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The Future in Motion

Achieving personalized in-vehicle sound zones with actuator-based headrests

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Achieving personalized in-vehicle sound zones with actuator-based headrests

Speaker

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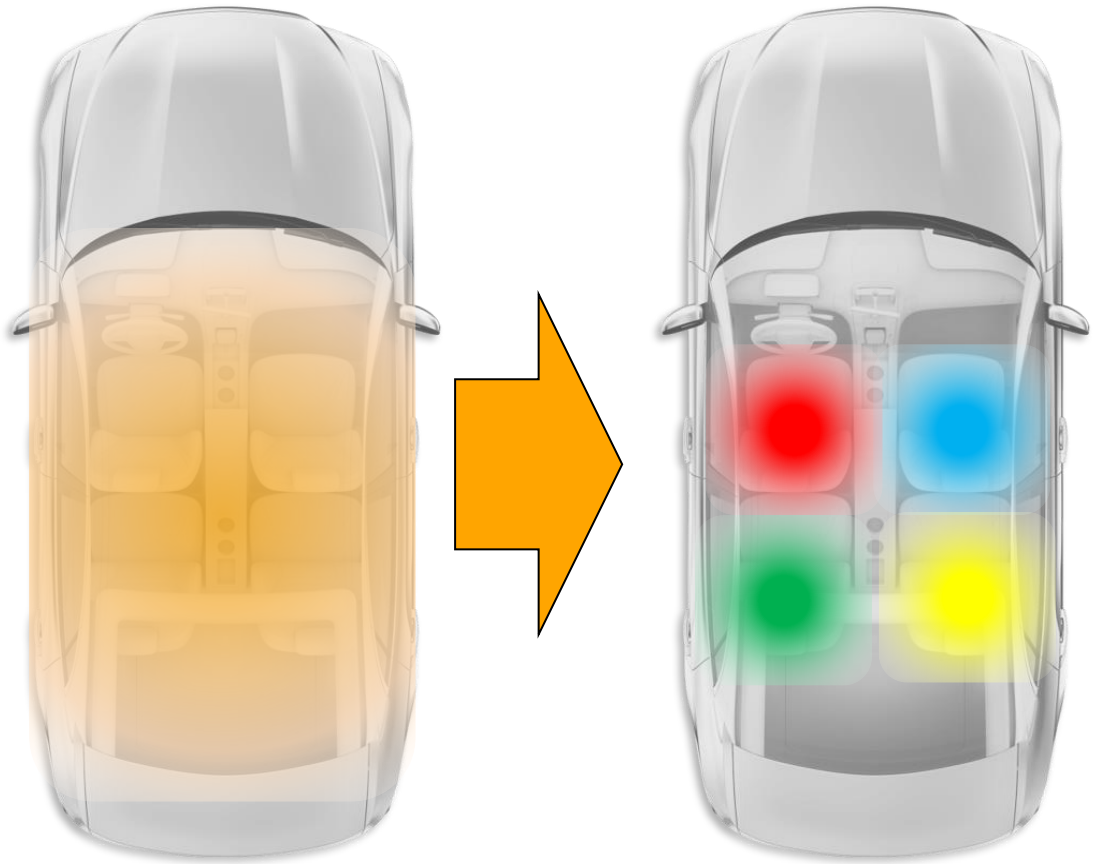
Achieving personalized in-vehicle sound zones with actuator-based headrests

Motivation



global sound **private audio zones**

› trend towards „shared mobility“ and „ride sharing“ [1]

› new mobility concepts demand best possible **comfort** and highest possible **privacy**

➔ customers request **individual private sound zones** instead of global sound representation

Requirements

› highest possible **sound quality**

› best possible **zone separation** between different sound zones

› best possible **channel separation** within a sound zone

› **invisible** integration

› low **cost**

› …

Achieving personalized in-vehicle sound zones with actuator-based headrests

Motivation

Option 1: headphones

+ low cost
+ very good channel separation
+ (maybe) best sound quality

– disturbing haptics
– prevents conversations

Option 2: sound field synthesis

+ no disturbing haptics
+ good sound quality

– many sound sources required (complex)
– high cost

Option 3: close-to-ear sound sources

+ no disturbing haptics
+ good sound quality
+ low cost

– out-of-position challenges

Agenda

1	**Concept of actuator-based sound systems**	**5**
2	Potential benefits and risks	9
3	Integration of actuators into seat headrests	14
4	Advantages of actuator-based headrests	18
5	Summary and conclusions	28

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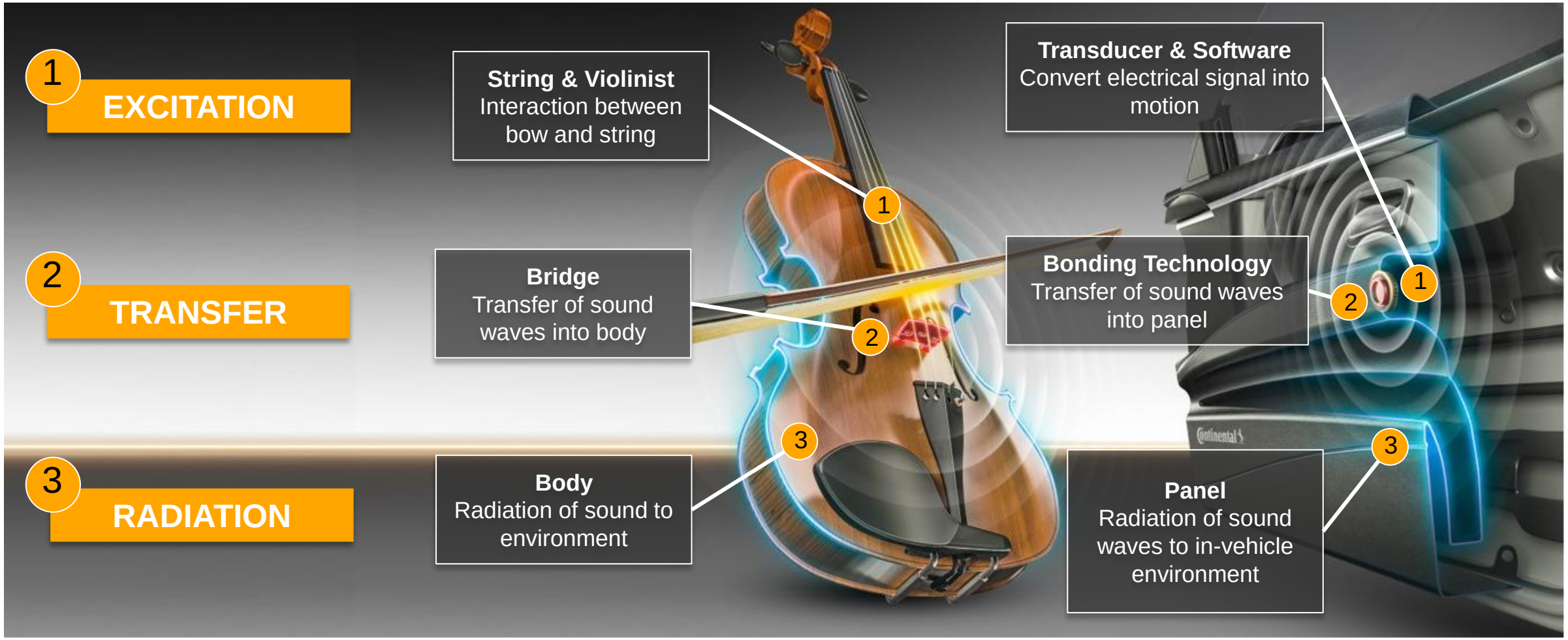
Concept of actuator-based sound systems



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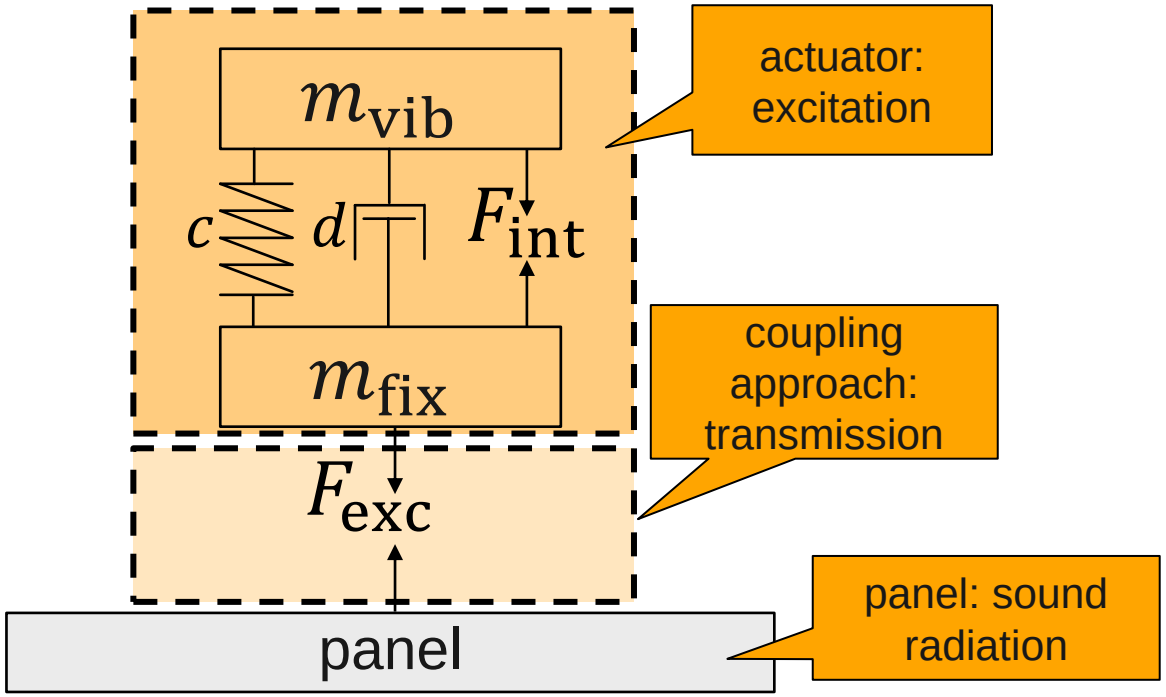
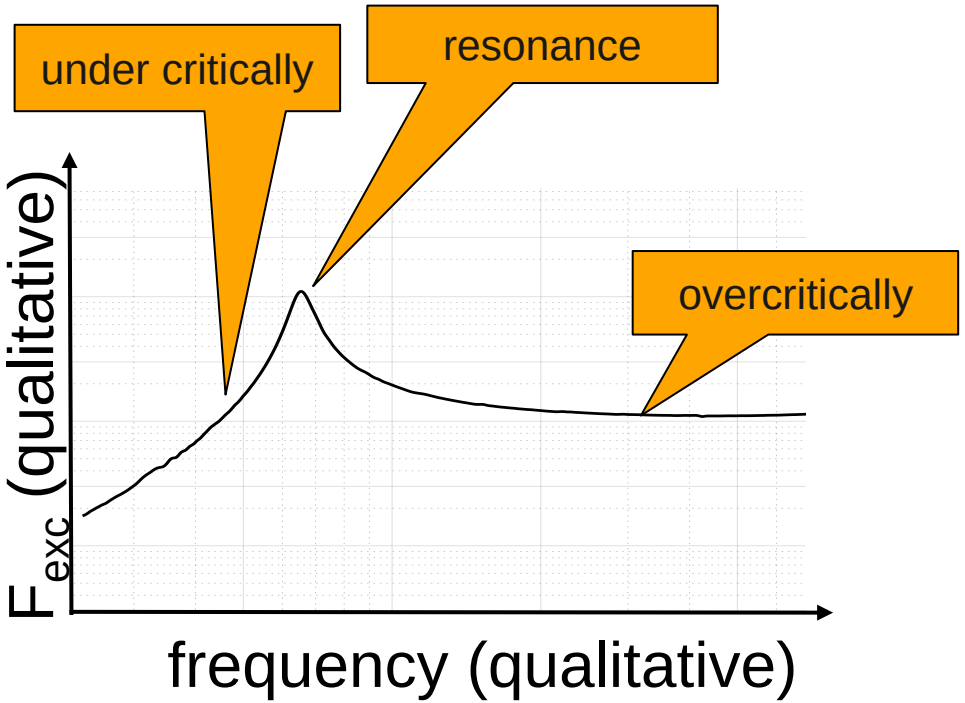
Concept of actuator-based sound systems





