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Lessons learned in application of ANC to broadband noise control in vehicles

2nd March 2023

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Low Frequency Noise Control

Passive Methods

- Fundamental structural design
  - Not always feasible
- Dynamic absorbers
  - Target specific modes
  - Significant weight penalty
  - Expensive
- Heavy layer
  - Weight penalty
  - Cost penalty

Active Noise Control

- Effective Low Frequency Control
- Light weight
- Can use existing hardware
- Processing Costs Falling
- Does not have to reduce noise!

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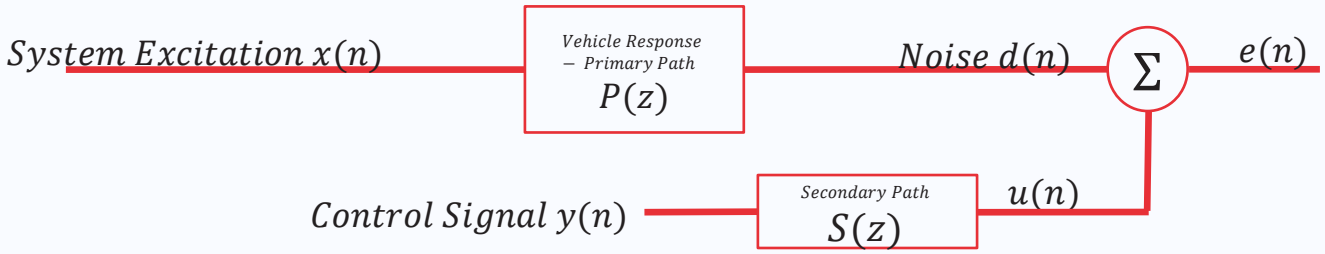
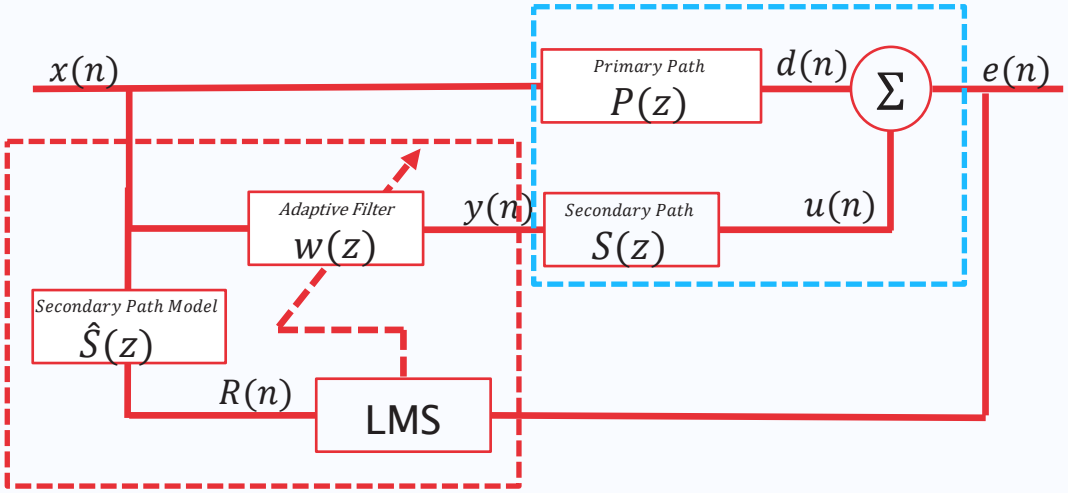
Physical principle of Active Noise Control

Active noise control relies on **matching** the original and the controlled sound field both

- **Temporally** (control/ signal processing)
- **Spatially** (acoustics)



Adaptive Control - FxLMS algorithm



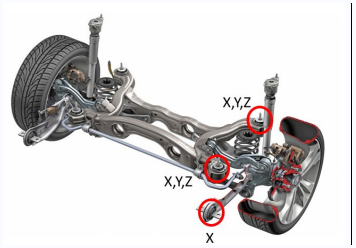
$$w(n+1) = w(n) + \alpha R(n) e(n)$$

- Tries to minimize *e(n)*
- Uses a gradient descent approach
- Contains a model of the secondary path
- Uses a step size α
- Higher α gives faster convergence
- Maximum α depends on system characteristics

