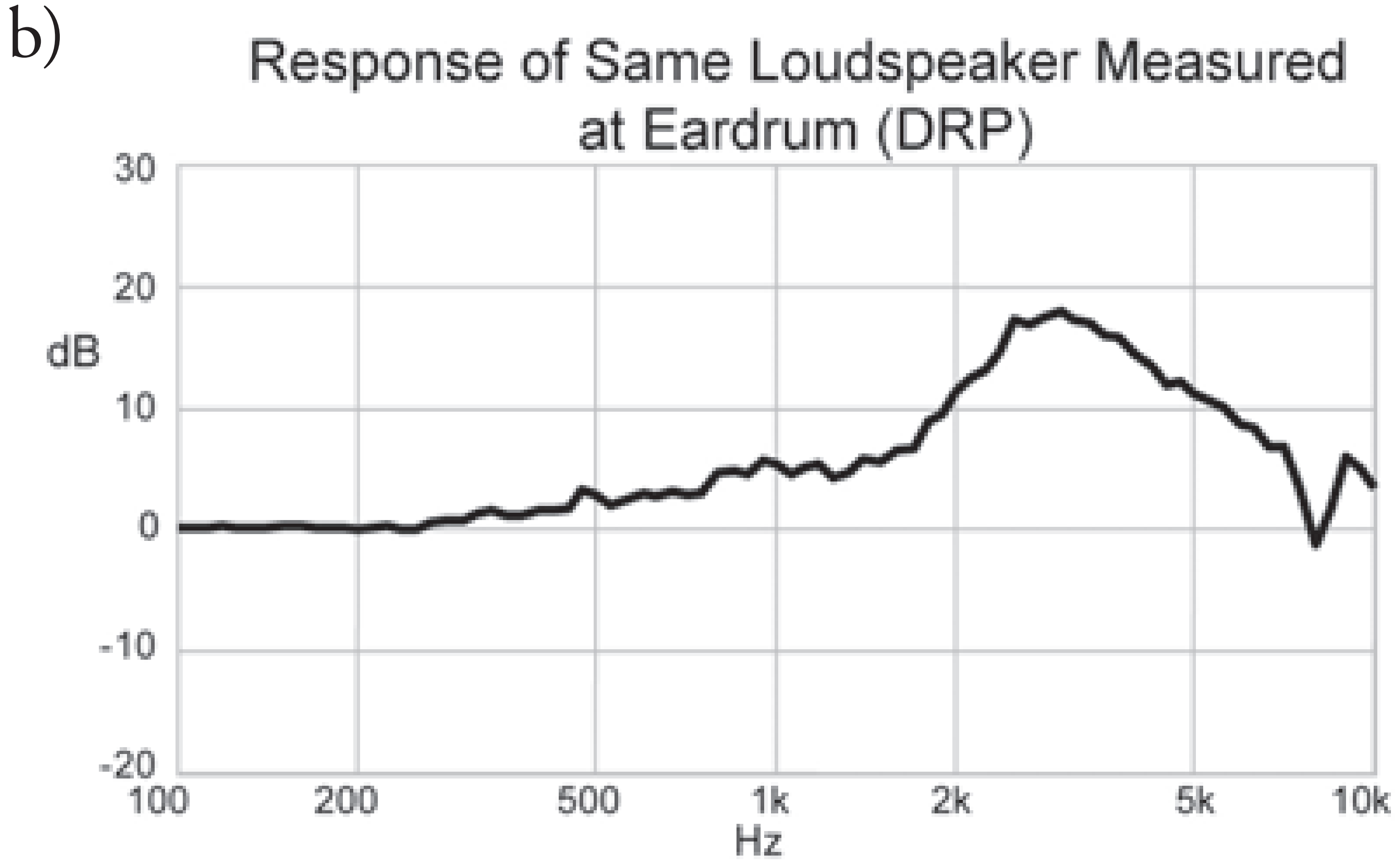
Magnitude Response

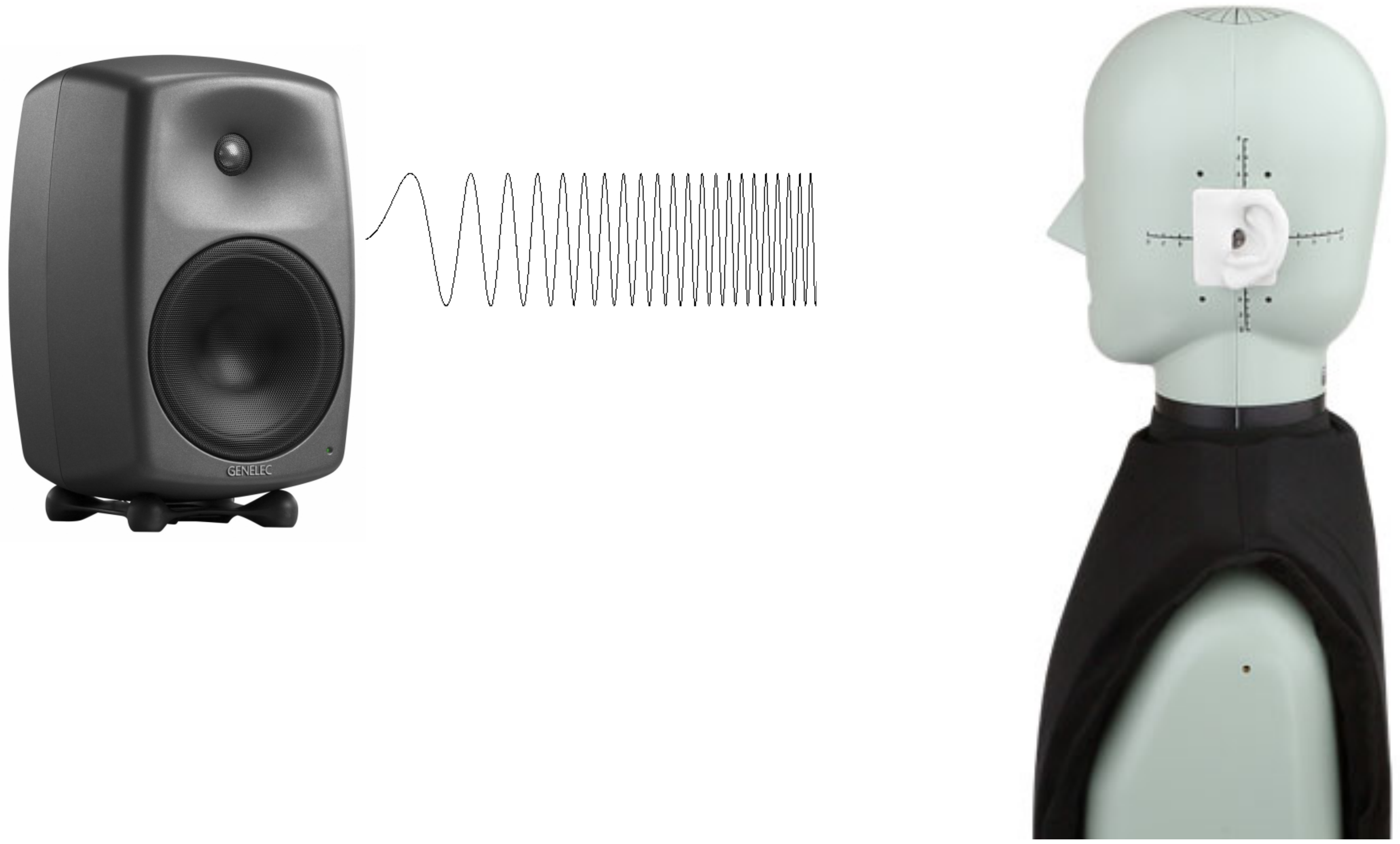
a)





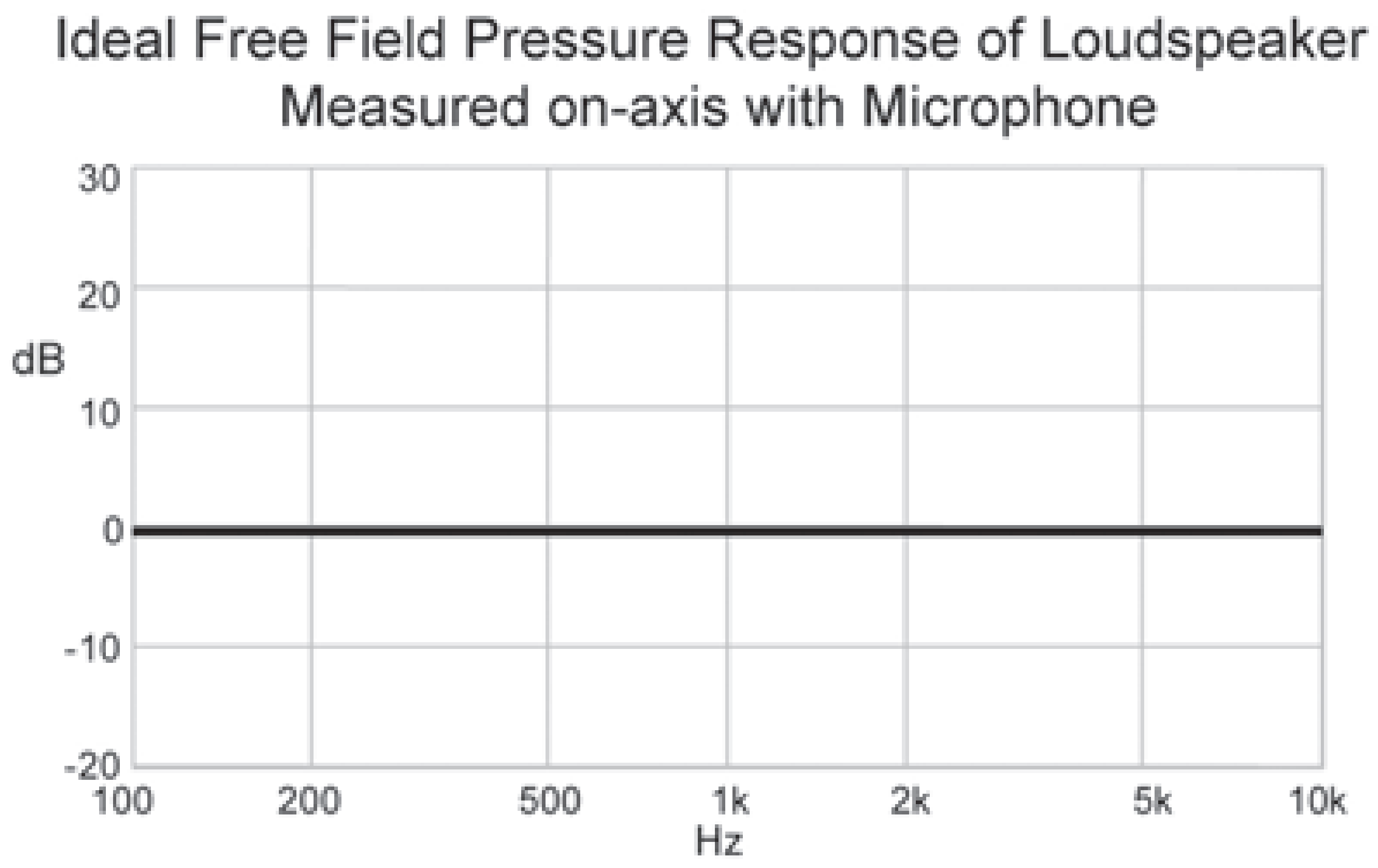
b)



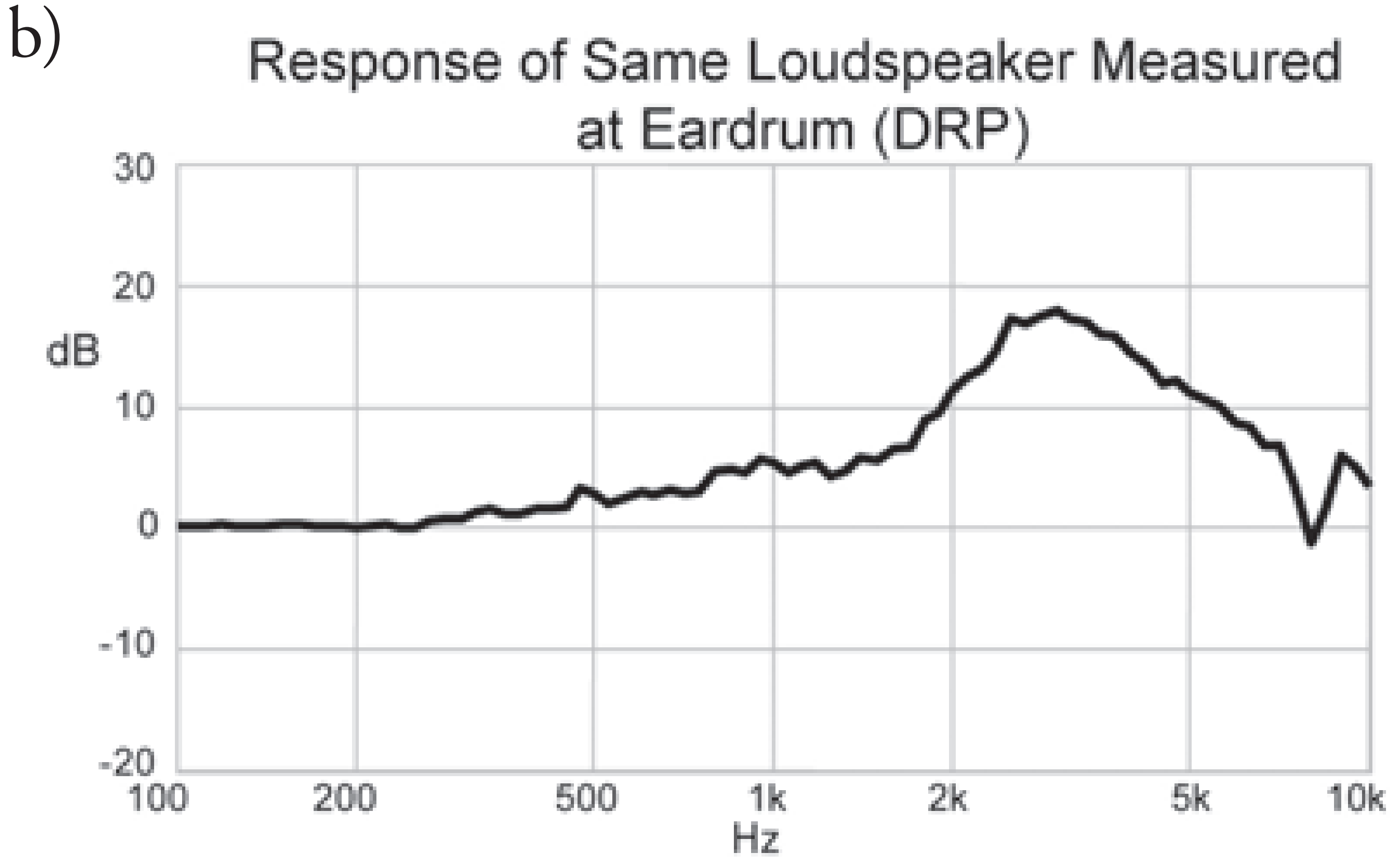


Magnitude Response

a)



b)



- Ideal free field (anechoic) response of an ideal (flat response) loudspeaker.
  - Reproduces all frequencies equally loud.

- Response of the ideal loudspeaker measured at the ear drum (DRP)
  - Includes the effects of torso, head, pinna, and the ear canal of the dummy head.

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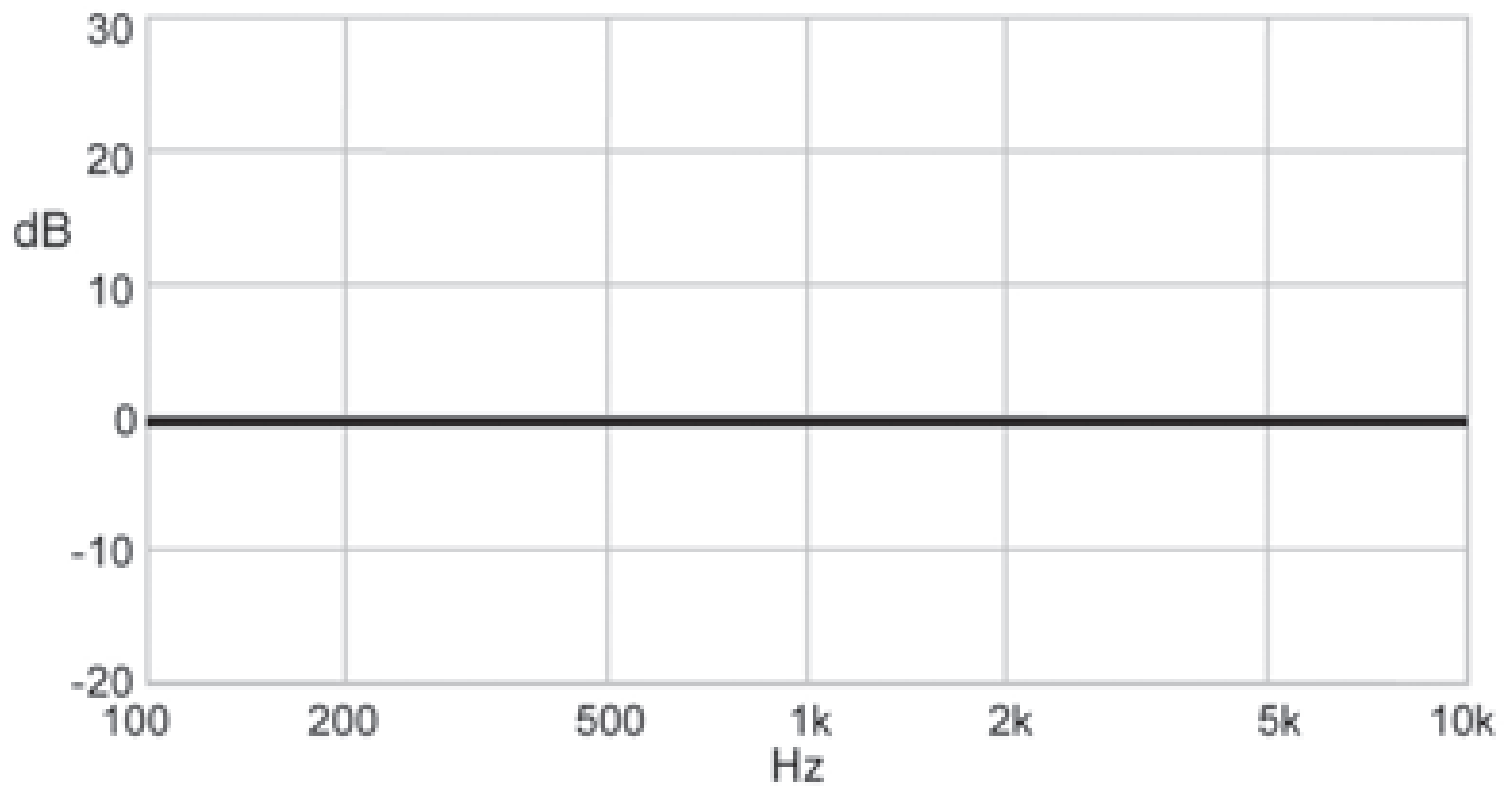
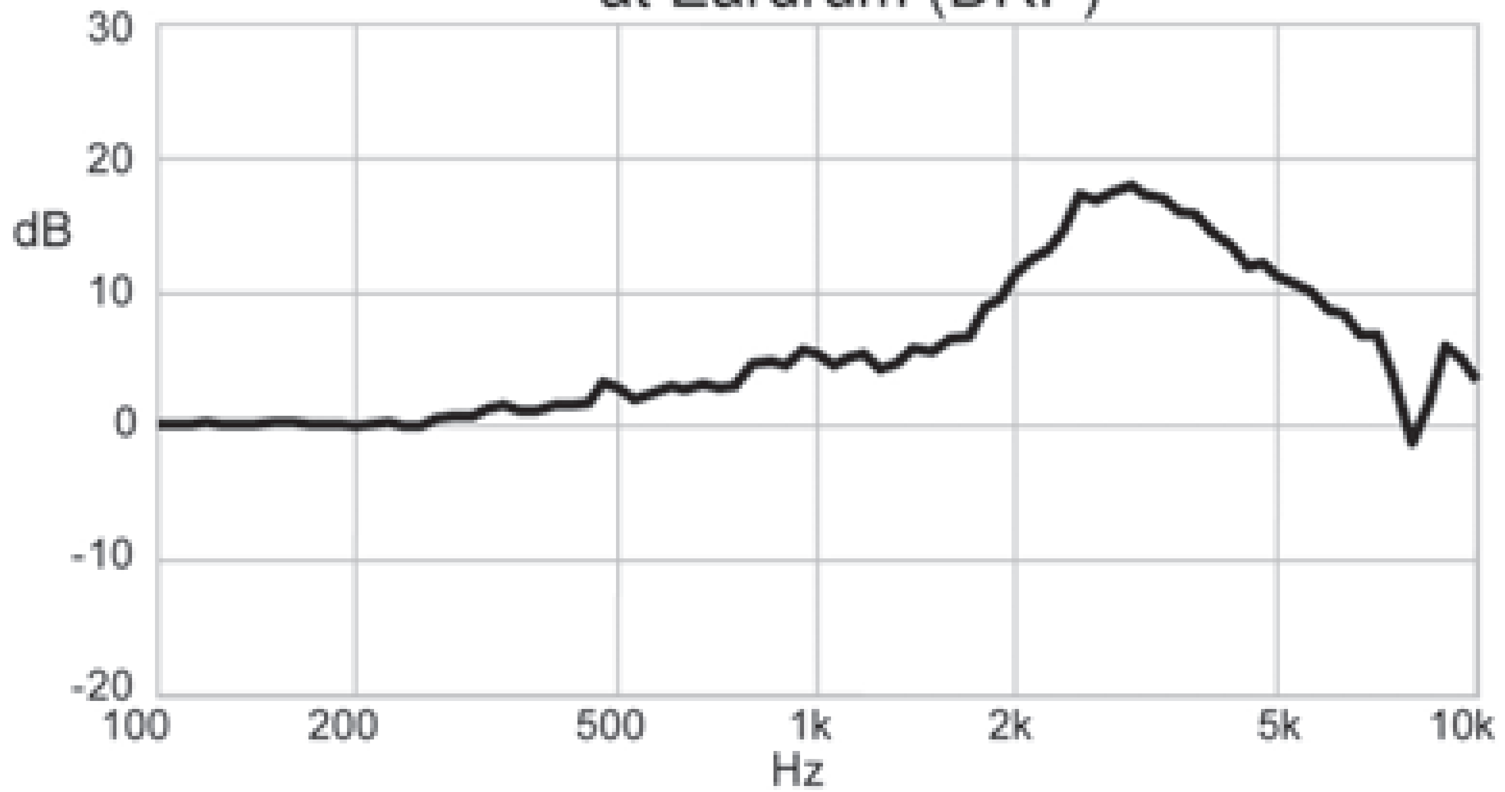
Magnitude Response

a) Ideal Free Field Pressure Response of Loudspeaker Measured on-axis with Microphone



b) Response of Same Loudspeaker Measured at Eardrum (DRP)



In order for a headphone to sound like an ideal loudspeaker, the magnitude response at the ear drum should look like in Fig. b)

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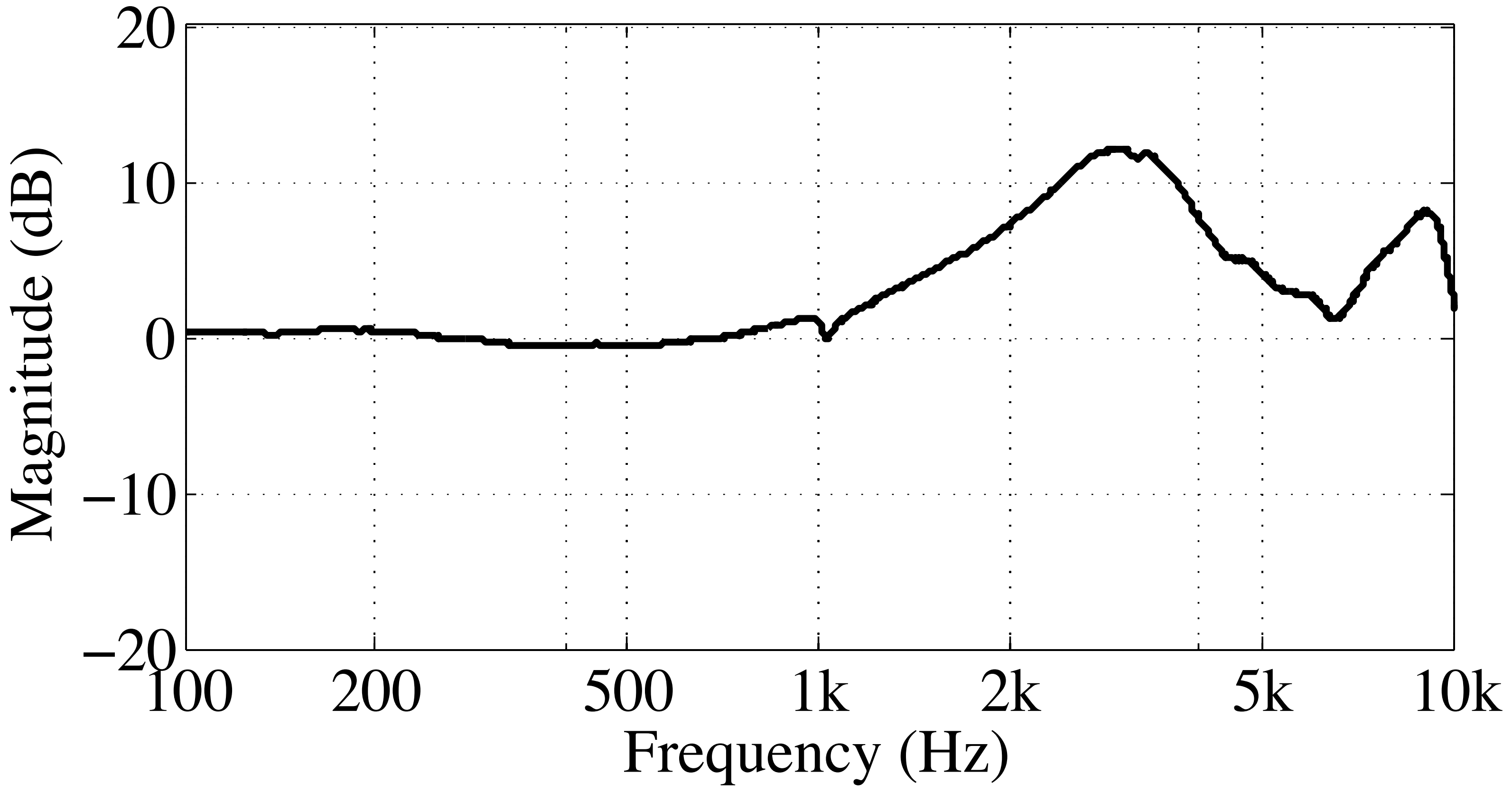
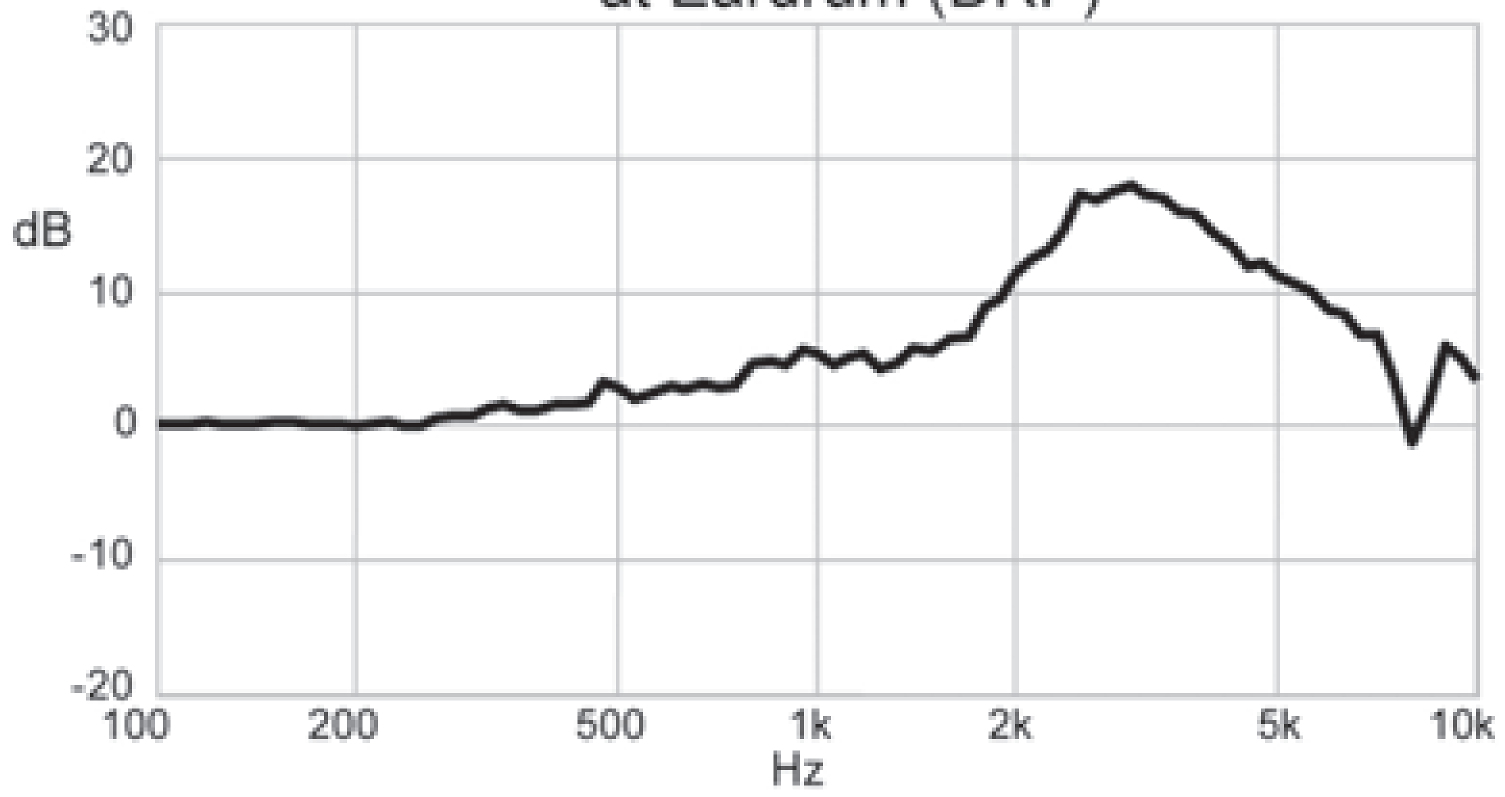
Magnitude Examples