representation as dual mass oscillator

depict from [2,3]

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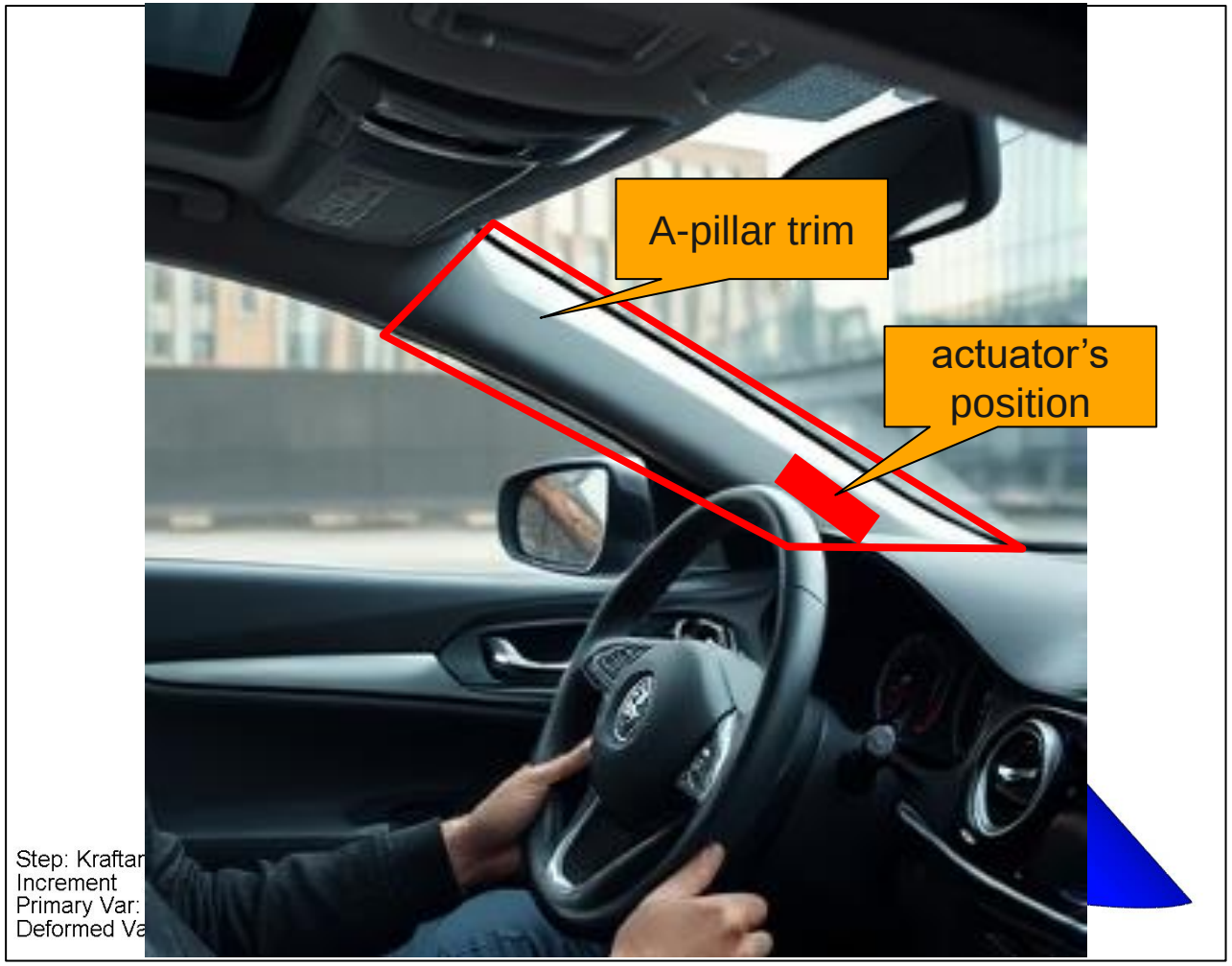
Concept of actuator-based sound systems



Panel

- **transfer** from force excitation to sound radiation
- generally **complex geometry** with variations in mass, stiffness, damping, etc.
- efficient sound radiation by matching impedances

➔ **actuator and panels need to fit to each other**

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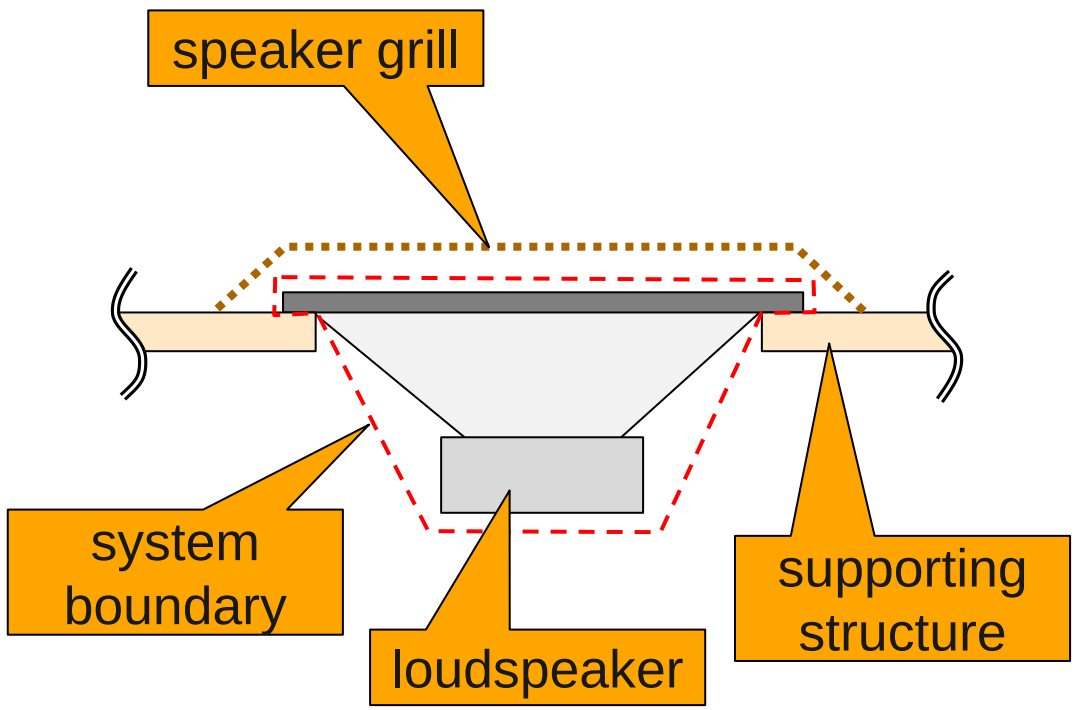
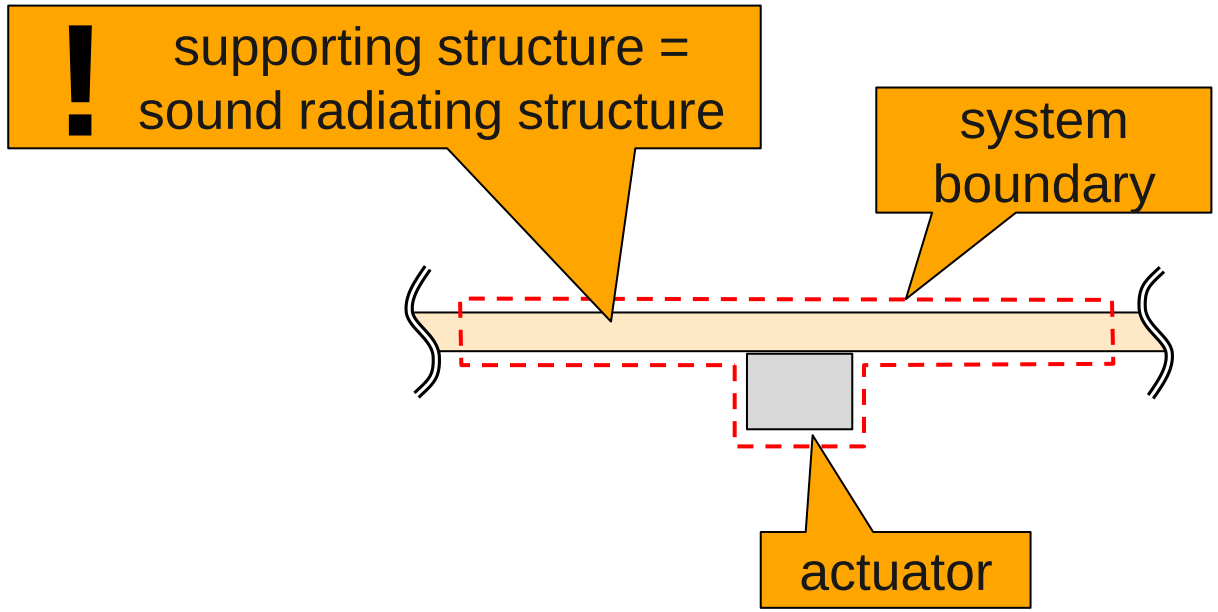
Achieving personalized in-vehicle sound zones with actuator-based headrests