$x(n)$ - reference input, $P(z)$ - transfer characteristics between the reference and error locations, $e(n)$ - error, $W(z)$ - control filters, adaptively calculated by the LMS block
$S(z)$ – transfer characteristics of the secondary path (control speakers to error locations), $y(n)$ - control effort signal

Implementation

References *x(n)*

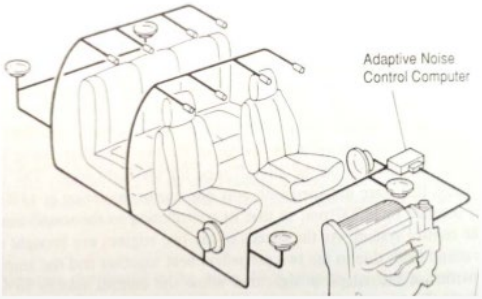


Error signal *e(n)*

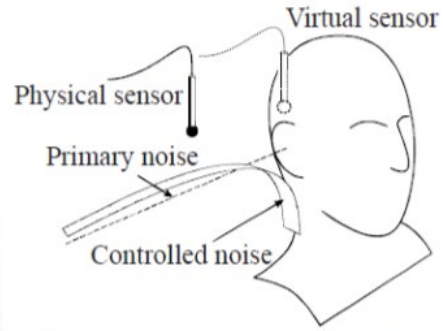
Control signal *w(z)*

Control signal *y(n)*

Global vs. Local active control



Installation of global active sound control



A schematic representation of local active control

- Global control attempts to control the whole space
- A single controller is used
- Can use the standard vehicle audio system – 4 or 5 loudspeakers in a typical car

- Local control targets a single occupant
- Each seat can have its own controller
- Requires two loudspeakers in or local to each seat

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Typical Computational Load

Full Space Control

- L sources (5)
- M references
- K error signals (5 or more)

Local / Seat Based Control

- L sources (2)
- M references
- K error signals (2)
- N seats (5)

FxLMS Algorithm

> 25M FIR Filter Operations

N x 4M FIR Filter Operations

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System References

- Suitable references are key to a successful implementation
- Need to be causal to the noise components in the vehicle
- Need to be in advance of the noise to be controlled
- Points on the vehicle structure are common (suspension etc)
- Microphones can be used in larger cavities

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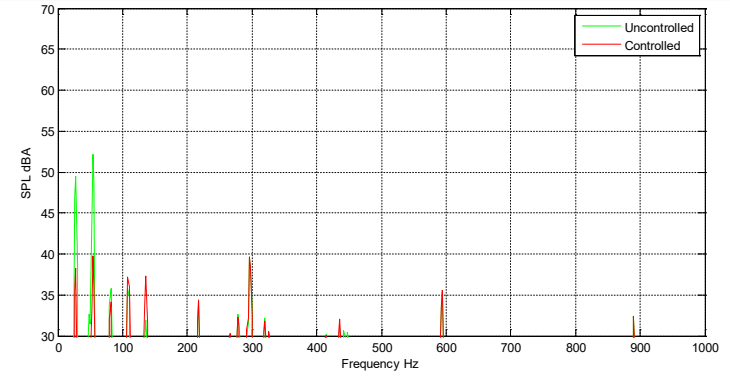
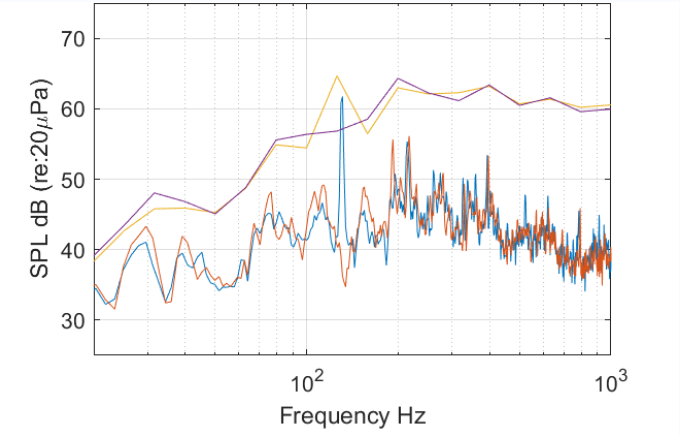
Single Source