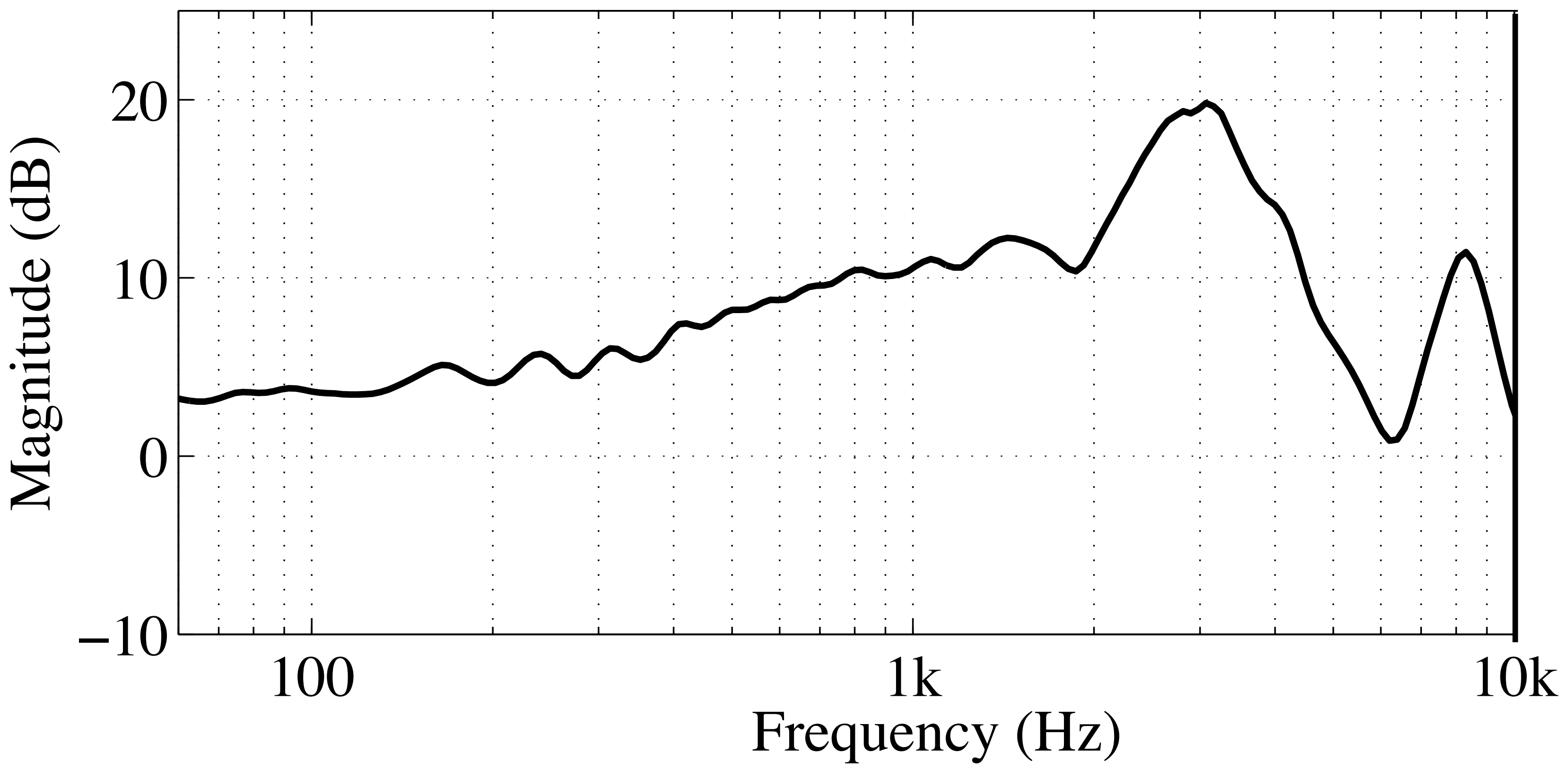
Sennheiser HD 650

- Measured using a dummy head

b)



“Ideal” loudspeaker measured from inside my ear canal (1cm)



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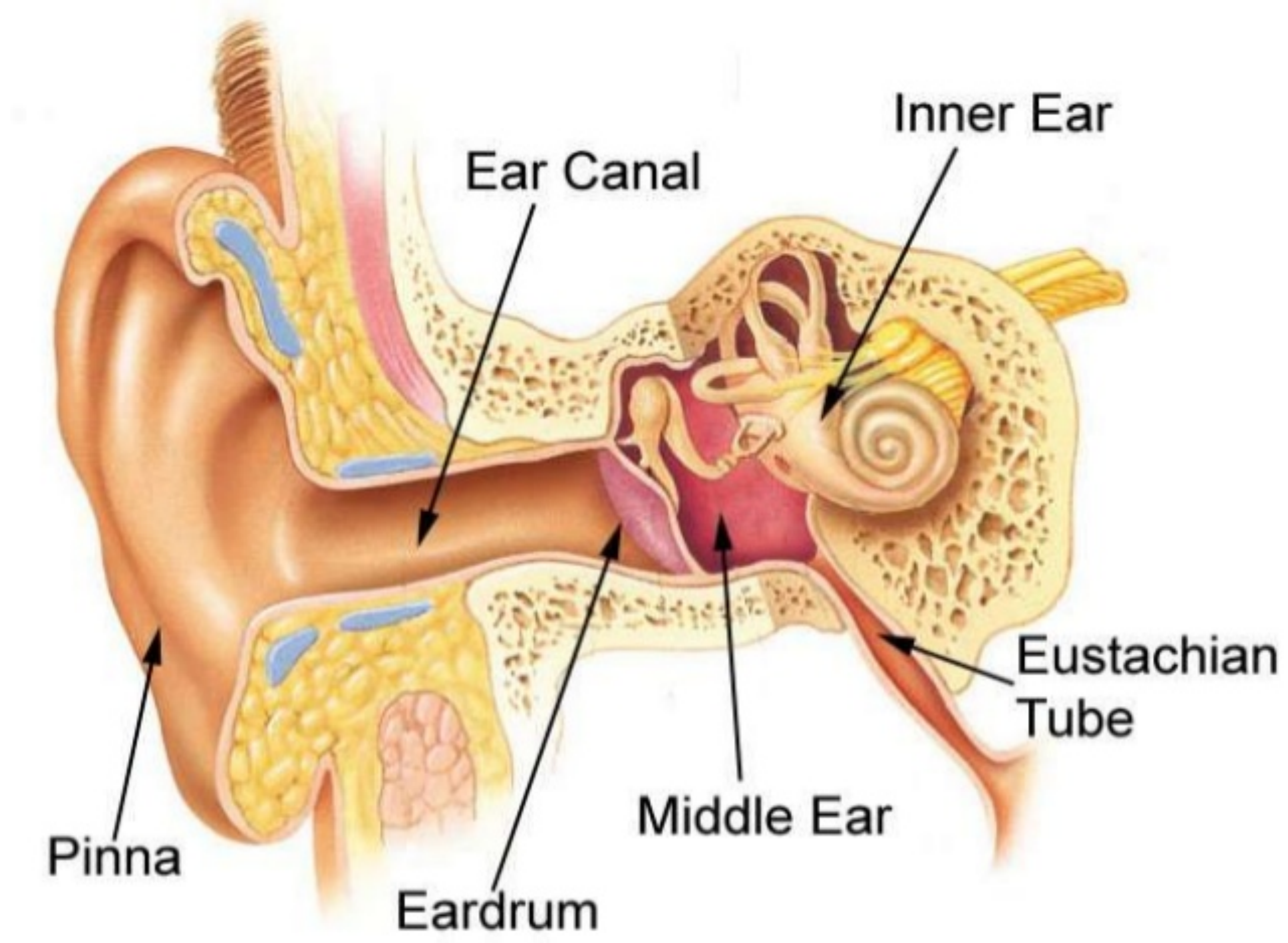
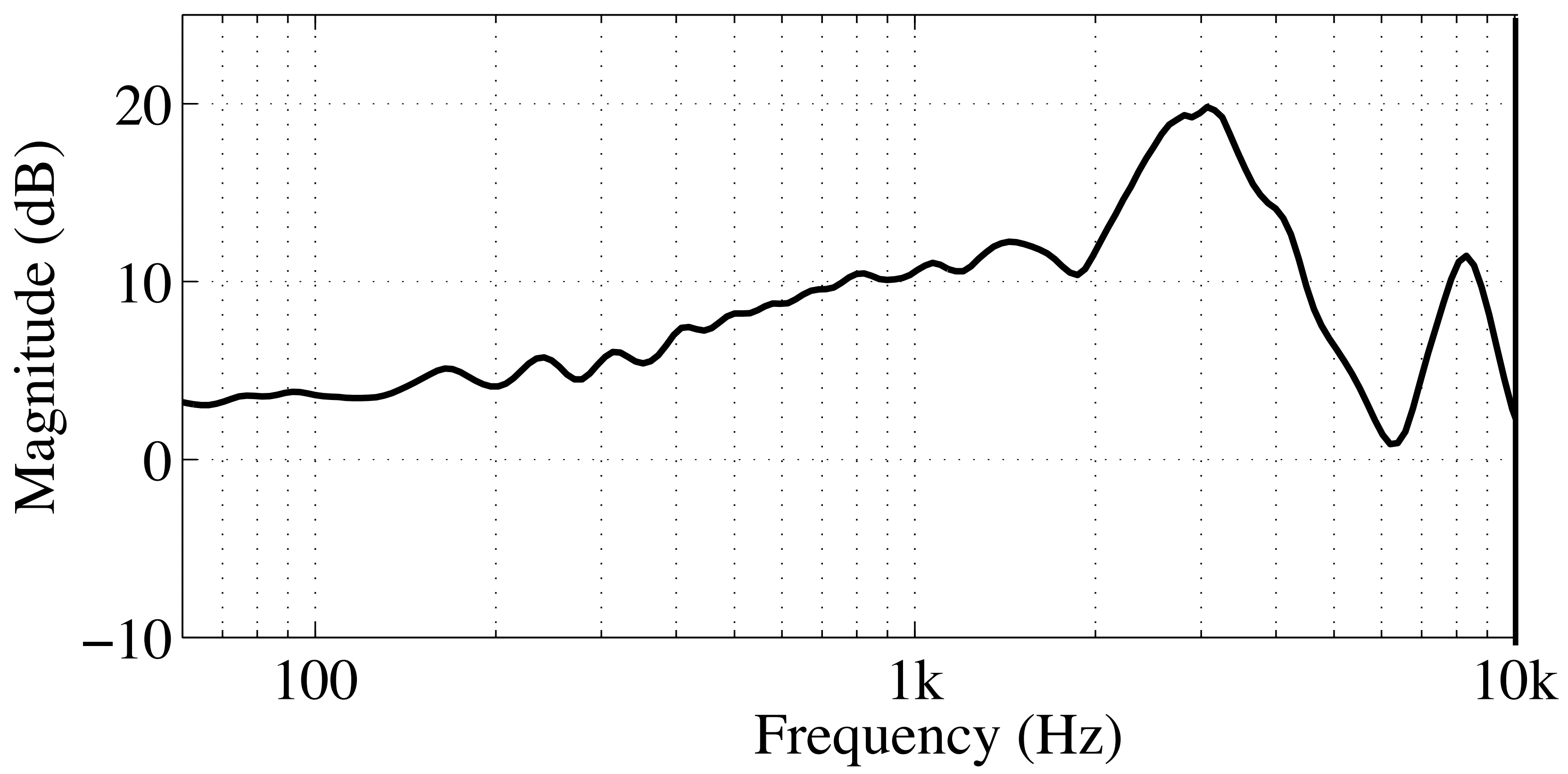
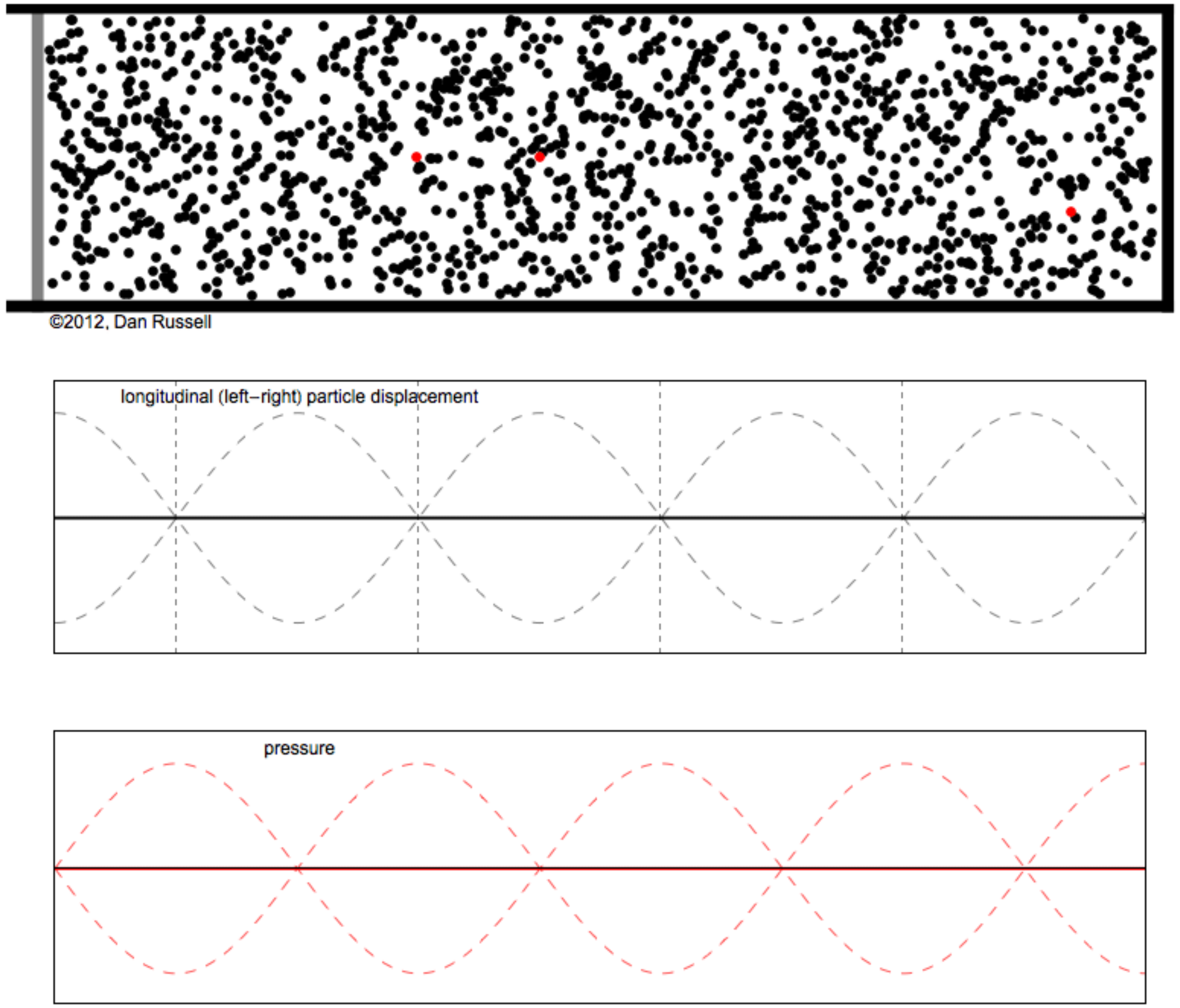
Ear canal Resonance



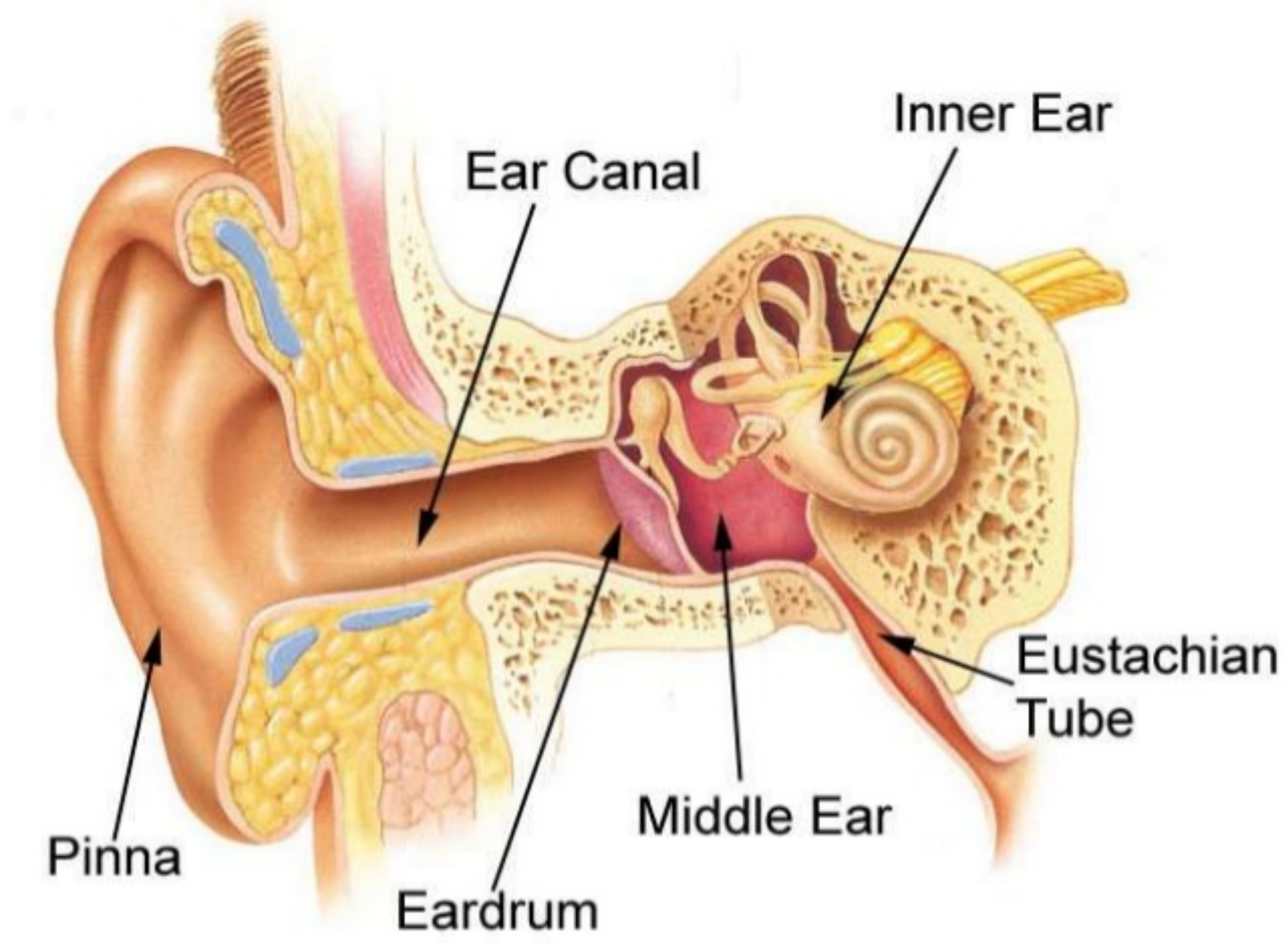


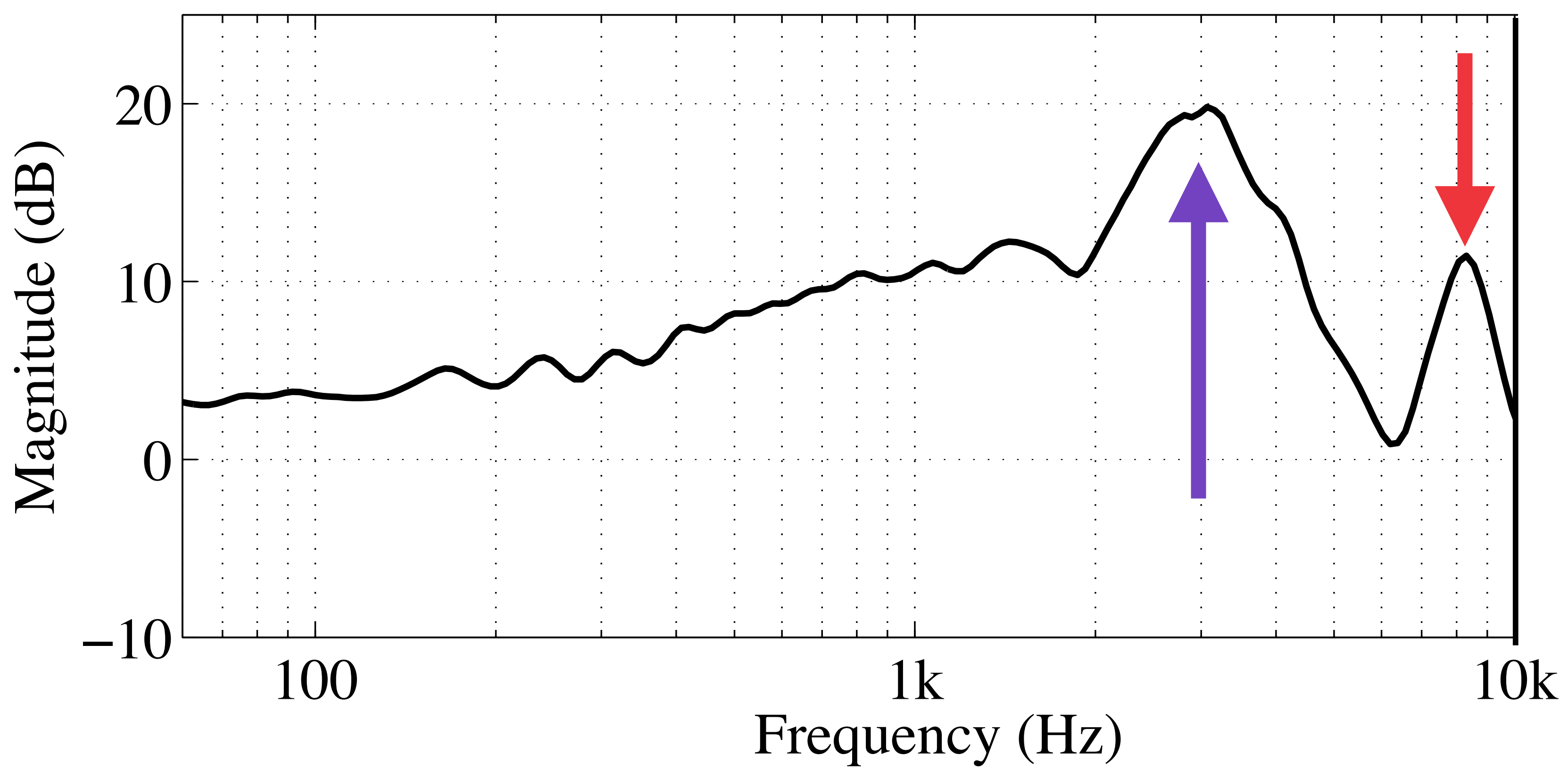
Ear canal acts as a quarter wavelength resonator



