

Active Sound Control in Cars

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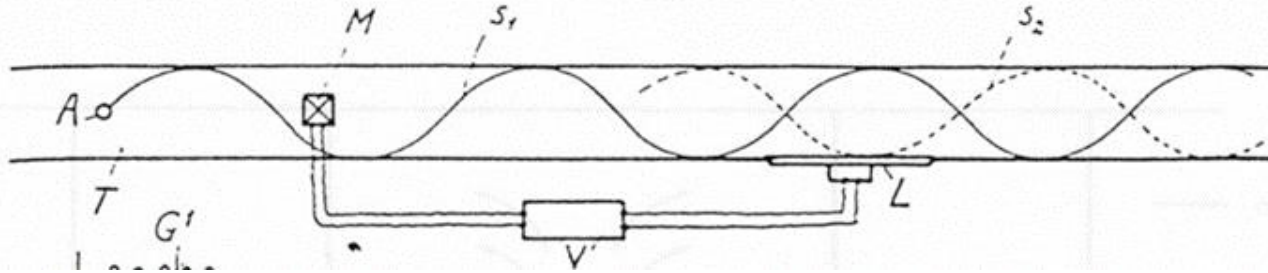
Active Sound Control in Cars

- **Background to active sound control in cars**
- **Current active noise control systems**
- **Active sound control in electric vehicles**
- **Local active sound control**

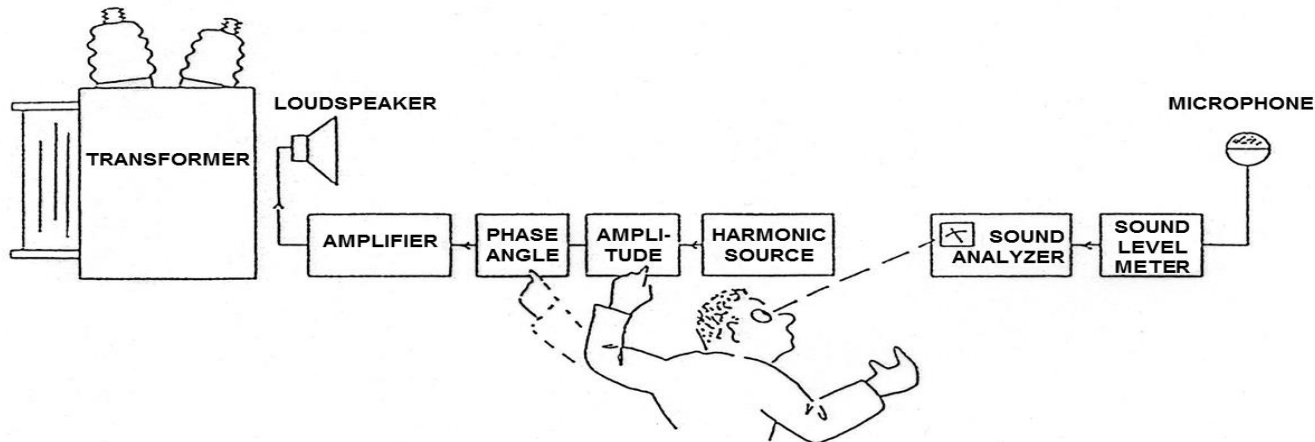
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Physical principles of active noise control

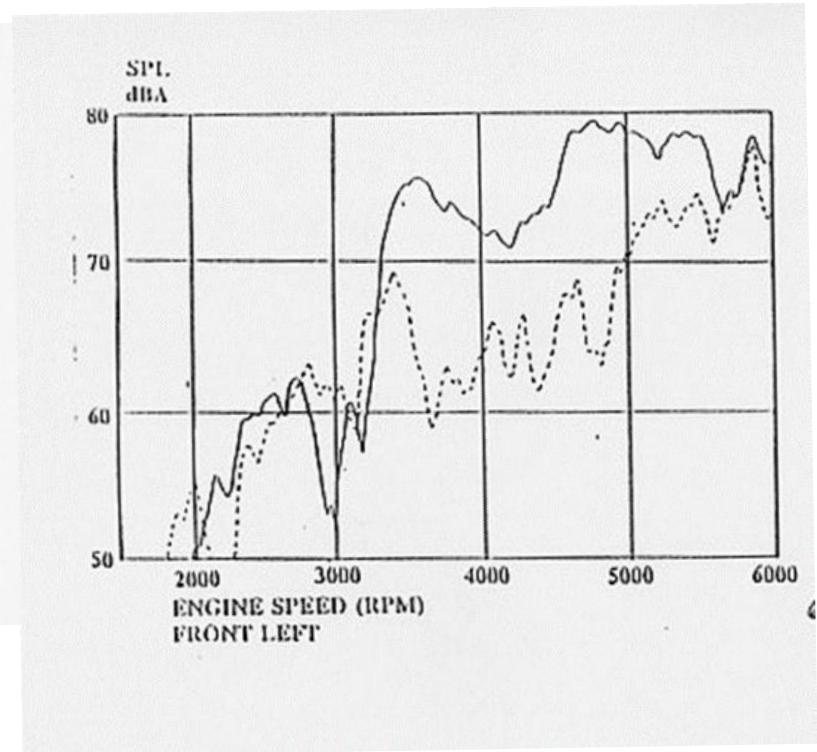
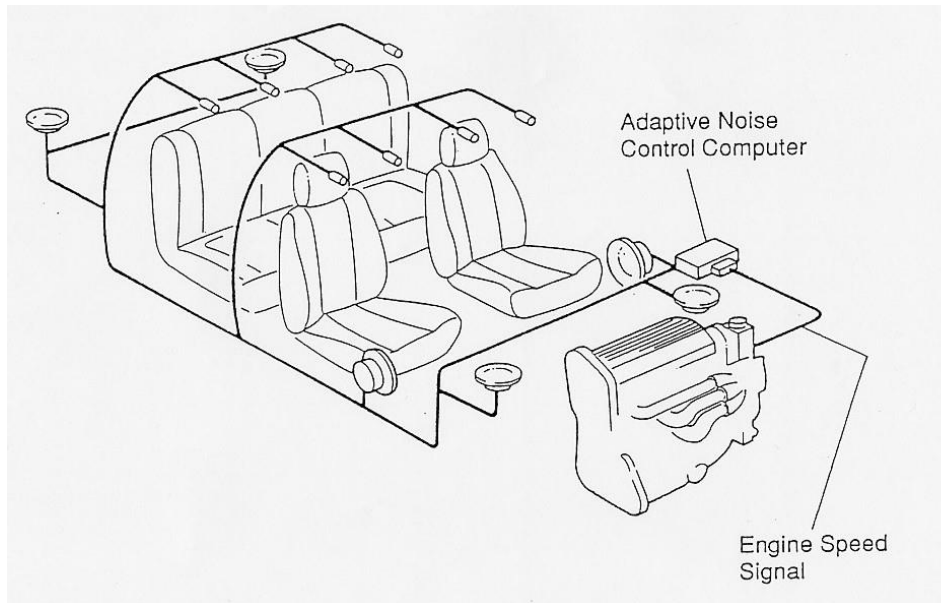