Potential benefits and risks





- for loudspeakers: system boundary of sound-generating device is clearly defined
- for actuators: supporting structure (e. g. headrest skin) becomes part of the sound system
  → **new way of developing a sound system by collaboration**

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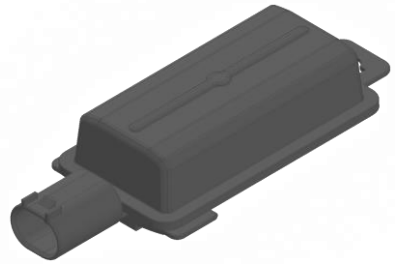
Potential benefits and risks

1000 - 8000 Hz	**Extended frequency range**	**100-20000 Hz**
Big and heavy (230g)	**Less volume/weight**	**Small and rectangular (78 g)**
Many variants plus fixation and grill	**Complexity**	**One design fits all**
Complex integration at curved surface	**Integration**	**Hidden integration at any position**
Narrow radiation and easy localization	**Wider spatial radiation**	**Wide radiation from large surface**
Opening and speaker grill needed	**Design freedom**	**No opening and grill needed**



AS Wide Range enables

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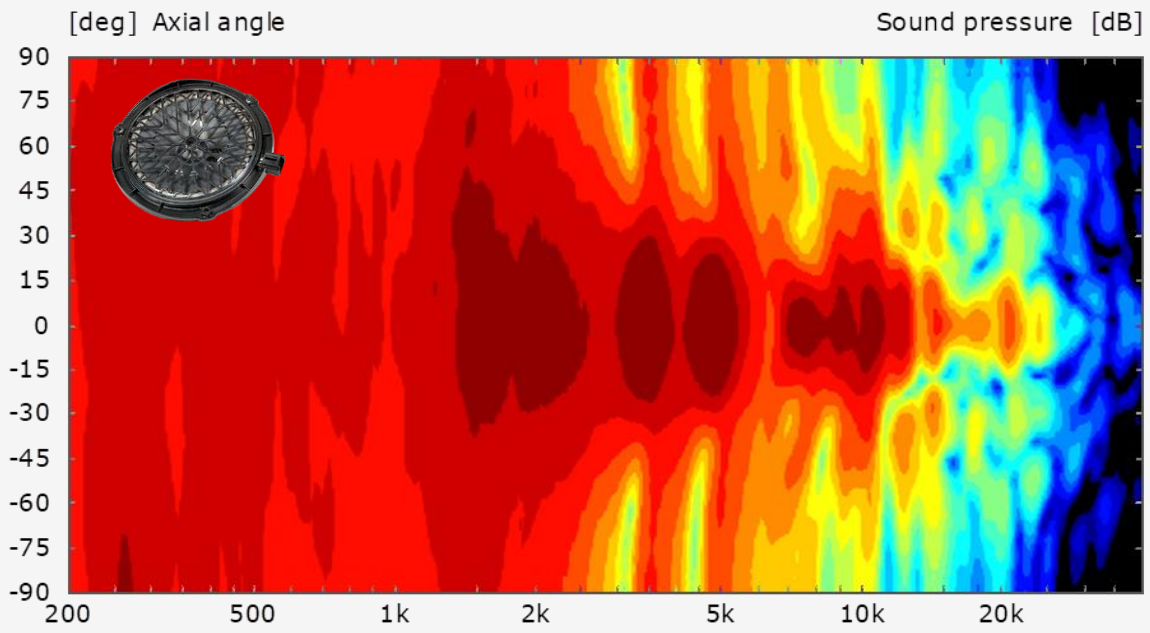
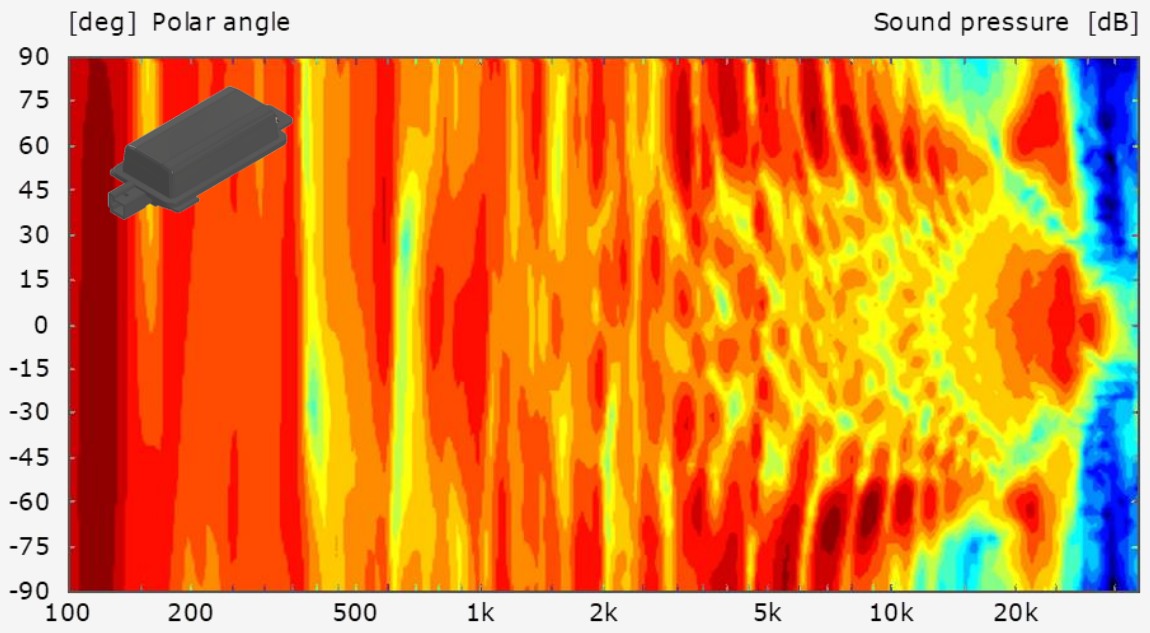
Potential benefits and risks



Sound focus from ca. 2kHz



Homogeneous radiation up to 10 kHz

Ac2ated Sound provides an immersive sound experience over large surfaces

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Potential benefits and risks

conventional round actuator		AS Wide Range
round: difficult integration	shape	rectangular: easy integration
none: risk of fails	housing	fully sealed
textile/plastic: will break easily	spring material	steel: strong and reproducible
one side: instable/labile **1x**	suspension	**2x** two sides: all-orientation stable

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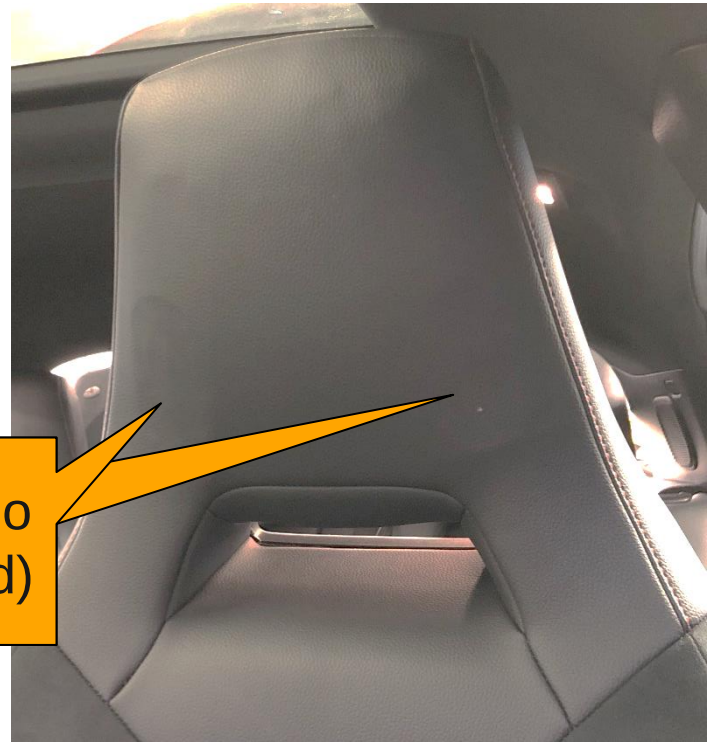
Integration of actuators into seat headrests

speaker-based headrest
(series solution)

actuator-based headrest
(prototype)