https://www.acs.psu.edu/drussell/demos/standingwaves/standingwaves.html

Ear canal Resonance

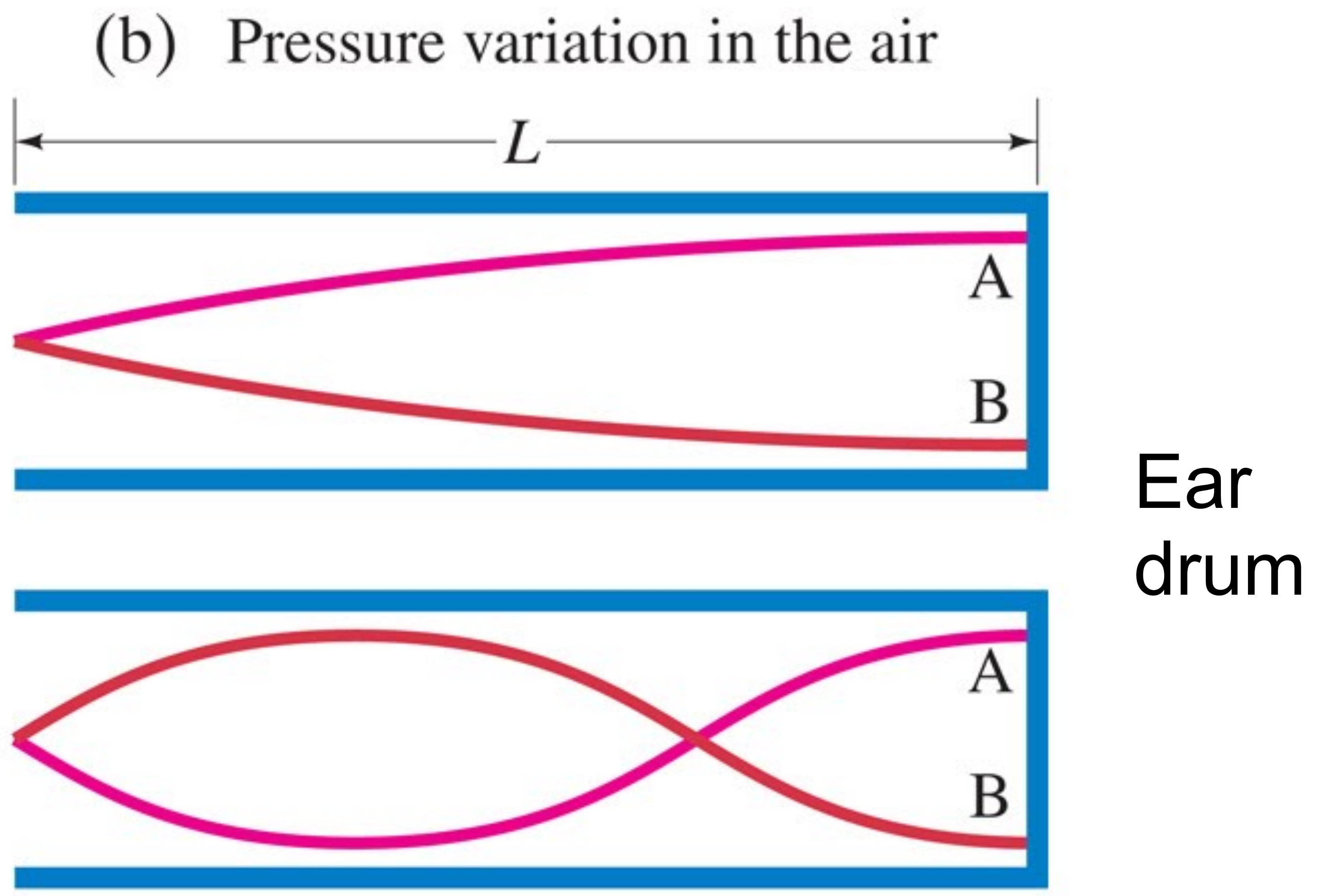




Ear canal acts as a quarter wavelength resonator
Tube with one end closed

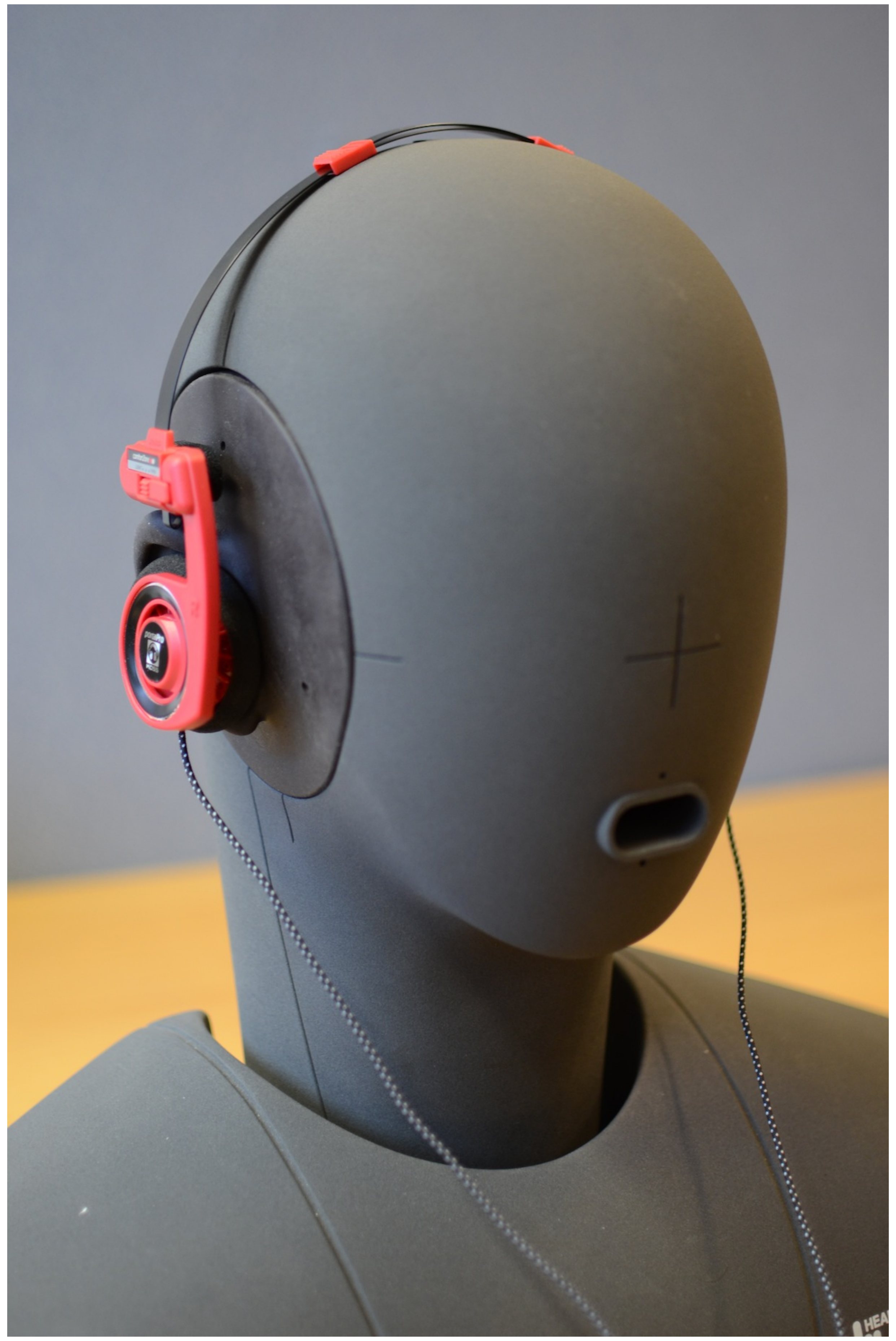
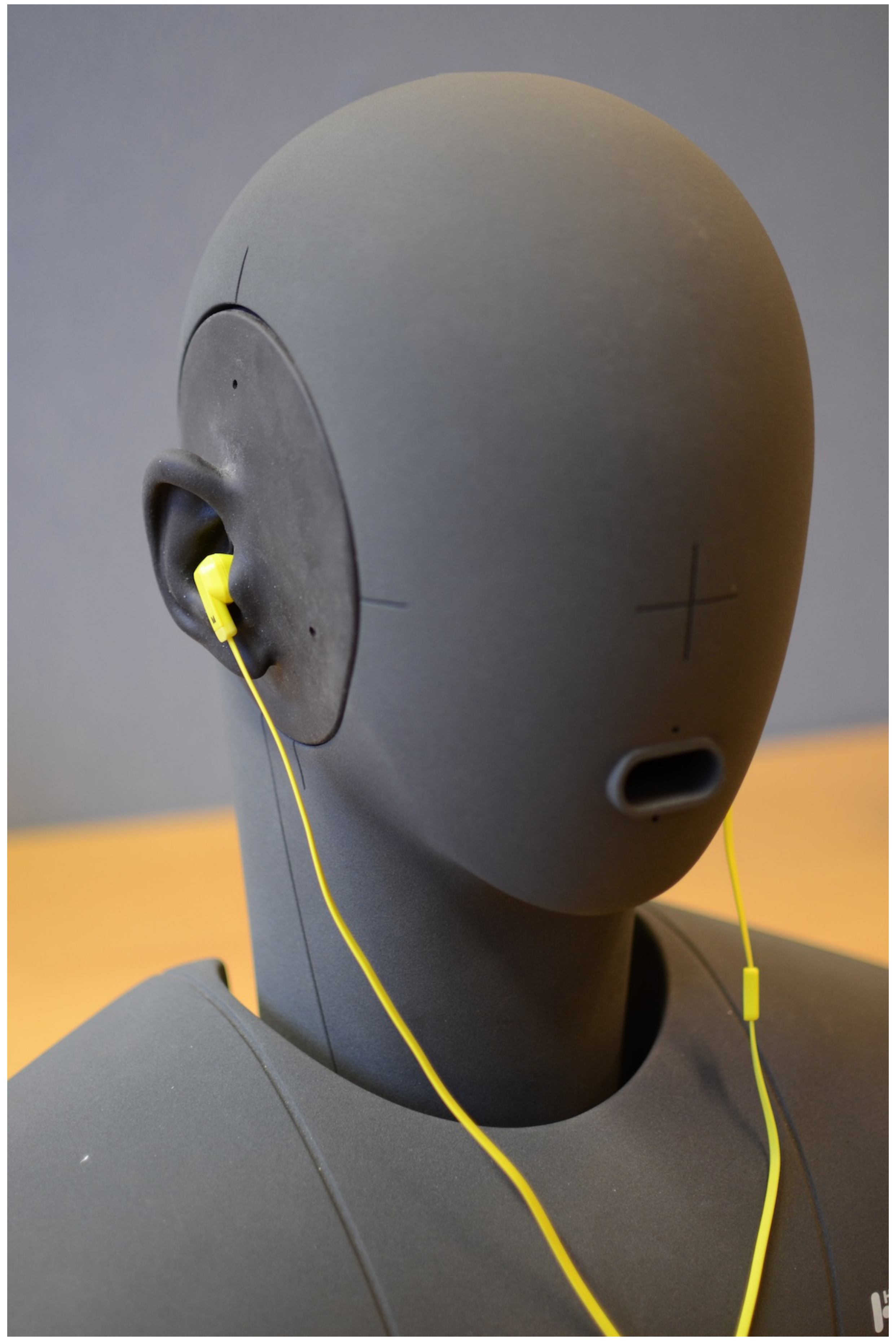
$$f = \frac{c}{4l}$$

$$f = 3\frac{c}{4l}$$

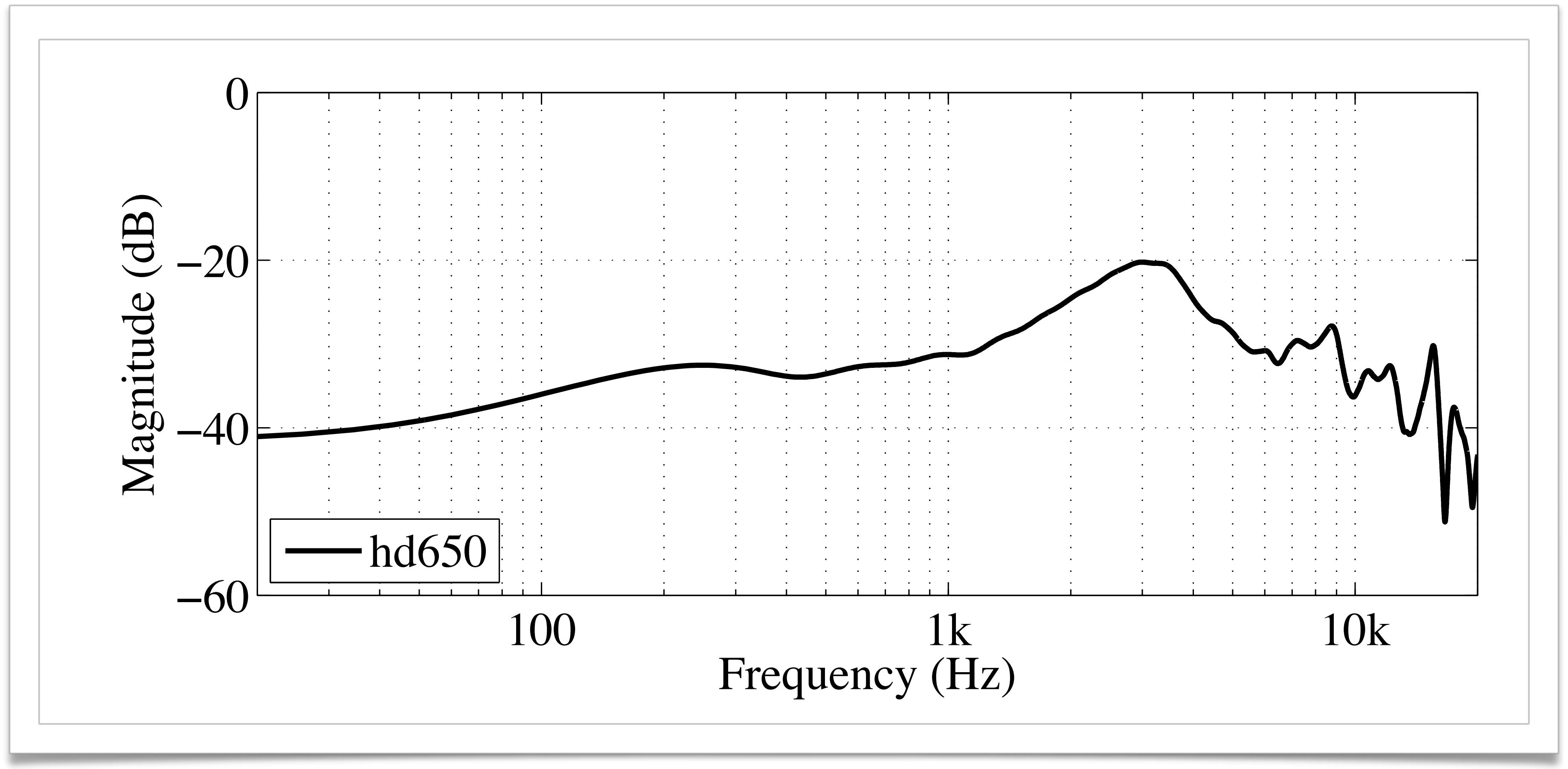


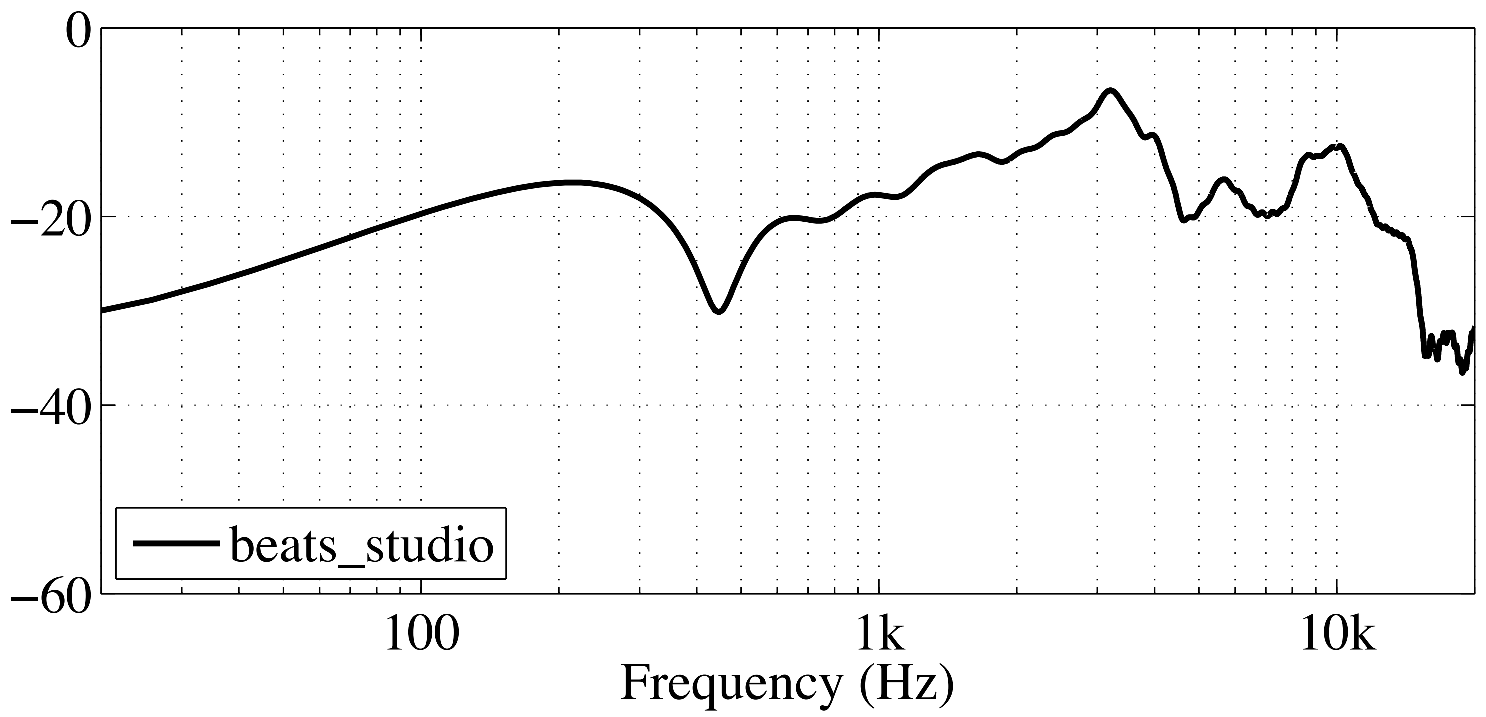
$$l = \frac{c}{4f} = \frac{343\,\text{m/s}}{4 \cdot 2900\,\text{Hz}} = 2.96\,\text{cm}$$