- If there is a single source (engine) very few references are required.
- A broadband control algorithm can reduced engine noise using one or two references
- Not as effective as tonal control algorithm but good for steady state control

Broadband Control Algorithm



Tonal Control Algorithm

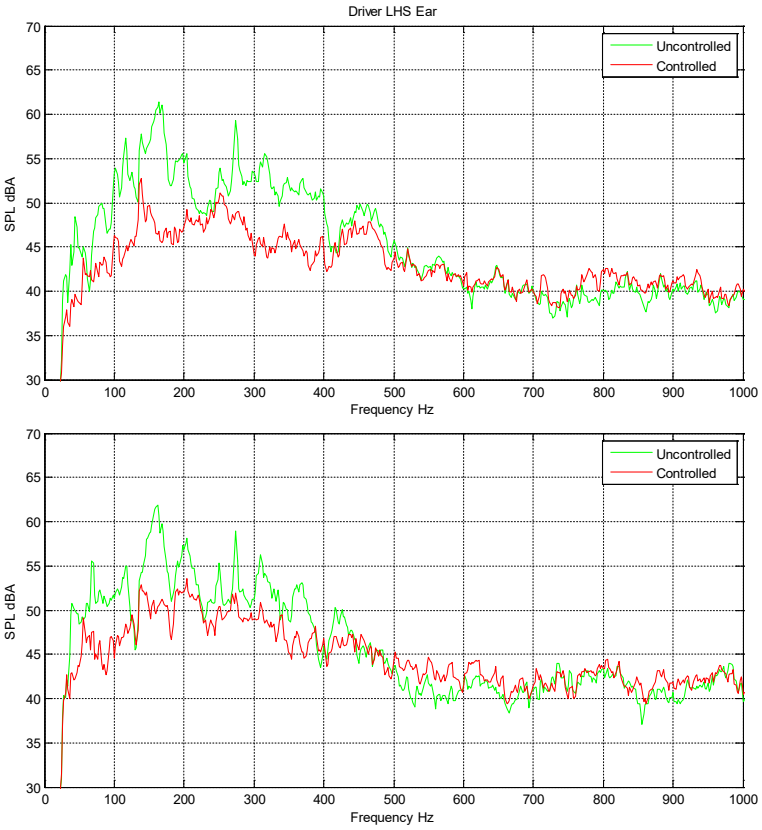


Road Noise Control – multiple sources

6 Error Microphones, 5 Speakers

16 References

8 References



Large number of references can capture most structural transmission paths.

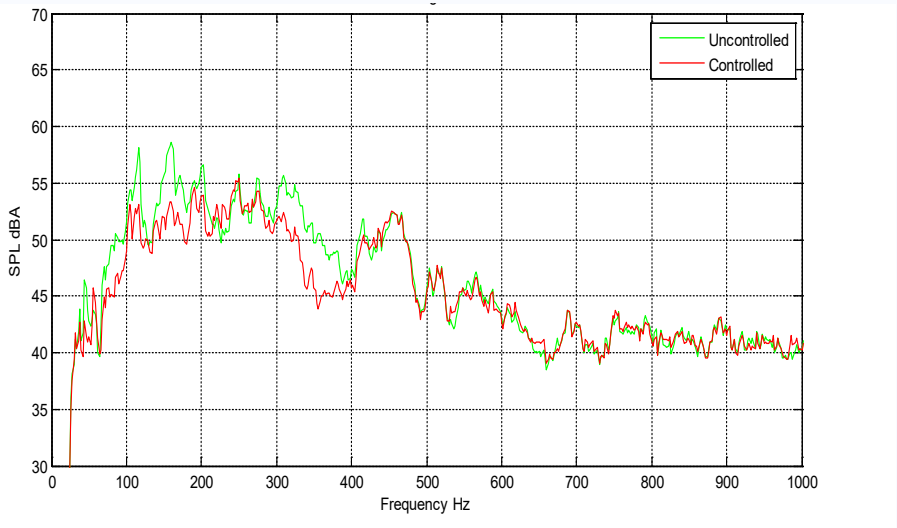
Very good noise reduction

Performance is still good with 8 references

These are simulations however..

Road Noise Control – actual setup

4 References 4 error microphones, 5 Speakers



Microprocessor was not capable of running close to an optimal setup in real time.