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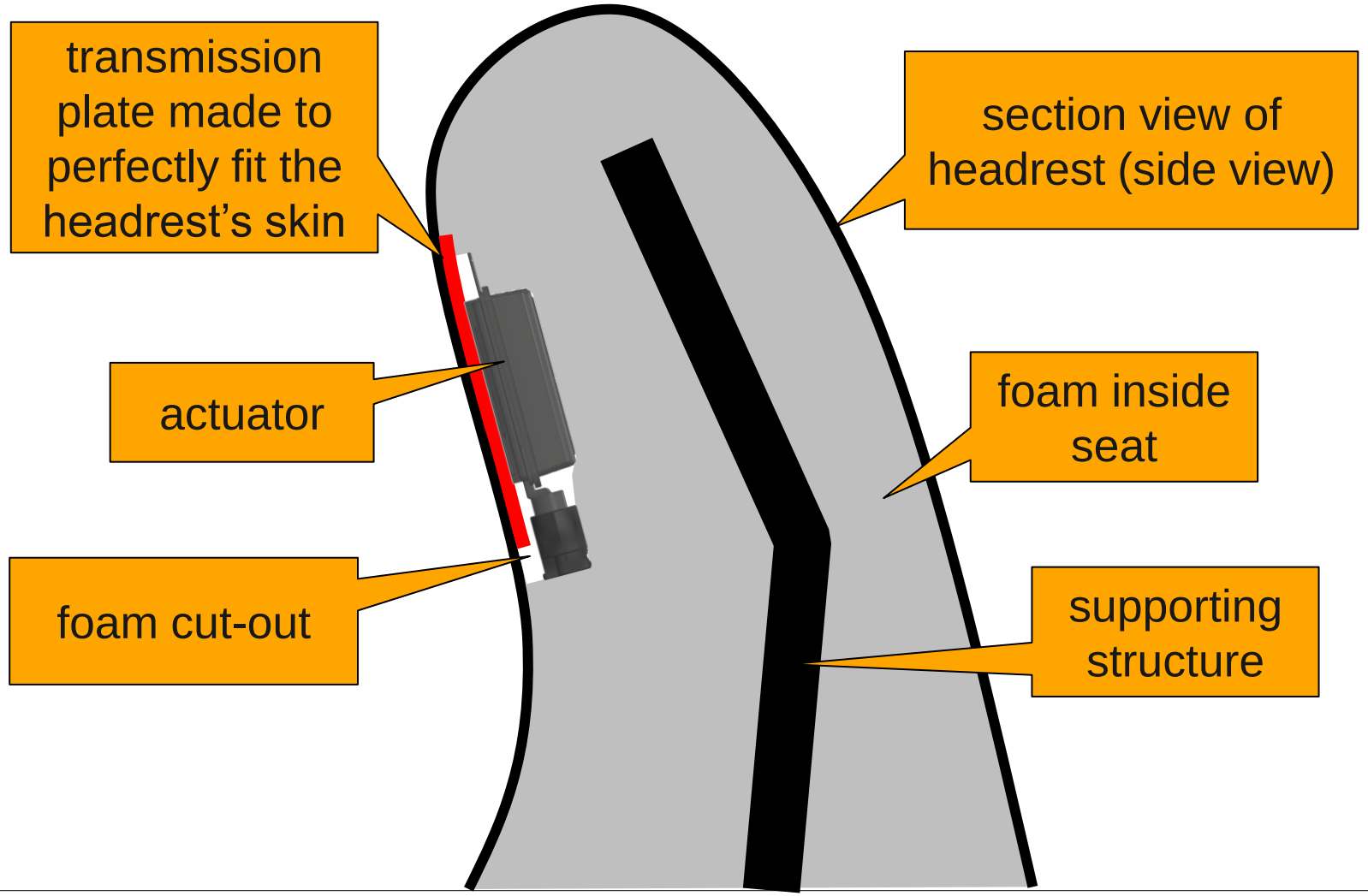
Integration of actuators into seat headrests



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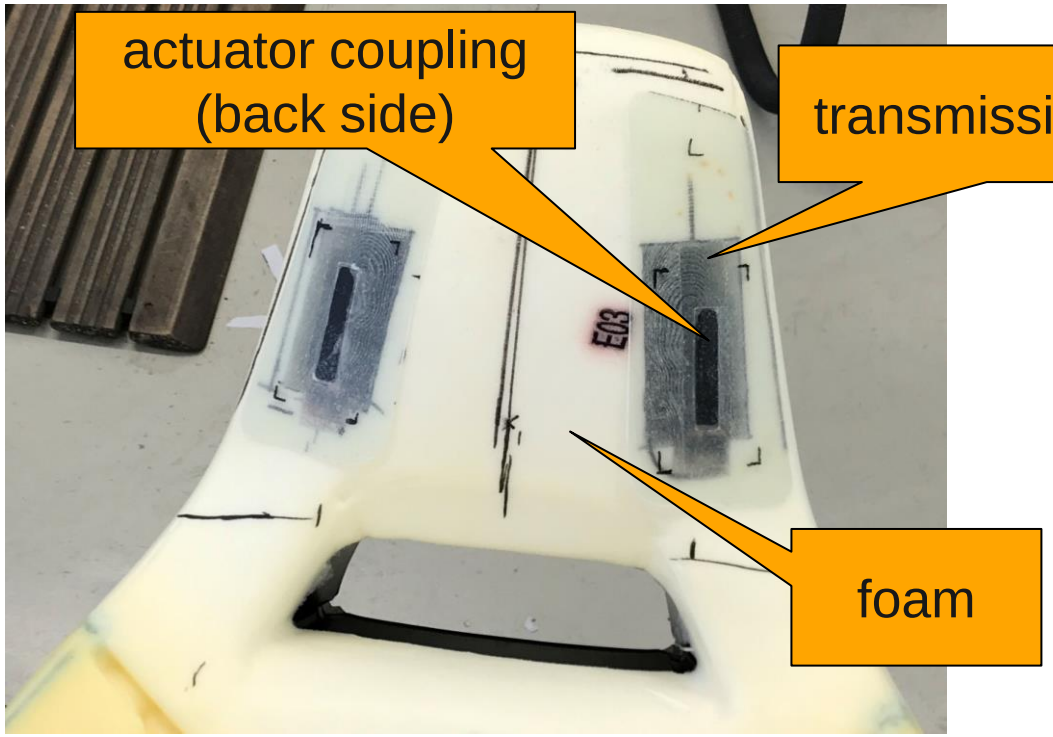
Integration of actuators into seat headrests

prototype build



final seat integration

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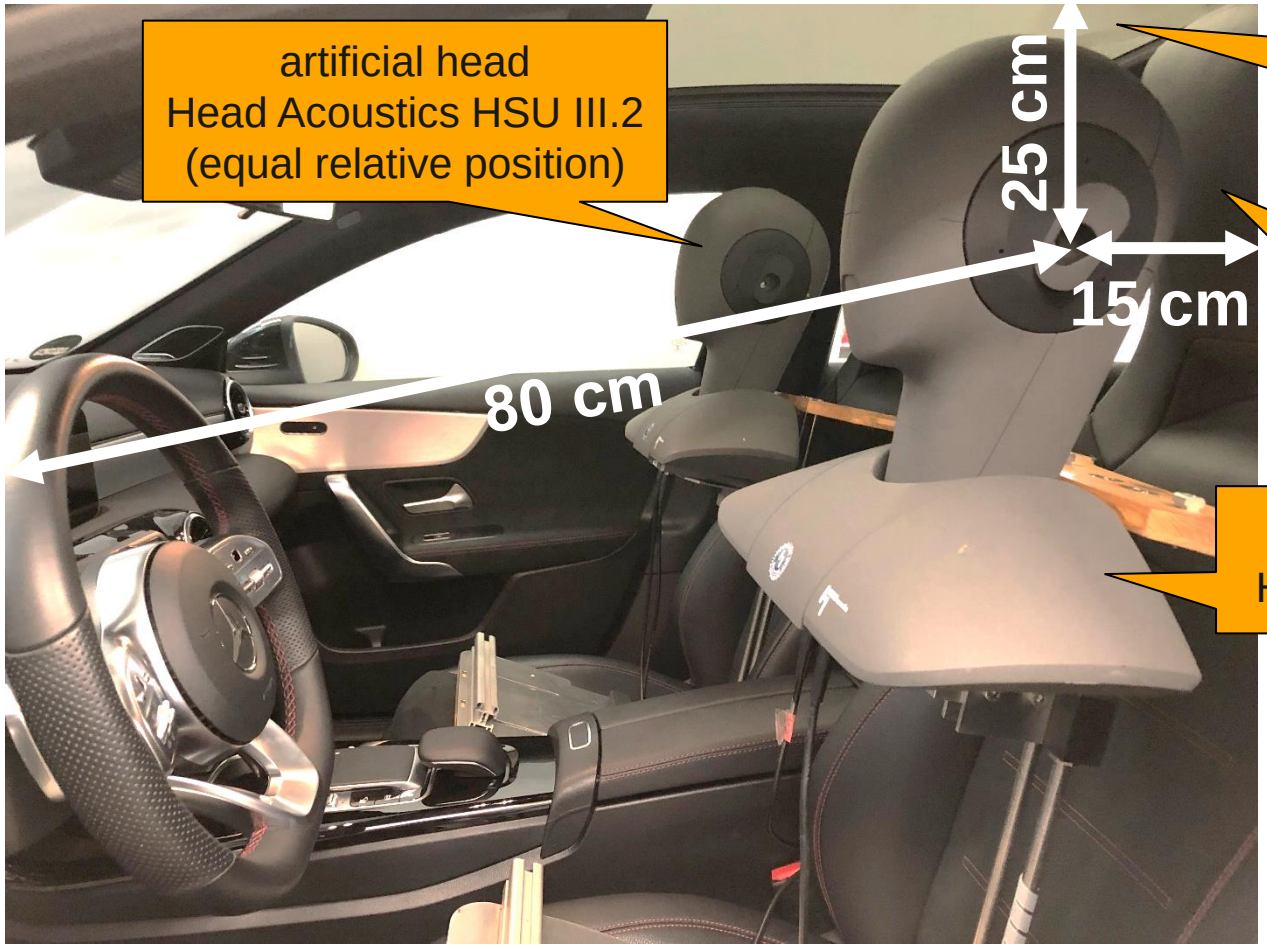
Advantages of actuator-based headrests – measurement setup

- **frontend**:
  Audio Precision APx 515 + 1701 Transducer Interface
- **excitation signal**:
  chirp, 20 Hz-20 kHz, 5 s
- **amplitude**:
  1 W_{nom} (=2 V_{rms} at 4 Ω_{nom})
- **3 averages** per measurement
- all vehicle doors and windows closed



