Aalto University
School of Electrical
Engineering

CS-E5530 Virtual Acoustics
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Audio Augmented Reality

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Augmented Reality vs. Virtual Reality

AUGMENTED REALITY (AR)

- An **enhanced version of reality** created by the use of technology to overlay digital information on an *image* of something being *viewed* through a device.

VIRTUAL REALITY (VR)

- An **artificial environment** which is experienced through sensory stimuli (such as sights and **sounds**) provided by a computer.

Merriam-Webster

Augment: Make something greater by adding to it.

Augmented Reality vs. Virtual Reality

AUGMENTED REALITY

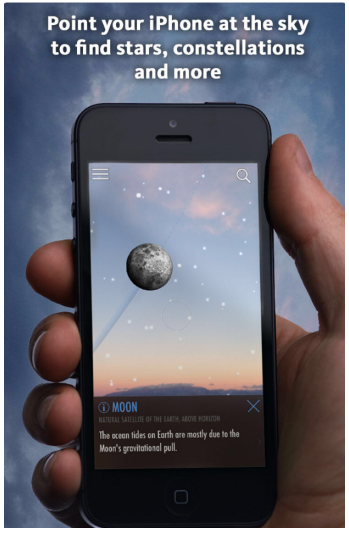
Terminator 2, 1991

VIRTUAL REALITY

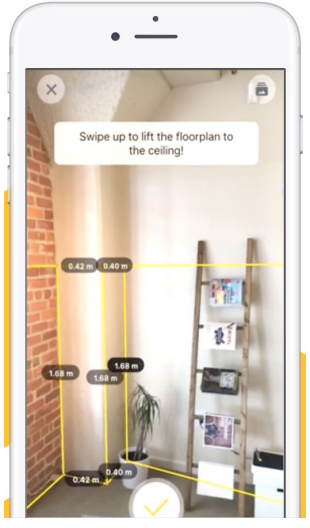
View Master, 1960s

Augmented Reality vs. Virtual Reality

AUGMENTED REALITY



SkyView



TapMeasure

Pokemon

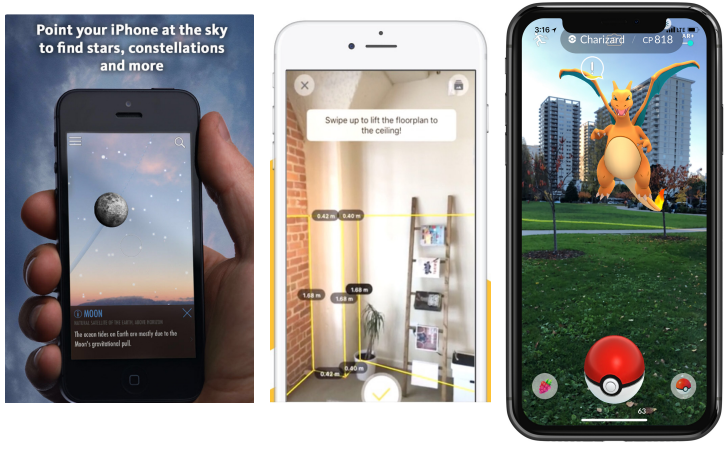
VIRTUAL REALITY

Oculus Rift

Augmented Reality

In screen-based AR applications, sound is rarely important

- In games, sound can change with the environment.
- When you get closer, sound gets louder
- Not what we mean by
  audio augmented reality (AAR)



Audio Augmented Reality (AAR)

AUGMENTED REALITY (AR)

- An **enhanced version of reality** created by the use of technology to overlay digital information on a sound of something being listened to through a device.

AUDIO AUGMENTED REALITY

- You need to hear the real sound environment around you!
  - *In real time*
  - *Perceptually unchanged*

➢ Add audio events on top of the real world sound environment

Audio Augmented Reality (AAR)

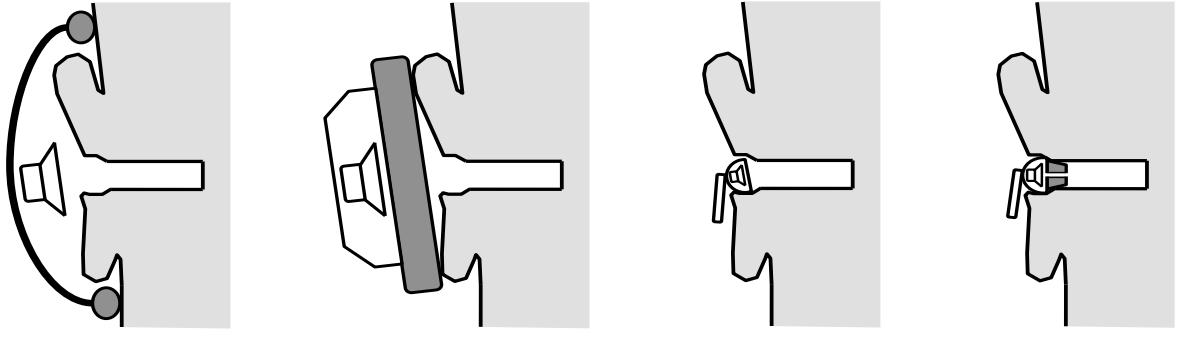
- Combines virtual sound sources with the real sound environment.
  - Sounds can be blended in or separated from the real world.
- Can be realized with a set of headphones containing binaural microphones.
  - Microphones capture the real world sounds.
    - *Also possible with bone-conducting headphones or with loudspeakers, no microphones needed.*

- Ideally, the headset should be acoustically transparent.
  - Surrounding environments should sound the same with and without headphones.

Headphones

Listening to headphones vs. listening to loudspeakers

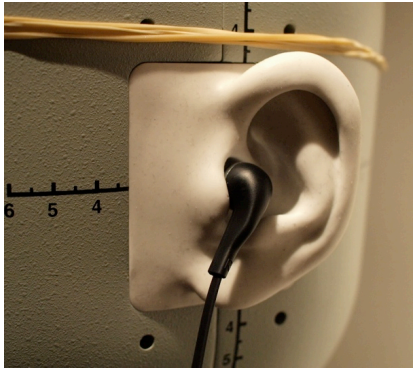
- Effects of the environment and the listener's body are lost,
- Almost perfect channel separation,
- Isolates the listener from their surroundings.
  - *More personal and less social*

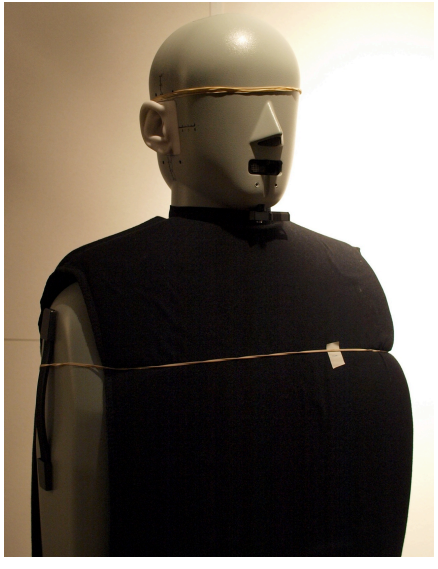


Circum-aural Supra-aural Intra-concha In-ear

Measuring Headphones

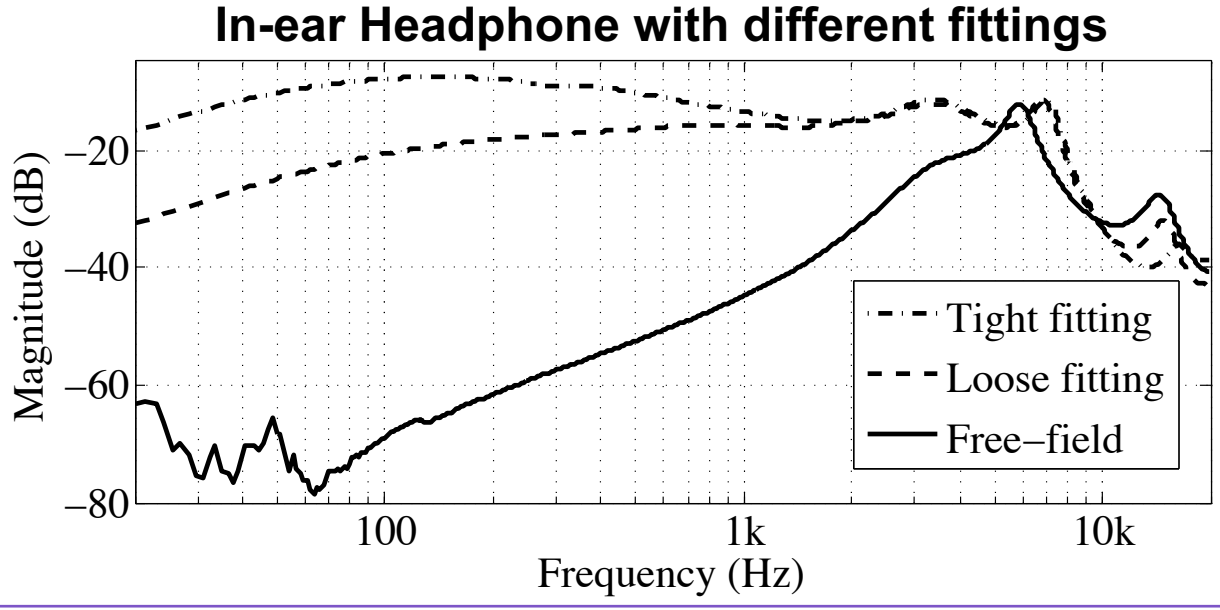
- Headphones are measured using a coupler, such as a dummy head or an ear canal simulator
  - Simulates the acoustical properties of a real ear
  - Microphone at the ear drum position