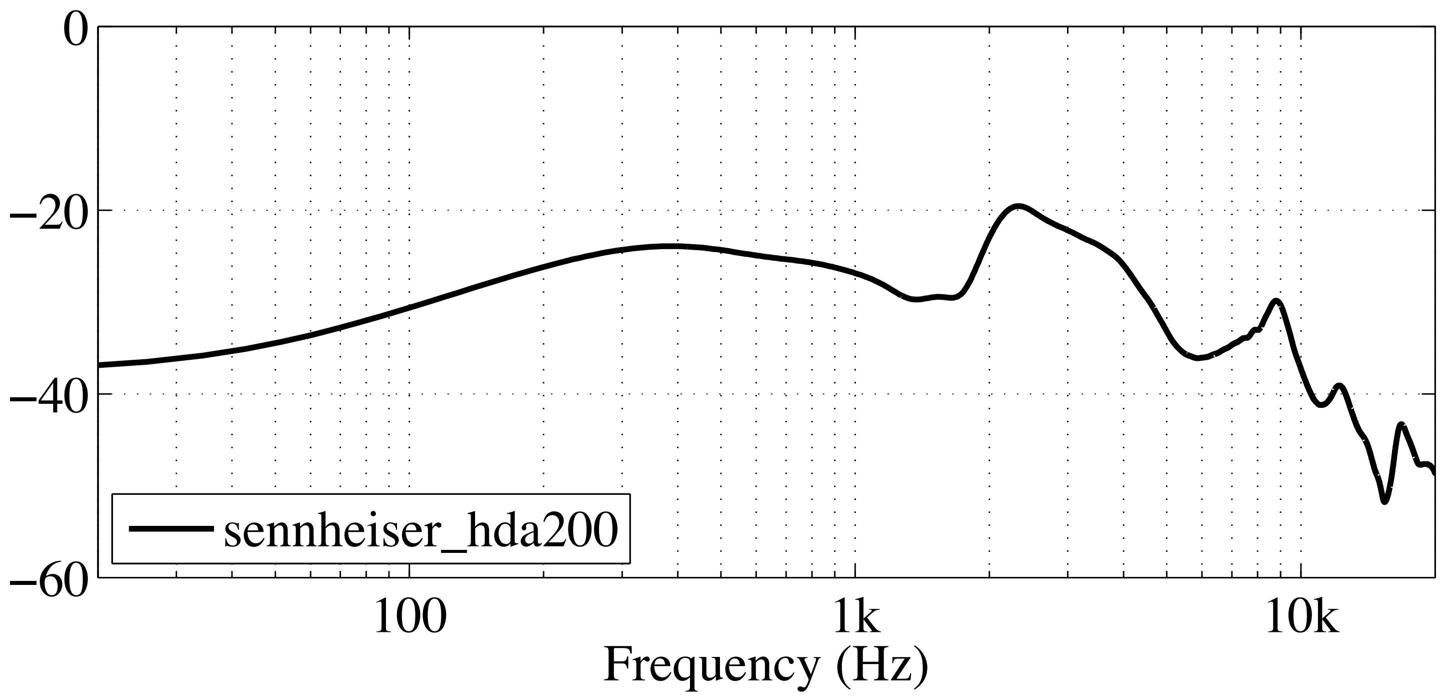
Measurements

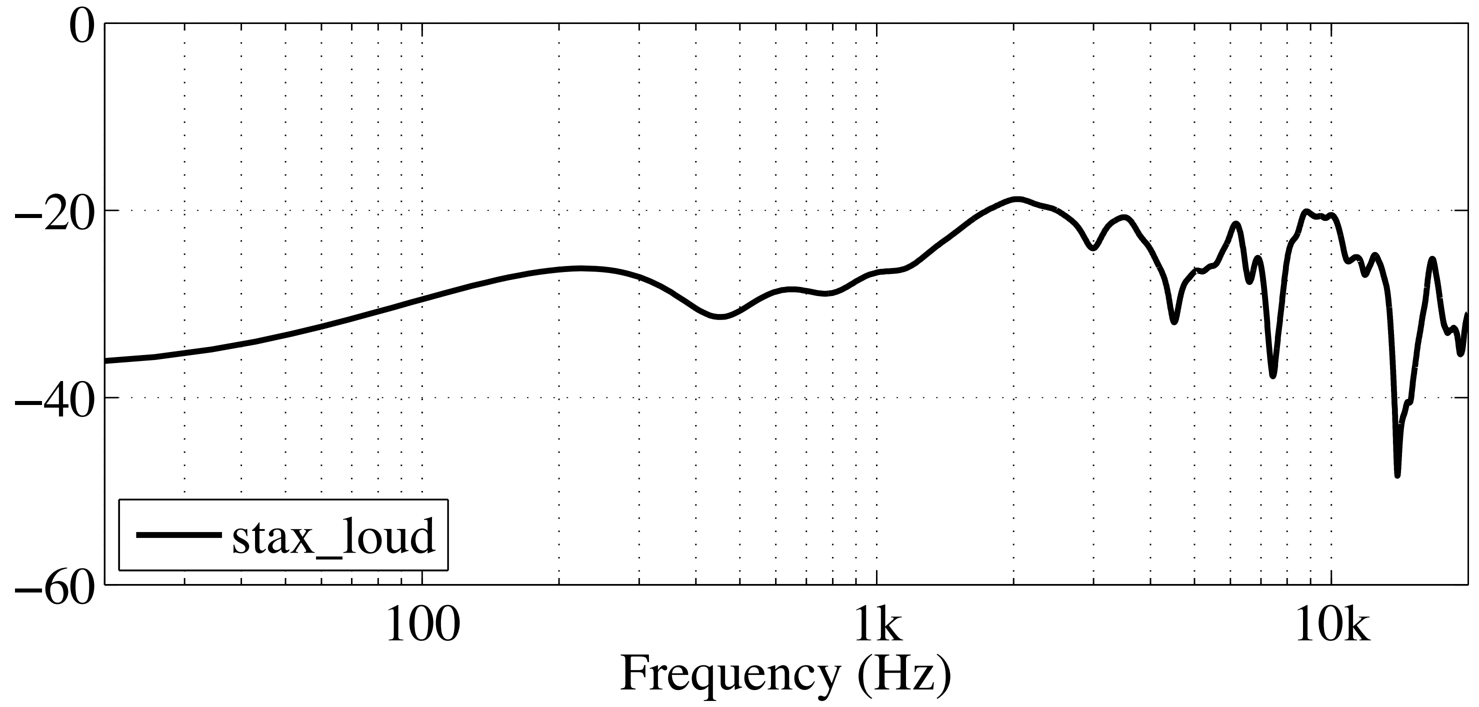




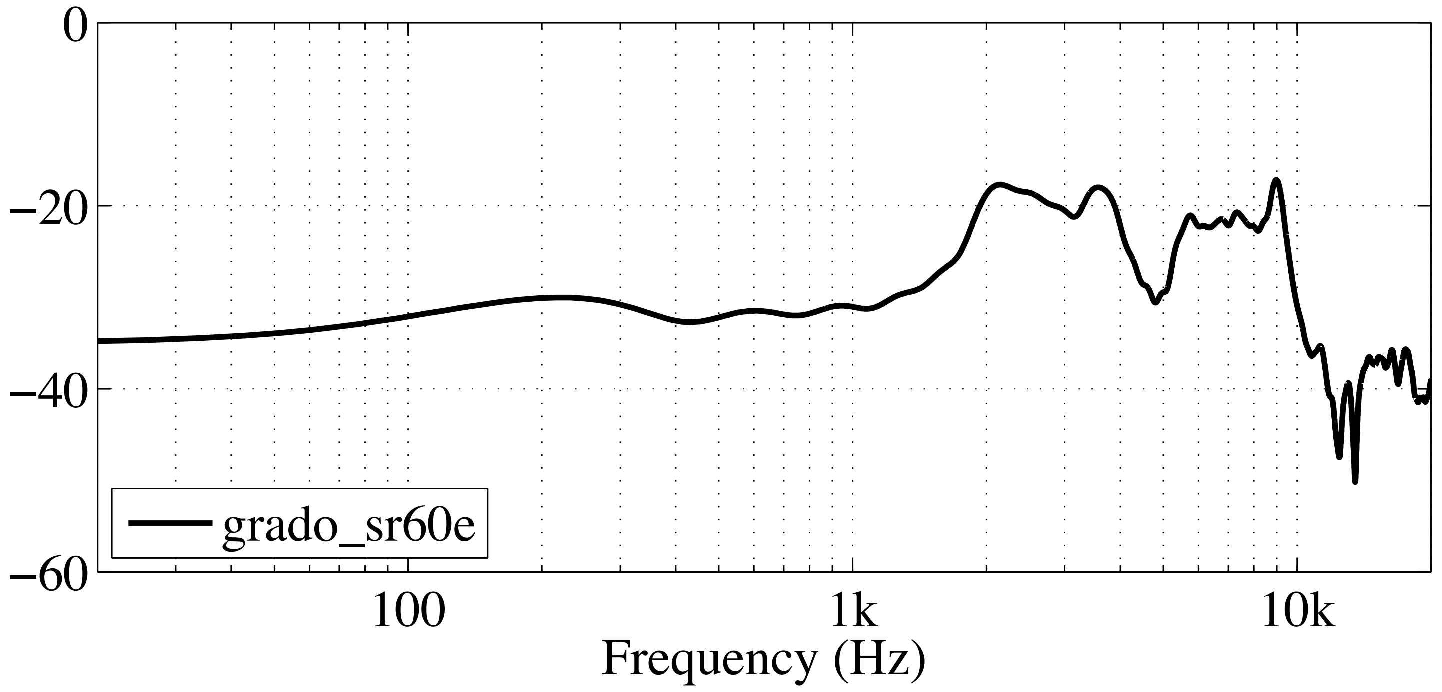
Measurements — Circum aural



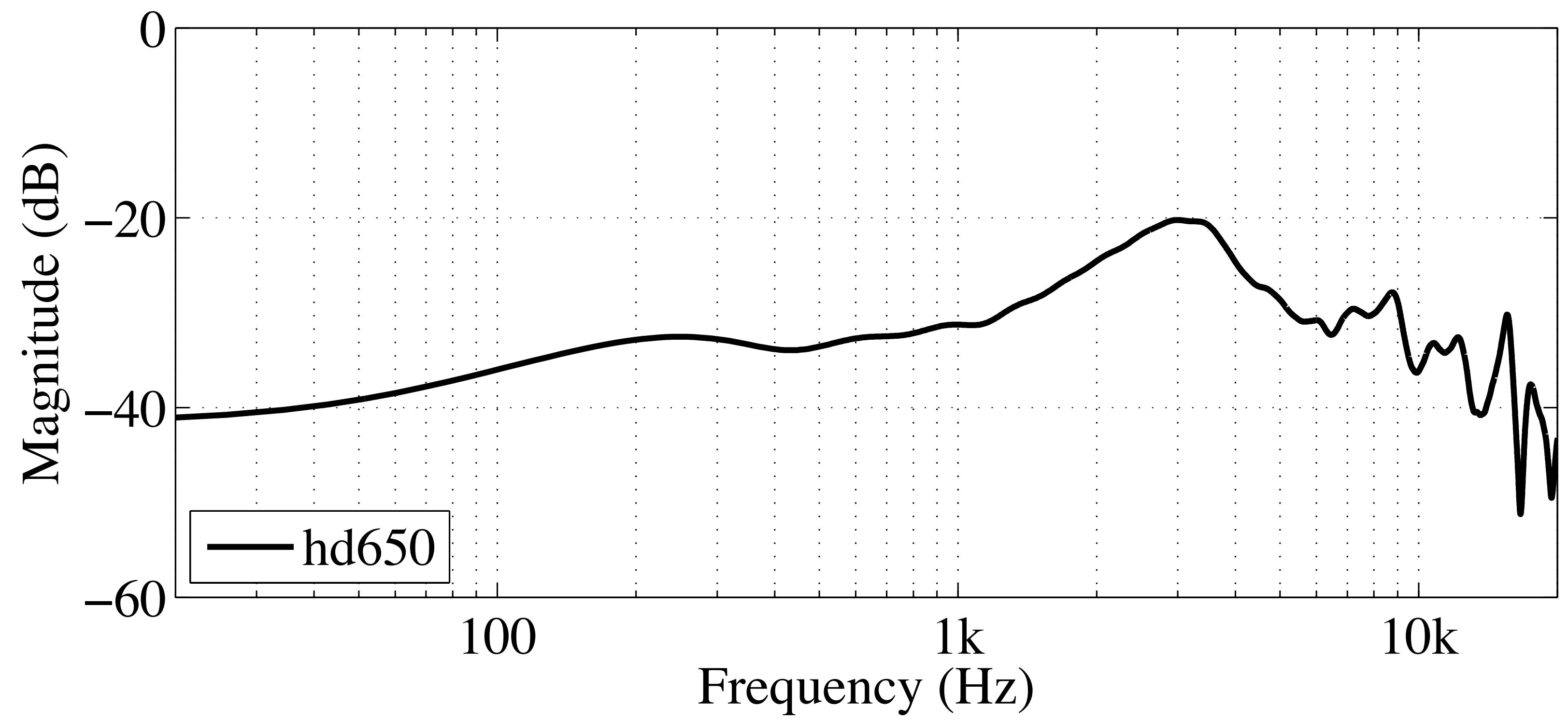


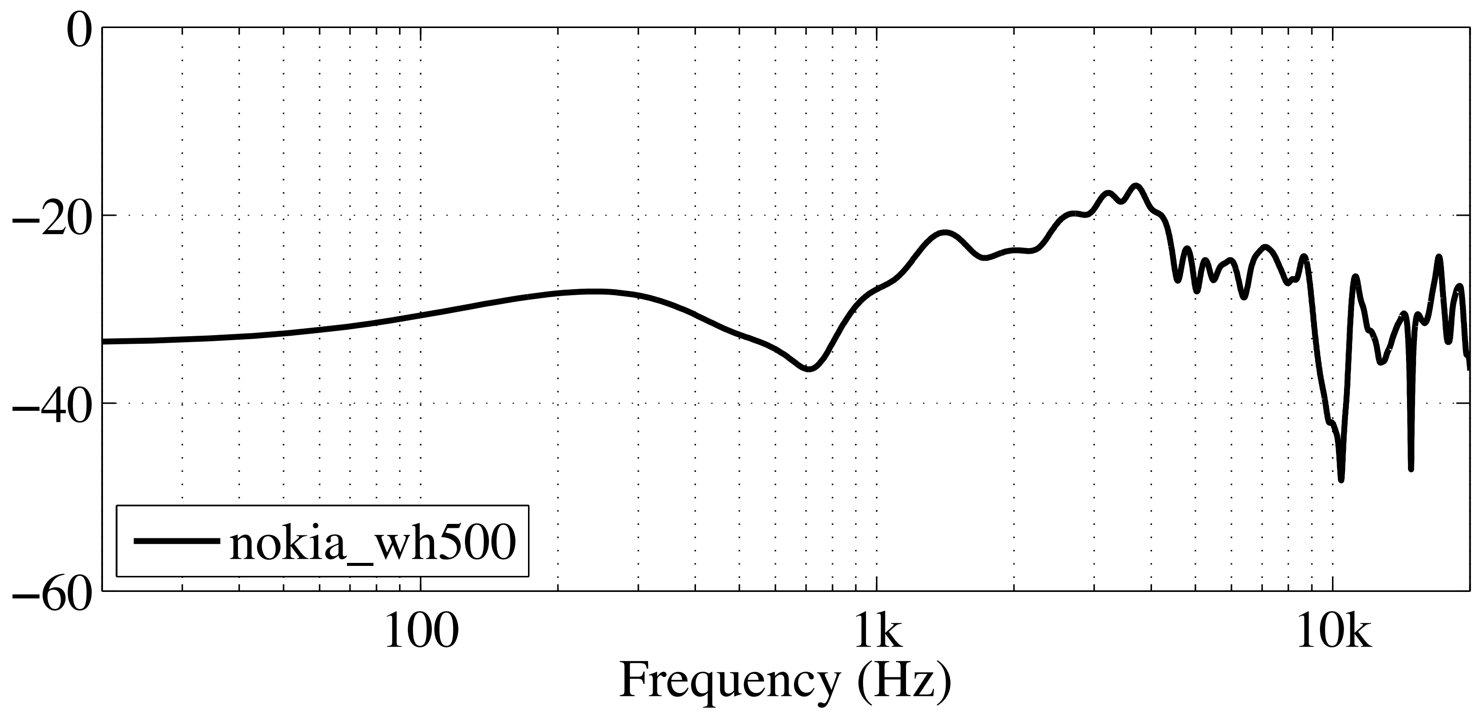


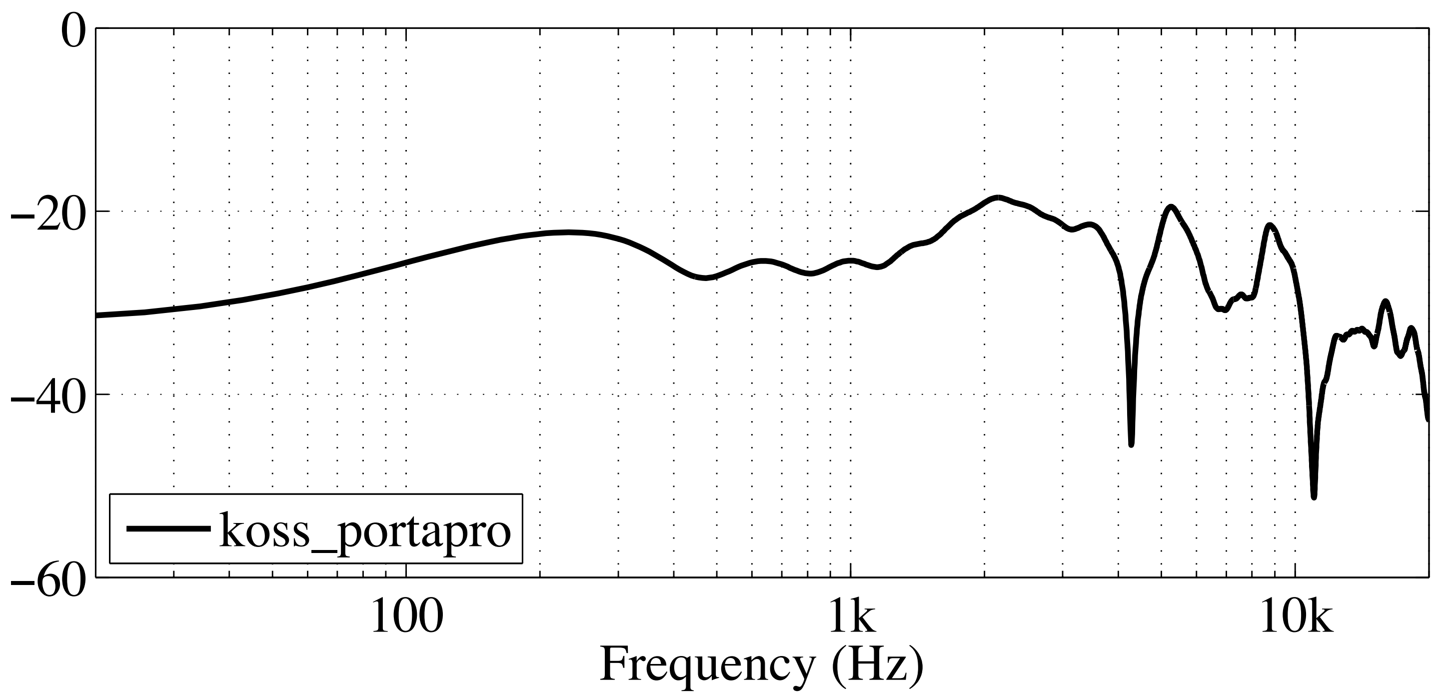


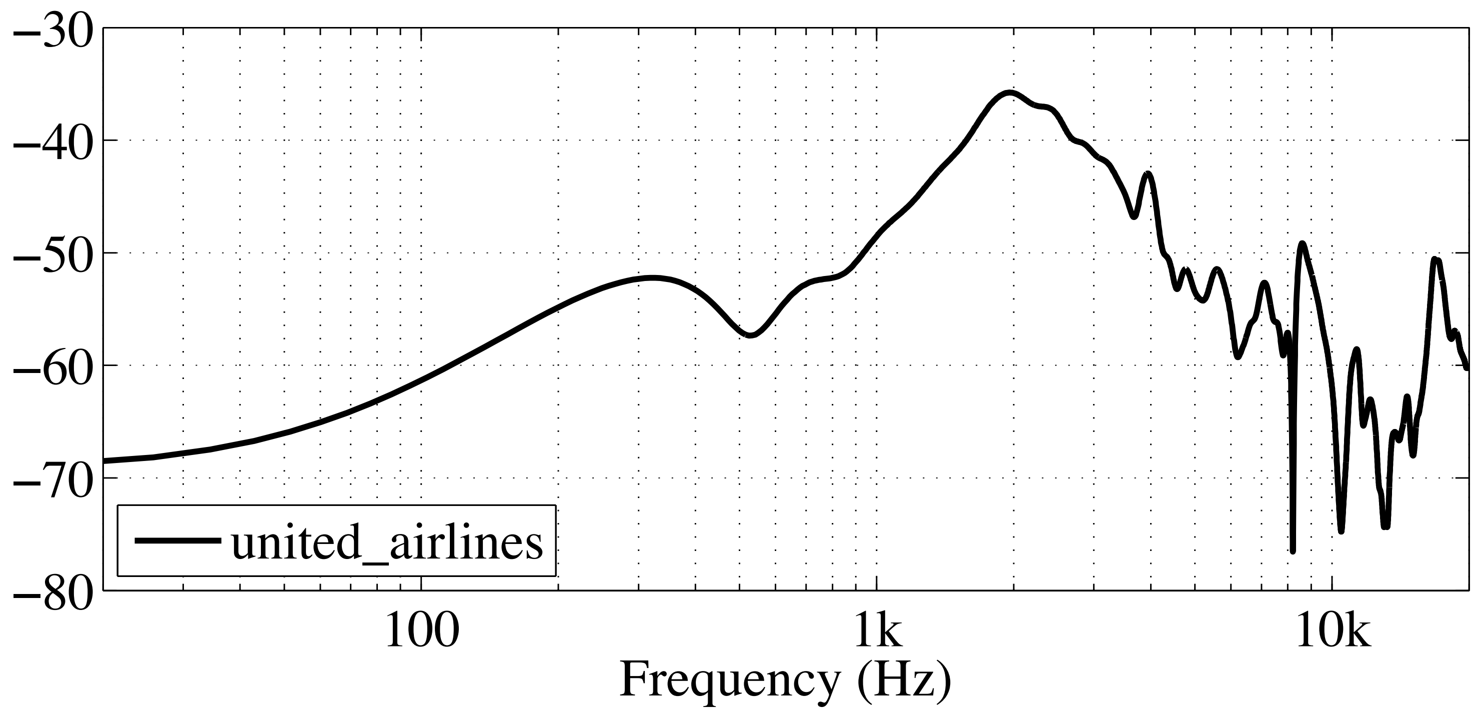


Measurements — Supra aural

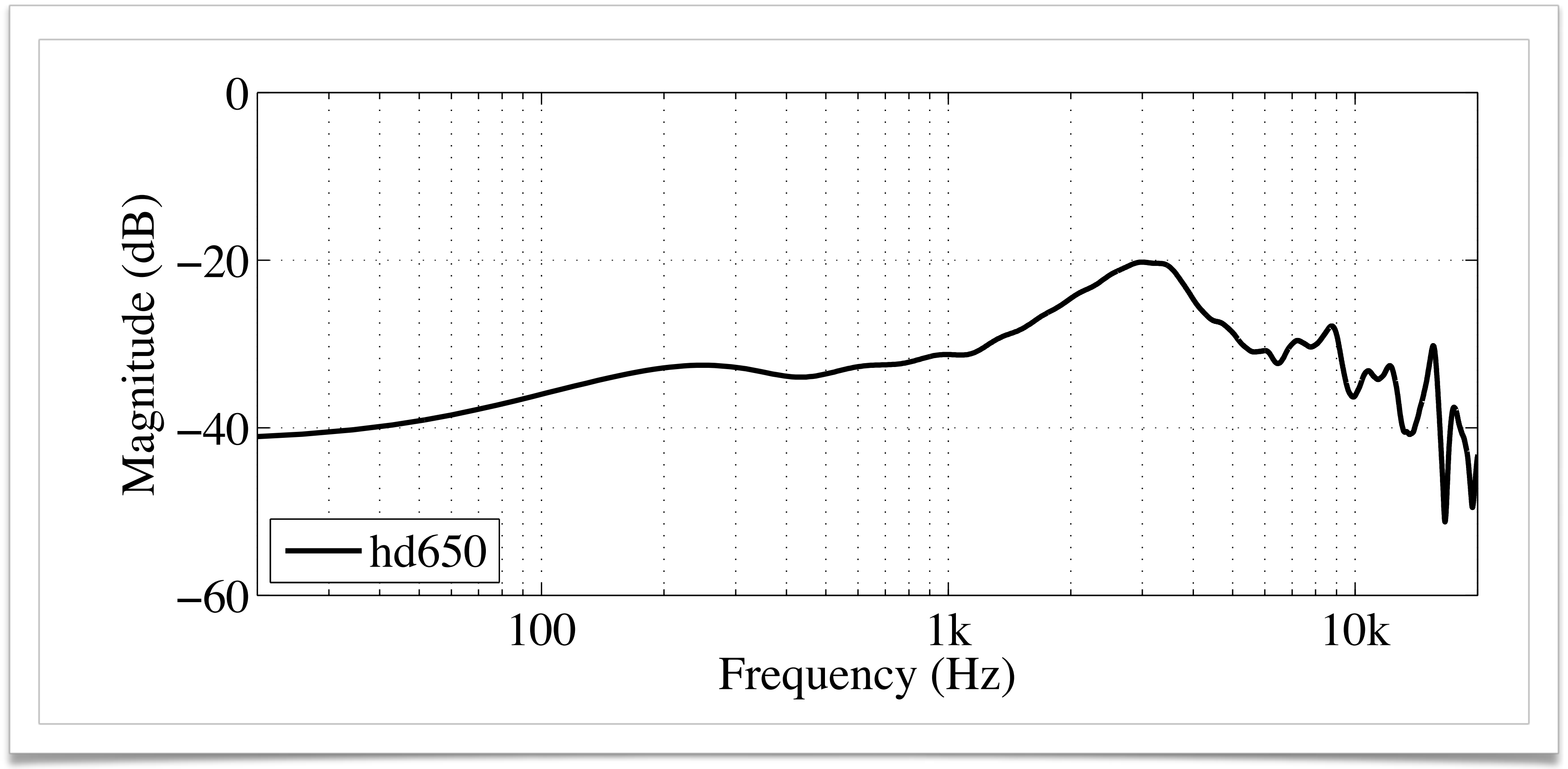


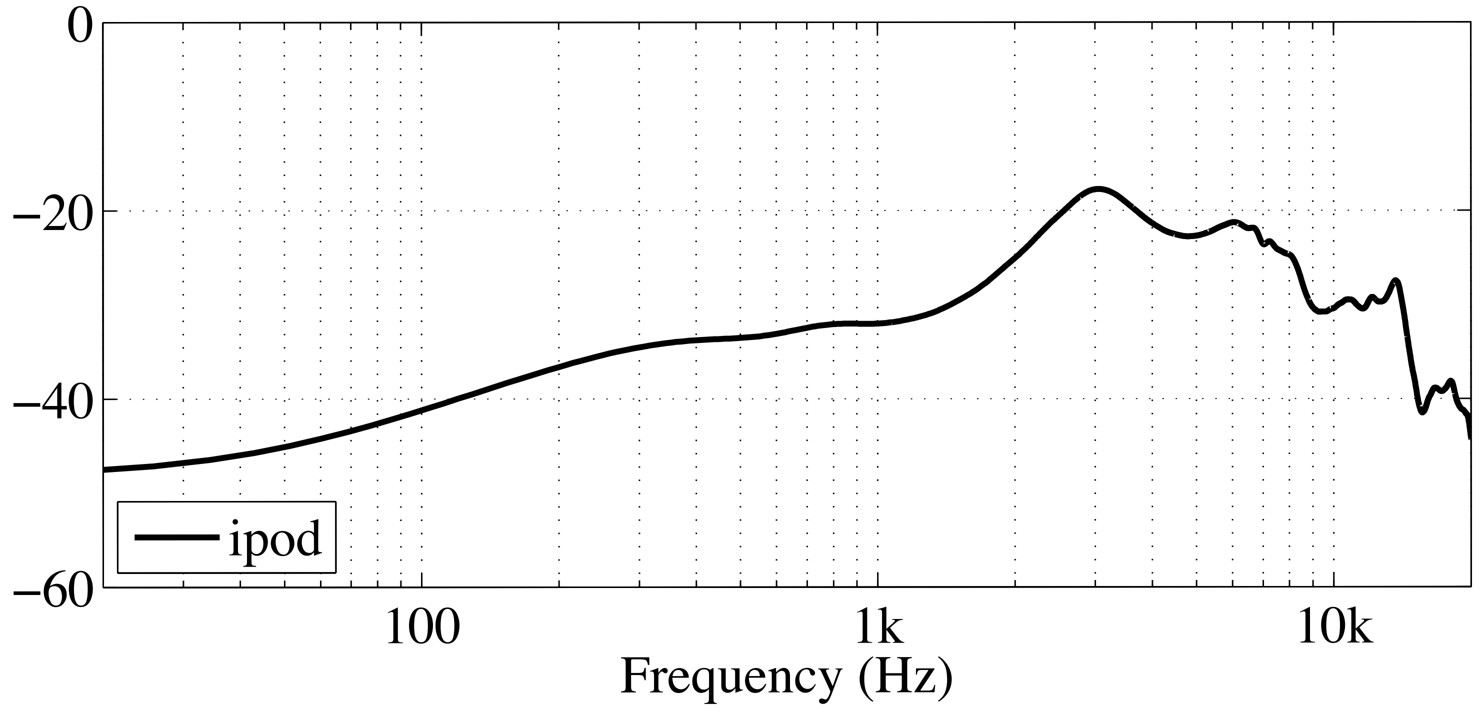


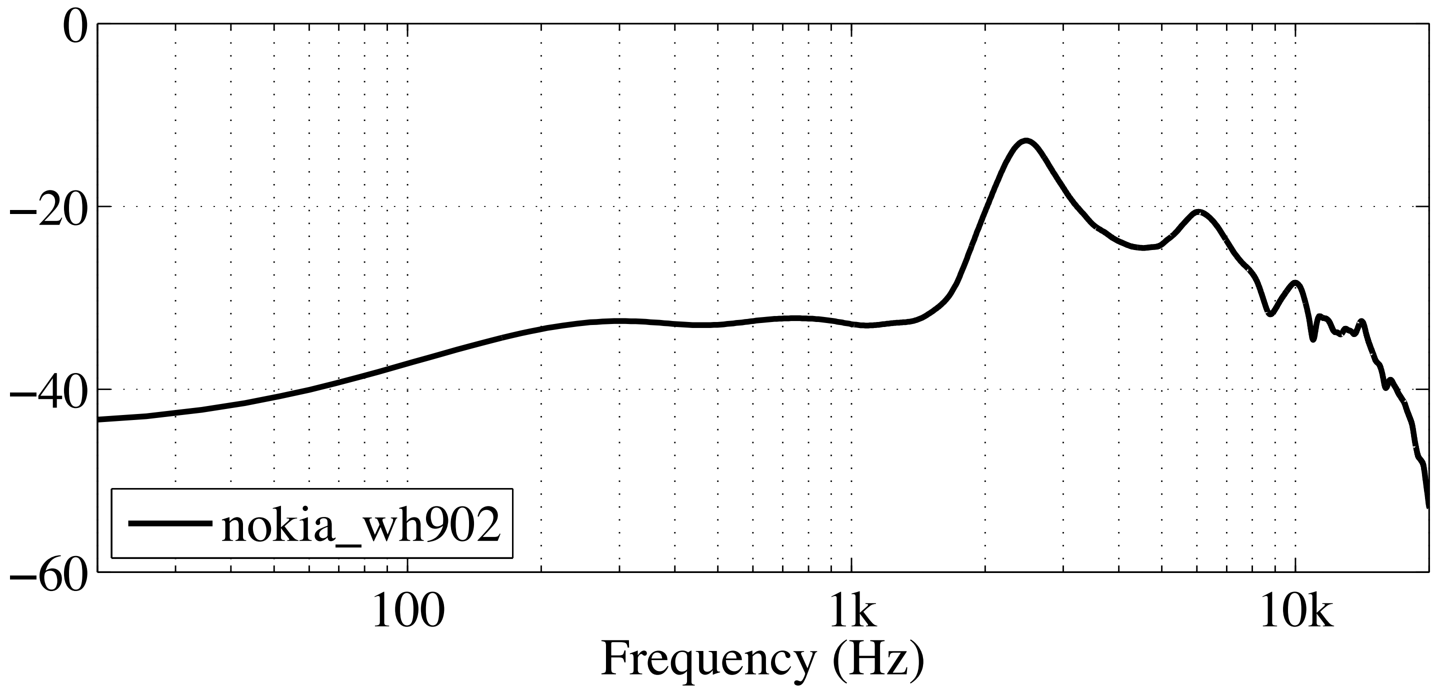


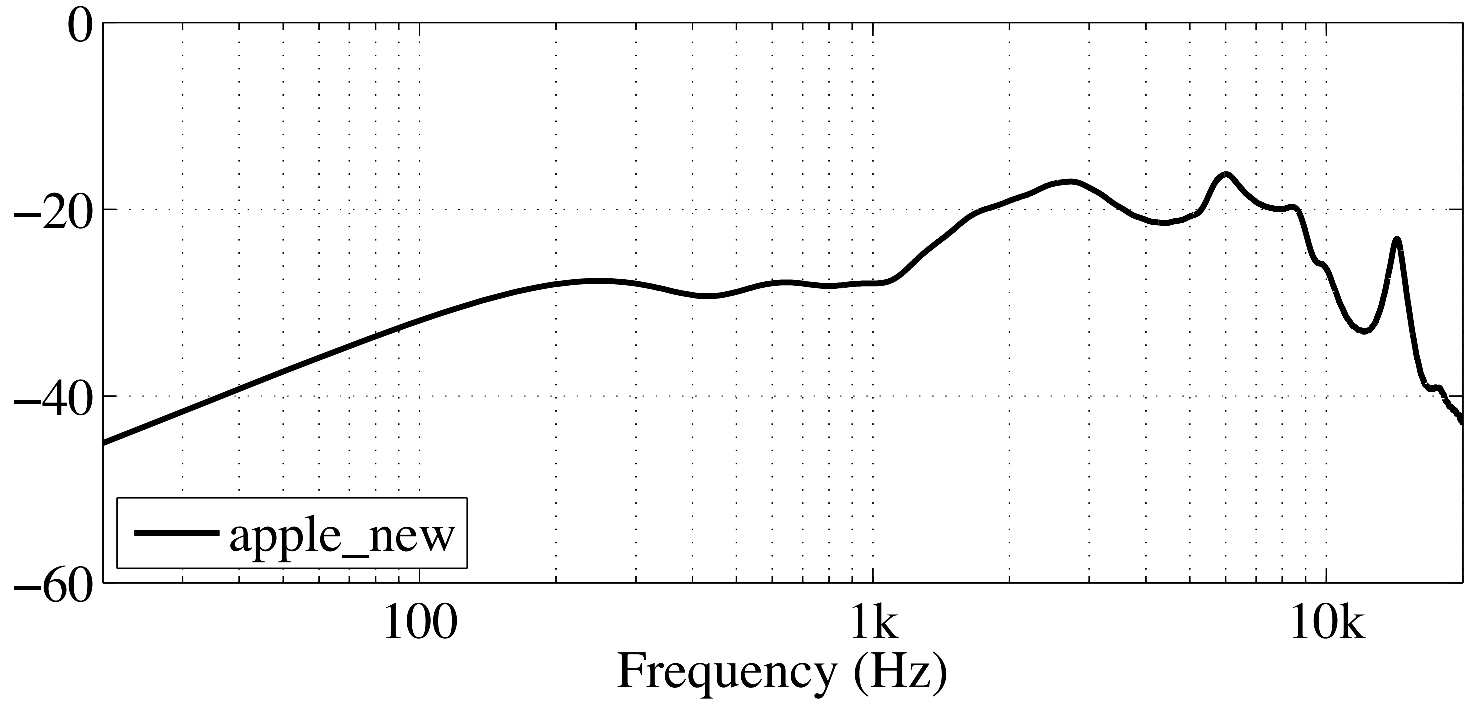


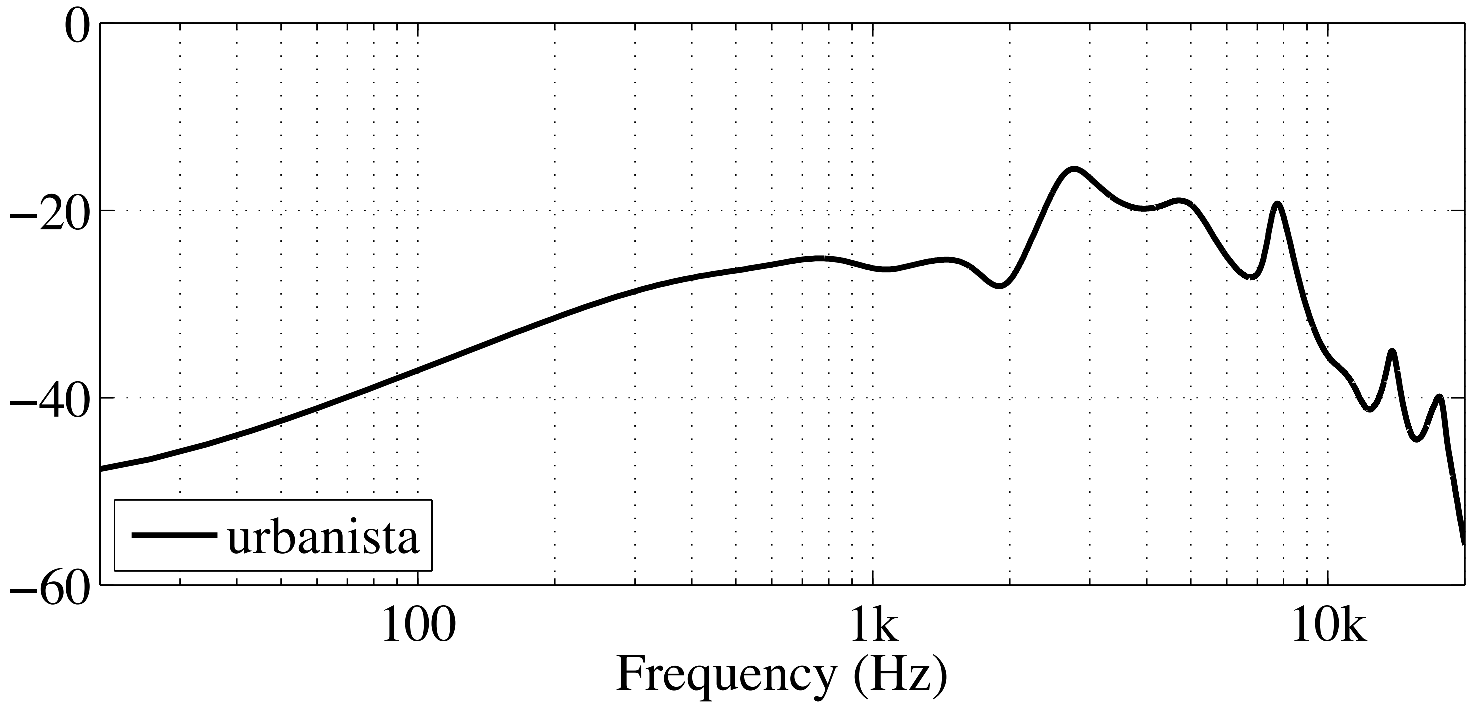