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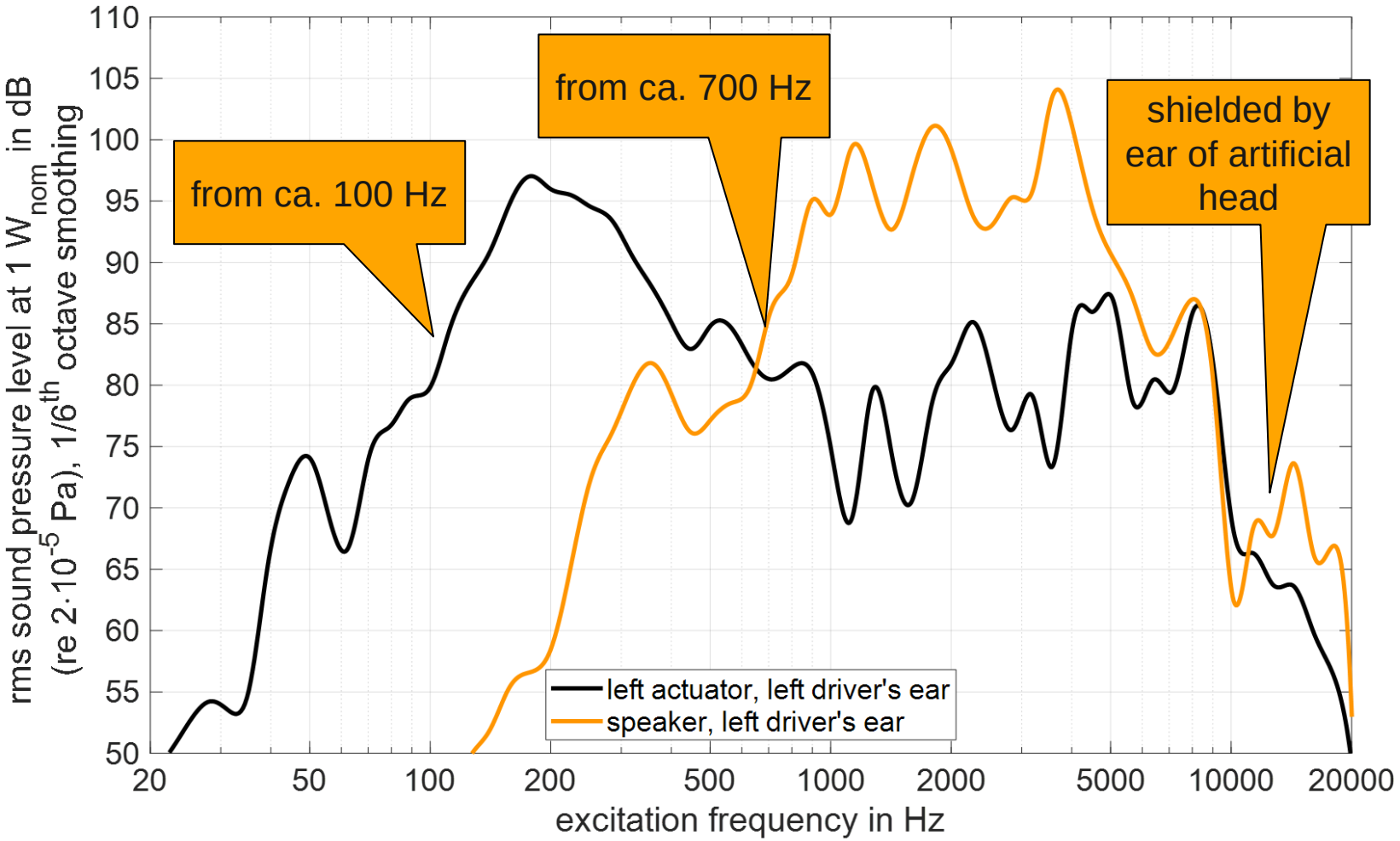
Integration of actuators into seat headrests – measurement results



Actuator:

- ca. 100 Hz – 10 kHz
- highest efficiency at ca. 200 Hz

Speaker:

- ca. 700 Hz – 10 kHz
- highest efficiency at ca. 4 kHz

➔ sound shielded by ear of artificial head from ca. 10 kHz

➔ actuator excites wide frequency range for a powerful sound experience

➔ **actuator is suitable to be used in active noise cancellation systems**

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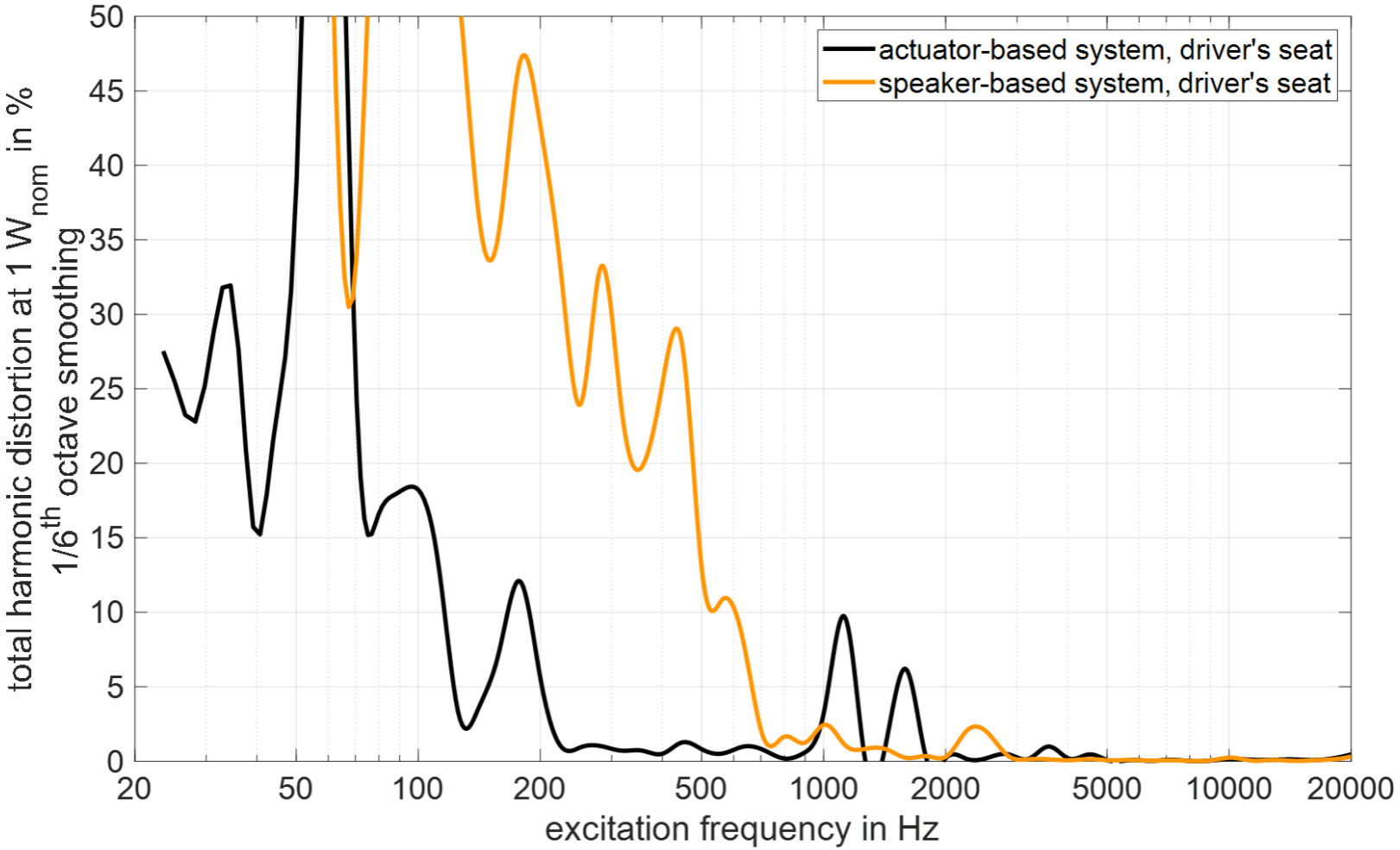
Integration of actuators into seat headrests – measurement results



Actuator:

› low THD for >200 Hz

Speaker:

› low THD for >700 Hz

➔actuators shows over all low distortions

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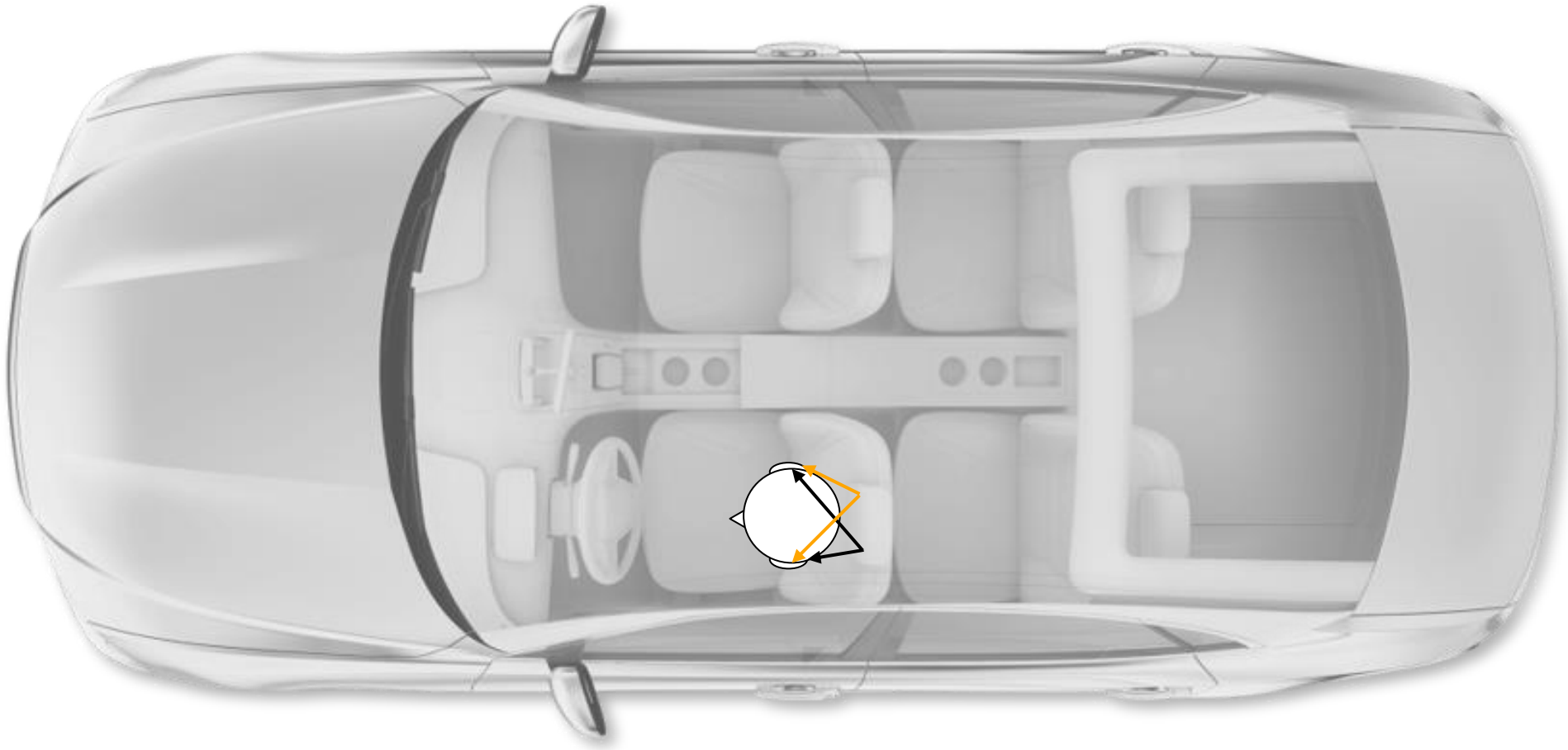
Integration of actuators into seat headrests – measurement results