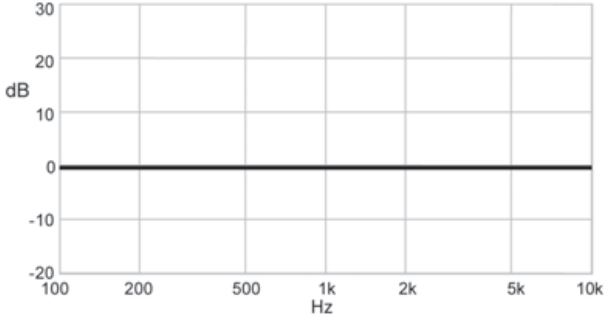
Measuring Headphones

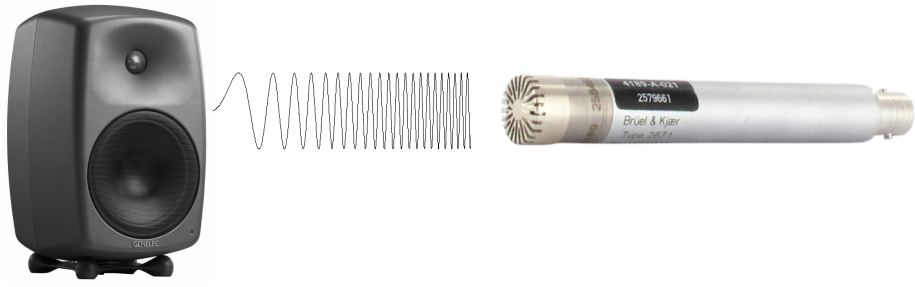
- Correct fitting of the headphone is important.



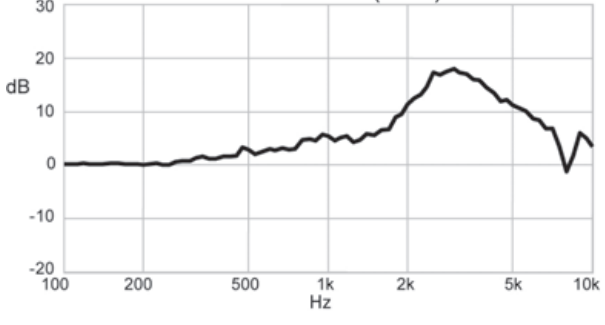
Headphones – Magnitude Response

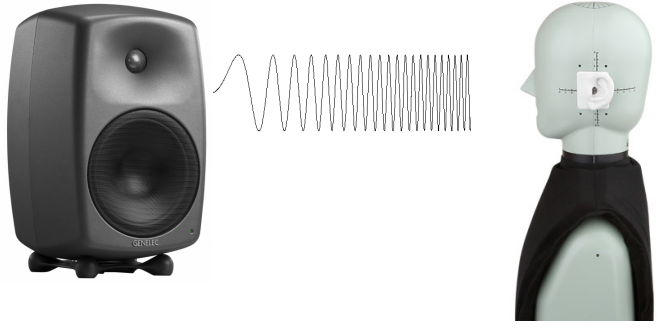
a) Ideal Free Field Pressure Response of Loudspeaker Measured on-axis with Microphone





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





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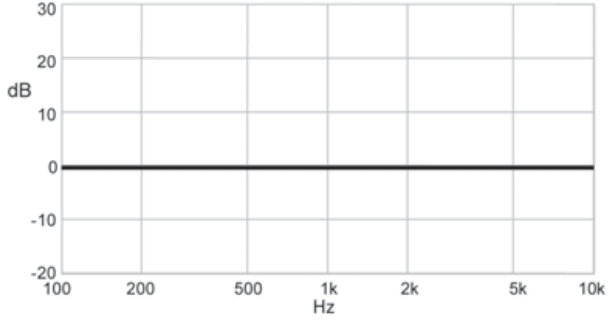

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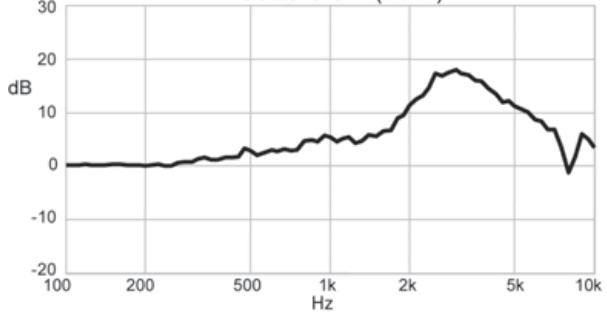

- Ideal free field (anechoic) response of a loudspeaker is flat.
  - All frequencies are reproduced equally loud
- Ideal loudspeaker response measured at the ear drum
  - Includes the effects of torso, head, pinna, and ear canal of a dummy head.

Headphones – Magnitude Response

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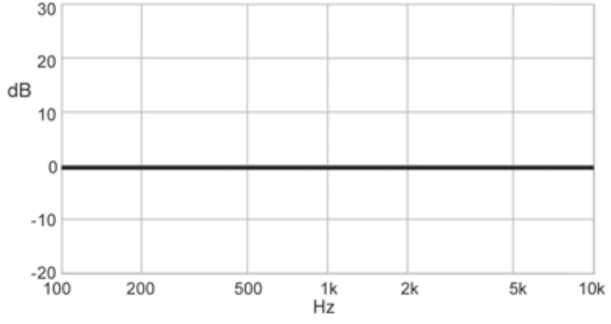

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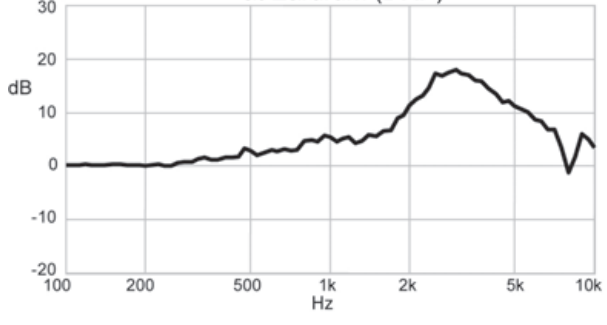
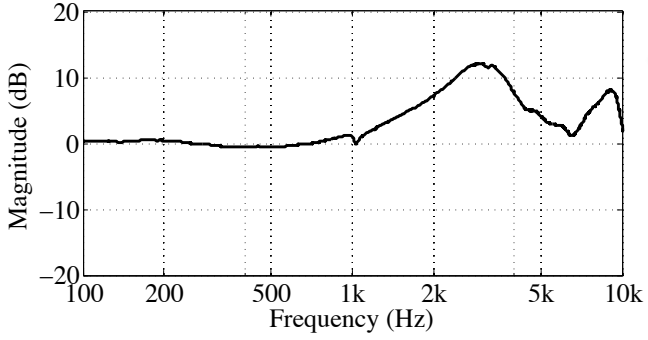


In order for a headphone to sound like an ideal loudspeaker, the magnitude response at the ear drum should look like Fig. b)

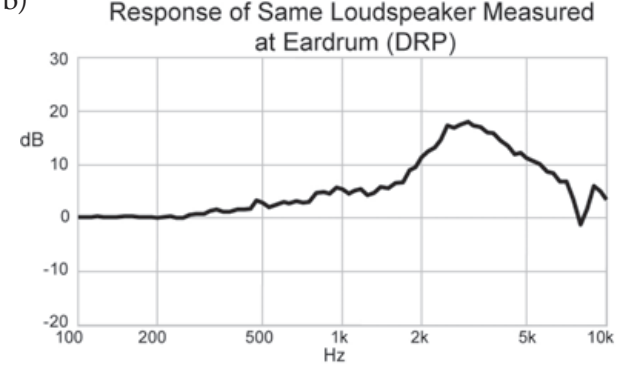
Headphones – Magnitude Response



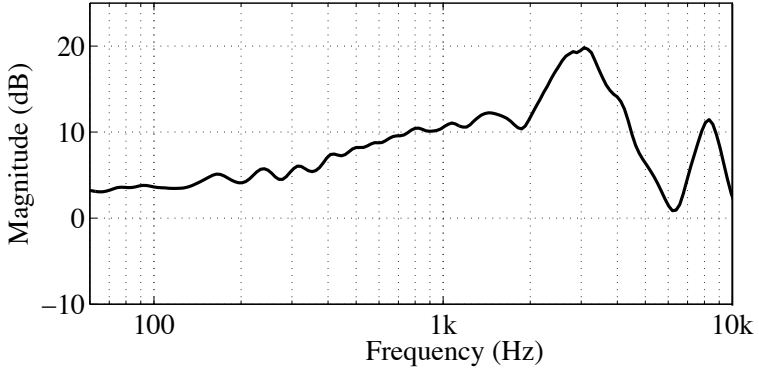
Sennheiser HD 650

measured using a dummy head

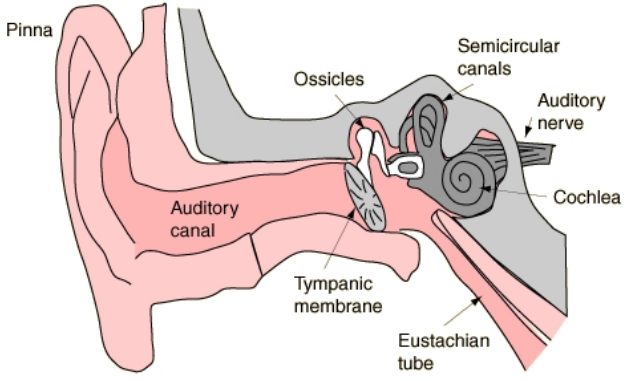
b)