Compromised performance

6 to 8 references now typical

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Changing Excitation

- Excitation mechanism can change with speed / load
- Structurally transmitted road noise can be less dominant at higher speed
- Airborne road noise
- Generally performance degrades at higher speeds as wind noise increases

Local ARNC	Front right (dBA)	Rear left (dBA)
50 km/h	4.4	6.2
70 km/h	4.1	5.5
100 km/h	2.9	4.1

System attenuation vs Road speed

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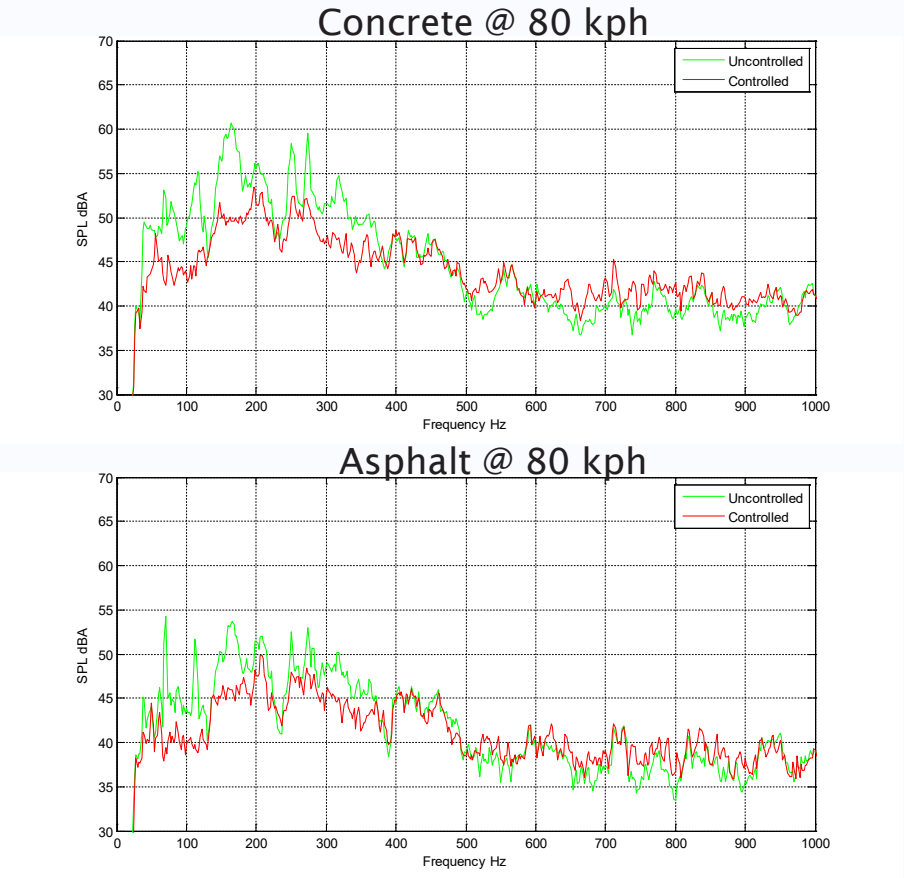
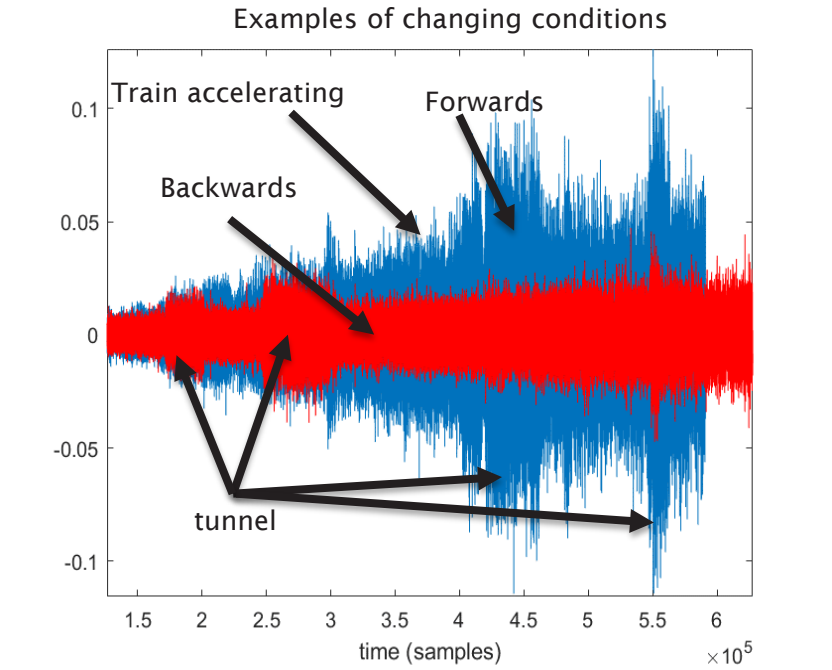
Reference Selection