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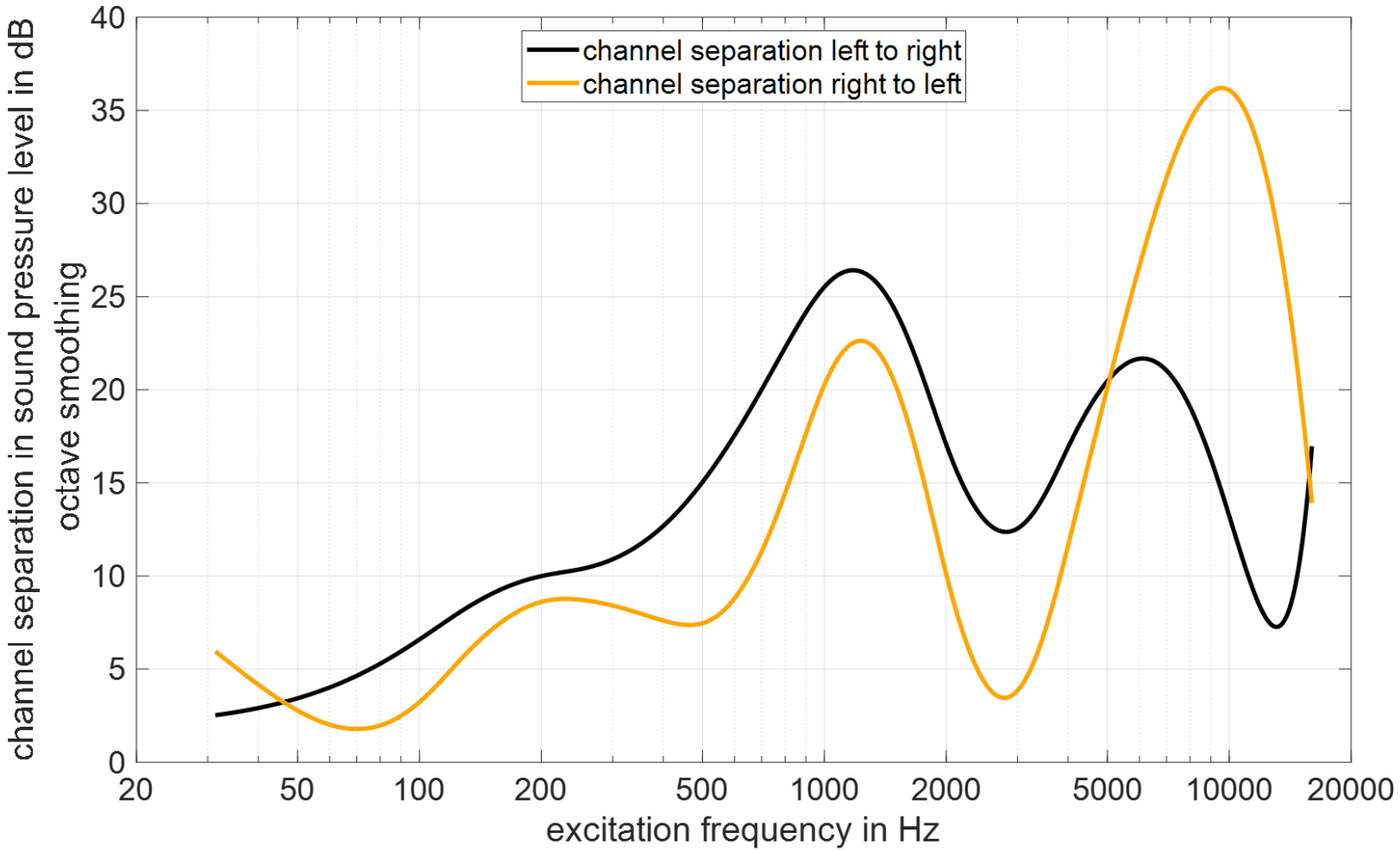
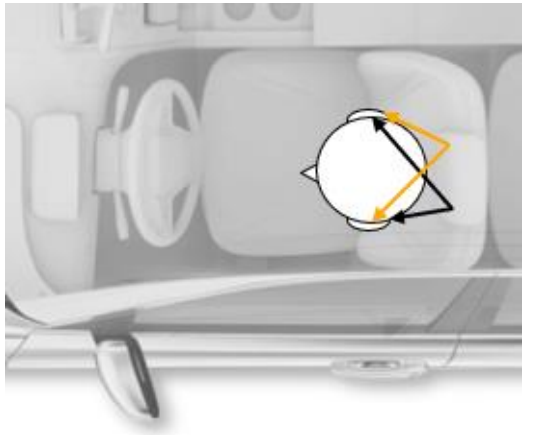


Channel separation

- better channel separation for higher frequencies
- reduced channel separation due to reflections
- note: 100% channel separation perceived from 18 dB [4]



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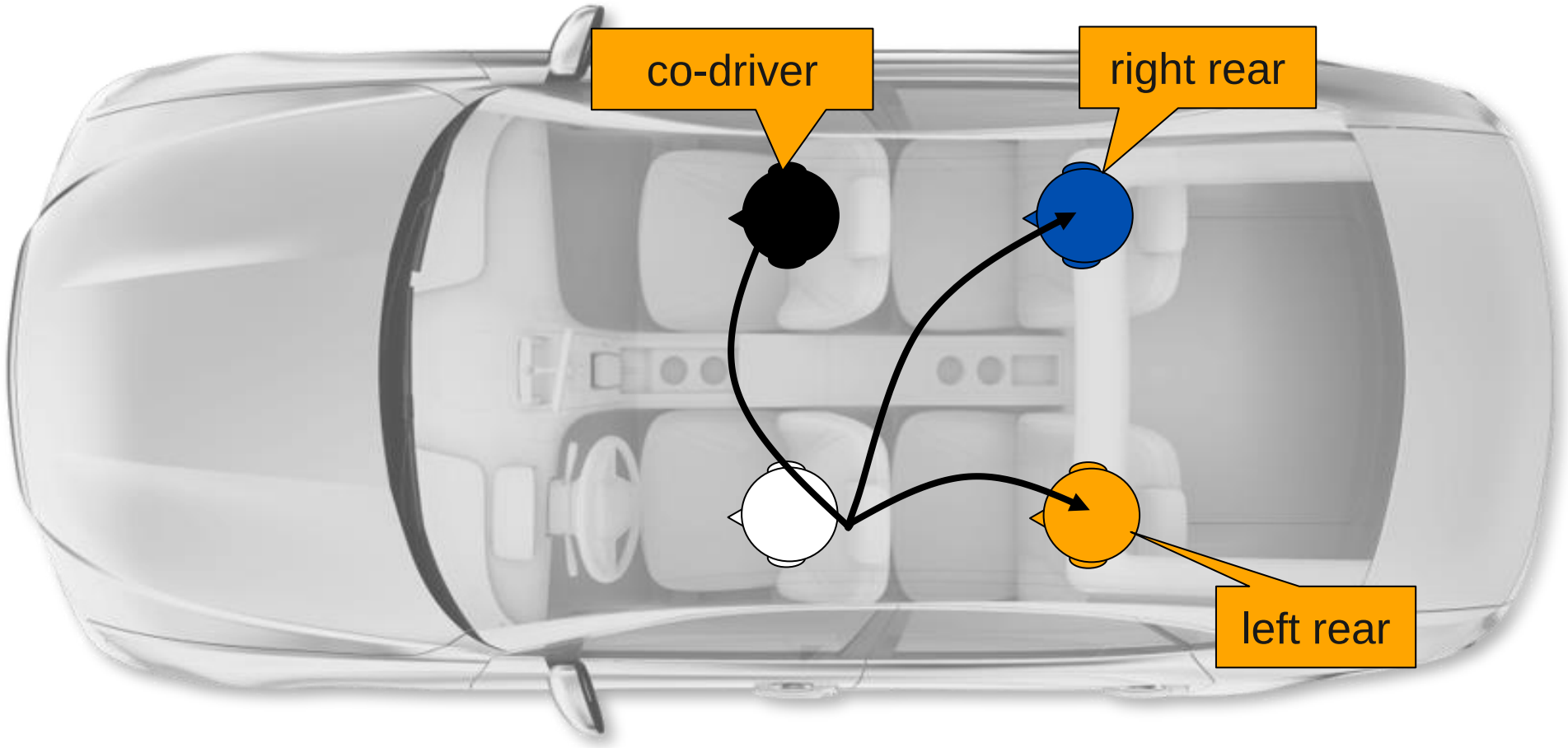