Paul Lueg 1936, Physical principles, linear superposition



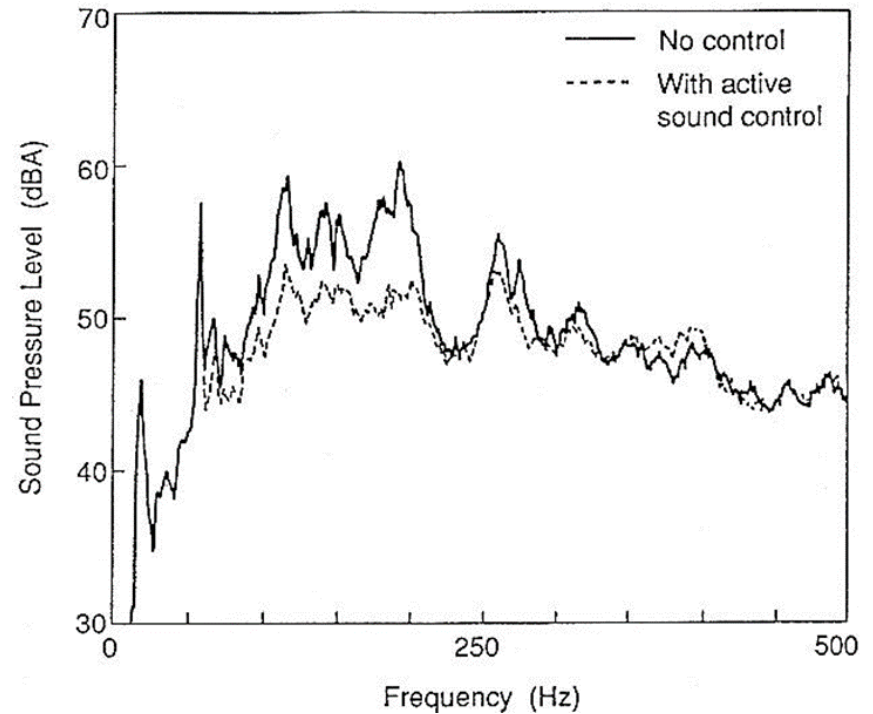
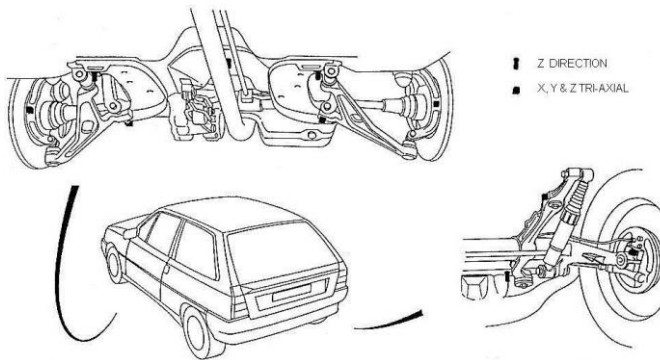
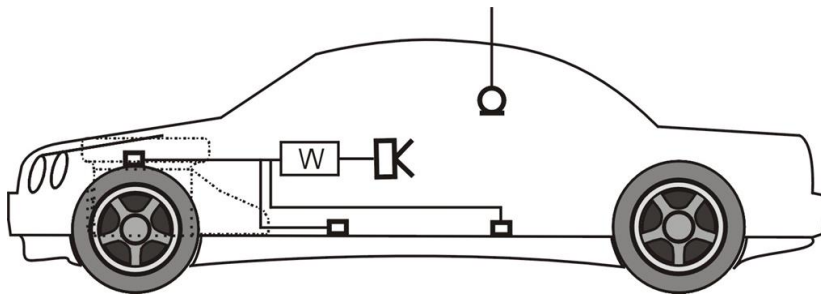
William Conover 1956, Adaptive controller

Active control of engine noise in ICE cars



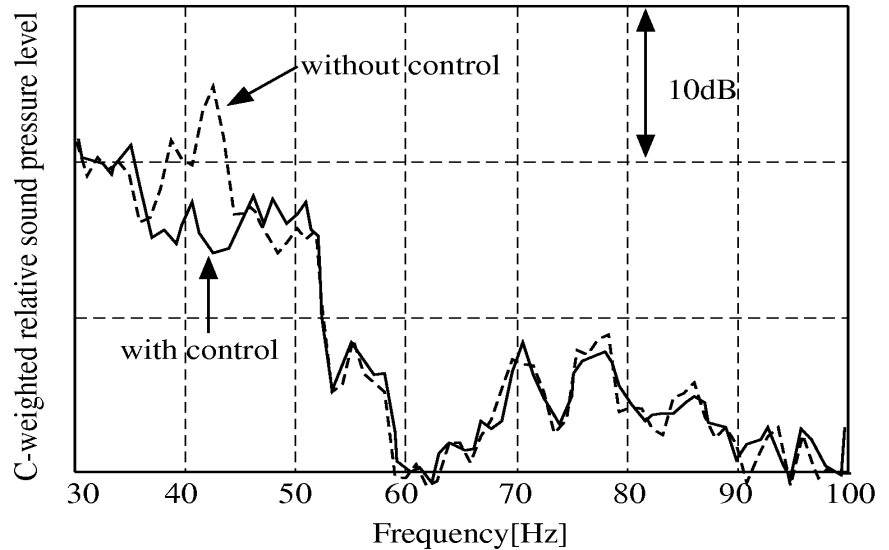
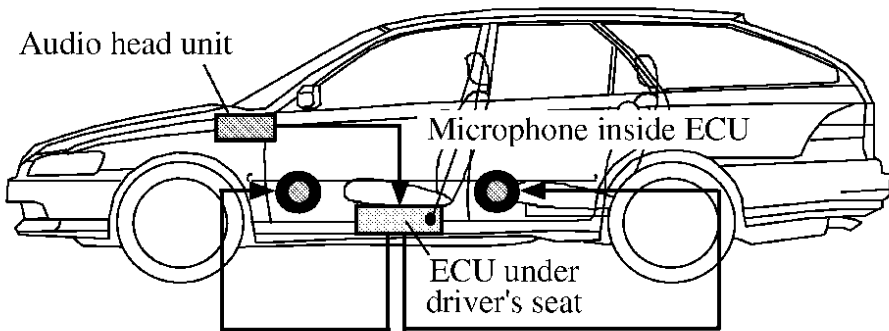
Elliott et al 1988, Digital multichannel controller

Feedforward control of *road* noise



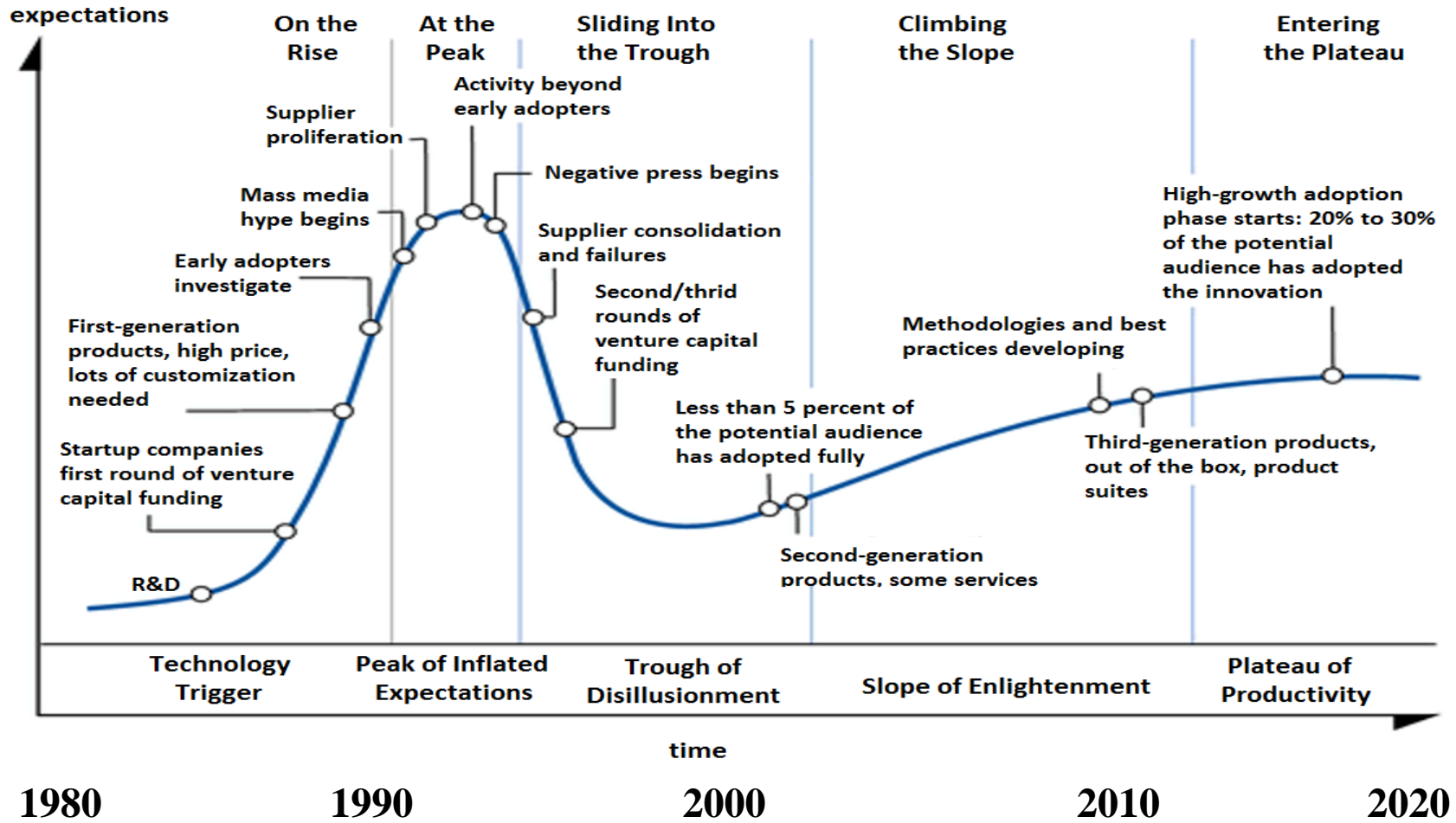
Sutton et al 1992, Reference signals from accelerometers