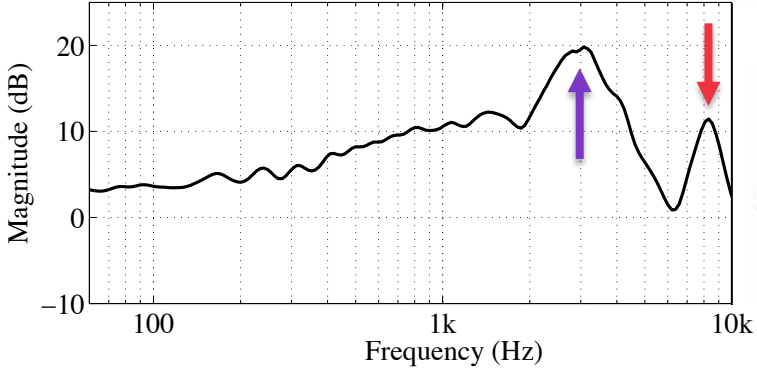


'Ideal' loudspeaker measured from inside my ear canal (1cm)



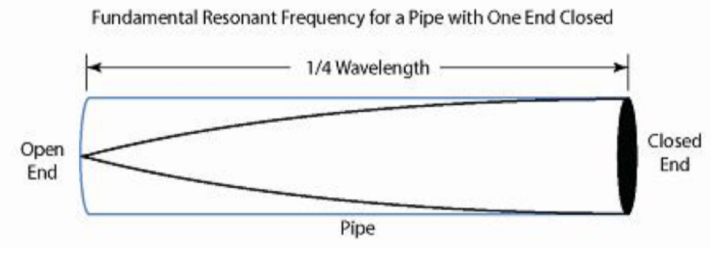
Headphones – Magnitude Response



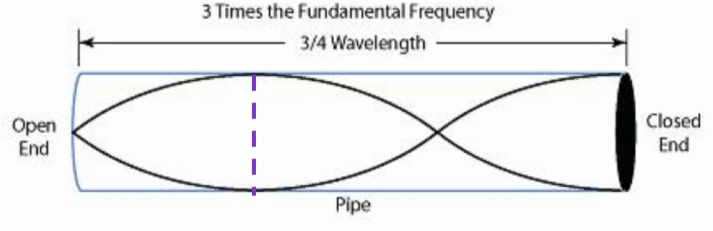


Ear canal

- Acts as a quarter-wavelength resonator

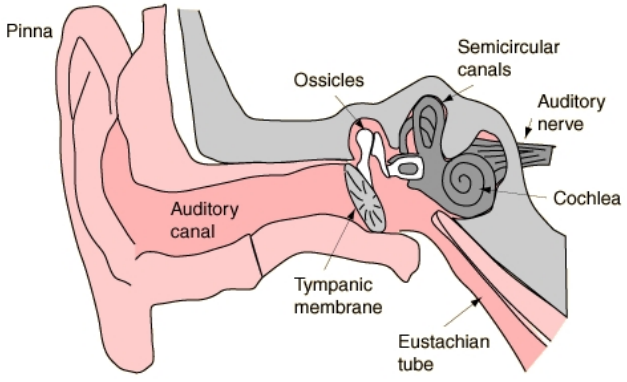


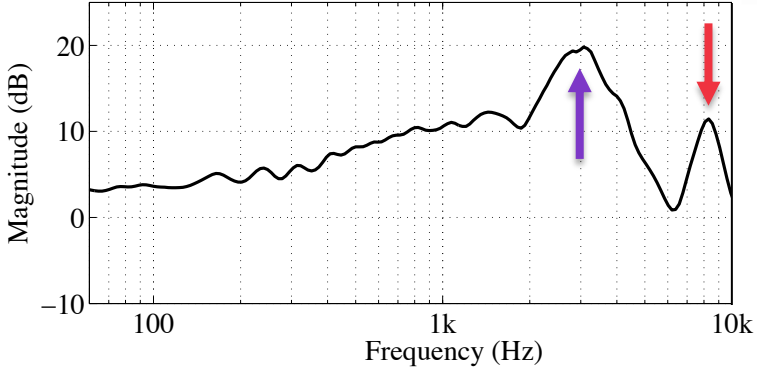
$$f = \frac{c}{4l}$$



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

Headphones – Magnitude Response





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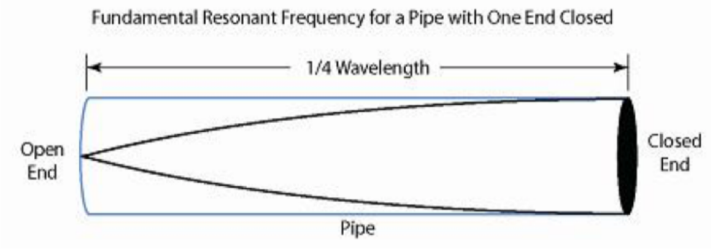
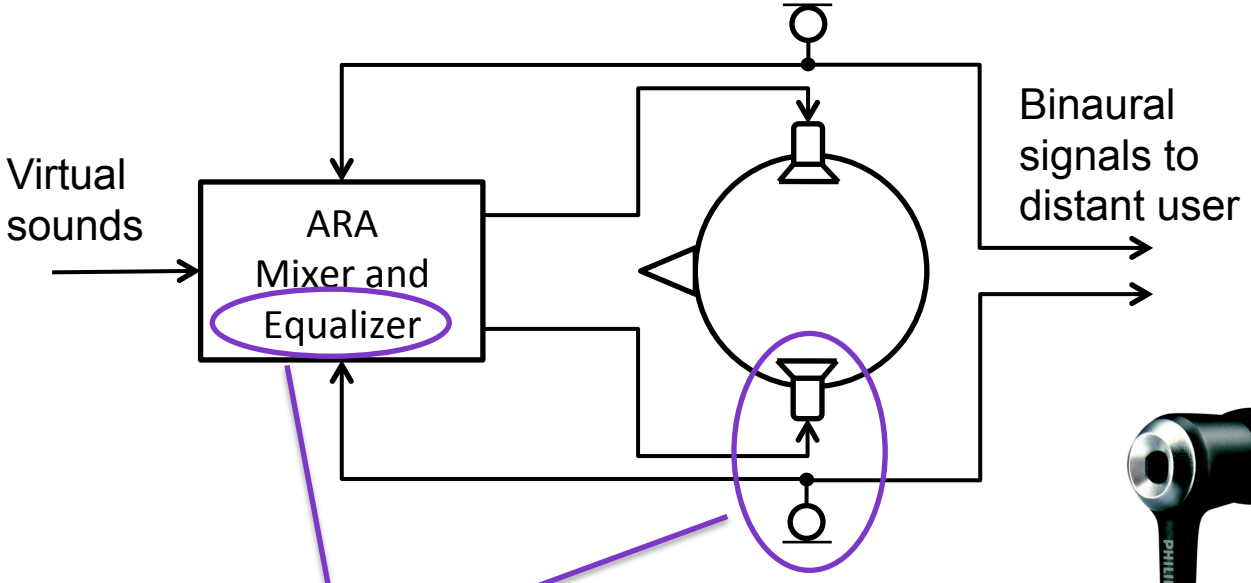