Measurements — Intra concha



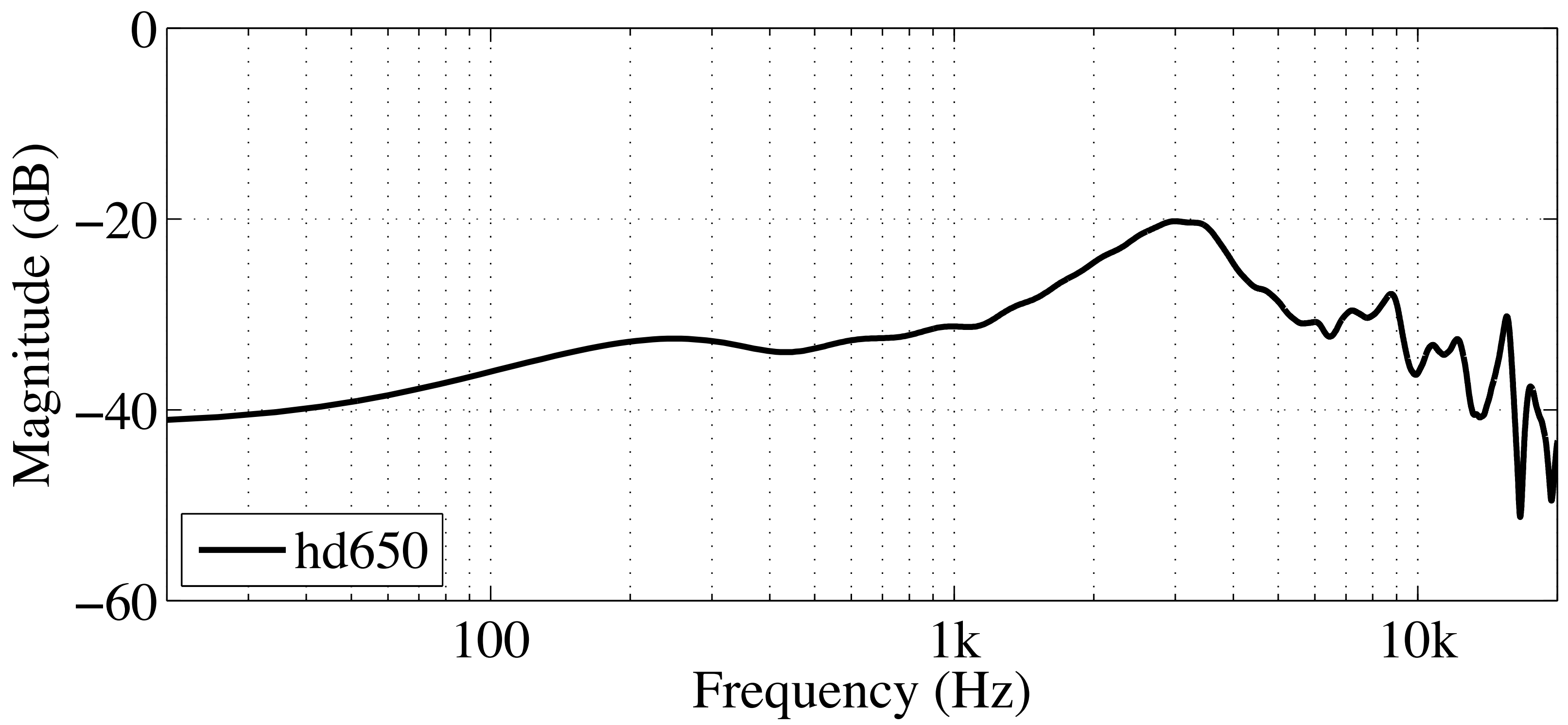


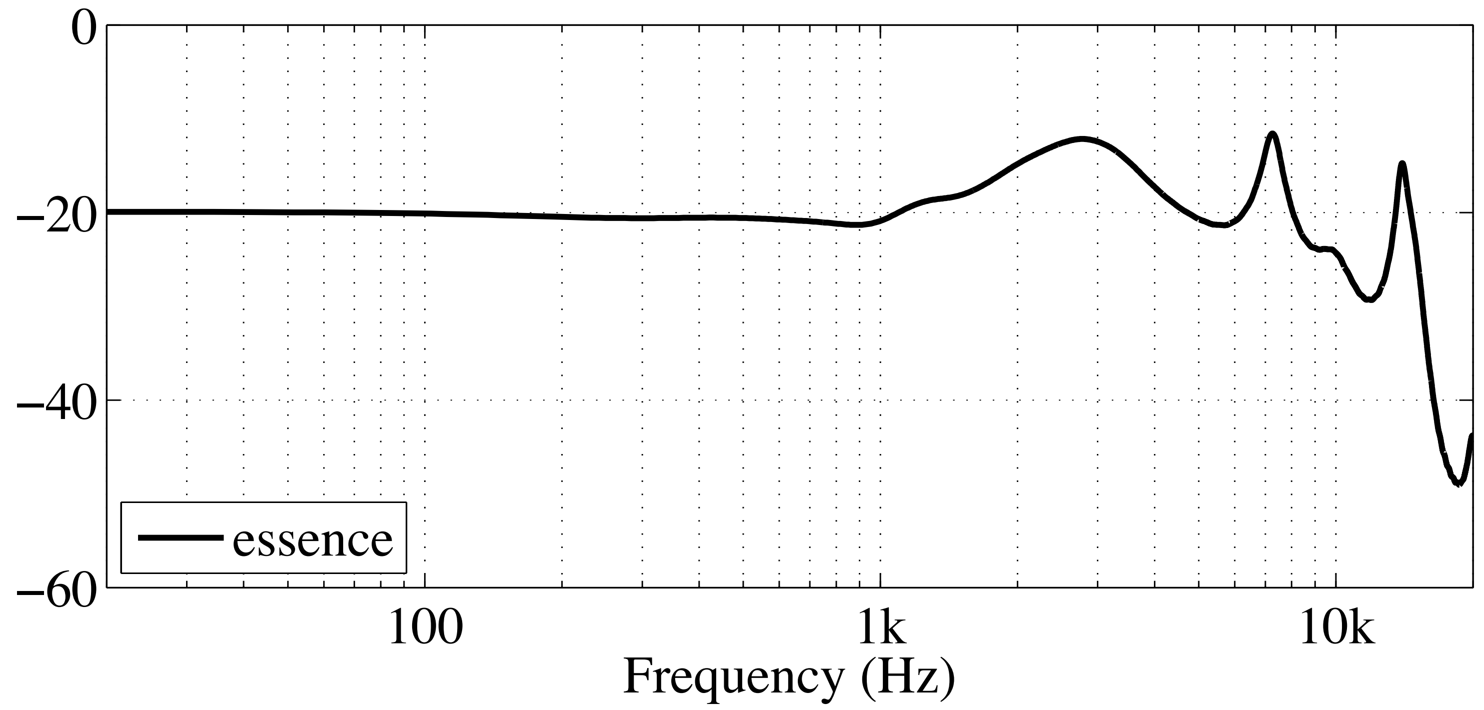


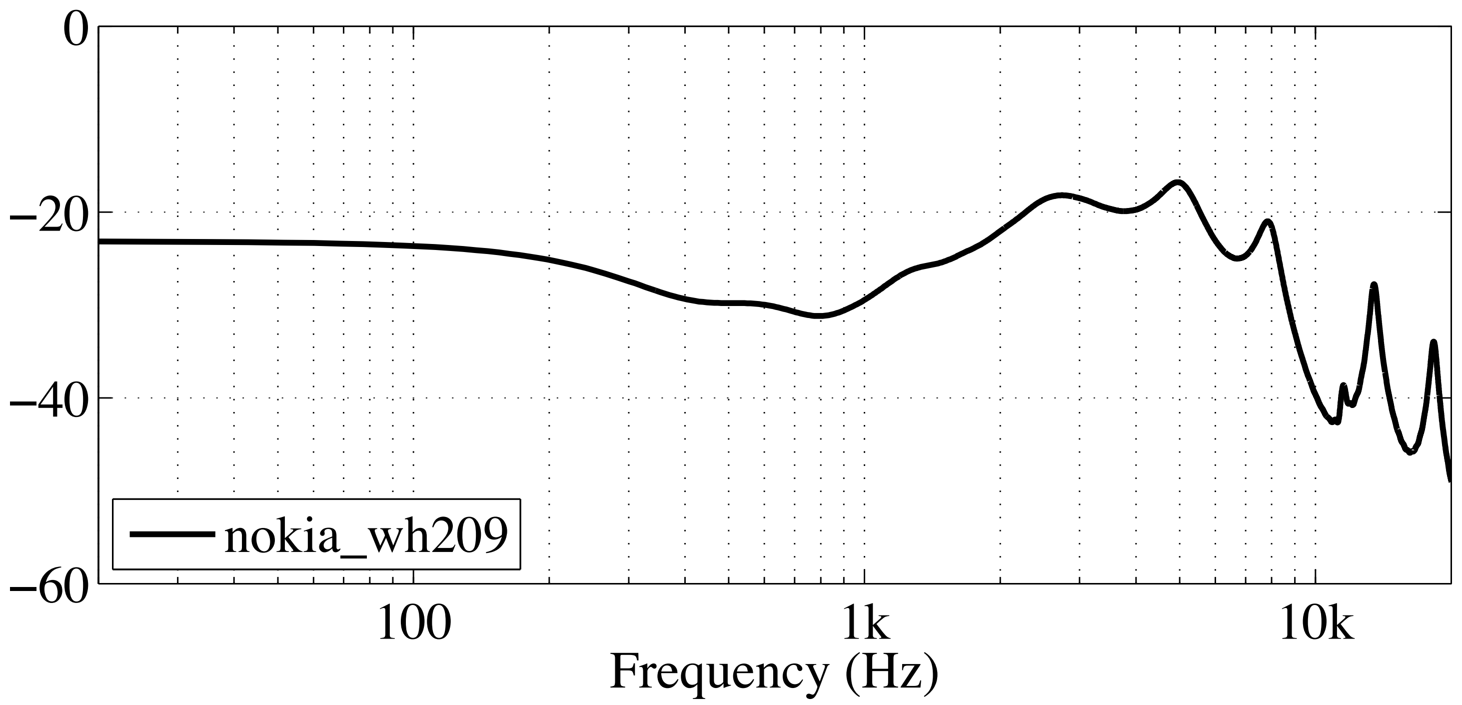


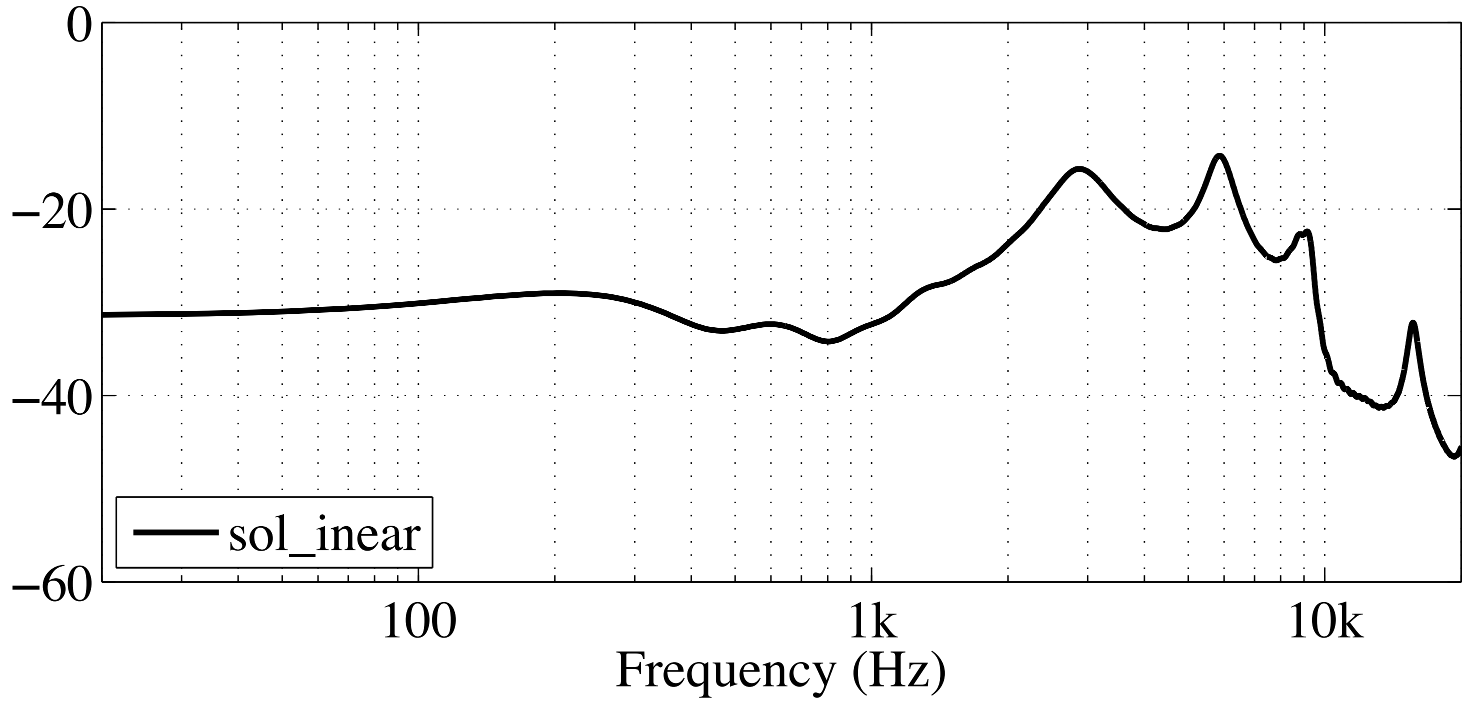


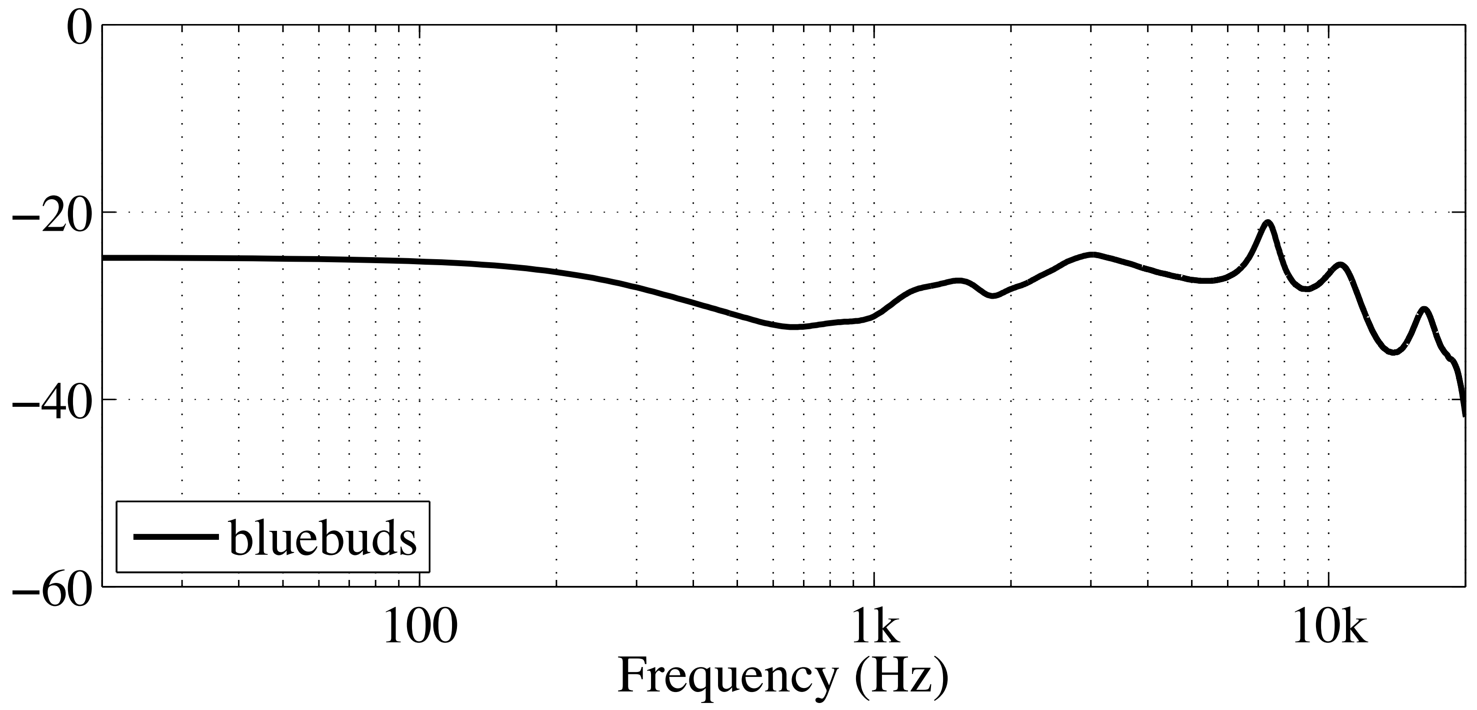
Measurements — In ear











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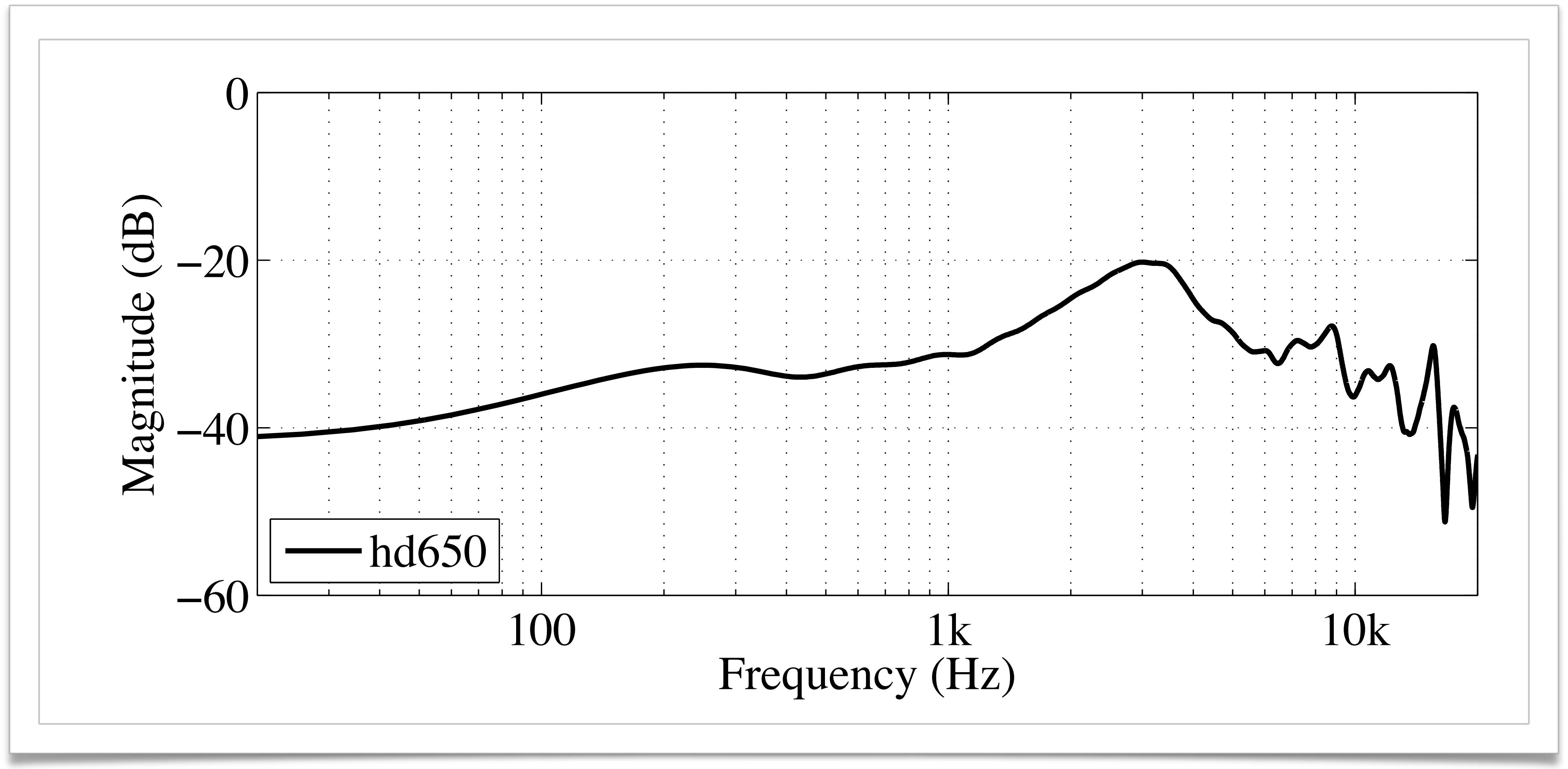
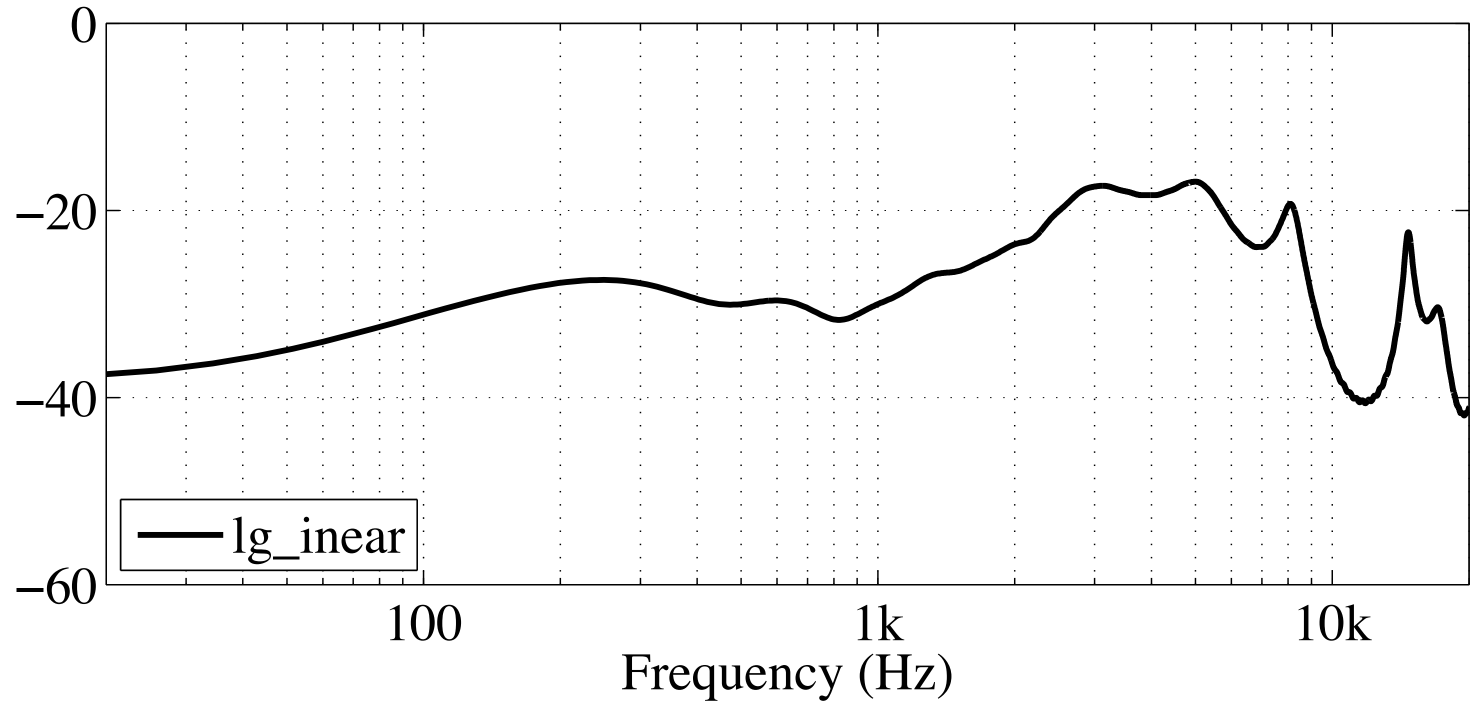
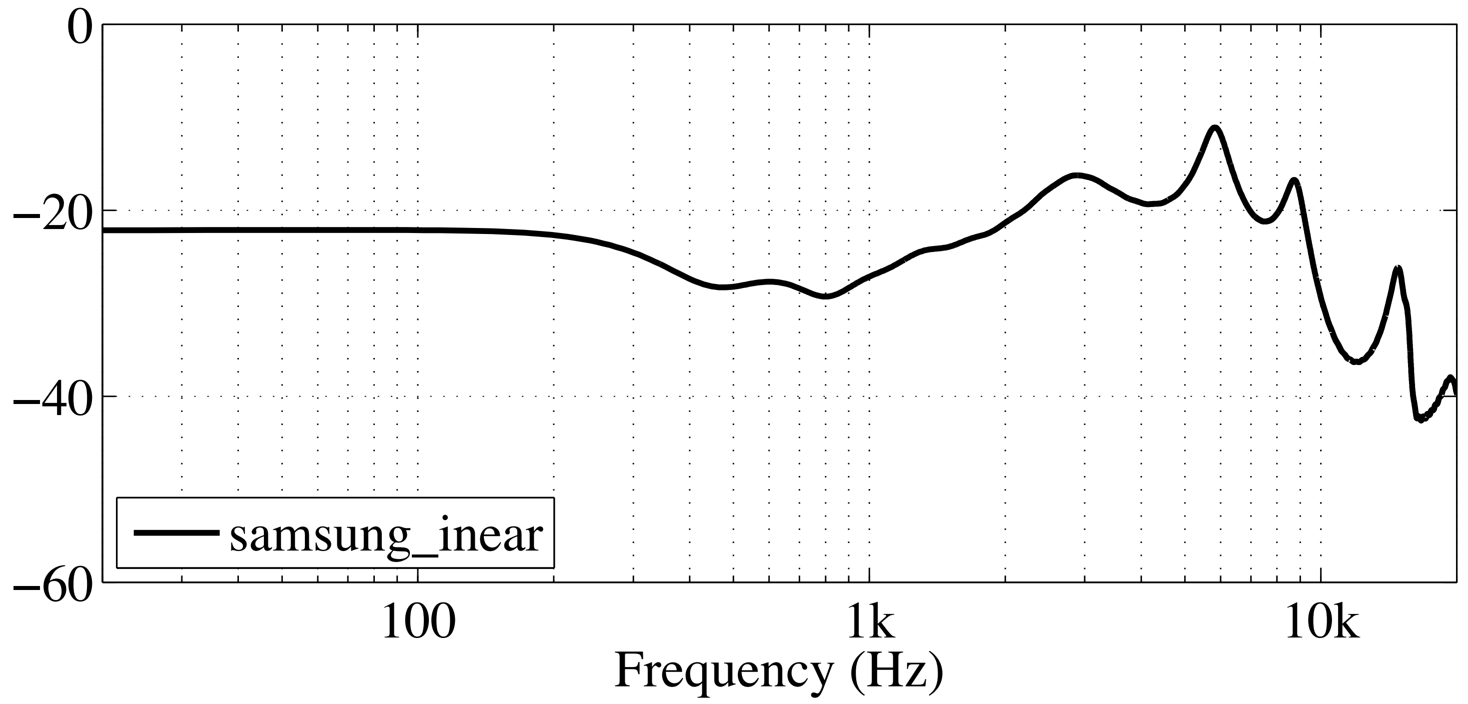
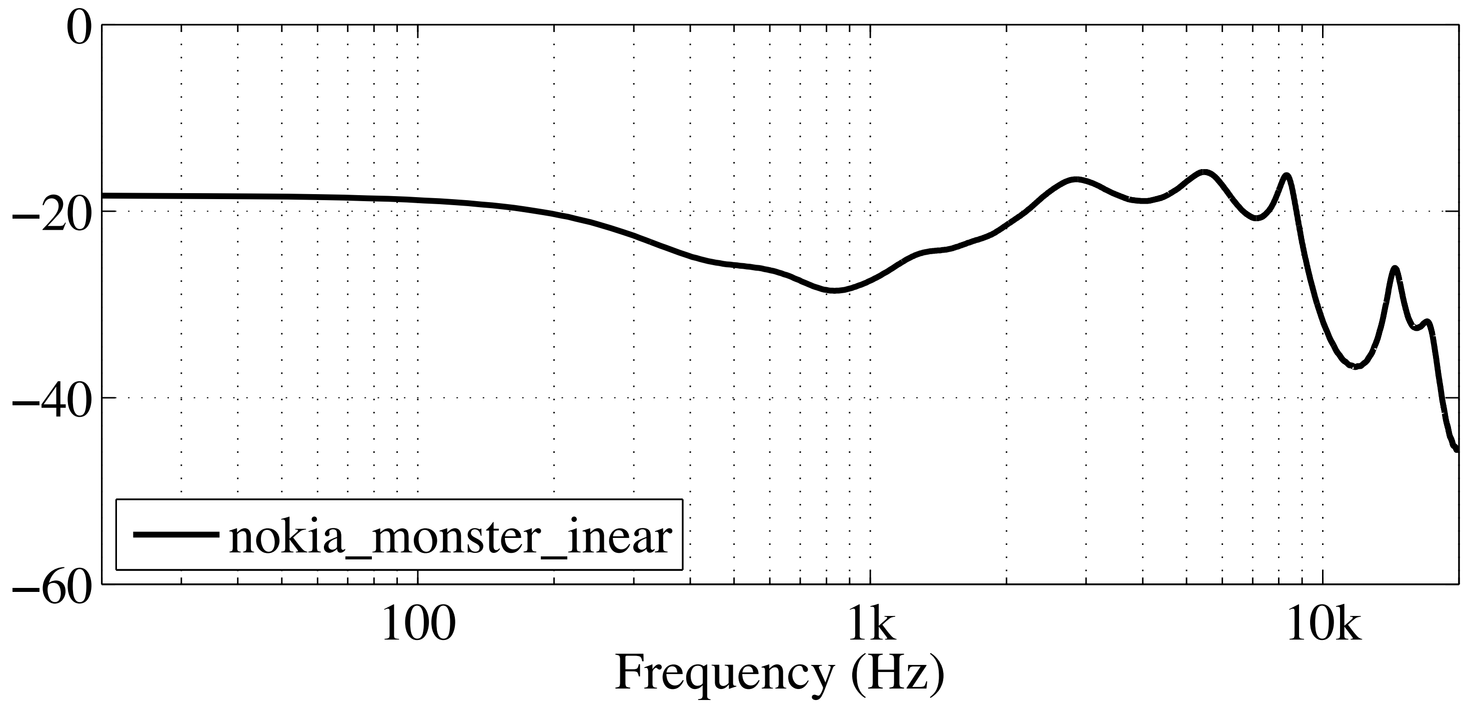
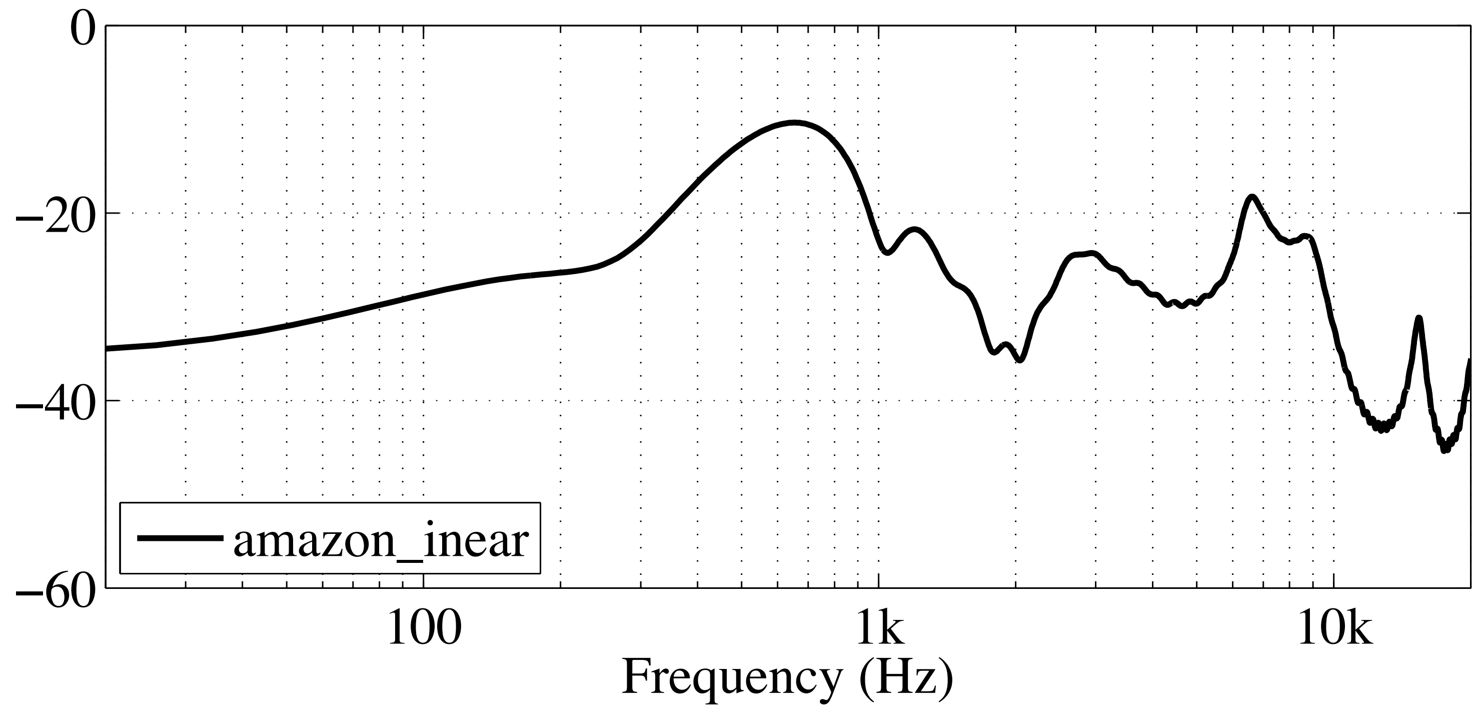
Measurements — In ear 2