Feedback control of road noise



Sano et al 1993, No external reference signal required for narrowband control

The “Hype Cycle” for Active Noise Control



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Current active noise control in cars

- *Many cars* are now fitted with some form of active sound control, whether advertised as such or not
- Costs reduced by *integration* of ANC hardware and software with audio DSP, amplifiers and loudspeakers
- Recent systems do not just attenuate undesirable sounds but also enhance desirable sounds to improve *sound quality*

Some Current Applications to Powertrain Noise in Cars



Lexus Infiniti (low frequency exhaust noise)



BMW M5 (enhanced V8 burble)



Ford Mondeo Vignale
(Engine drone and sports boost)



Range Rover PHEV(low revs charge sustain)

Sound Profiling or “Active Sound Design”

Attenuating unwanted engine orders and *enhancing desired engine orders*

e.g. to make a 4 cylinder engine sound like a V8 during cylinder deactivation

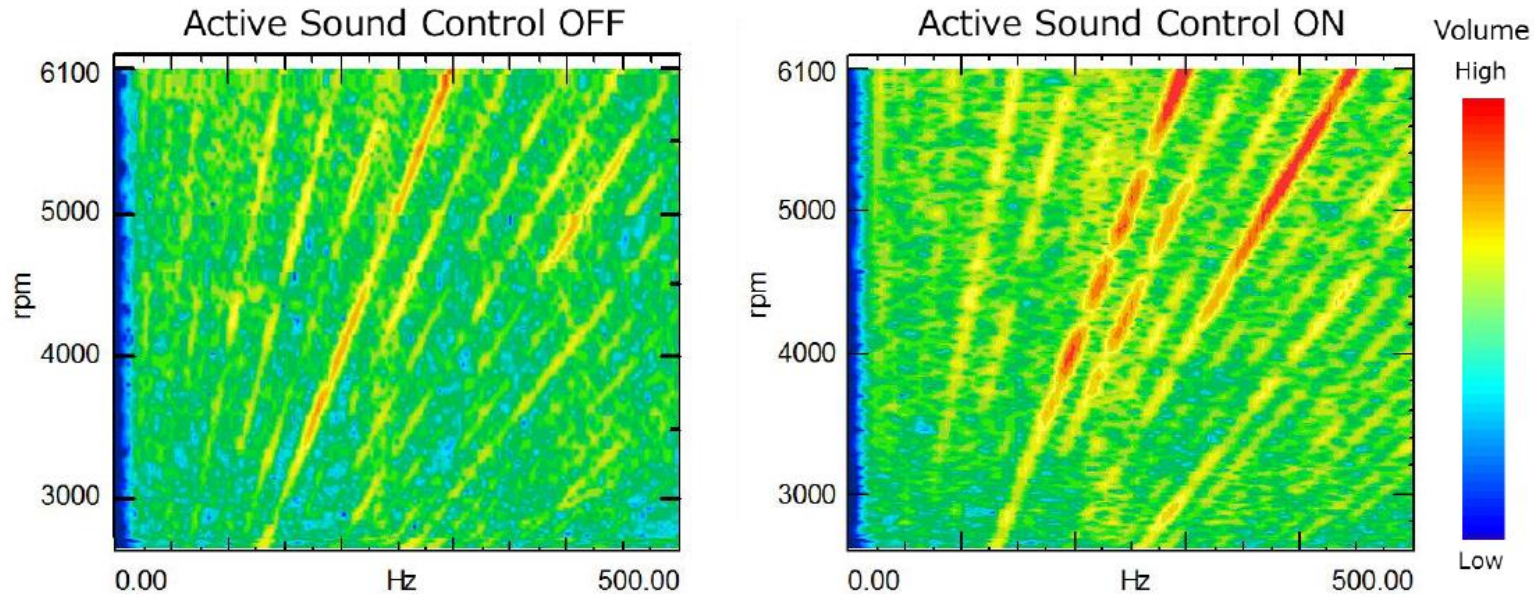


Audi A8
“cylinder on demand”
V8 to 4 cyl



Honda Accord
“Variable cylinder management”
V6 to 3-4 cyl

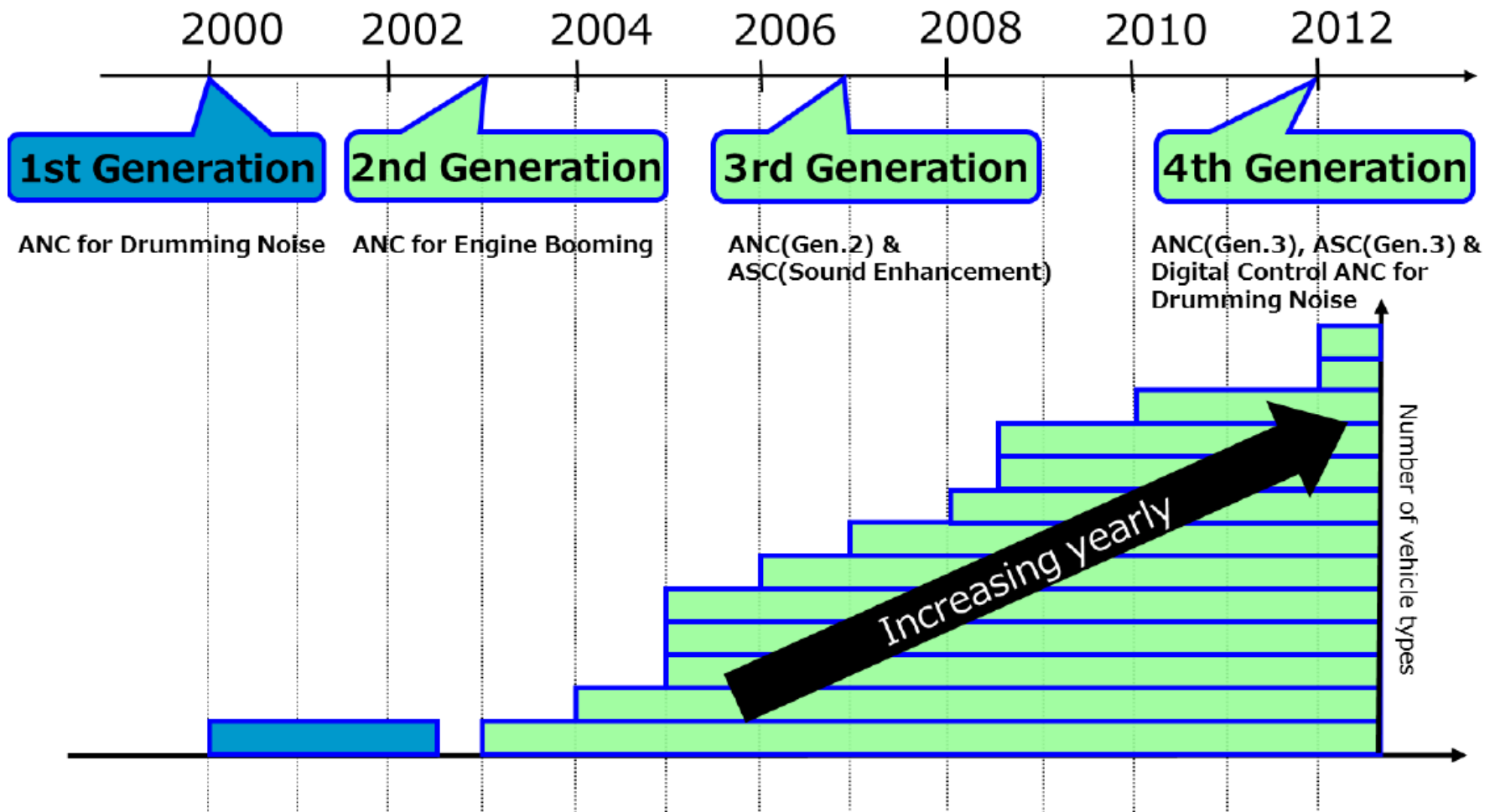
Active control of engine orders for sound quality



The aim here was to enhance acceleration sound to give a “powerful” sound at mid RPM and a “nimble” sound at high RPM