$$f = \frac{c}{4l}$$

$$l = \frac{c}{4f} = \frac{343\ \text{m/s}}{4 * 2900\ \text{Hz}}$$

$$= 2.96\ \text{cm} \quad \text{(effective length)}$$

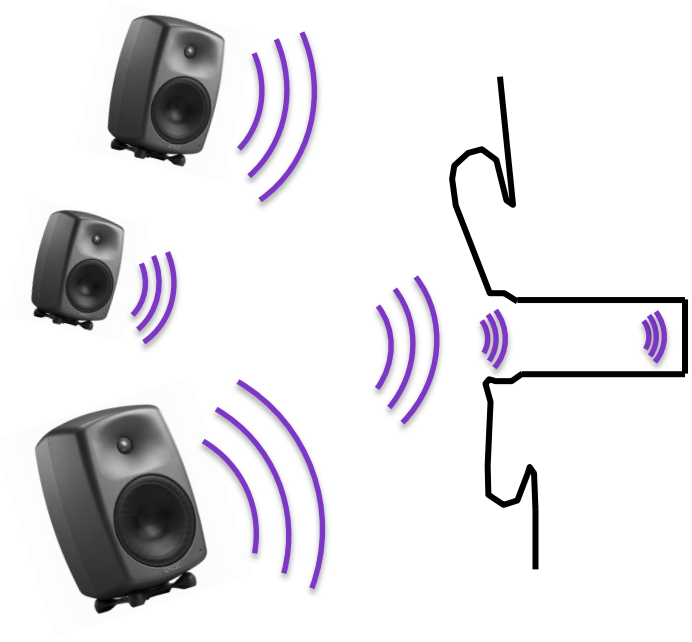
AAR System

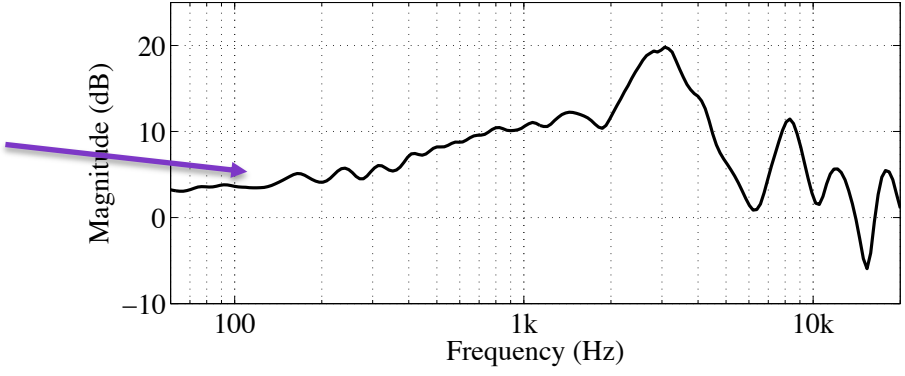


Hear-through headset

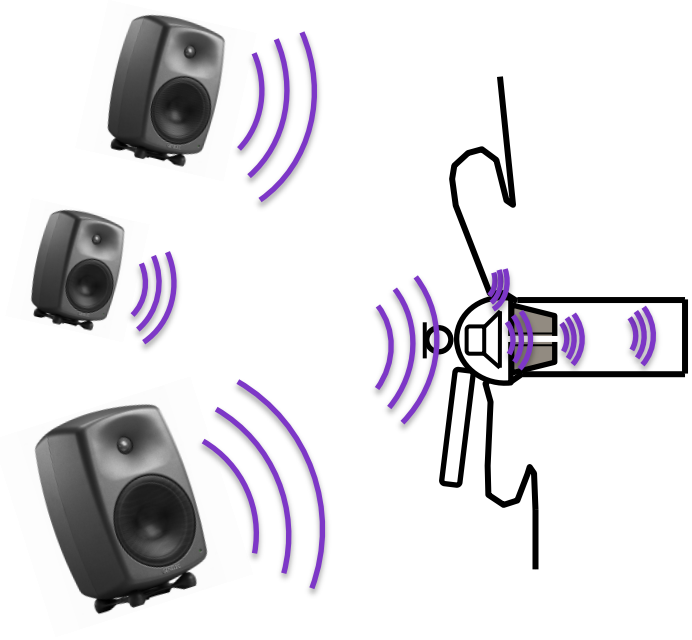
- Prerequisite for AAR system

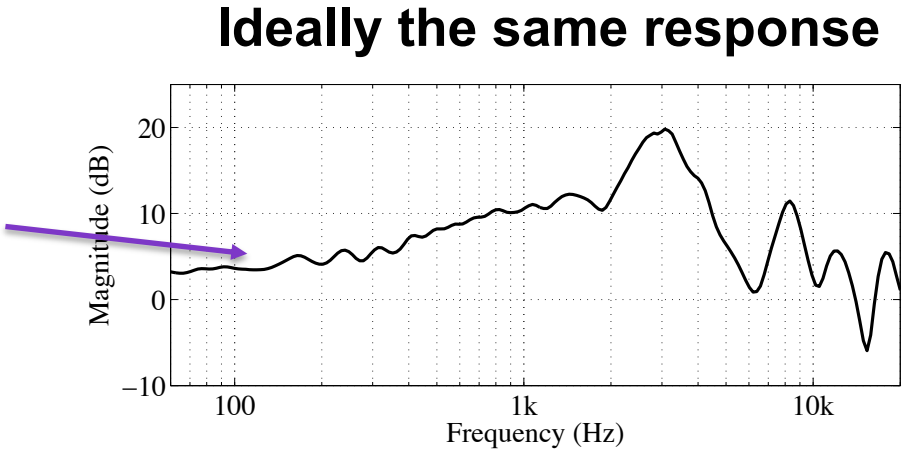
Hear-Through – Open Ear



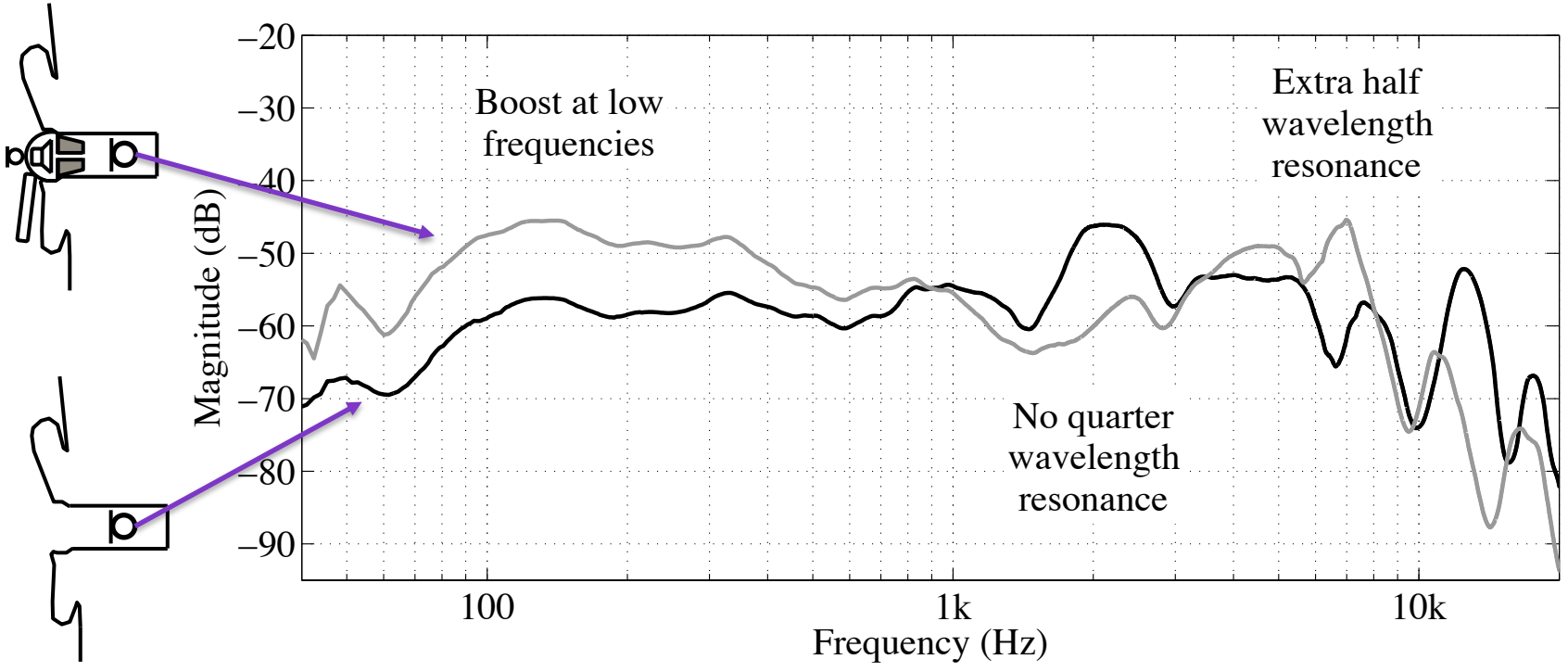


Hear-Through – Closed Ear





Open Ear vs. Closed Ear



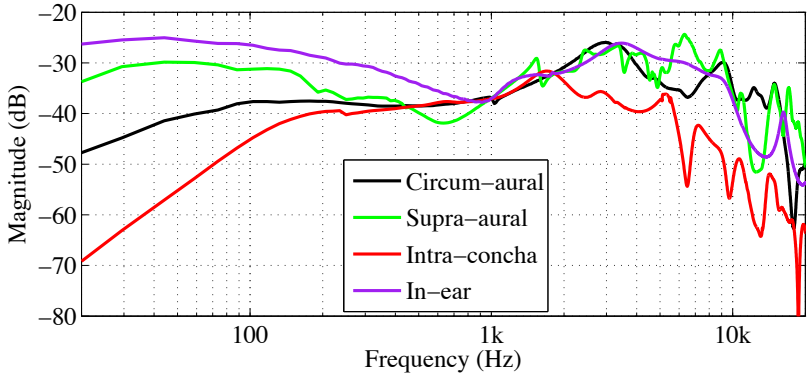
Open Ear vs. Closed Ear

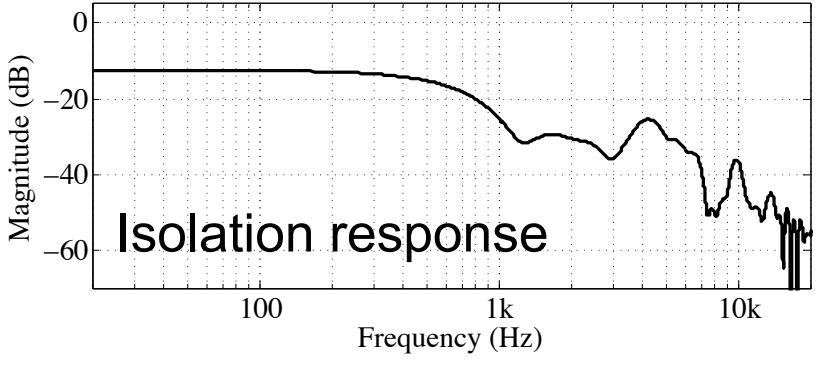
Boost at low frequencies

- In-ear headphones often emphasize low frequencies
  - Pressure chamber principle

- Passive isolation is worst at low frequencies