- Many potential reference positions
- Sensor cost, system complexity and computational load dictate number used.
- Selection is difficult due to combinations available (6 locations from 40 possible 3,838,380 combinations)
  - Multiple coherence
  - Partial pressure
  - Engineering judgement

- Complicated by selection of target
  - Road surface
  - Operating condition
  - Occupant location



Application to High Speed rain

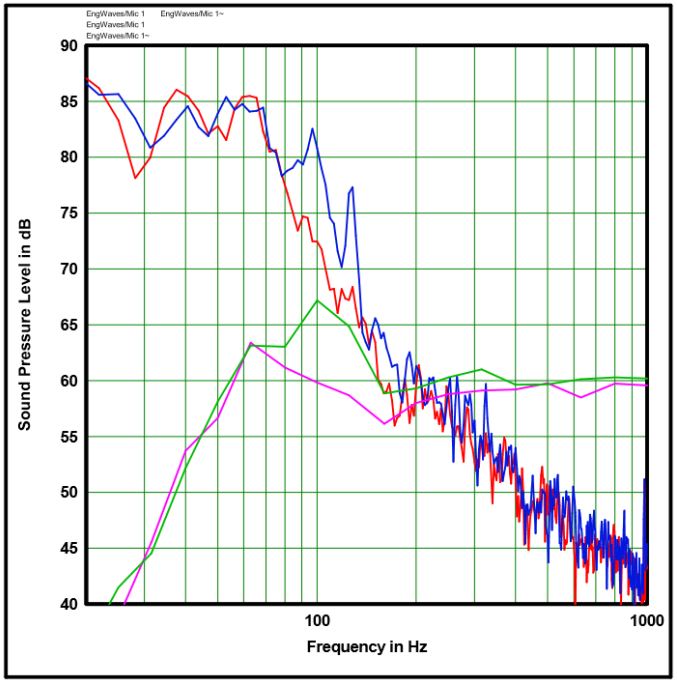


- Distributed sources over the whole cabin
- Mostly due to aerodynamic noise mechanisms at high speed
- Varies with direction of travel, operating conditions and terrain
- Broadband and tonal components
- Machinery noise (tonal sources)