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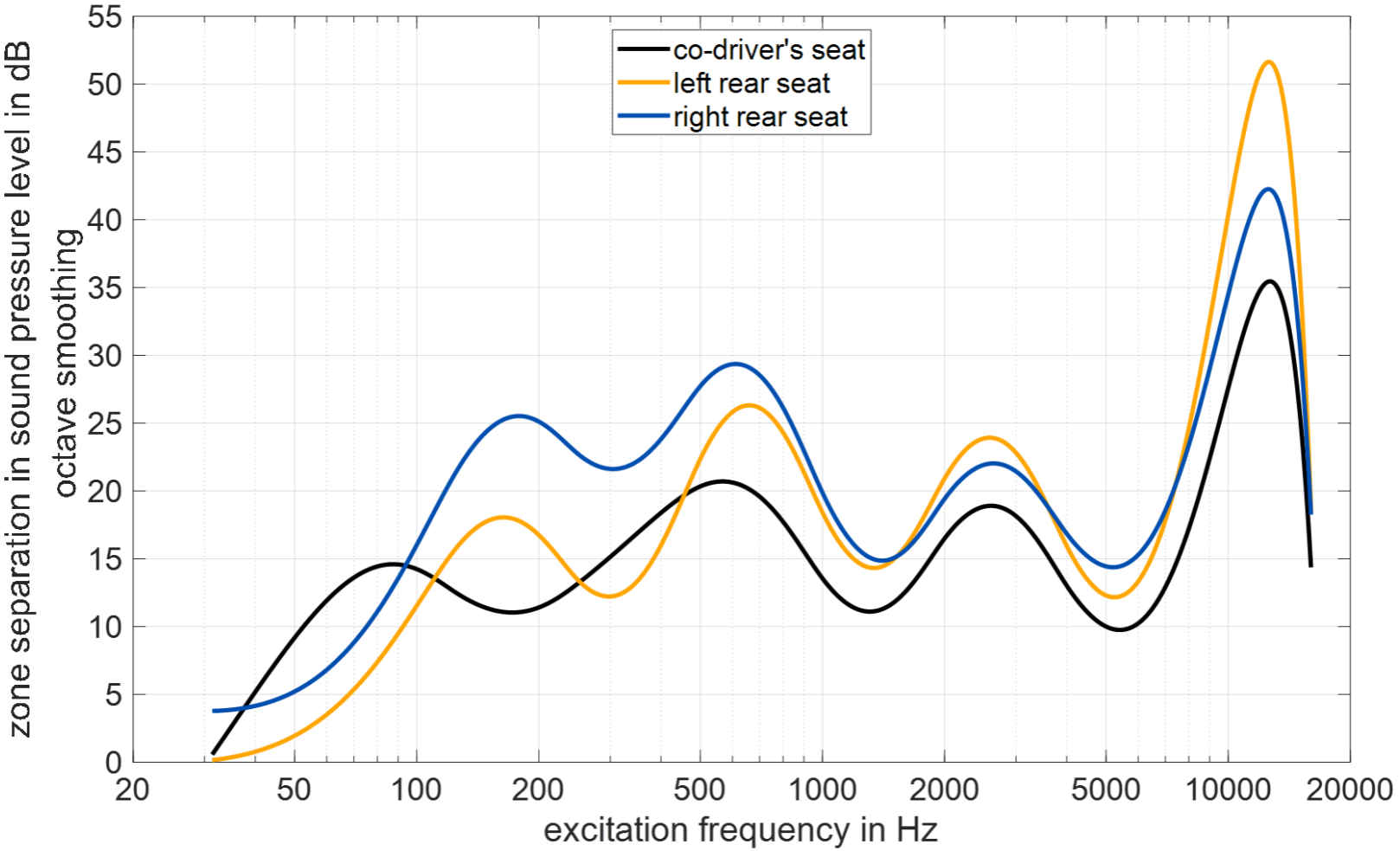
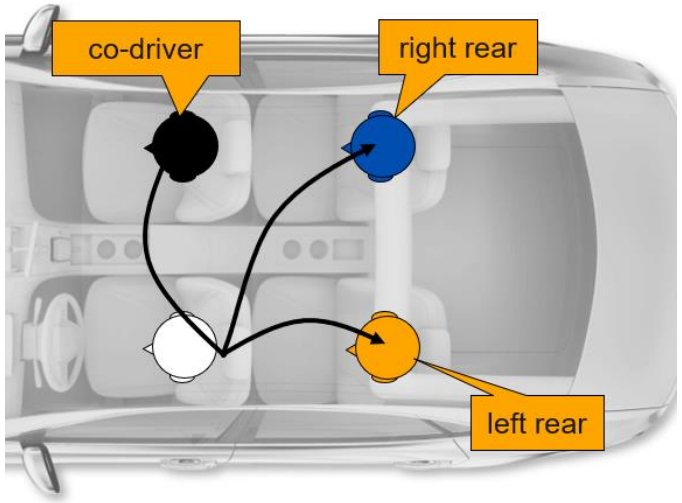


Zone separation (no support by sound algorithms)

- from 100 Hz always >10 dB
- better zone separation for higher frequencies



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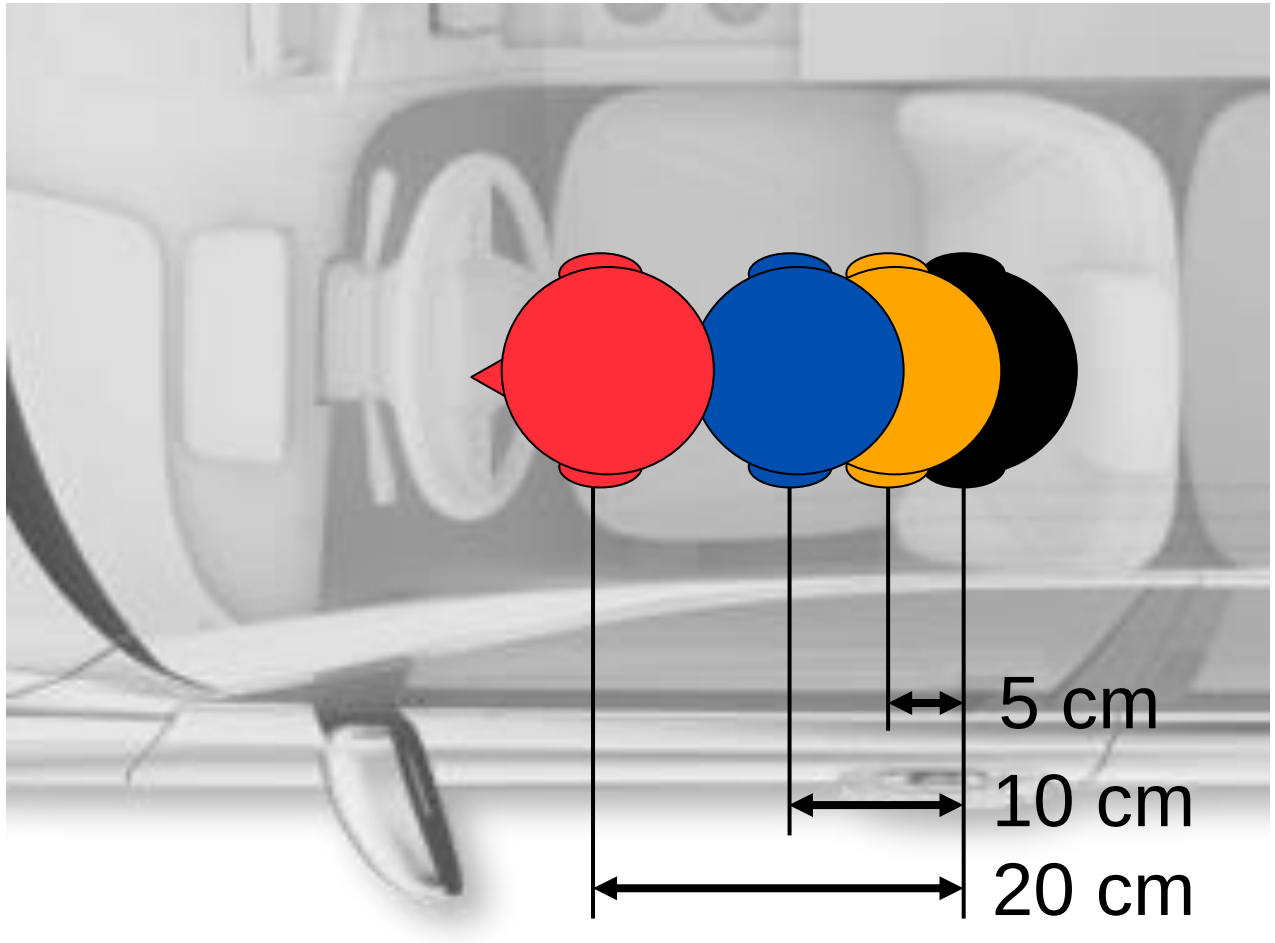

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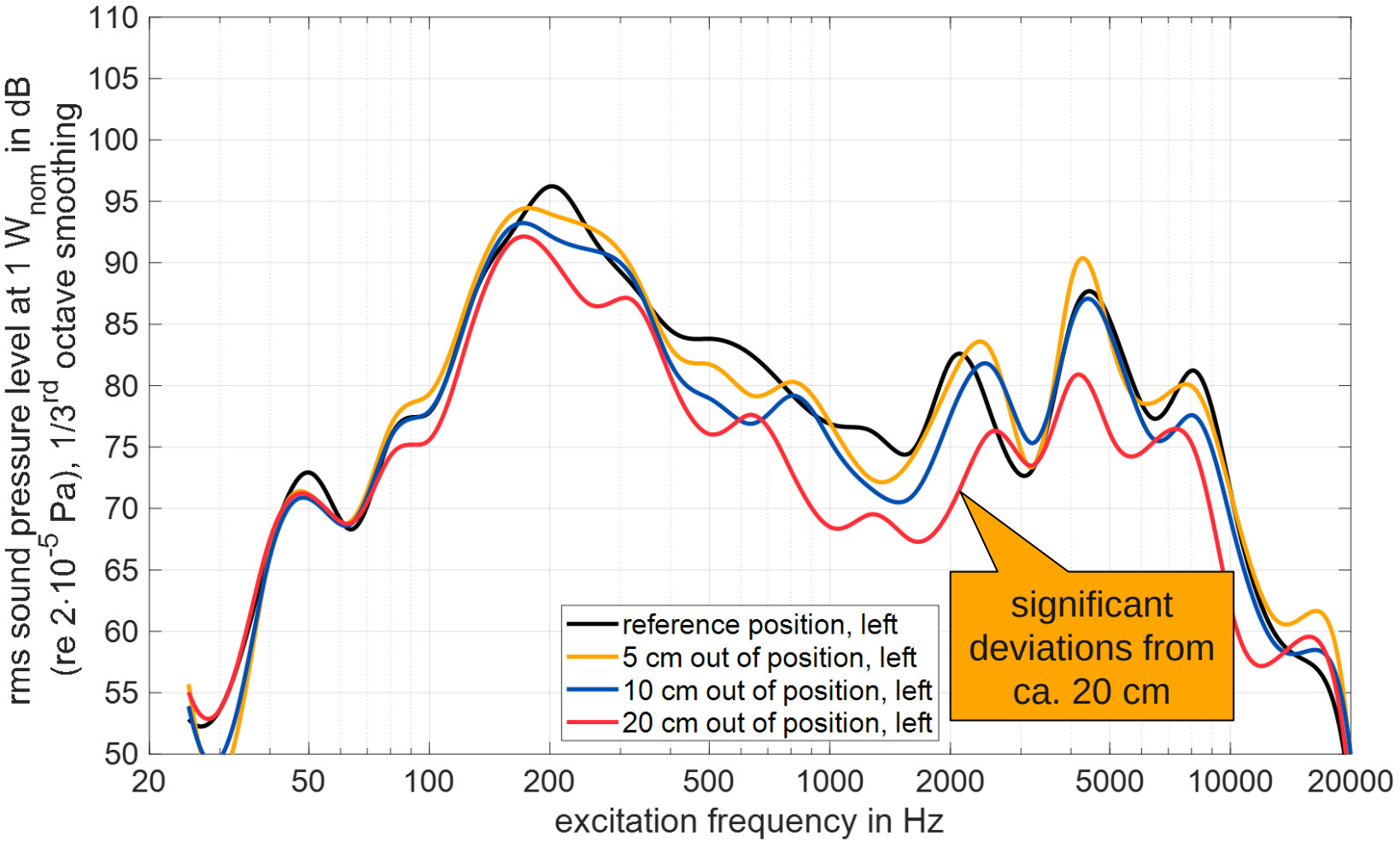
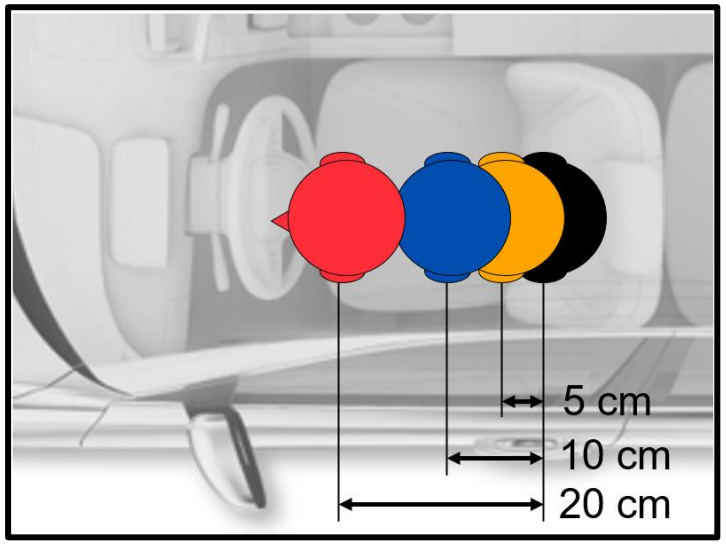


out-of-position

- not relevant up to ca. 10 cm
- significant deviations from ca. 20 cm



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Achieving personalized in-vehicle sound zones with actuator-based headrests
Summary and conclusions