  - Low-frequency sounds leak through the headphones

Magnitude response

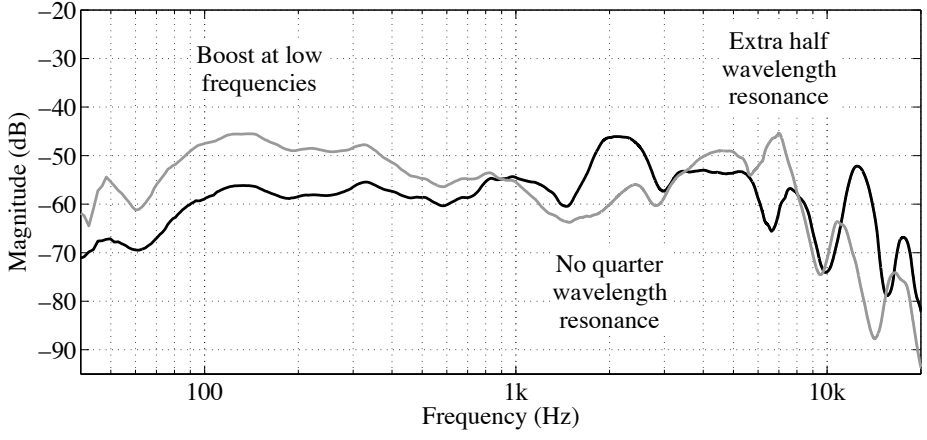




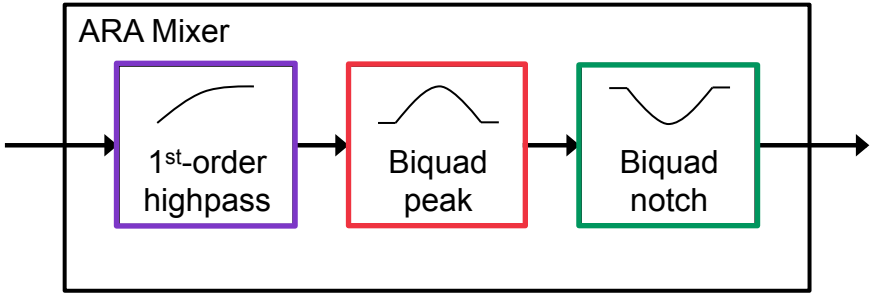
Open Ear vs. Closed Ear

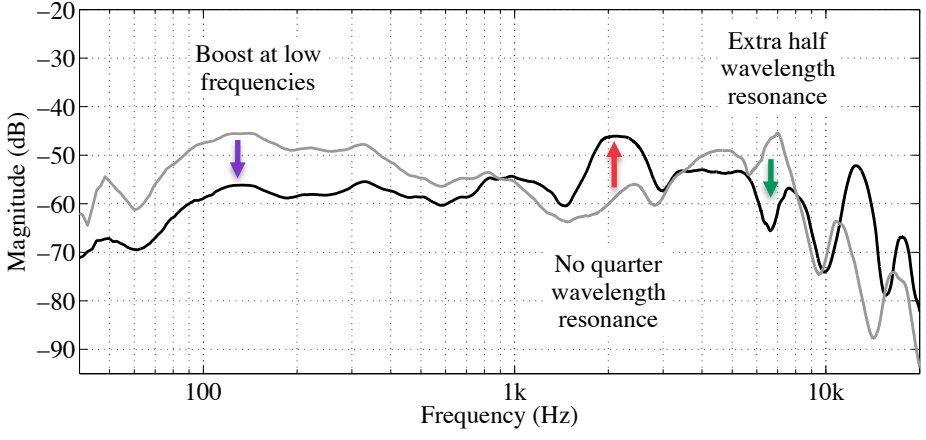
Headphone blocks the open end of the ear canal

- Prevents the **quarter wavelength** resonance from occurring,
- Creates a **half wavelength** resonance.



Equalizer





1st-order highpass

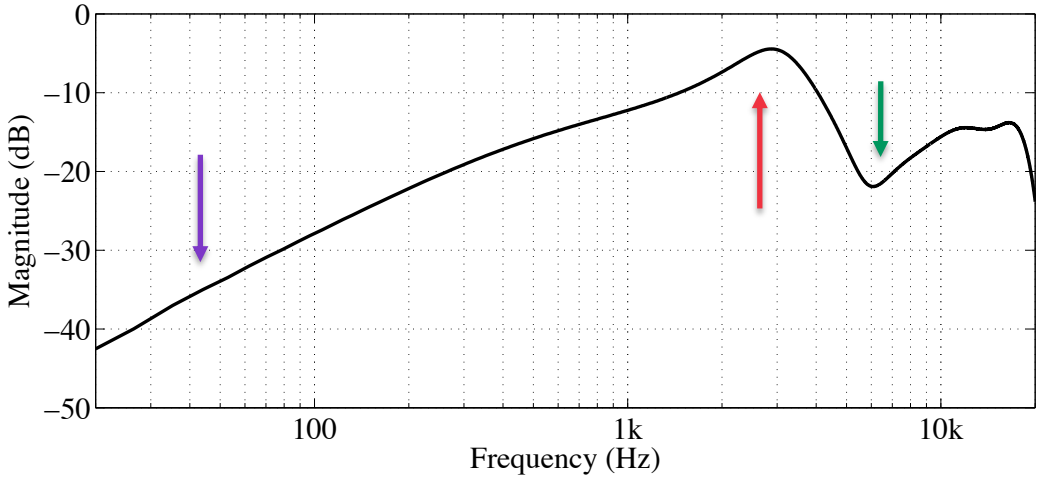
- Limit the bass reproduction

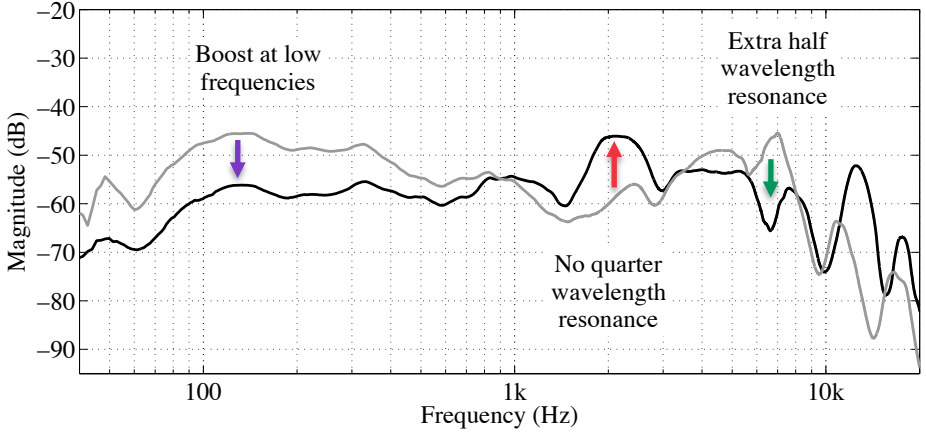
2nd-order biquad peak

- Create the missing quarter wavelength resonance

2nd-order biquad notch

- Remove the extra half wavelength resonance





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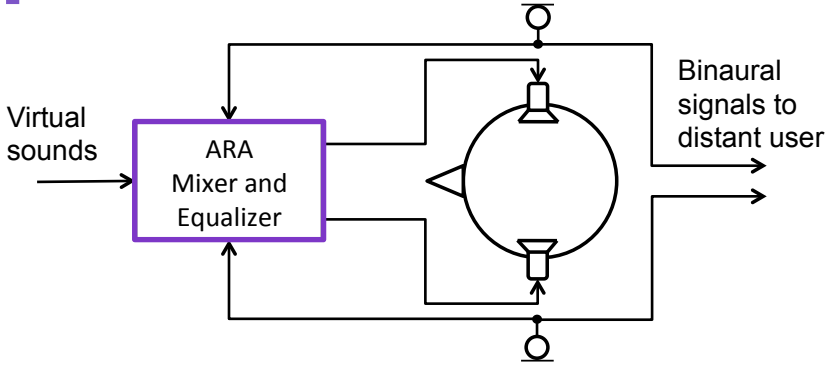