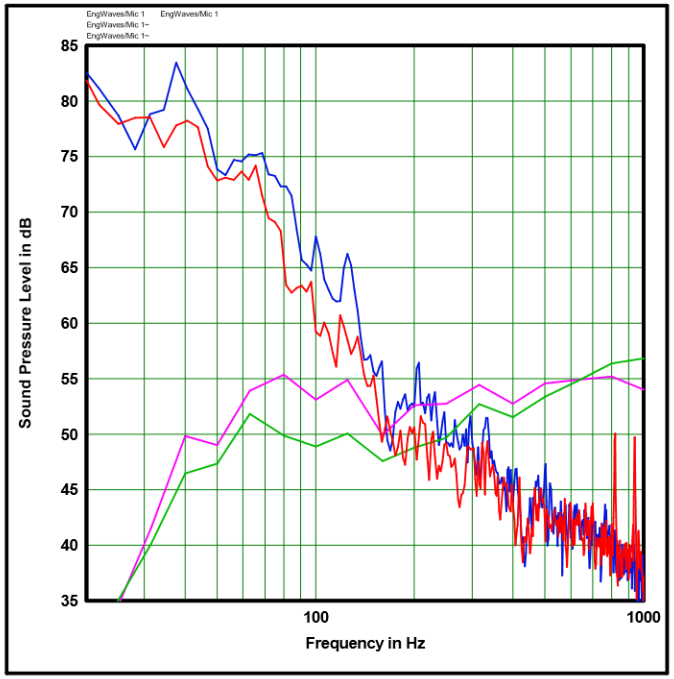
Noise Reduction at 300 kph

- 30 references microphones, 300 km/h

Travelling Forwards

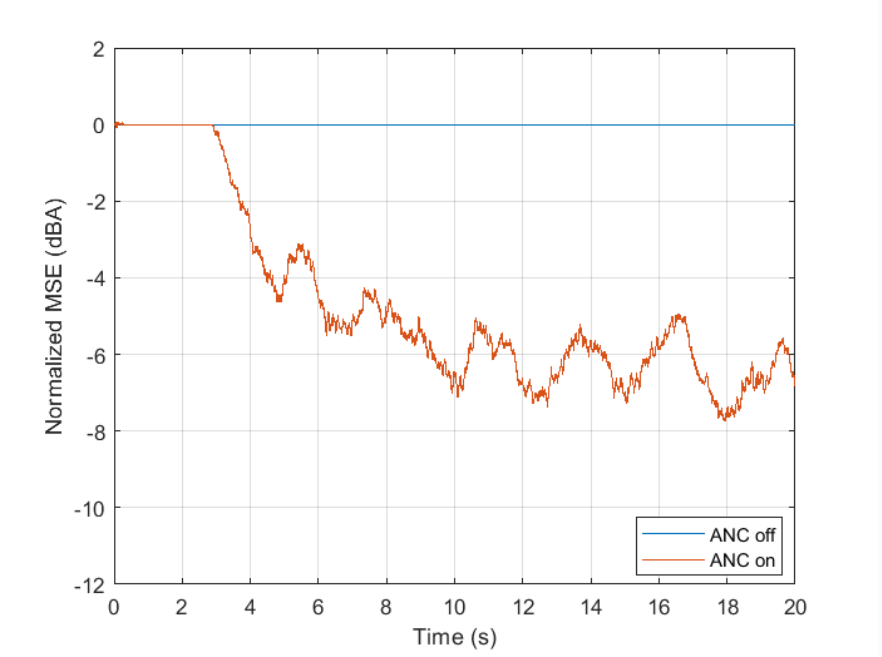


Travelling Backwards



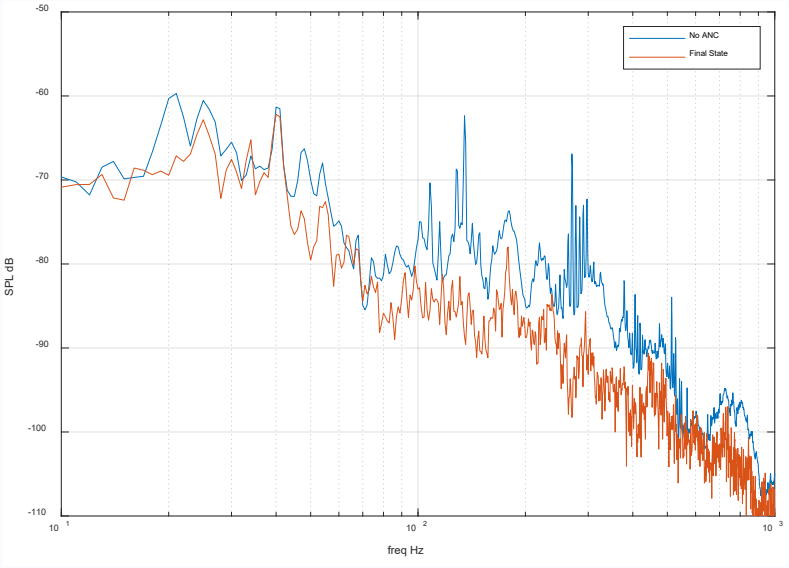
Controller Parameters

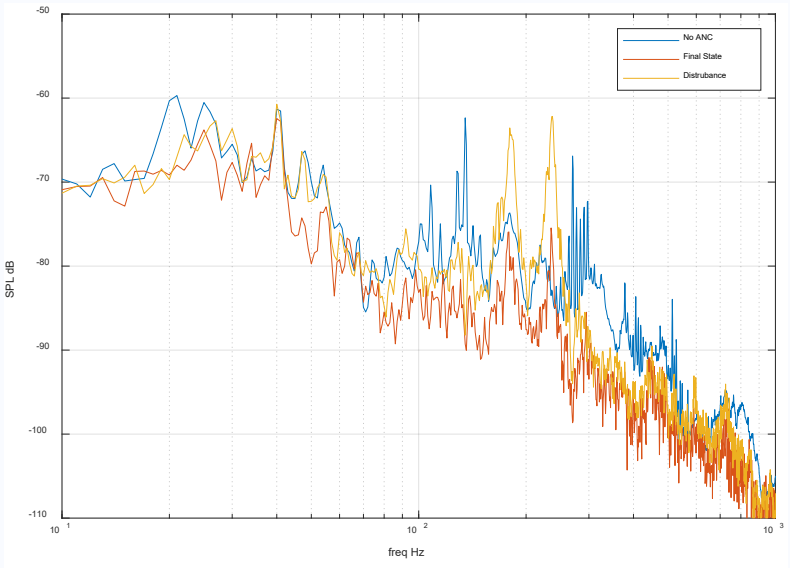
- Convergence speed is critical
- Most real world excitation is non-stationary
  - Changing road surface
  - Changing vehicle speed
- Most reduction occurs in 1st 5 to 10 seconds