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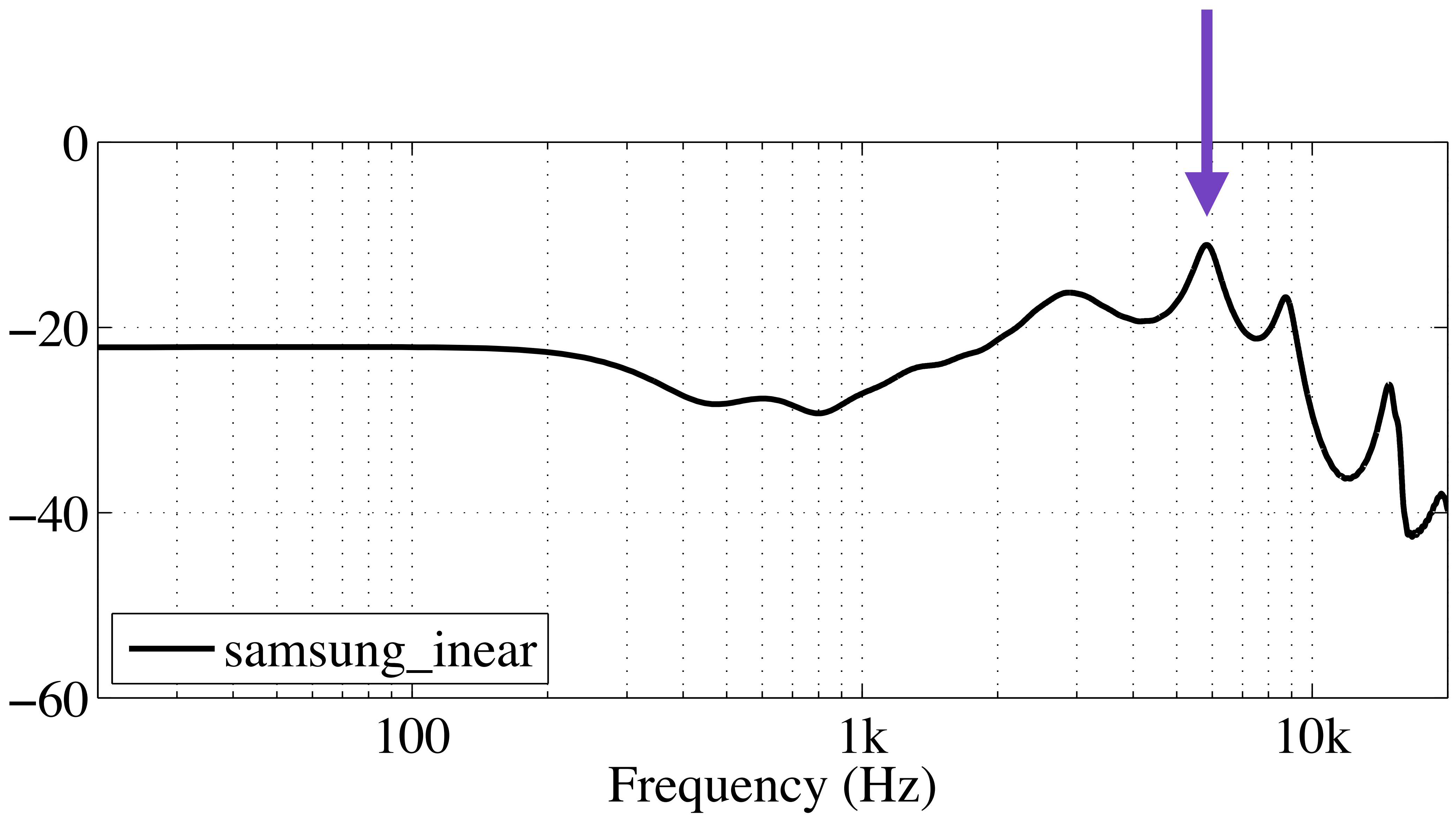
In-Ear Headphone Properties

Half wavelength resonator (Instead of a quarter wavelength)

- In-ear headphone closes the other end of the tube
  - Tube that is closed at both ends
- Acts as a half-wavelength resonator
  - Creates an **unnatural** half-wavelength resonance
  - Kills the **natural** quarter-wavelength resonance
    - Has to be reintroduced by design

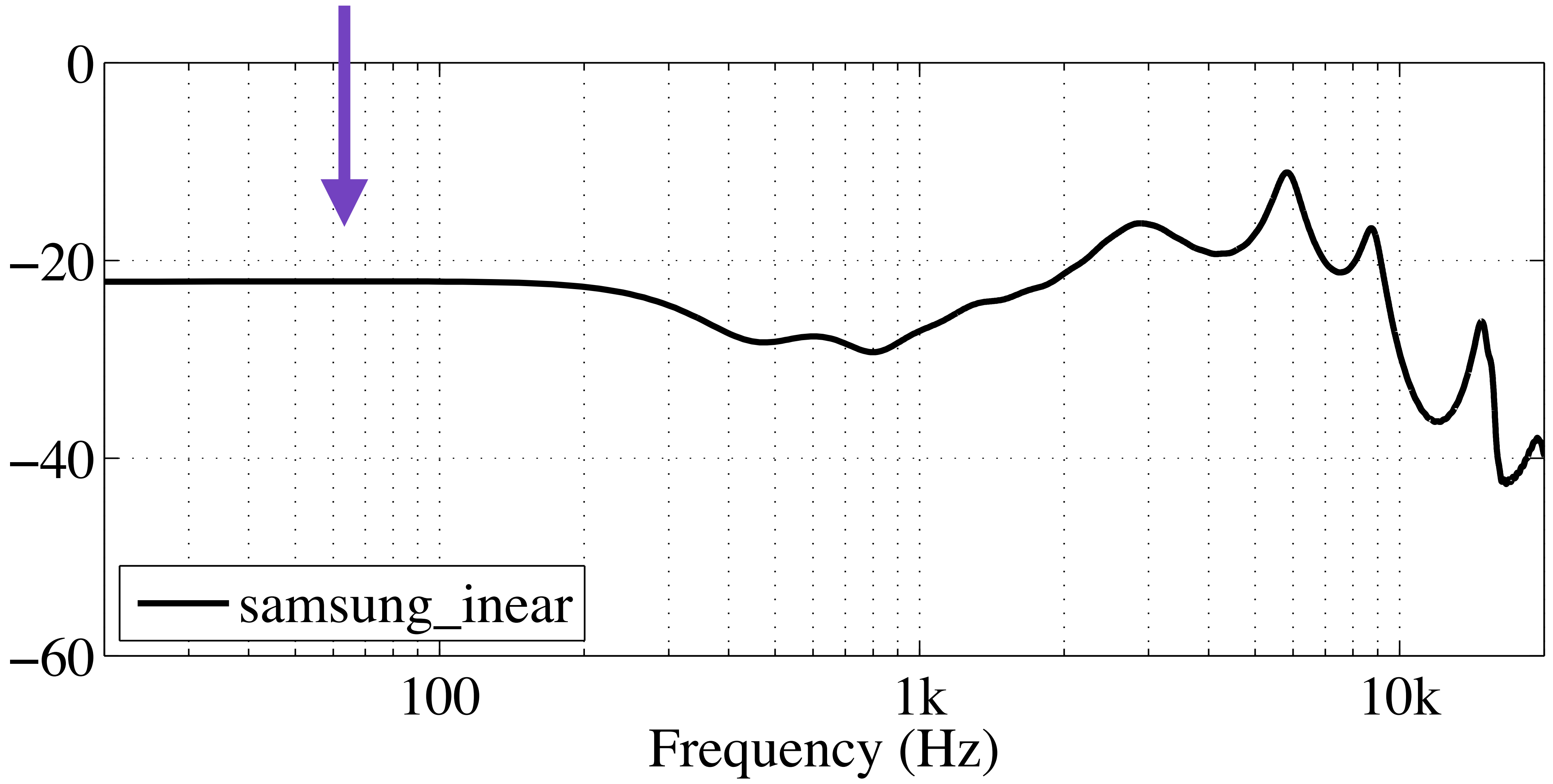


In-Ear Headphone Properties

Pressure Chamber Principle

- Affects low (and middle) frequencies in small, airtight enclosures.
- Headphone driver pumps the air inside the ear canal cavity producing a sound pressure proportional to the driver excursion.
- Sound pressure is distributed uniformly in the volume.

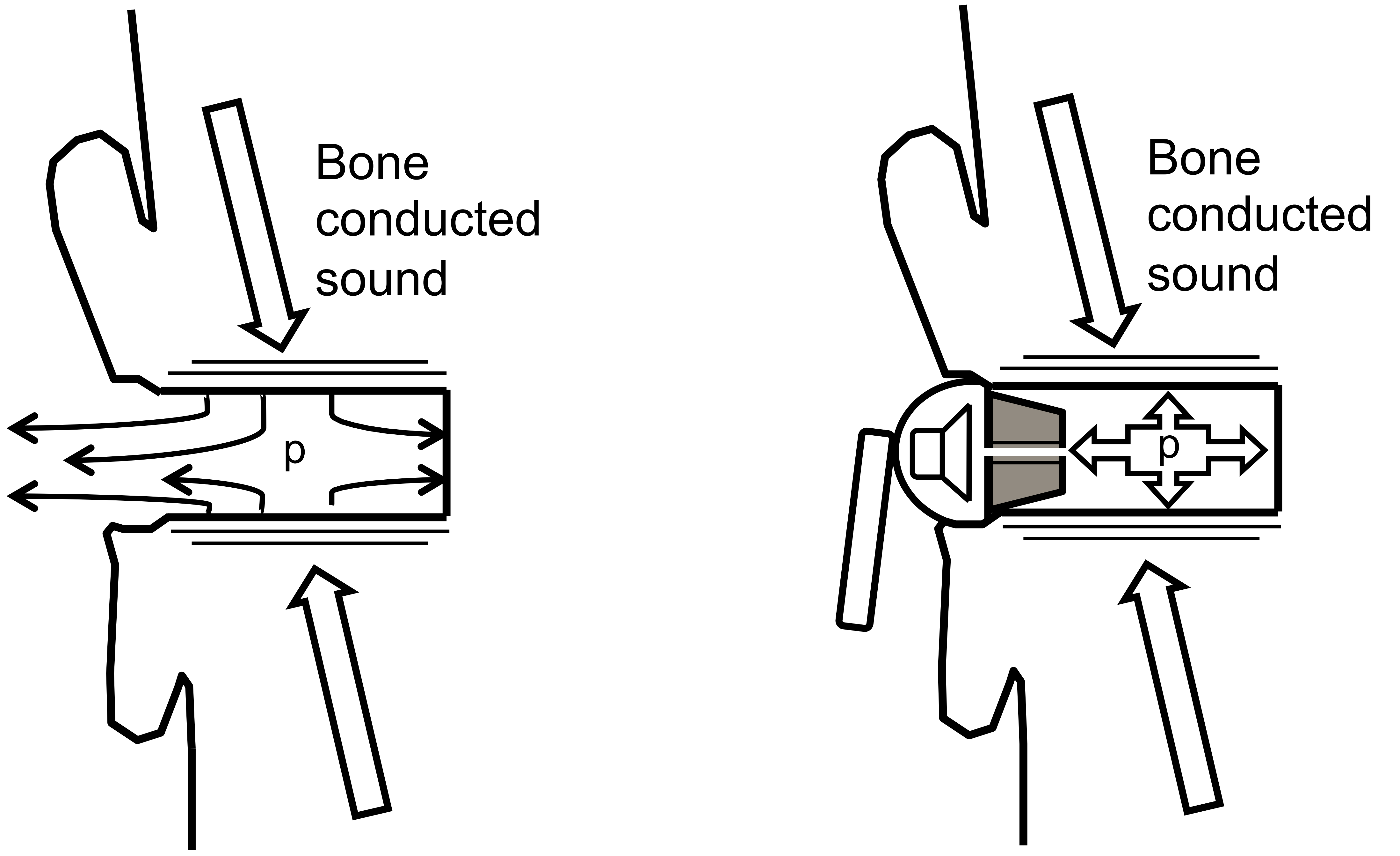
➡ High SPLs at low frequencies



In-Ear Headphone Properties

Occlusion Effect

- Refers to a situation where one's ears are blocked by headphones and their own voice sounds loud and hollow.
  - Due to the bone conducted sounds that are conveyed to the ear canals.
  - Headphone blocks airborne sound.
- The occlusion effect is experienced as annoying and unnatural.

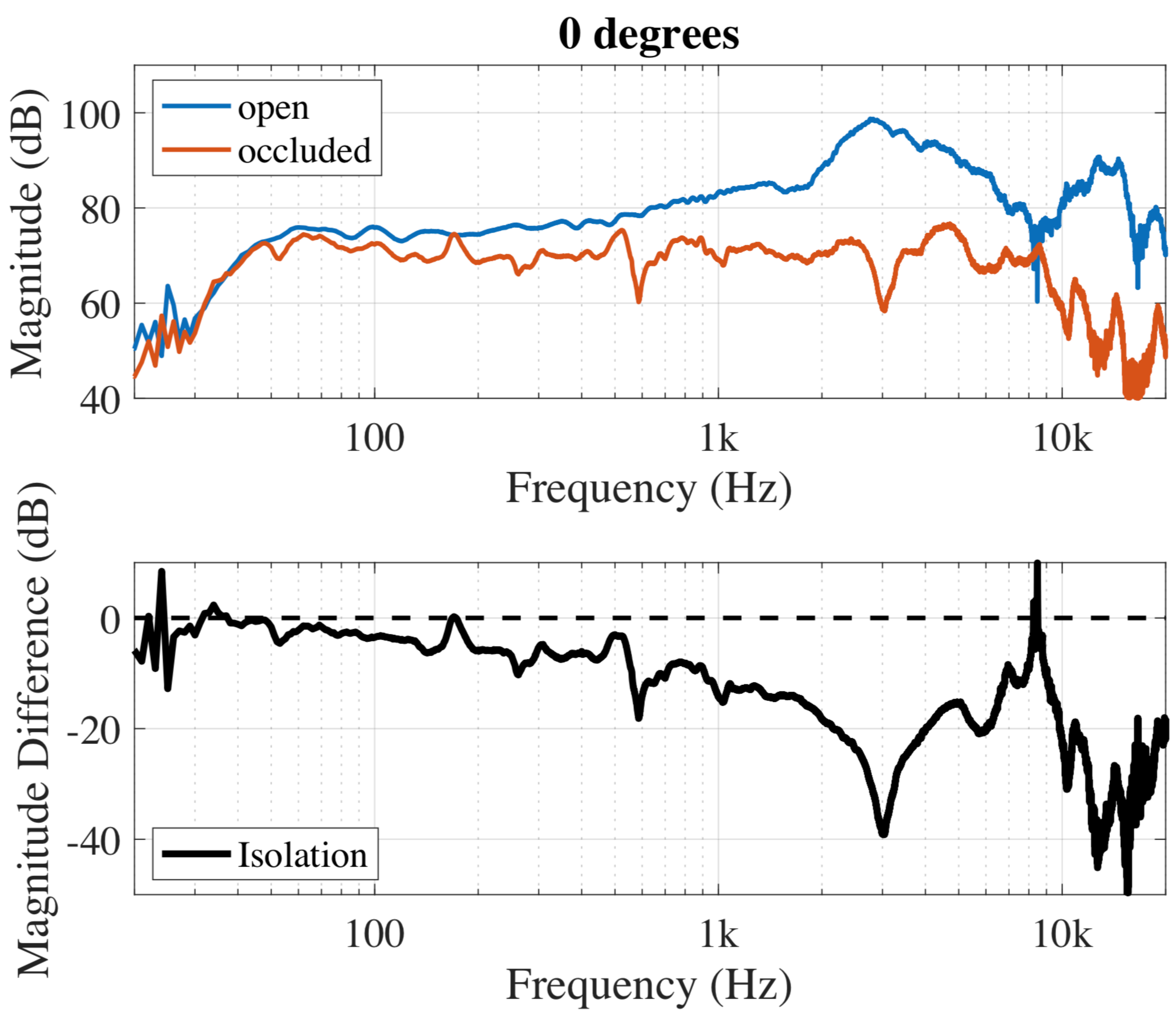


Measuring Isolation

The difference between the

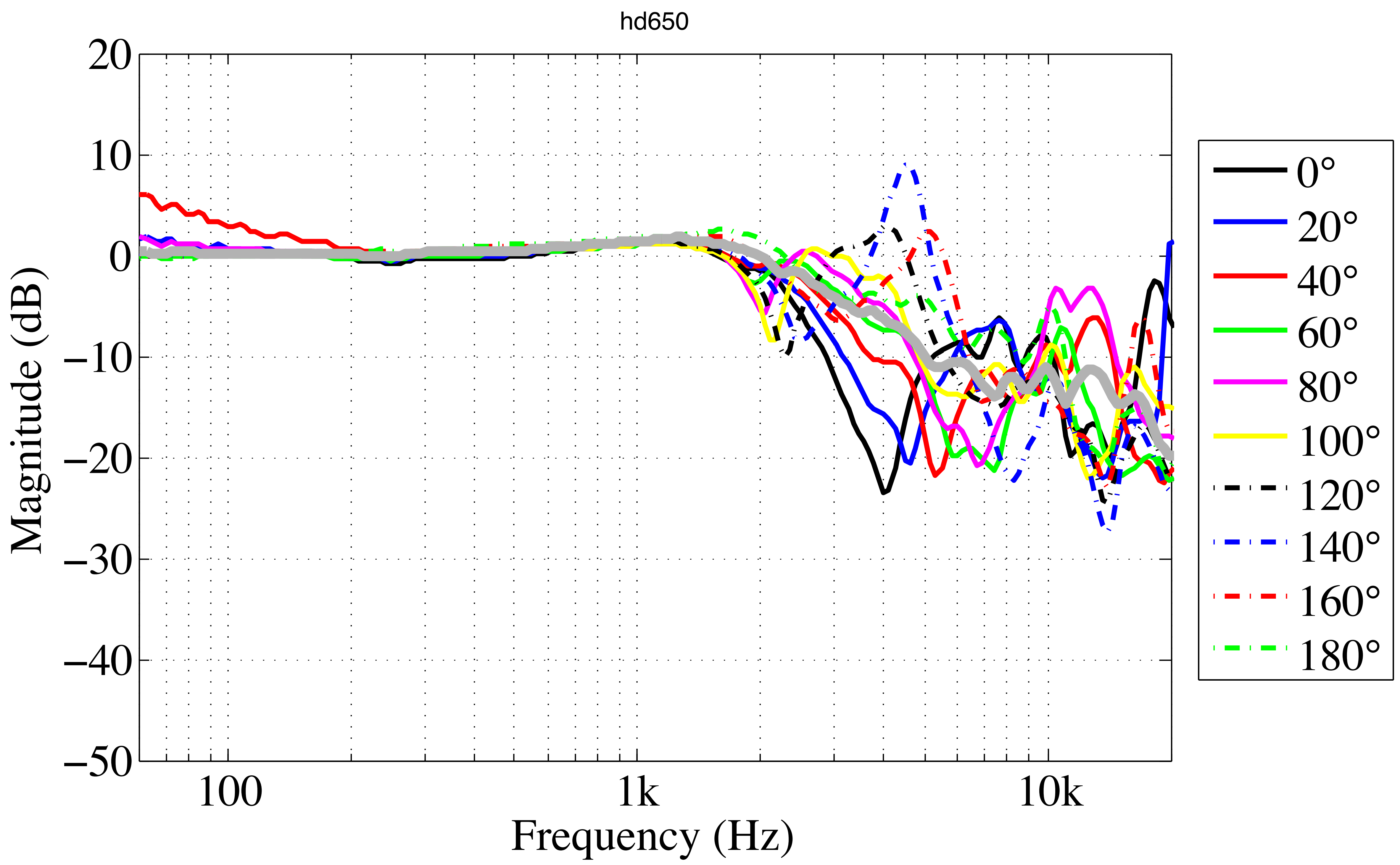
- **open ear** response, and
- the response when **wearing headphones,**

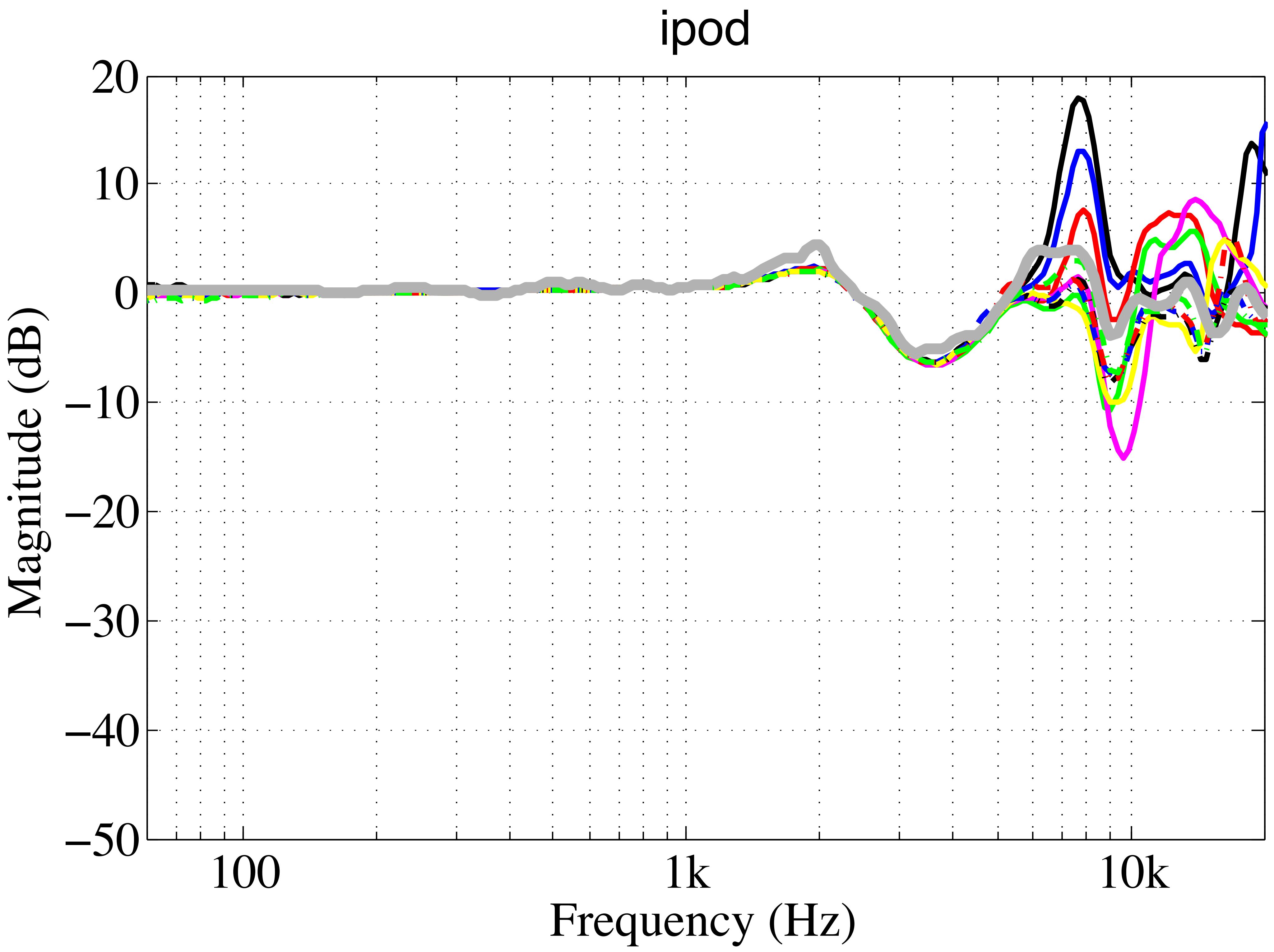
with external sound source.