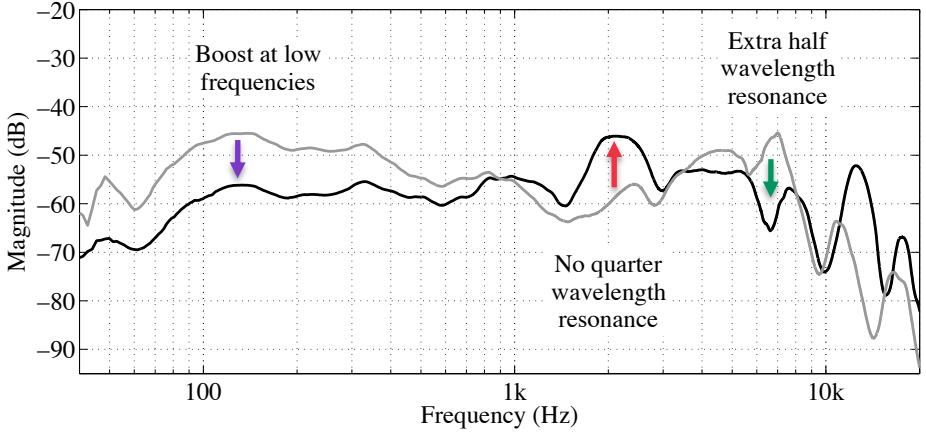

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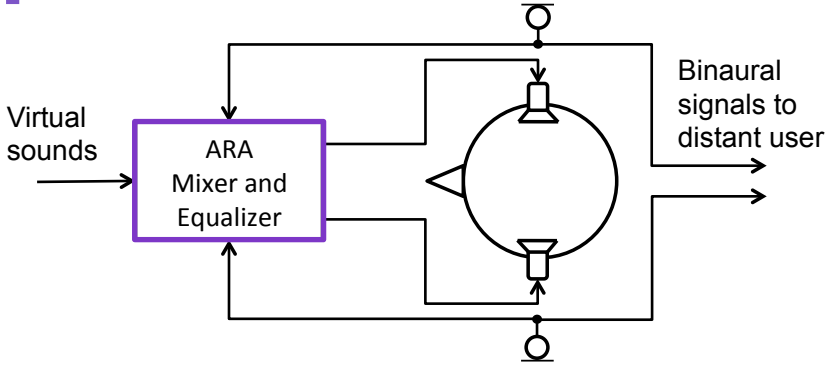
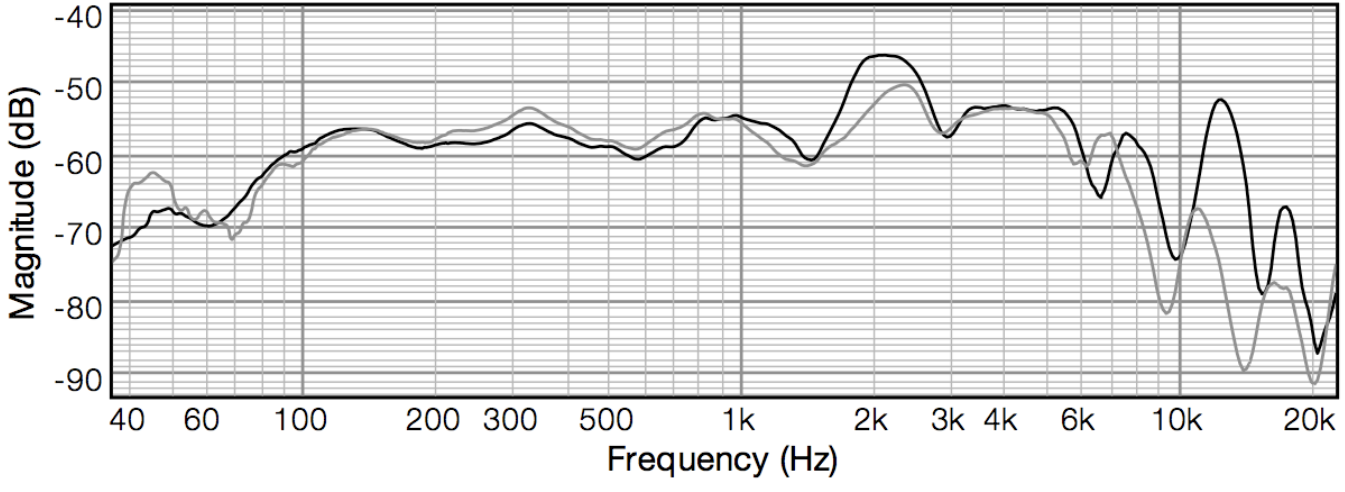
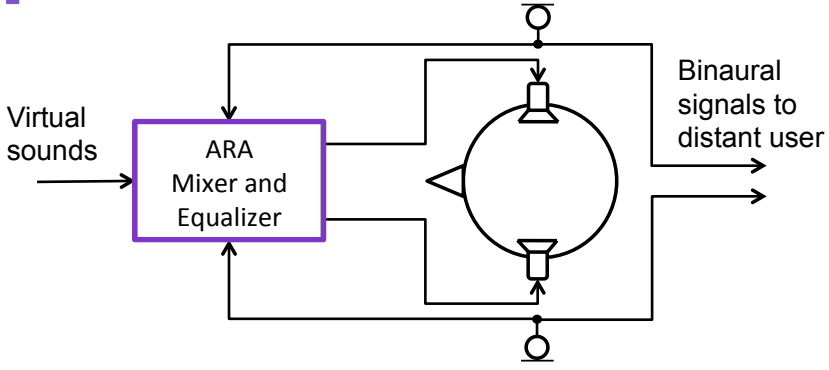
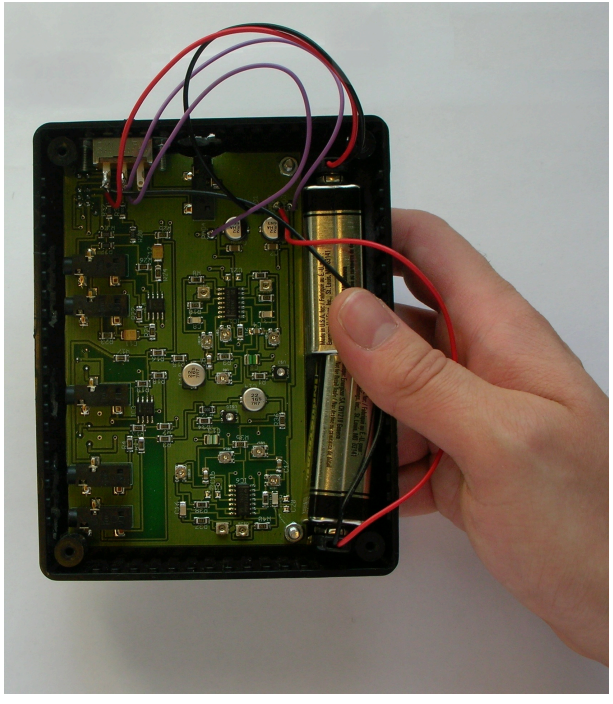