Reproduced with kind permission of Toshio Inoue, Honda R&D Ltd

Advancement and Commercialization of Honda ANC³

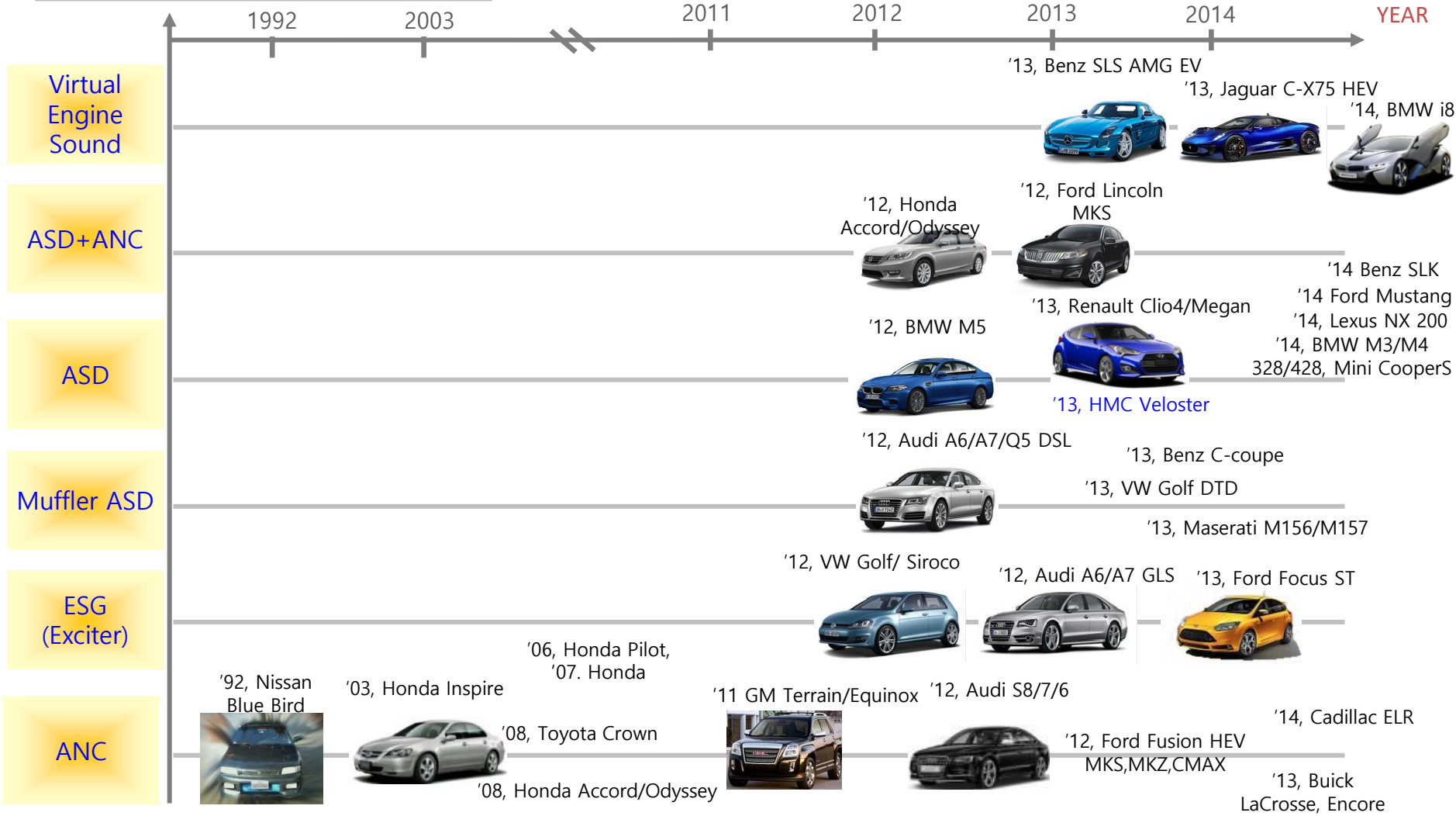


Honda ANC is applied to 13 types of vehicle and 1 million ANC-equipped vehicles are produced every year all over the world.

Reproduced with kind permission of Toshio Inoue, Honda R&D Ltd

II. Engine Sound Design

ANC/ASD trend



Commercial Active Sound Design tools

Siemens: Design and evaluate irresistible interior and exterior vehicle brand sounds. The electrification of the powertrain brings active sound design to the next level. Although artificial sound served mainly the sound quality and emotional considerations in ICE vehicles, sound design becomes functional and an integral aspect of the driving experience in the electrified vehicles.

<https://www.plm.automation.siemens.com/global/en/products/simulation-test/active-sound-design.html>

Ansys: Active Sound Design for Electric Vehicles
ASDforEV, a tool that enables you to test and finely tune active sound design candidates for electric or quiet ICE vehicles

<https://www.ansys.com/en-gb/resource-center/webinar/active-sound-design-for-electric-vehicles>

Active Sound Control in Cars

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Active sound control in electric vehicles

- No low frequency engine noise, so broadband *road noise* is more dominant
- Tonal noise is still present but at higher frequencies due to motor and gear *whine*
- “Active Sound Design” = reduction *or masking* of unwanted noise + reproduction of sounds giving feedback to driver
- Sound *reproduction* may be by audio loudspeakers inside the car, or vibration actuators on the structure

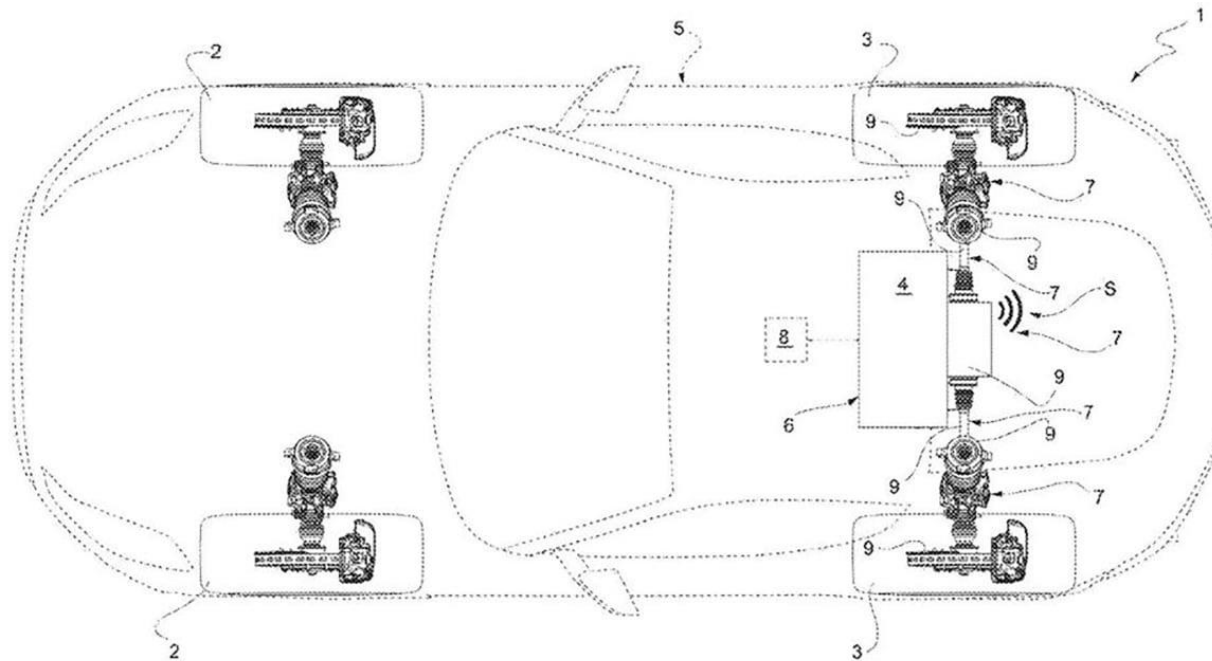
Structural actuators for active sound design



<https://www.sound-booster.com/en/sets/electric-vehicle.html>

Electric motor noise enhanced by tailoring drive waveform

FIG. 1



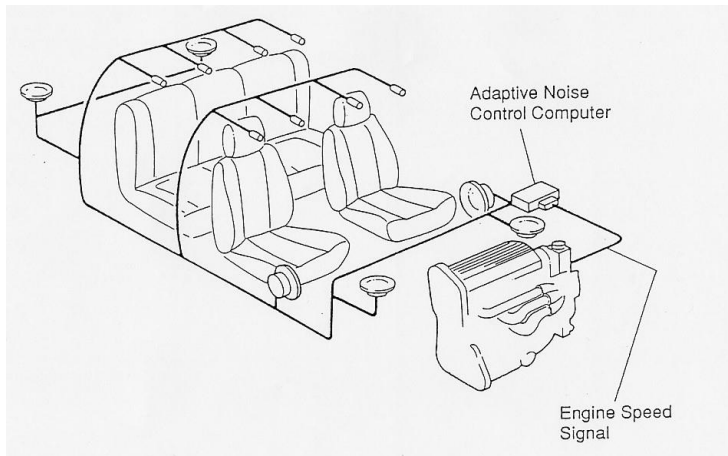
acoustic system **6**, which has the function of generating a sound through the electric motor **4**, so that the sound perceived by the people seating in the passenger compartment **5** of the car **1** is “pleasant”, namely corresponds to the desires/expectations of the occupants of the passenger compartment **5** of the car **1**, and/or is useful while driving in order to understand the conditions of the motor.