Measuring Isolation

Isolation depends on the angle of the sound source





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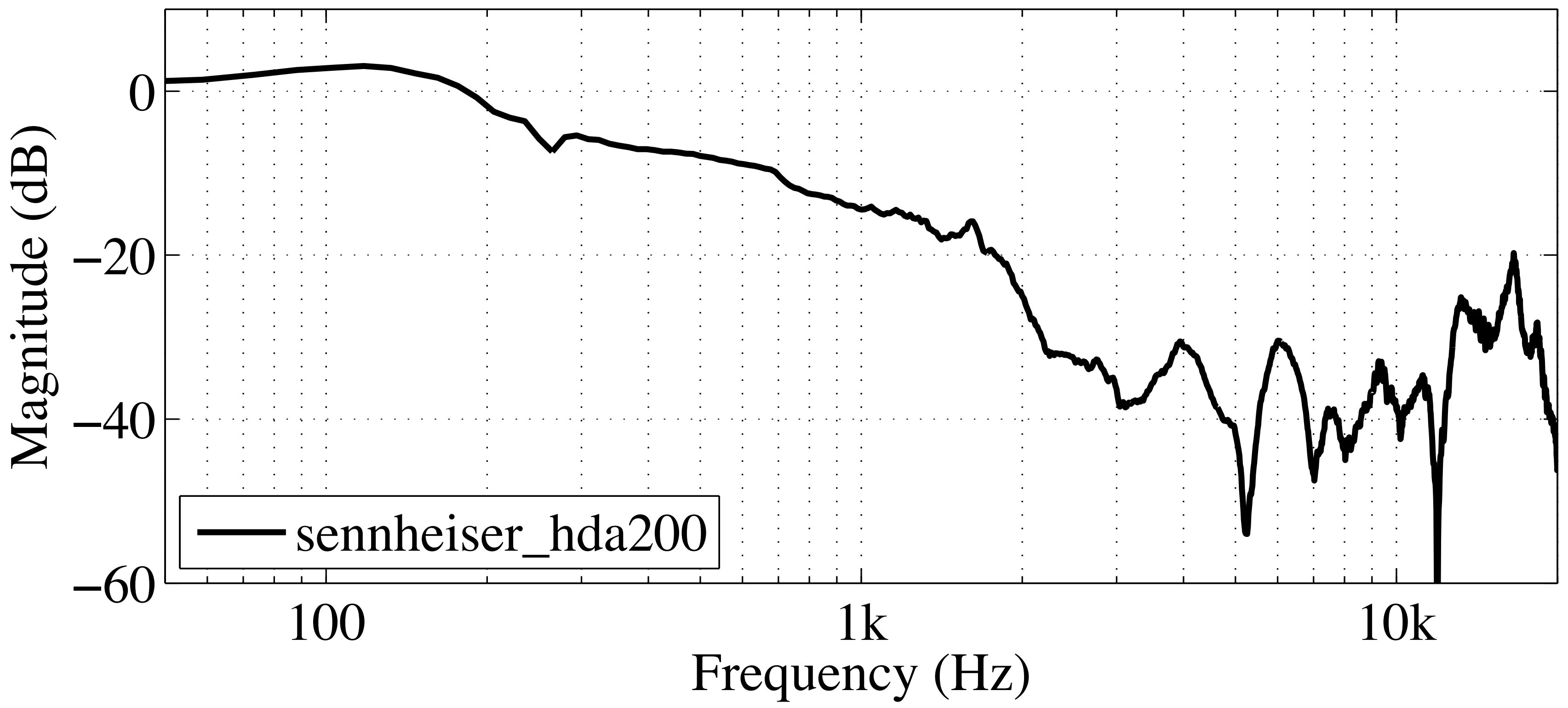
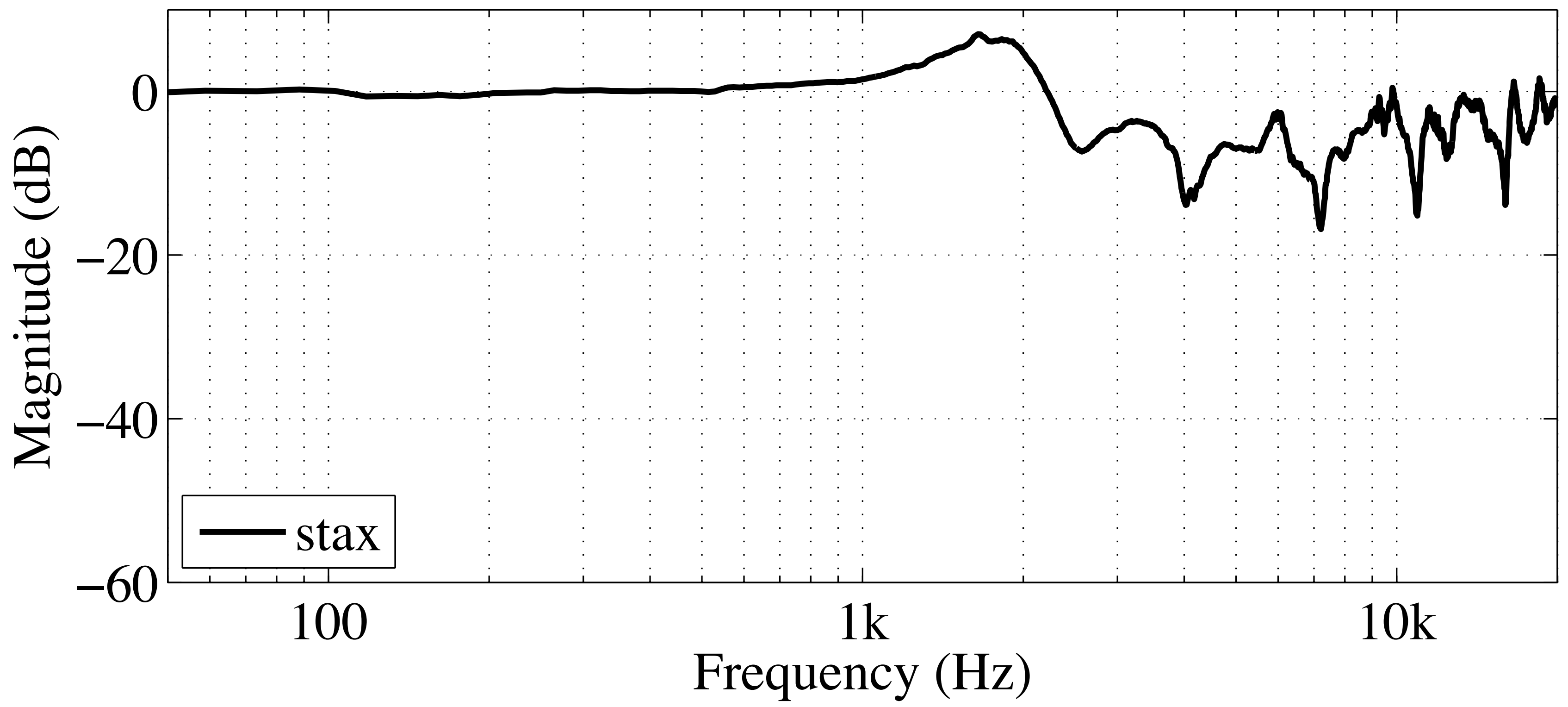
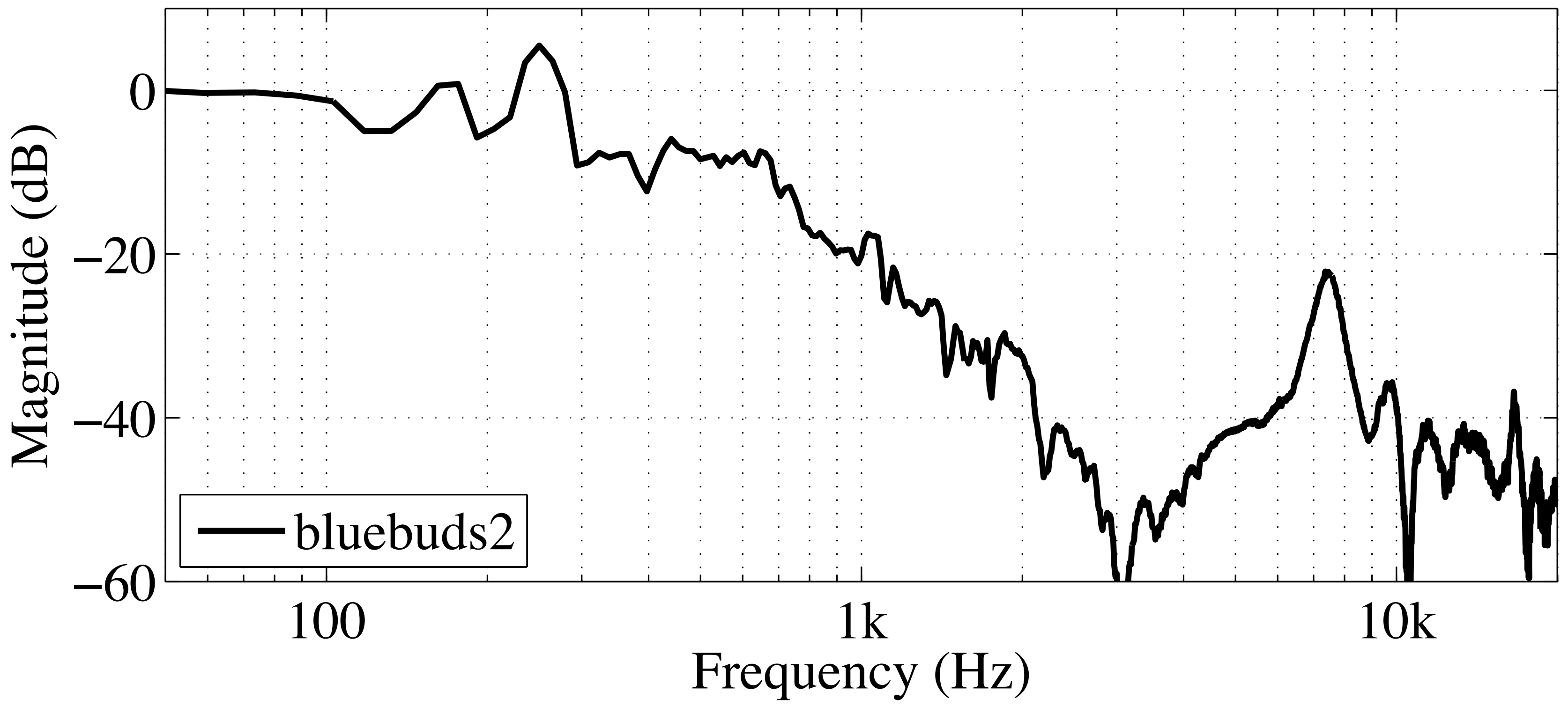
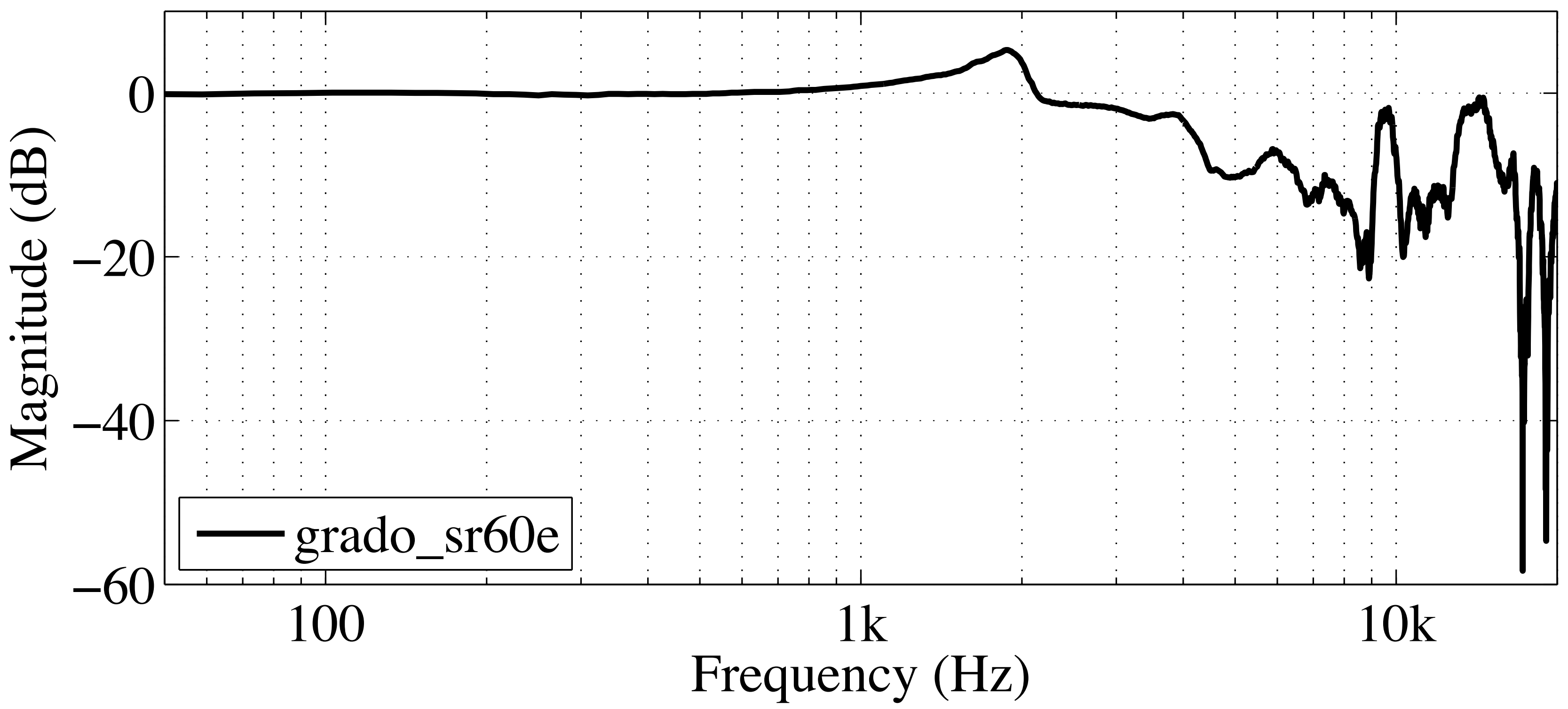
Isolation Measurements



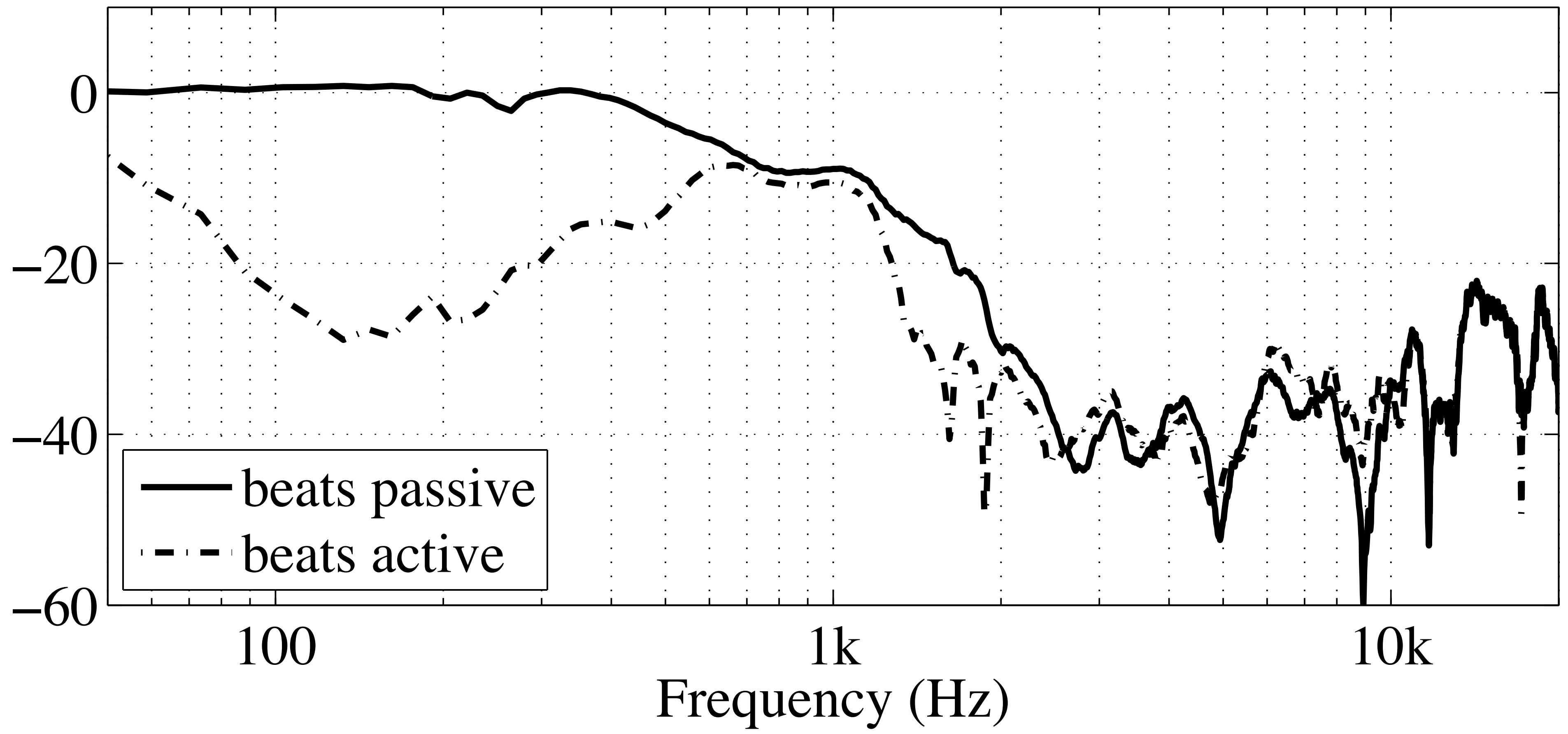


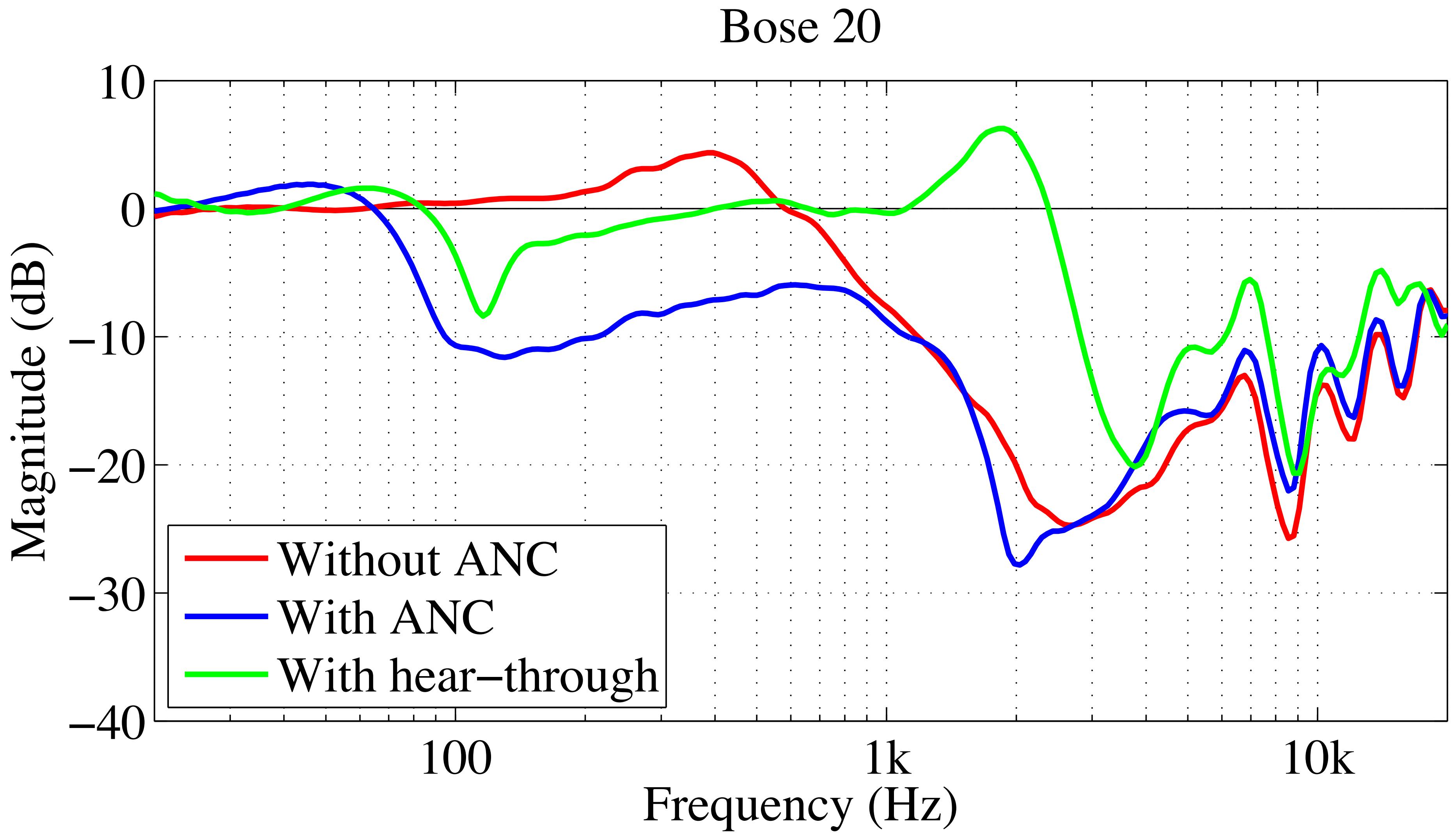


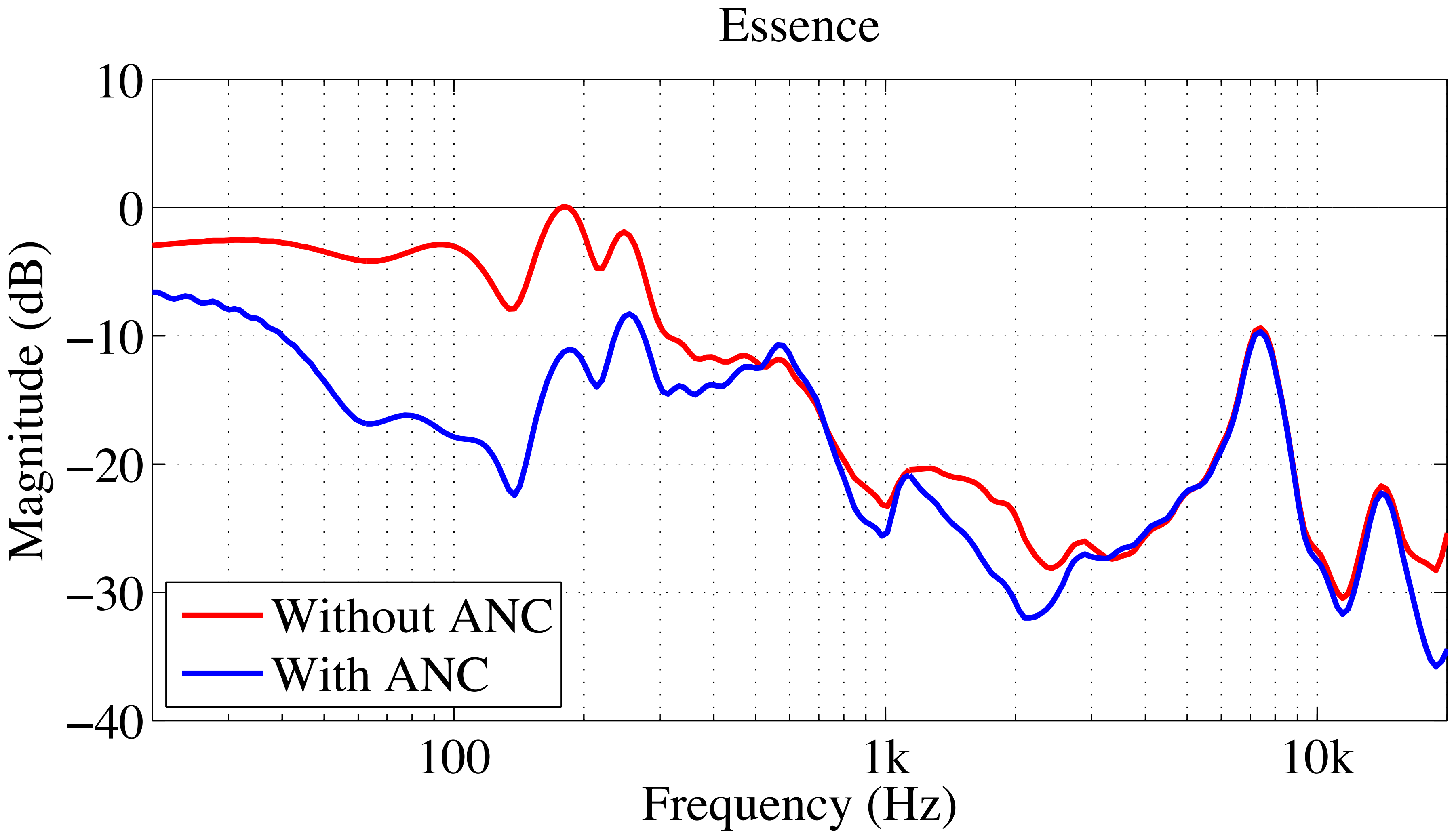


Measured with a sine sweep (loudspeaker at 40°)