Equalized response



Equalizer

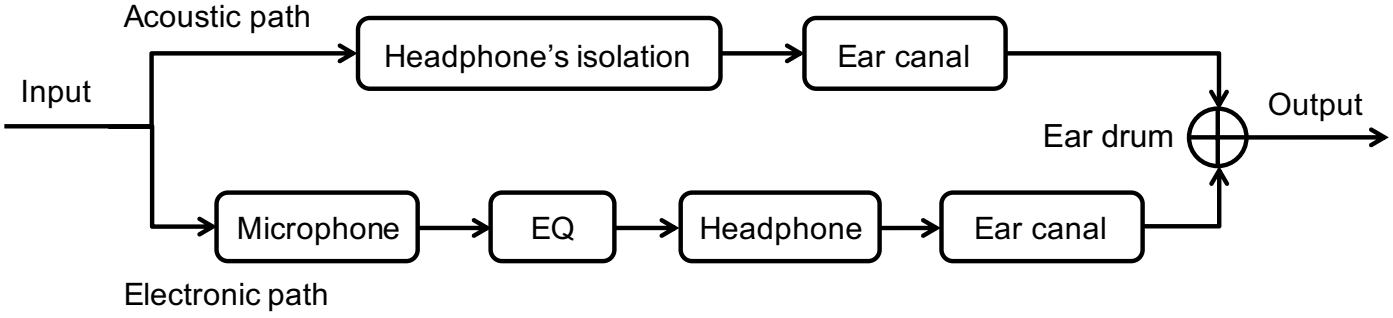




Analog implementation

- Low latency
  - Real time
  - To avoid comb filtering effect

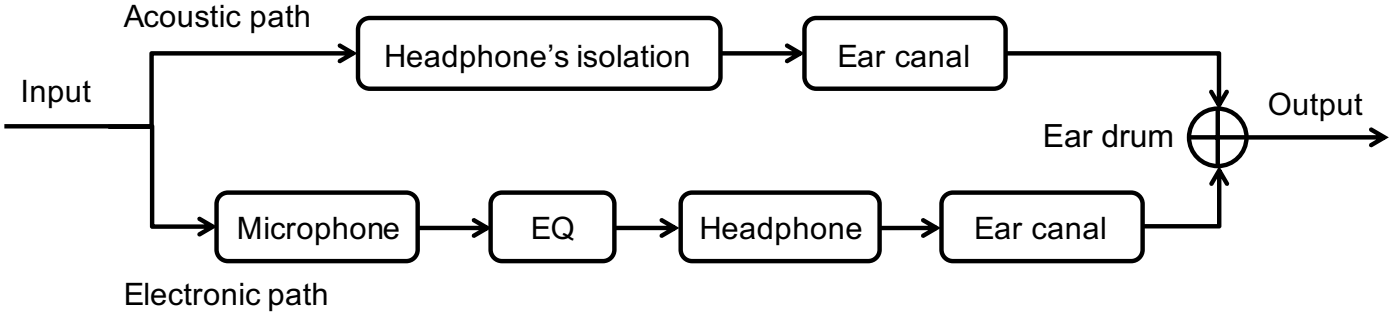
Comb Filtering Effect

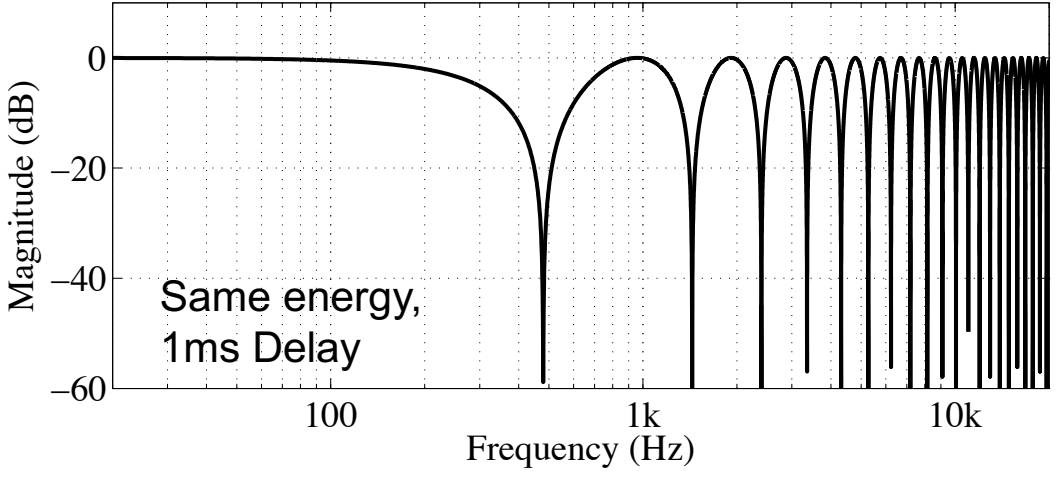


Adding a delayed copy of a signal to the signal itself causes comb filtering effect

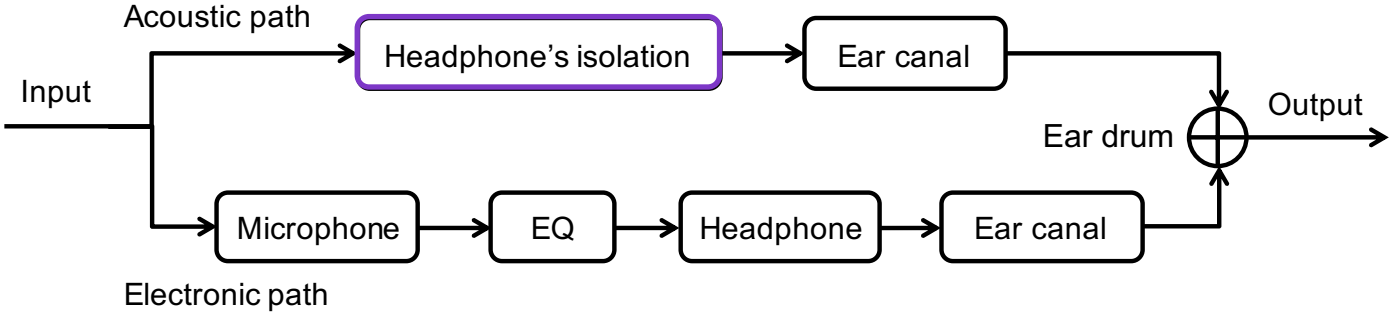
- User hears a sum of the leaked sound (acoustic path) and the sound reproduced with the headphone (electronic path)

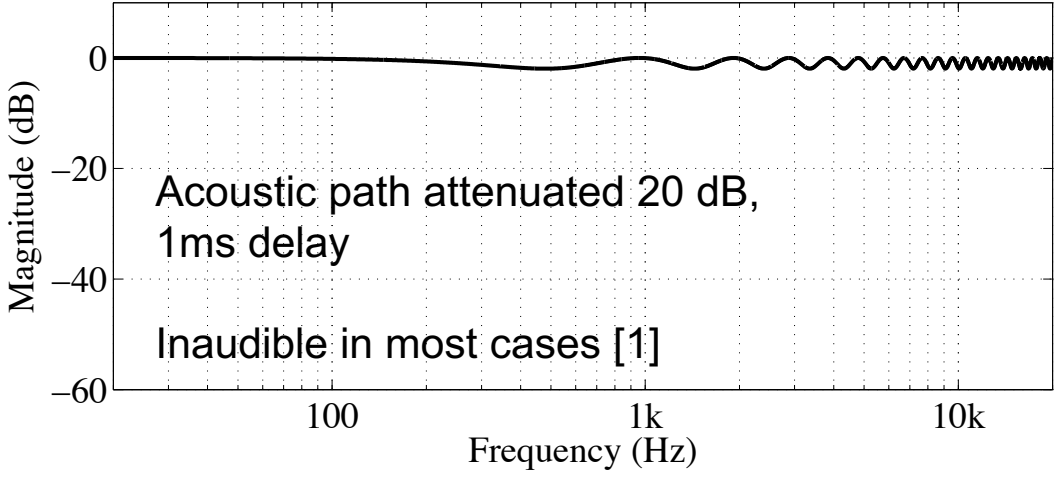
Comb Filtering Effect





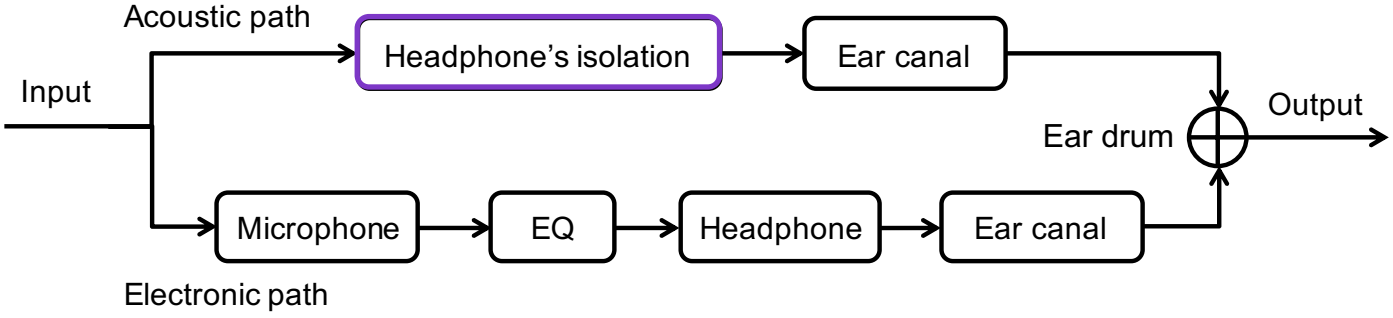
Comb Filtering Effect

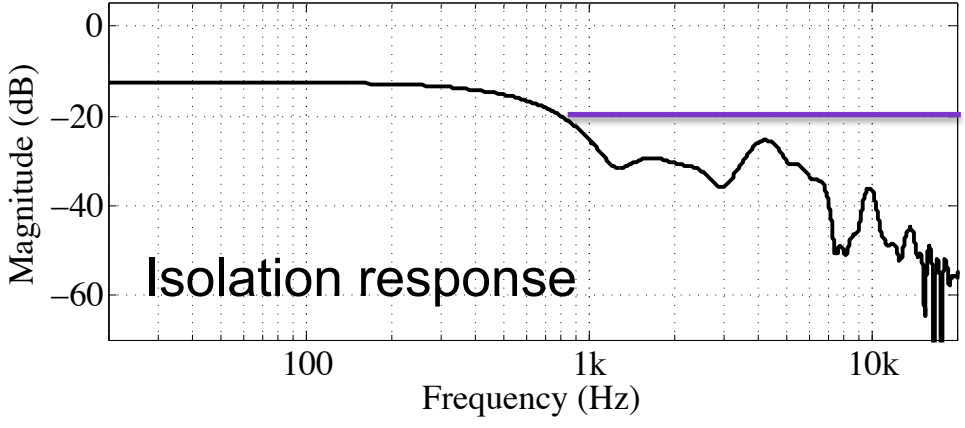




[1] J. Rämö and V. Välimäki, "Digital Augmented Reality Headset",*Journal of Electrical and Computer Engineering*,vol. 2012.