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Summary

- **Concept** of actuator-based sound systems
- Potential **benefits and risks**
- **Integration** of actuators into a **headrest** (private sound zone, ANC, enhancement of global sound experience)
- **measurement results** in vehicle

Conclusions

- actuators can be integrated in headrest **invisibly** (no perforation required)
- actuator-based headrests might radiate a wide frequency range with more low-end than speaker-based headrests
- particularly suitable for **active noise cancellation** (ANC) and **road noise cancellation** (RNC)

Next steps

- implementations of **software algorithms** to improve localization and improve channel separation
- **combination** of infotainment and ANC/RNC functionalities

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[2] G. Banks und N. Harris (1998): „The Distributed Mode Loudspeaker – Theory And Practice“, Microphones & Loudspeakers – AES UK Conference, 1998

[3] N. J. Harris und M. O. J. Hawksford (2000): „Introduction to distributed mode loudspeakers (DML) with first-order behavior modelling“, IEE Proceedings – Circuits Devices and Systems, 2000

[4] D. Stotz (2011): „Computergestützte Audio- und Videotechnik“, 2. edition, Springer Verlag

Thank You

BACKUP

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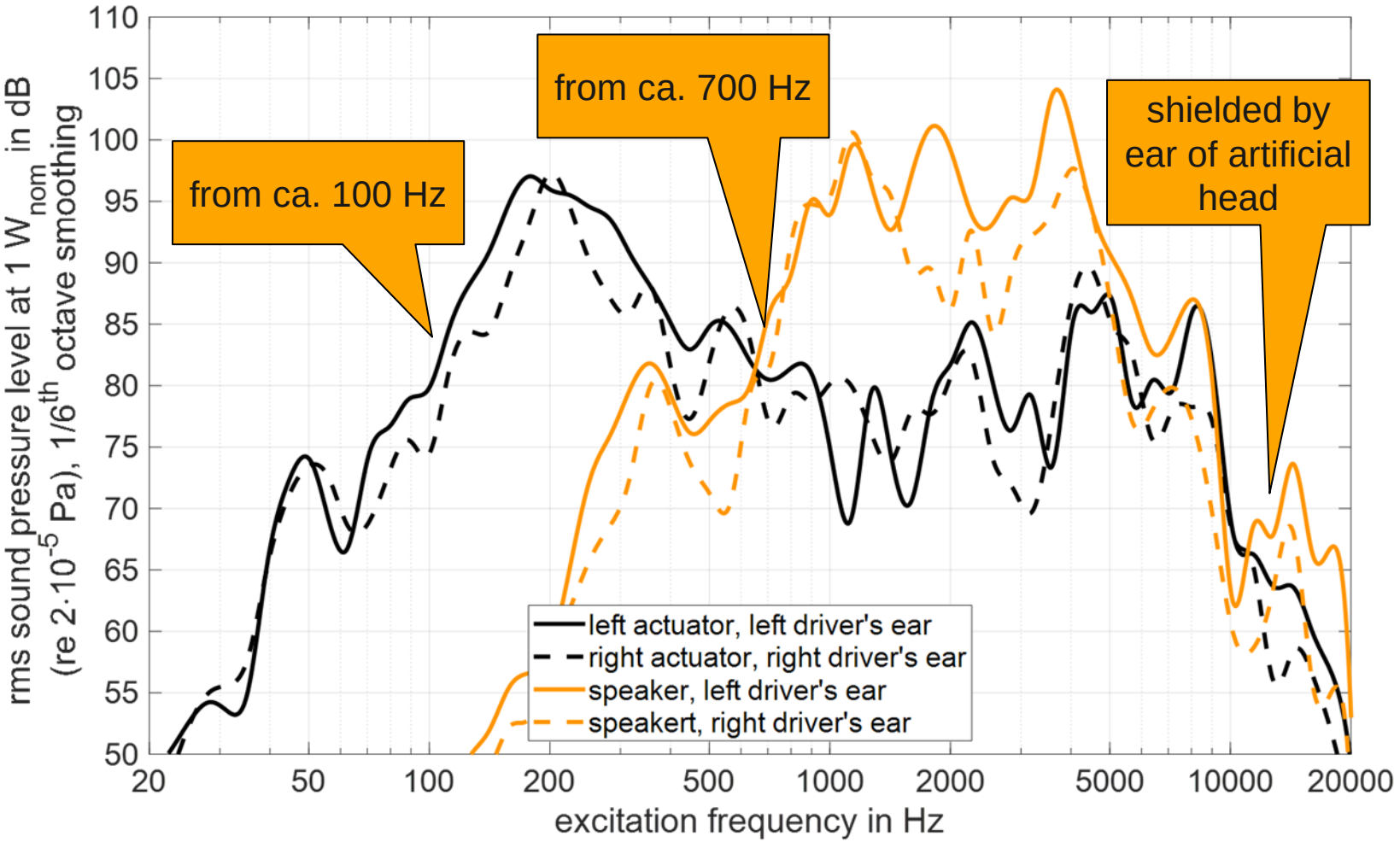
Integration of actuators into seat headrests – measurement results



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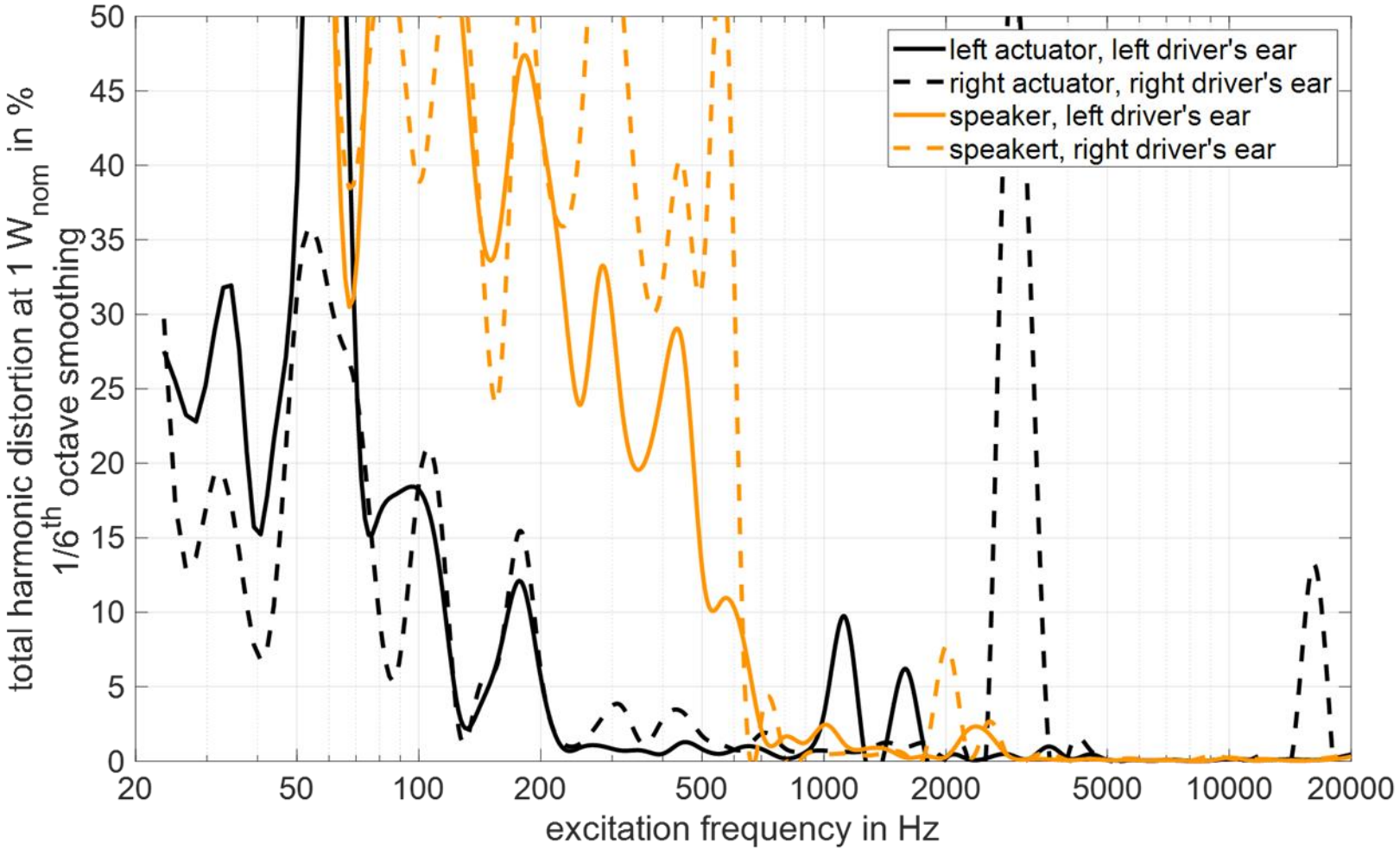

Actuator:

- low THD for >200 Hz
- THD peak at 3 kHz due to low radiation of fundamental tone

Speaker:

- low THD for >700 Hz
- THD peak at 600 Hz due to low radiation of fundamental tone

➔actuators shows over all low distortions

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Integration Examples AS Wide Range