Isolation — ANC







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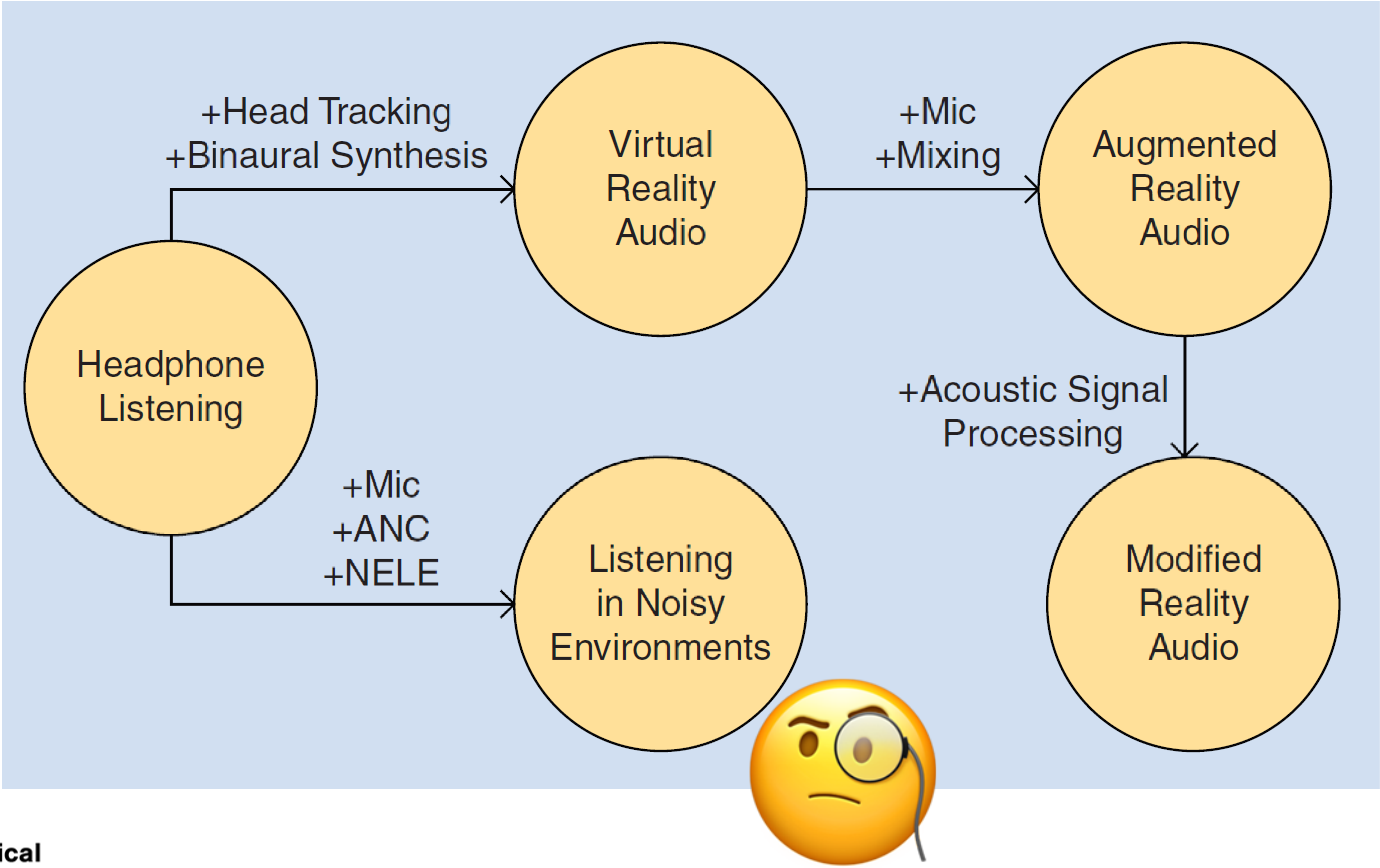
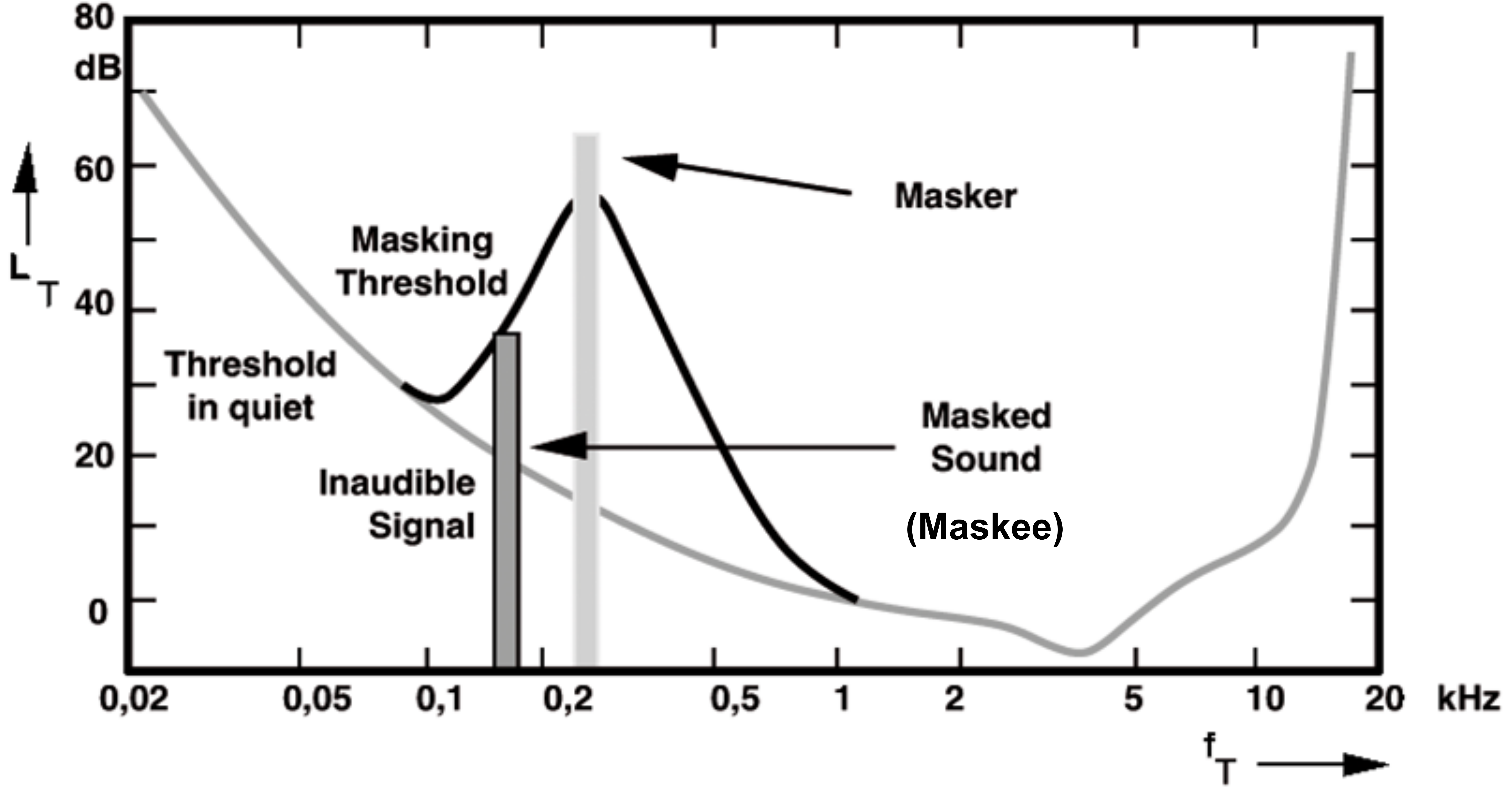
Use Cases for Headphones



Auditory Masking



Auditory Masking

Masking occurs when one sound affects the perceived loudness of another sound

- Masking threshold is the SPL of a maskee necessary to be just audible in the presence of a masker.
- Masker can hide the maskee completely or partially
  - Partial masking reduces the loudness of a target sound, but does not mask it to be inaudible.
- Usually evaluated using critical bands (Bark, ERB).

Magnitudes and Isolations

Sennheiser HD 650

Nokia WH-500

iPhone (old)

Sennheiser CX300

Music

Noise

Music +
Noise

Headphone Simulation in Noise

- The ambient noise isolation capability of headphones has become an important design feature,
  - mobile usage of headphones takes place in noisy listening environments.
- Auditory experience achieved with a certain pair of headphones cannot be evaluated solely by listening to the headphones in a quiet environment.

Audio Engineering Society

Convention Paper

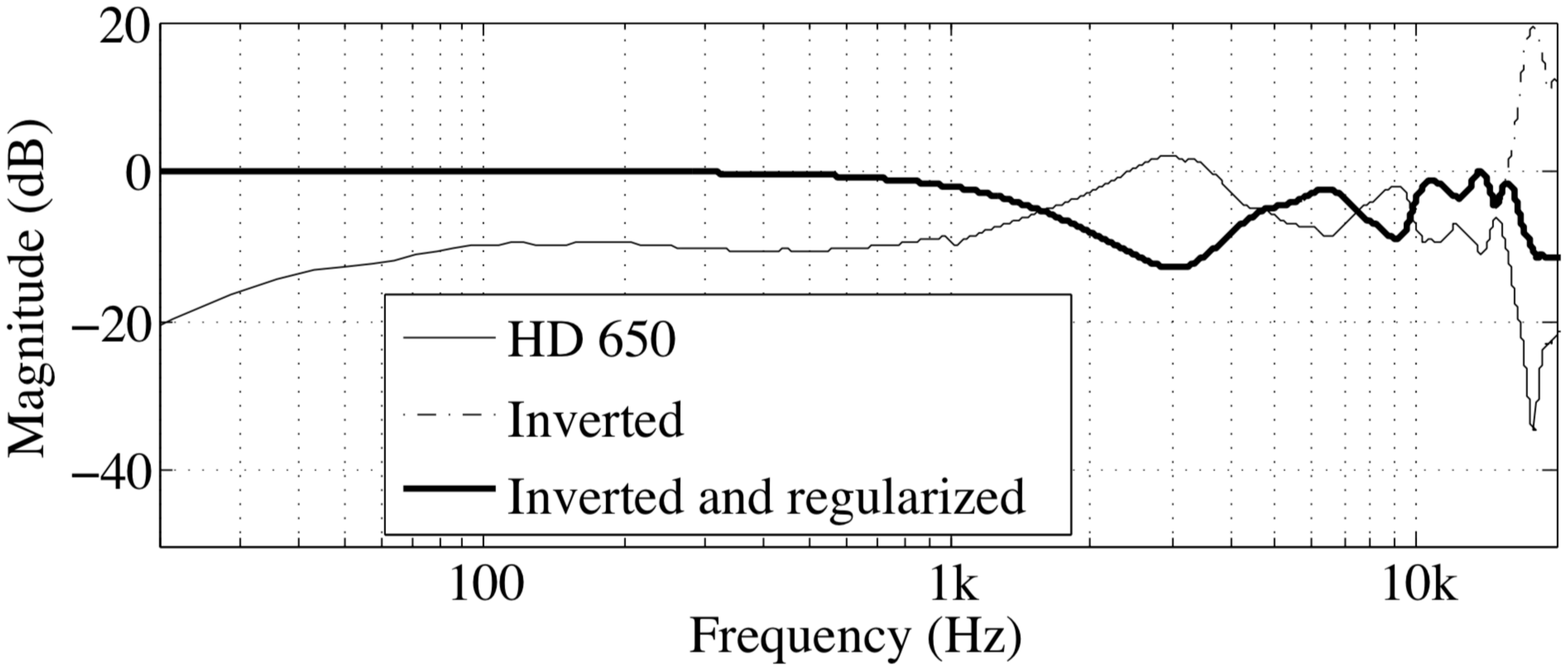
Presented at the 132nd Convention
2012 April 26–29 Budapest, Hungary

Signal Processing Framework for Virtual Headphone Listening Tests in a Noisy Environment

Jussi Rämö[1] and Vesa Välimäki[1]

Headphone Simulation in Noise

HD650 were equalized to have a flat magnitude response at DRP



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Signal Processing Framework for Virtual Headphone Listening Tests in a Noisy Environment

Jussi Rämö[1] and Vesa Välimäki[1]

Perceived Response in Noise

- Real-time simulator illustrating how background noise alters the timbre of music in the presence of noise.
- Based on auditory masking models and isolation capabilities of different headphones.
  - Masking threshold estimation
  - Partial masking estimation
- Components of the music that are masked are suppressed.

AES 45TH INTERNATIONAL CONFERENCE, Helsinki, Finland, 2012 March 1–4

Perceptual Frequency Response Simulator for Music in Noisy Environments

Jussi Rämö[1], Vesa Välimäki[1], Mikko Alanko[1], and Miikka Tikander[2]

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Correspondence should be addressed to Jussi Rämö (jussi.ramo@aalto.fi)

ABSTRACT

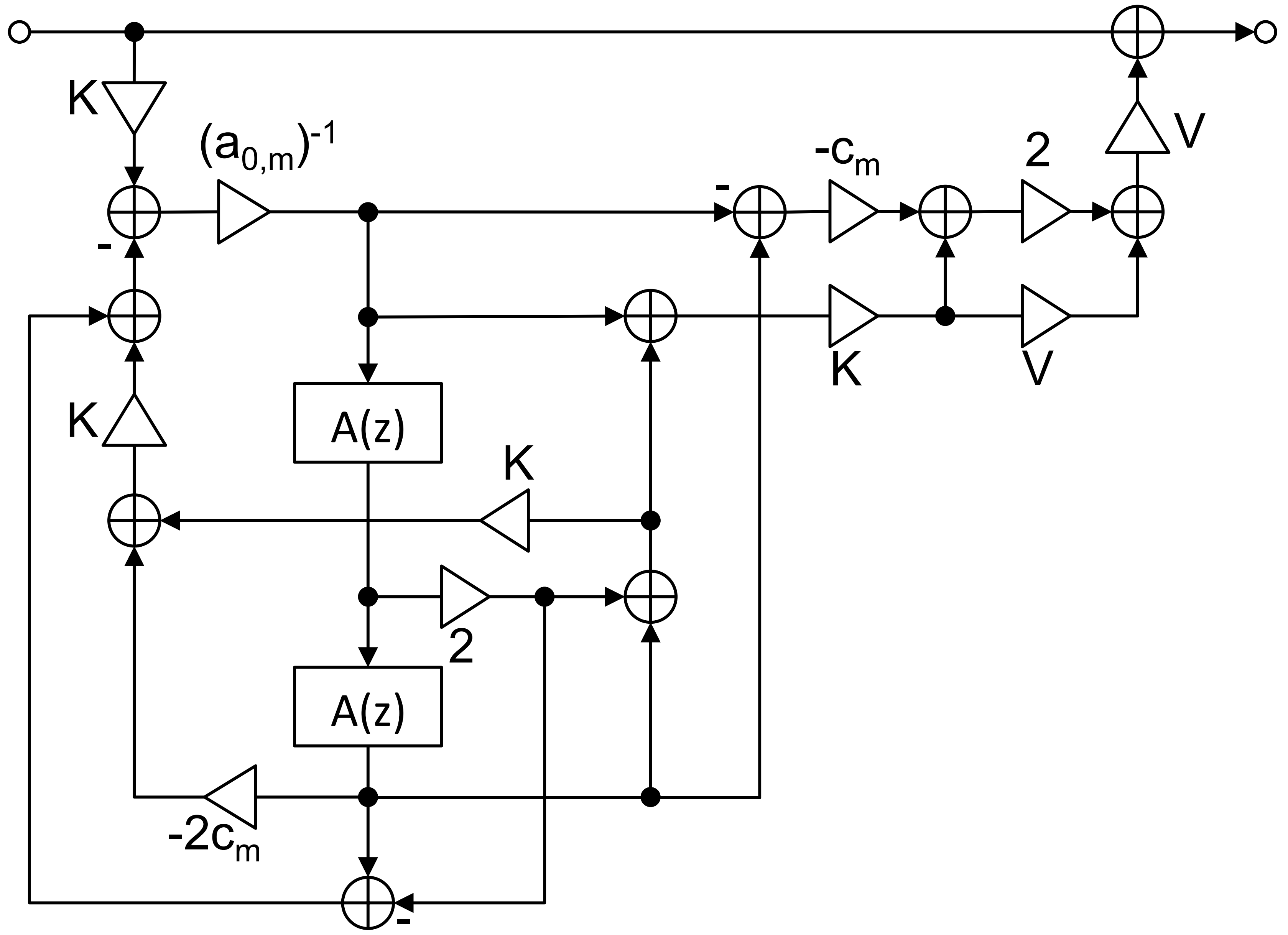
A perceptual simulator for music in noisy environments is described. The listening environments where people use their headphones have changed from quiet indoor environments to more noisy outdoor environments. The perceptual simulator utilizes auditory masking models and the isolation capabilities of different headphones to simulate the auditory masking phenomenon. A real-time demonstrator using Matlab and Playrec was implemented, which illustrates how the background noise alters the timbre of the music. It can be used with either headphones or loudspeakers. Informal listening tests showed that the simulator is operating correctly in most cases. However, when there is great amount of energy at the lowest frequencies of the background noise, the masking threshold is predicted to be too high.

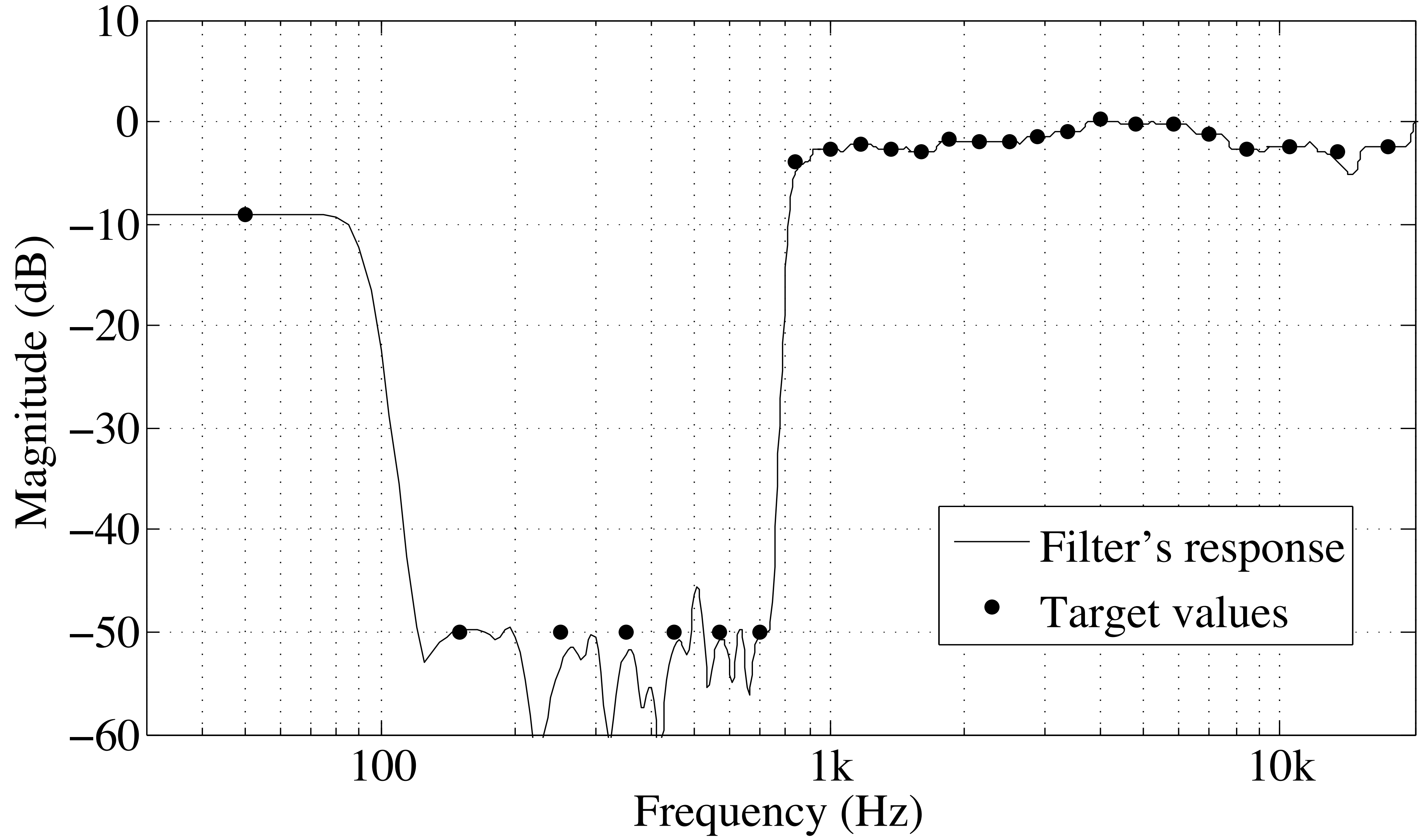
Perceived Response in Noise

Implemented with a high-order graphic equalizer

- 3 cascaded 4th-order sections for each critical band

4th-order section

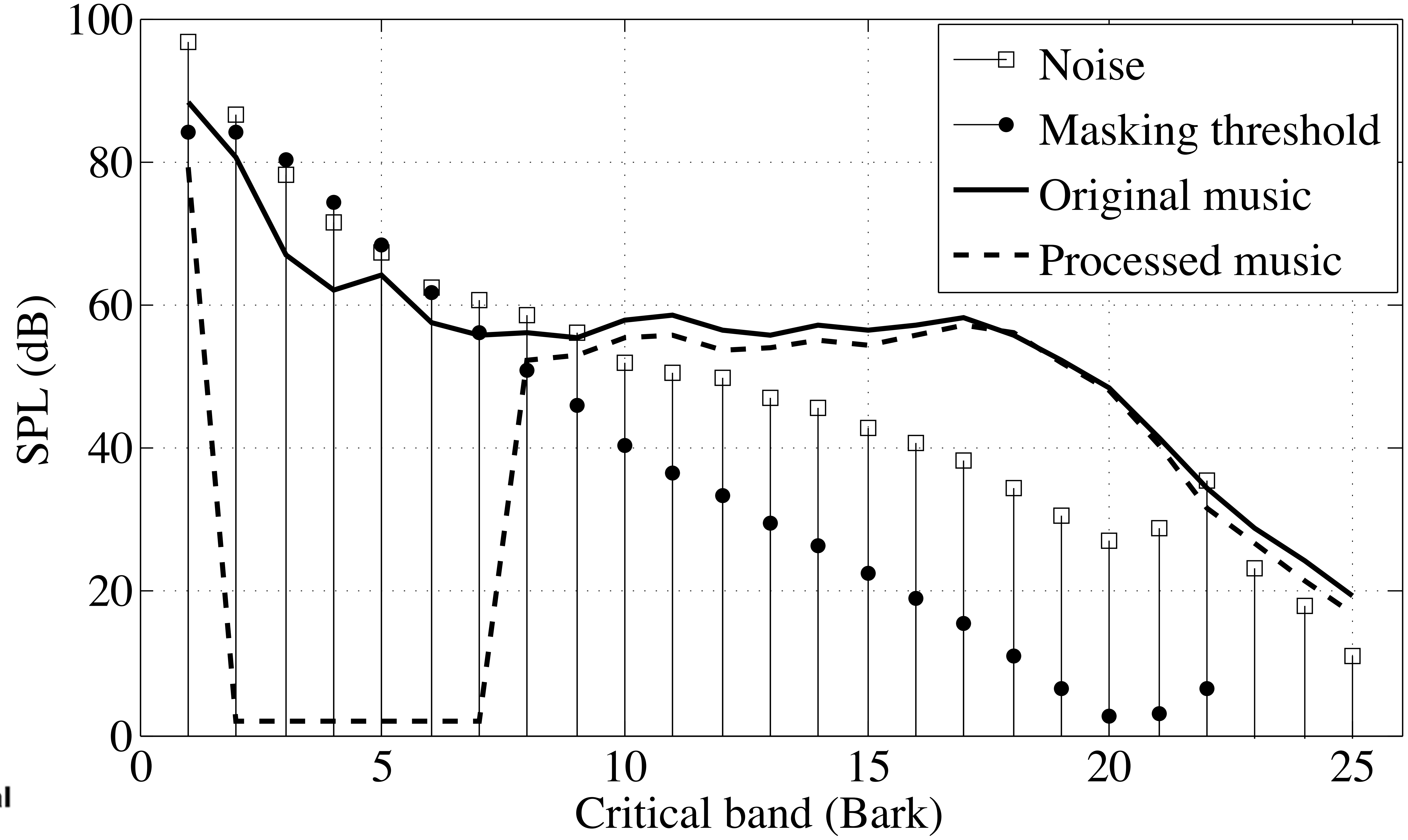




Perceived Response in Noise

Example analysis of a 200 ms frame

Original music

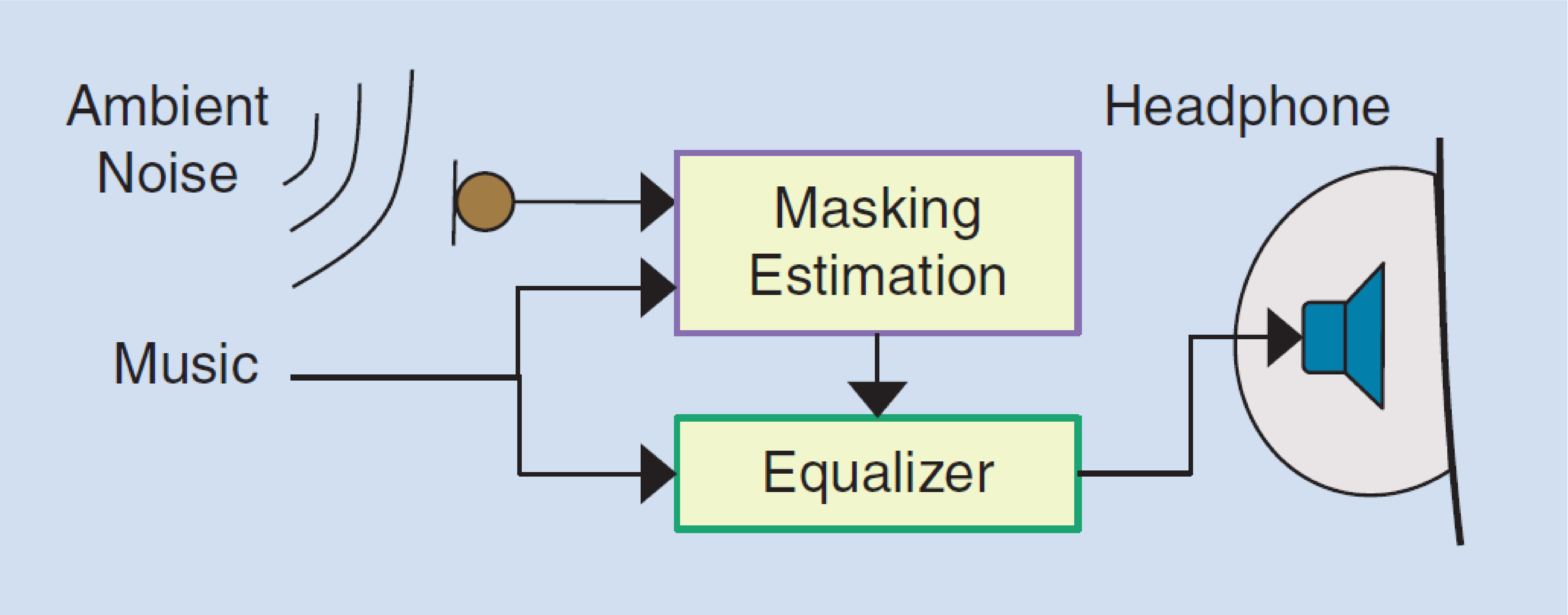


In-ear

Intra-
concha

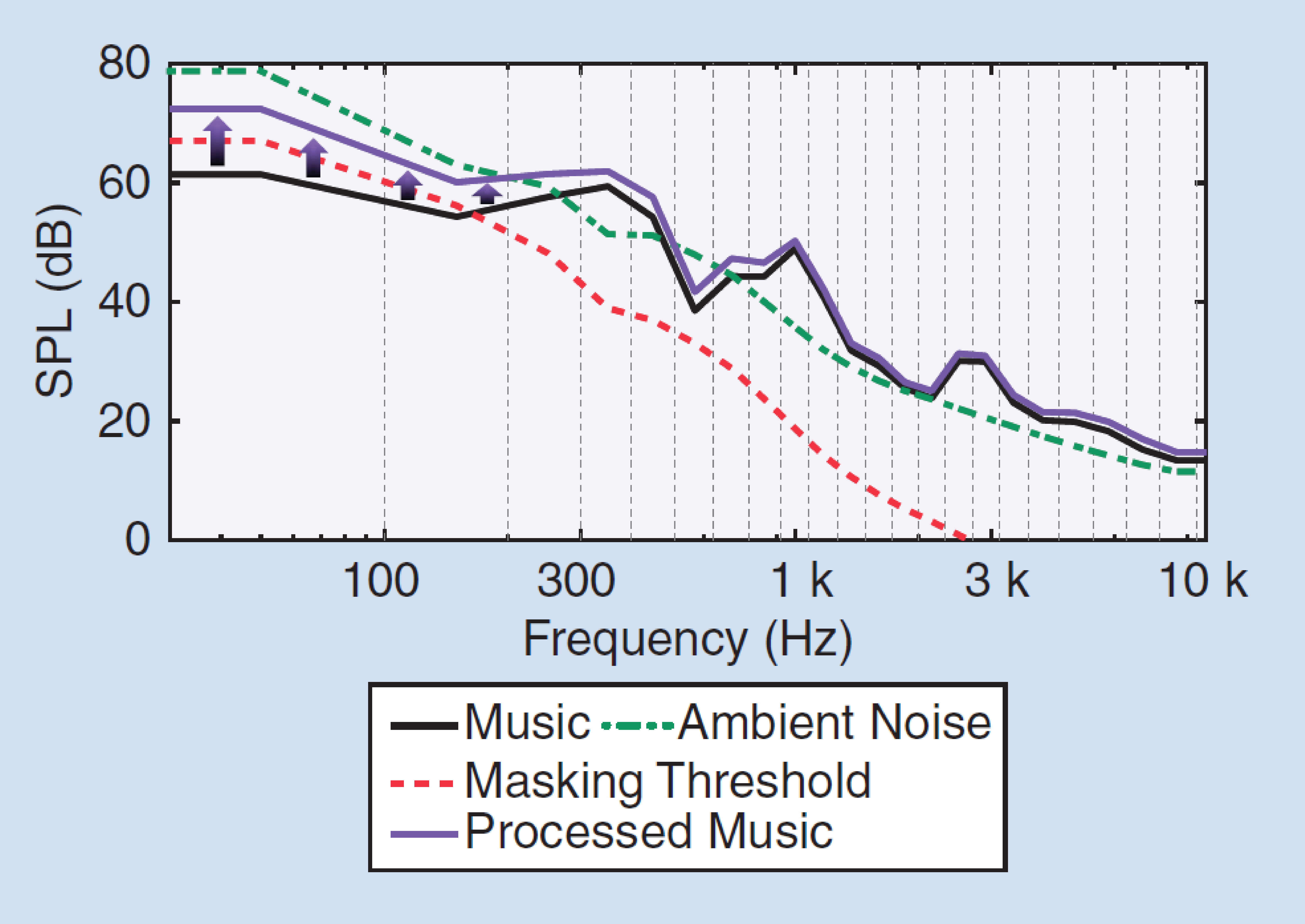
Perceptual EQ

Perceptual Headphone Equalization for unmasking music in noisy listening environments.



Ref. Rämö et al. ICASSP 2013, Vancouver, Canada

Perceptual EQ



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