Comb Filtering Effect





Application: Live EQ

- Captures ambient sounds around the user, equalizes the audio signal, and reproduces the sound with in-ear headphones
- The primary goals of LiveEQ:
  - *Protect the hearing of a user during a loud concert*
  - *Provide good, or even enhanced, sound quality during a concert with reduced loudness*
    - User-controllable
  - **Users may enjoy a live concert with better sound quality for longer periods of time within safe noise exposure levels**

Application: Live EQ

- Typical way to protect one's hearing during loud concerts is to use earplugs
  - *Earplugs typically attenuate the sound unevenly across frequencies, excluding musicians earplugs*

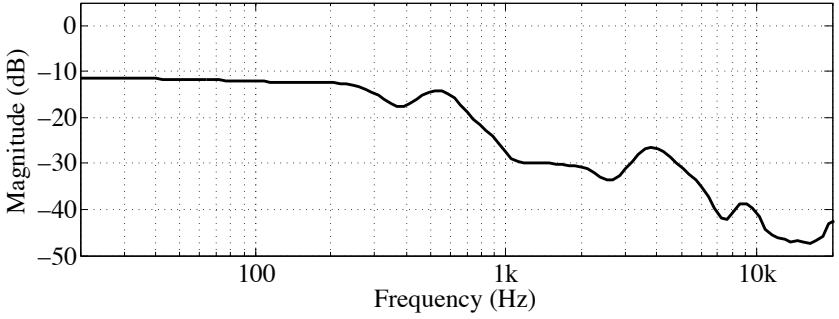
- LiveEQ uses the efficient passive isolation of in-ear headphones to provide attenuation
  - *Also frequency dependent attenuation*
  - *Can be corrected using the real-time LiveEQ processing*

Application: Live EQ

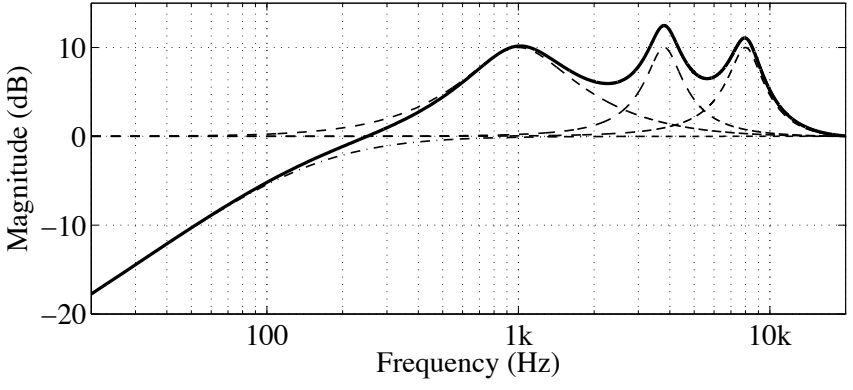
Equalizer

- Can be arbitrary
- We implemented a graphic equalizer
  - *First-order low shelving filter*
    - Limit bass sounds
  - *Three 2nd-order filters*
    - Midrange - Vocals/Lead (400-2600 Hz)
    - Upper midrange – Presence (2.6-5.6 kHz)
    - High end – Brilliance (5.2-10 kHz)
- A good starting point is to have a flat attenuation

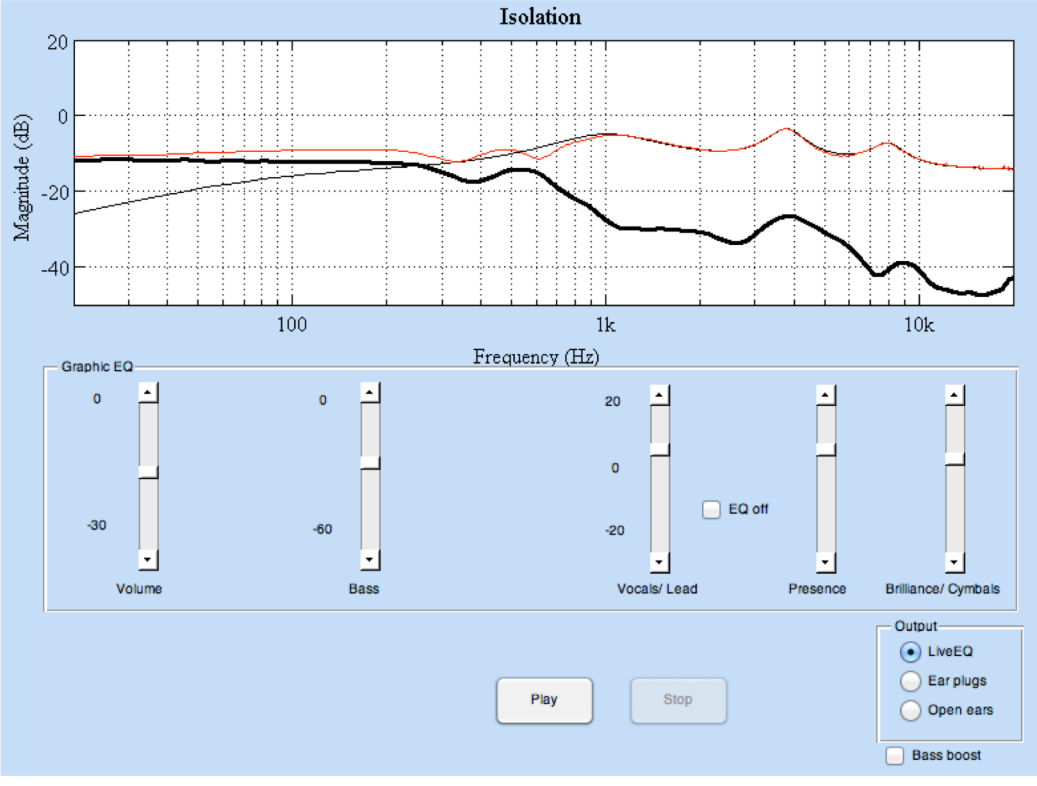
Headphone Isolation



Graphic Equalizer



Application: Live EQ



- Isolation of the headset
- Equalizer response
- Perceived LiveEQ sound

LiveEQ

Earplugs

Original

AAR in commercial products

Real-World Volume

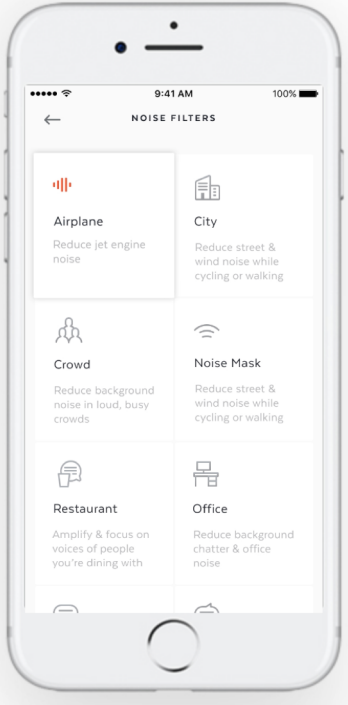
Smart Noise Filters

Listening Profile

Speech Amplification

Music Streaming

Phone Calls



https://hereplus.me

AAR in commercial products

(Not really)

Google Pixel Buds
- Real-time translation with Google Translate
- Google assistant

Bragi Dash Pro
”Audio Transparency” lets you mix music and your surroundings.

Beoplay E8
- Transparency mode
- Siri & Google assistant

Bose

SoundWear

Frames

Bose AR, the world's first audio-only augmented reality platform.
Coming soon…

Ears free – Hear your music and surroundings

Bose

TechHive:

Bose has announced collaborations with ASICS Studio, Strava, TripAdvisor, TuneIn, and Yelp.

- Think educational tutoring, gaming, fitness coaching, meditation, and more.

Bose won’t reveal any details about the first wave of available apps until March, at the South by Southwest (SXSW) music/film/interactive media conference

https://www.techhive.com/article/3337530/headphones/bose-frames-review.html#tk.rss_all

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