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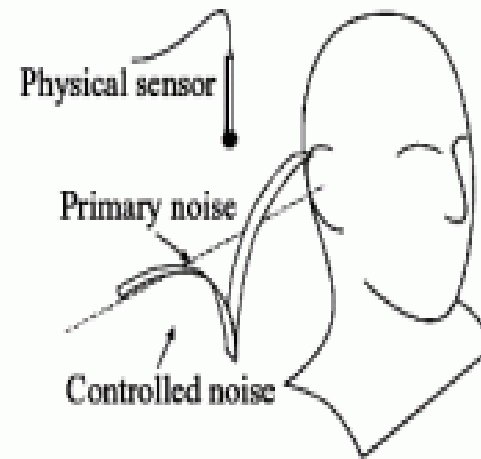
Global vs Local active control in cars

Global active sound control



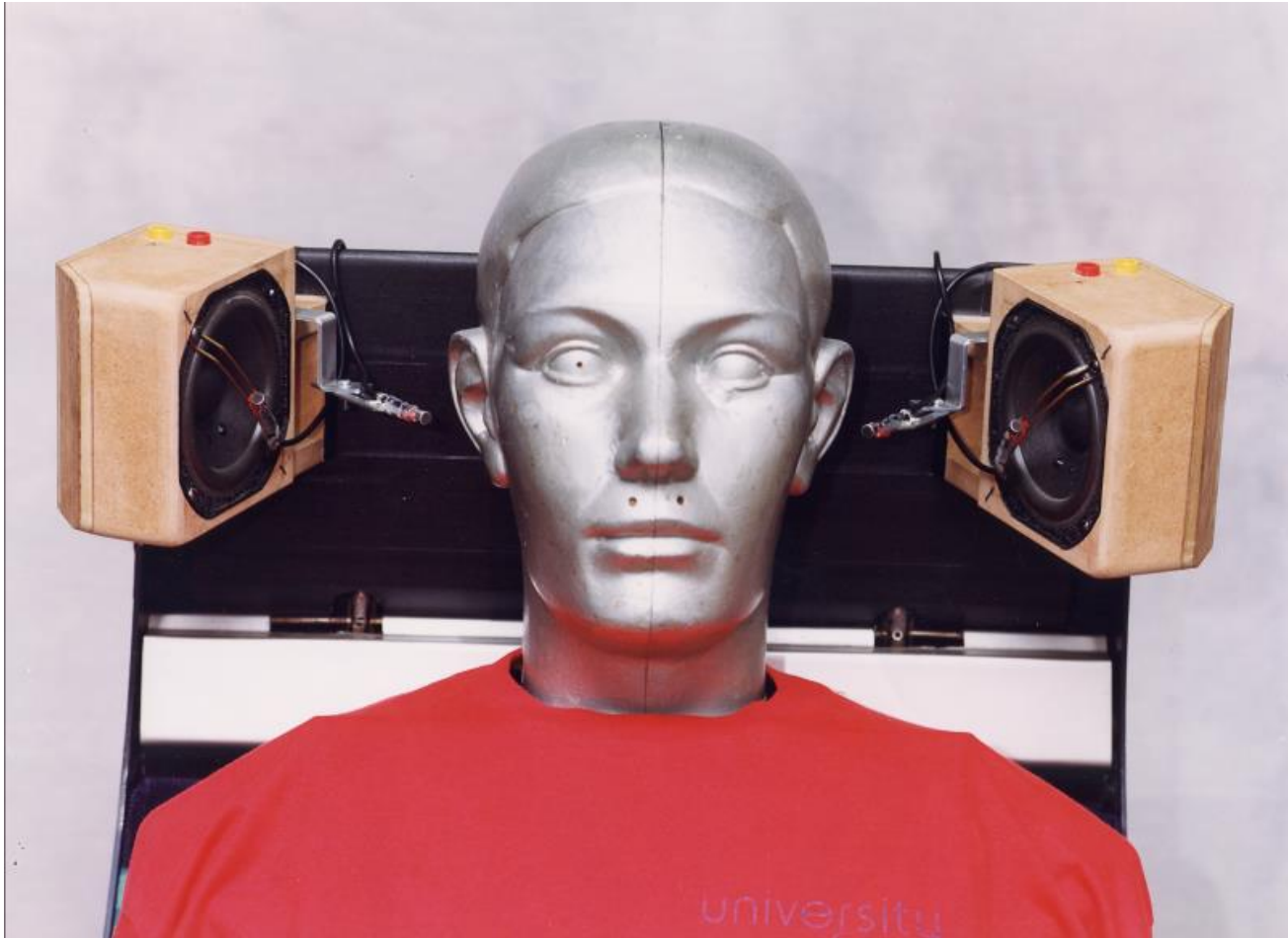
A limitation of global control, using remote microphones and loudspeakers, is that significant attenuation is only achieved at frequencies **up to about 250 Hz** in a car, due to high acoustic *modal density*

Local active sound control



Local control, with close-spaced microphones and loudspeakers, creates a “zones of quiet” around a microphone, which is about **1/10 of an acoustic wavelength** in extent, i.e. 34mm at 1kHz: Upper frequency depends on whether the listeners ear is within this zone

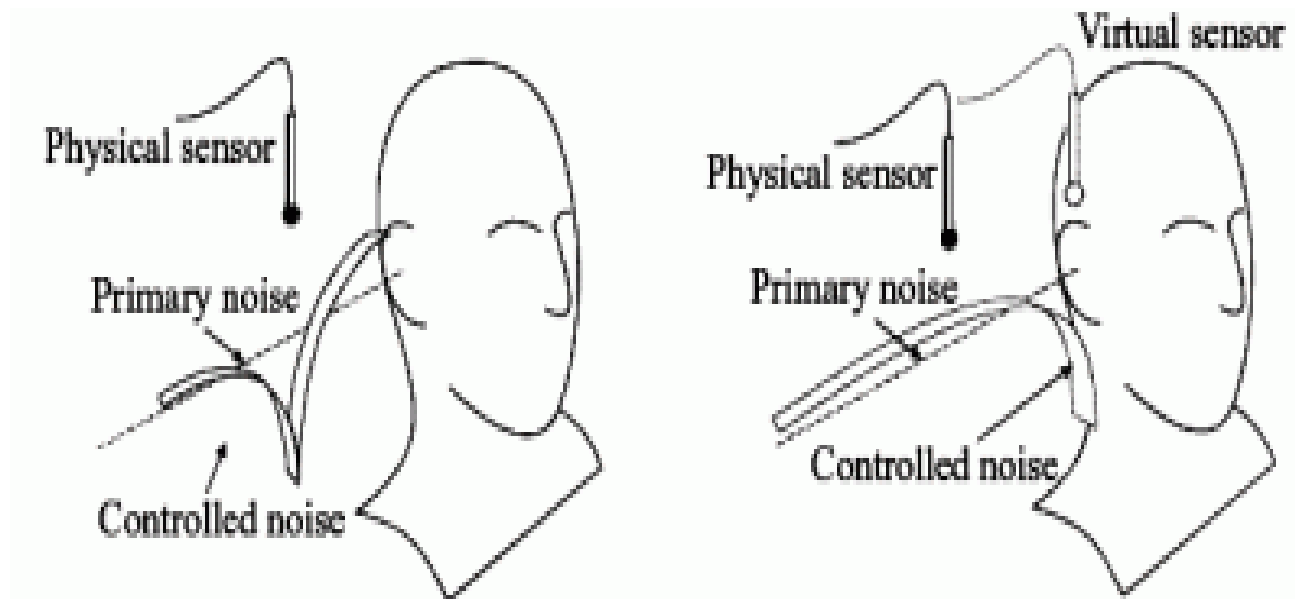
Microphone location



Locating physical microphones at the ears would be dangerous...

Virtual sensing of error signals

Virtual sensing: The error signals at the virtual sensor can be estimated from the physical monitoring sensors (*Moreau et al 2008*).



The position of the virtual sensor can be moved electronically e.g. in response to positional information from a head tracker

Head tracking using a Microsoft Kinect in a car

Head Tracking

Head Coordinates (cm)

1.17 12.0 105.

Head Rotation (degrees)

Pitch Yaw Roll

7.44 -22. 5.56

Right ear coordinates (cm)

3.25 -2.1 11.9

Left ear coordinates (cm)

4.04 -3.6 4.23

Right ear No. Left ear No.

22 42

ANC Tracker

Tracking ON : 1 -> 2
Tracking OFF: 2 -> 1

1 2

<<-Press to Zero Kinect

<<-Tracking


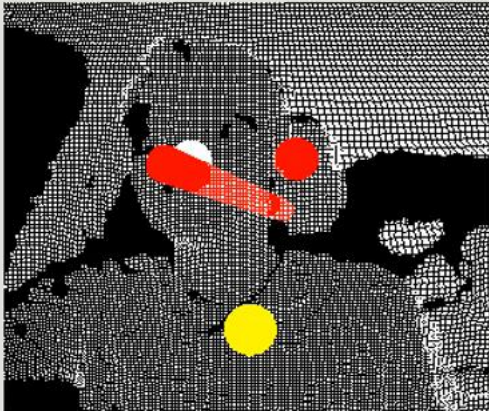
<<- Start Kinect

Body Tracking

Body Position No. 8

Body : forward from a nominal (cm) 2.358

Body sideways (cm) -1.3

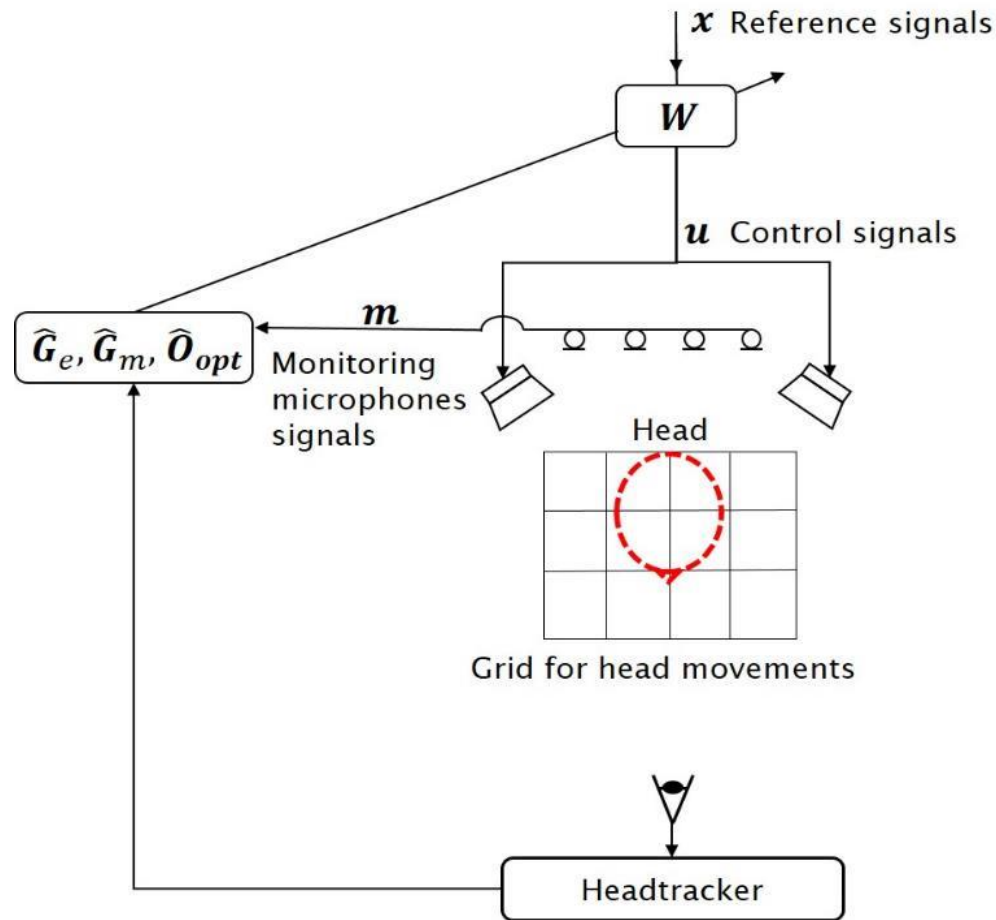


Automotive eye and gaze tracking



Currently used for drive
alertness and attention
monitoring

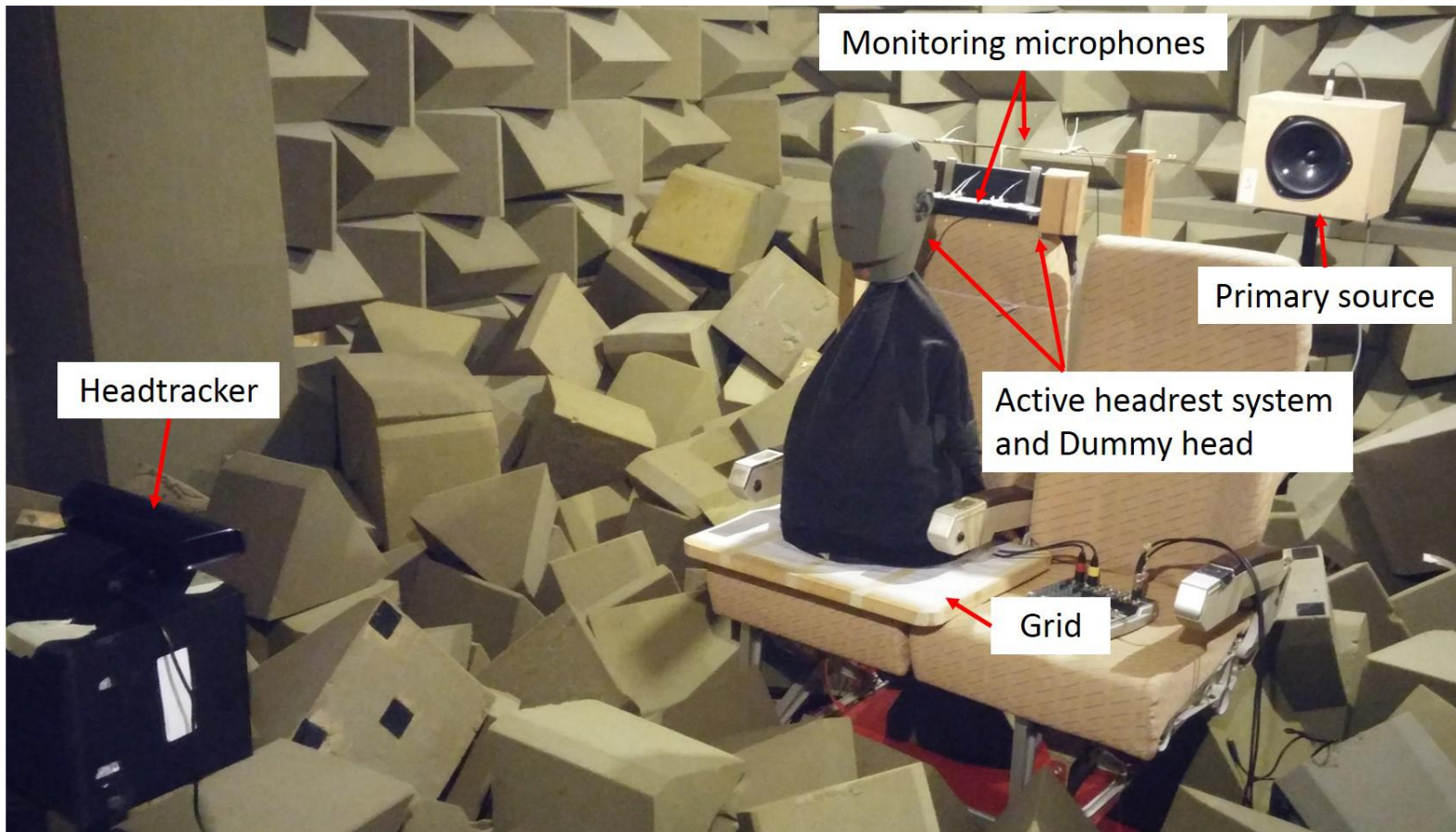
Tracked Local Control



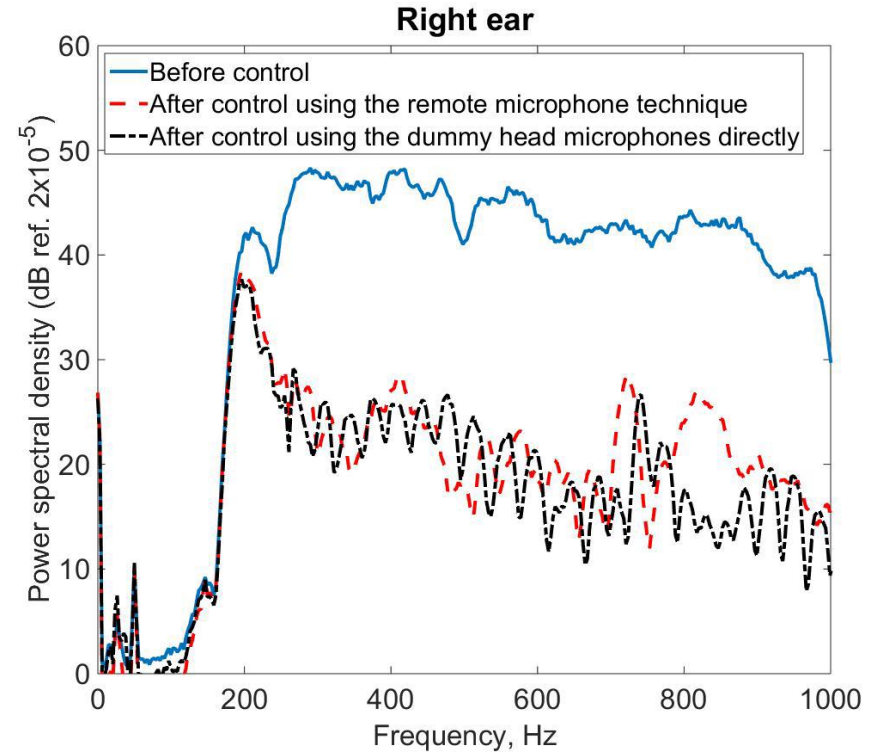
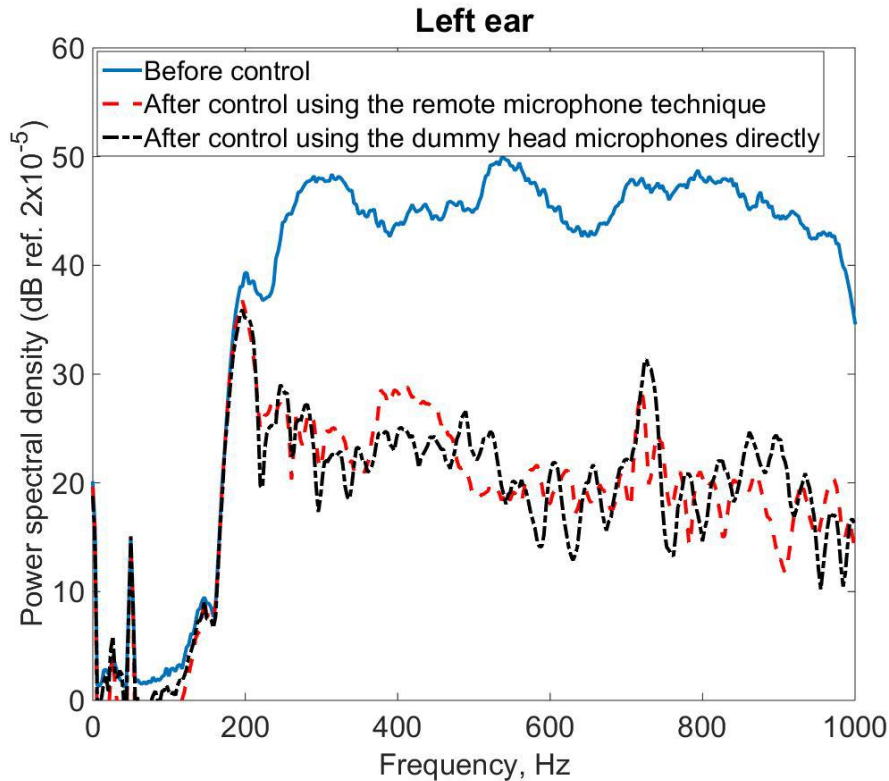
An active headrest system, integrated with a head-tracking device and using virtual sensing with local monitoring microphones

(Elliott et al 2016)

Laboratory experiments on local control with head tracking



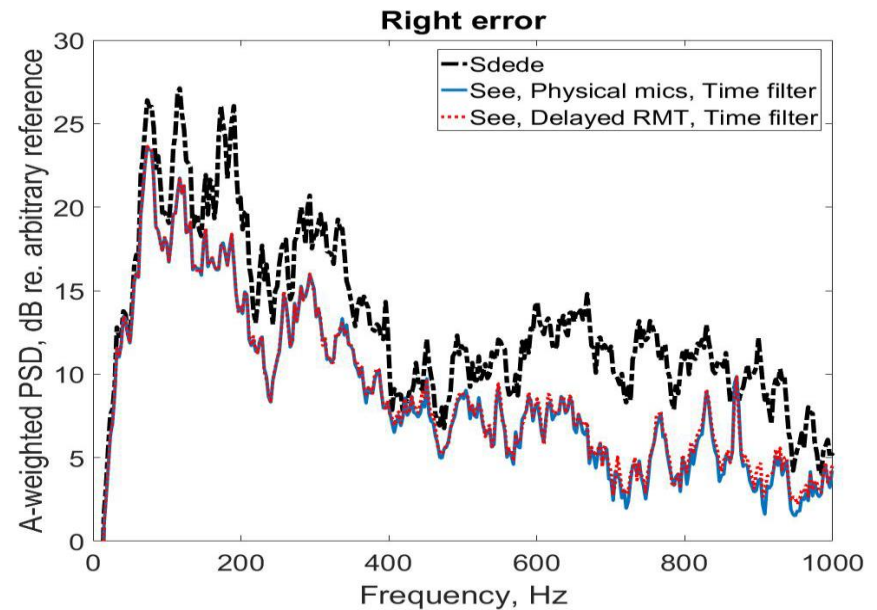
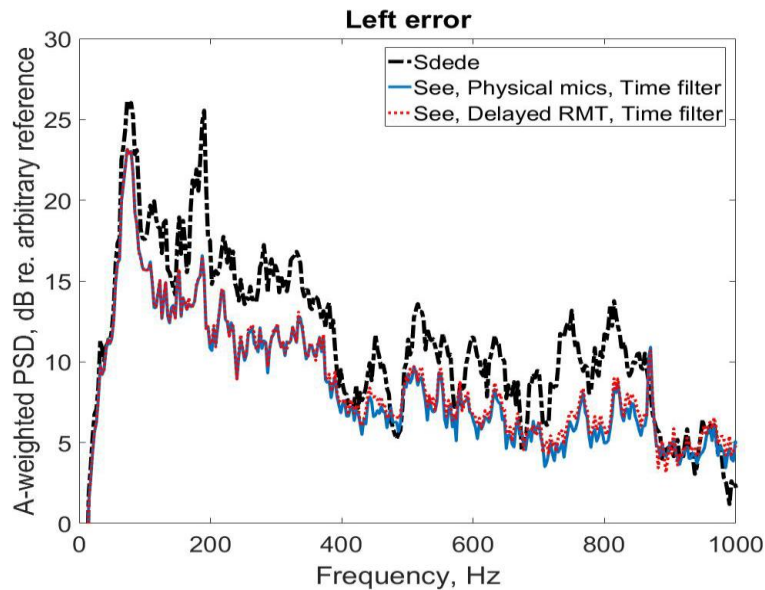
Results of laboratory experiments controlling broadband noise



Elliott, Jung & Cheer Nature Scientific Reports March 2018

Predictions of local control performance in a large SUV

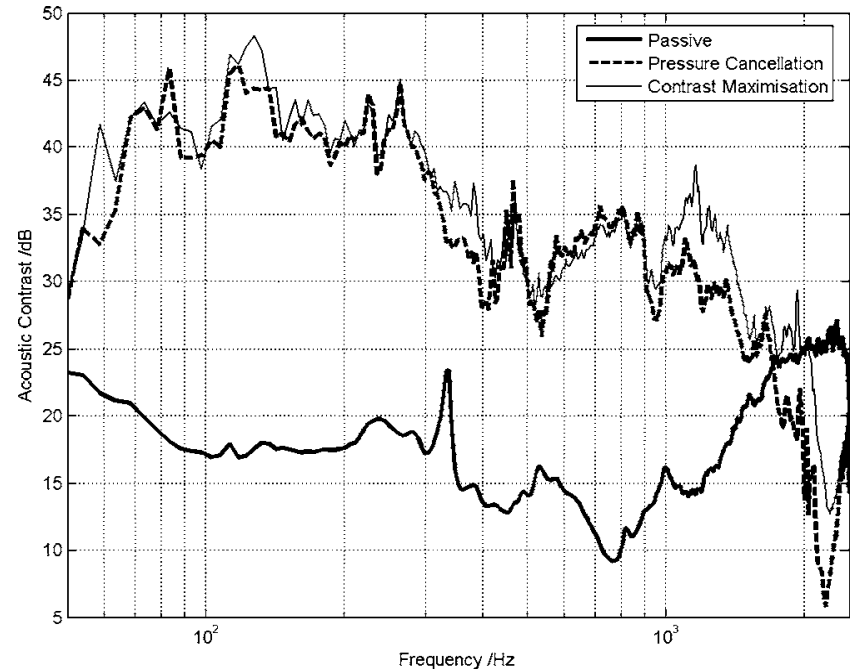
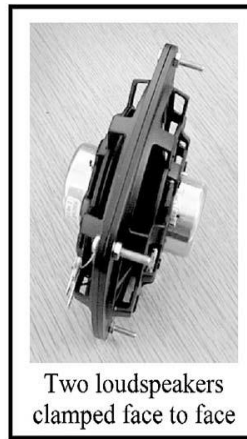
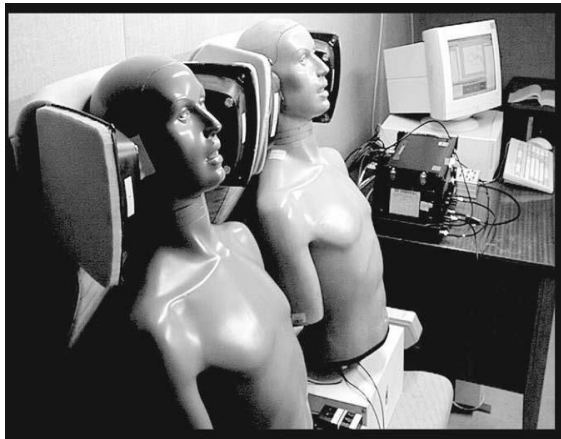
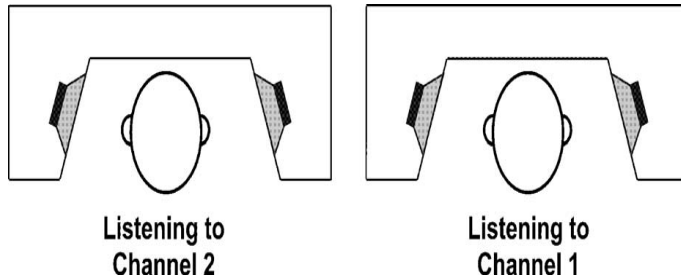
(Jung et al 2018)



Summary

- Active sound control in cars , originally developed in 1980s, has been combined with sound reproduction to give “**active sound design**”, now widely used in many ICE vehicles
- In **electric vehicles**, controlling road noise becomes more important, as well as ensuring a pleasant sound and providing feedback to the driver
- Global active control has a limited frequency range, but the **local active sound control** systems currently being developed can significantly extend the frequency range, particularly if using virtual sensing and head tracking

Early sound zone system

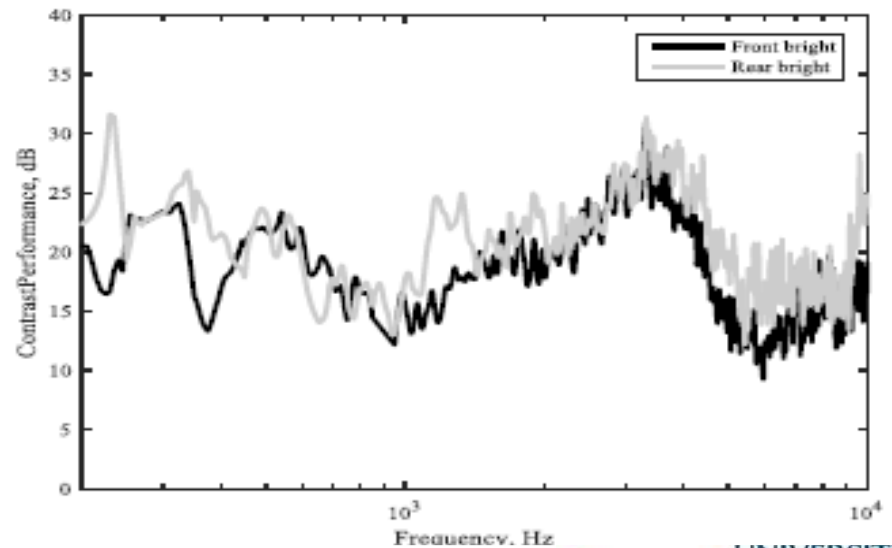


Personal (zonal) audio



Example of acoustic contrast (ratio of mean square levels in two zones) for an experimental system using loudspeakers in the doors at low frequencies and loudspeakers in the roof at high frequencies

Liau et al JAES 2017



Earlier concern about Active Sound Design for IC vehicles

**“America’s best-selling cars and trucks are
built on lies: The rise of fake engine noise”**

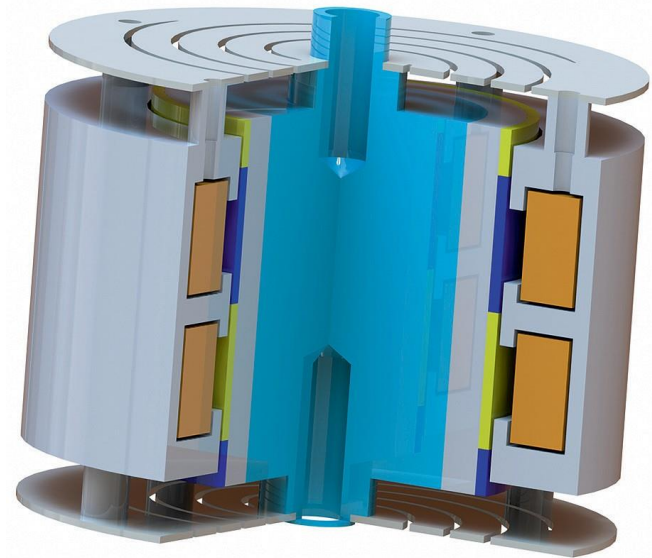
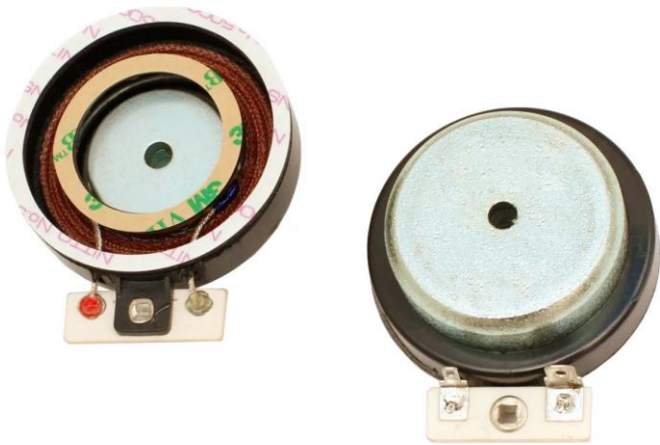
Washing ton Post 2015

Now there is an industry in generating
aftermarket sound for electric vehicles

<https://www.sound-booster.com/en/sets/electric-vehicle.html>

<https://milltekshop.com/active-sound/>

Moving magnet vibration actuator



<https://www.tectonicaudiolabs.com/audio-components/audio-exciters/>

<https://link.springer.com/article/10.1007/s>

Active control with head tracking





- **“Active Sound Control” = reduction of noise + reproduction of audio**