- Subjectively difficult to detect
- Turn it off to demonstrate it!



Controller Parameters

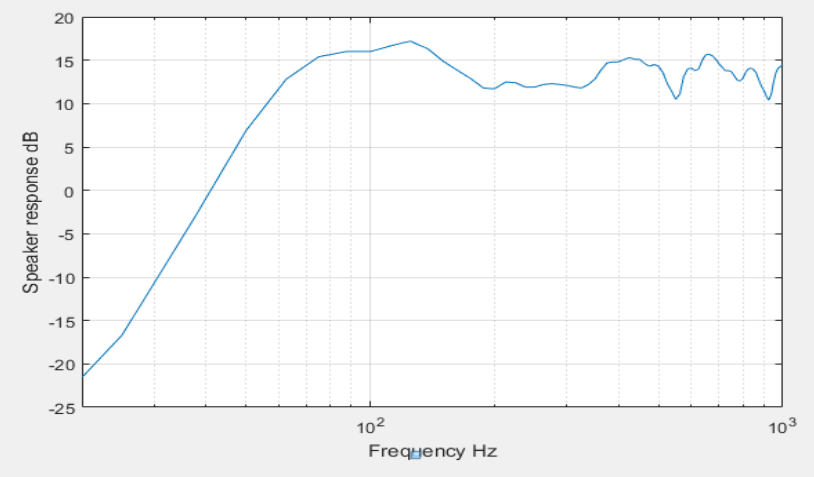
- Increasing convergence rate improves performance but can induce instability
- Impulsive excitation can lead to temporary amplification
- Leakage can reduce instability but often at the expense of performance



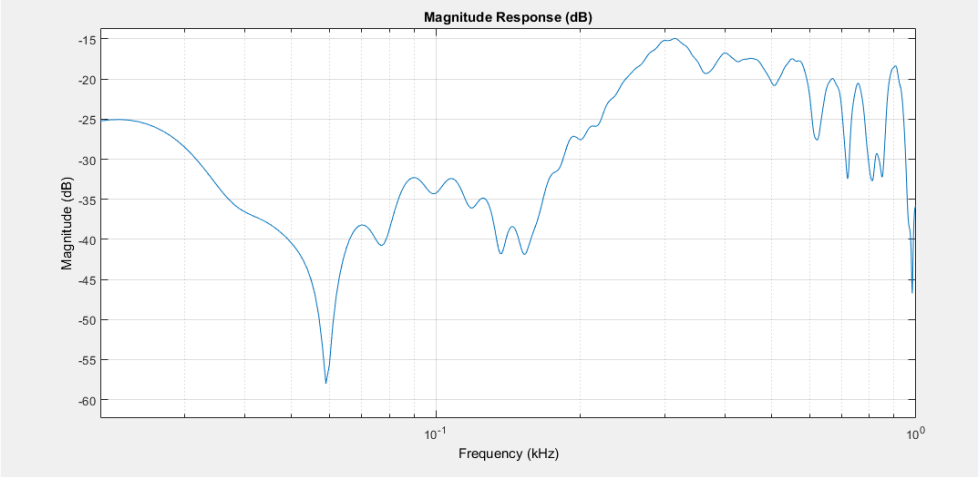


Loudspeaker Performance

Suitable Response characteristic



Measured Response

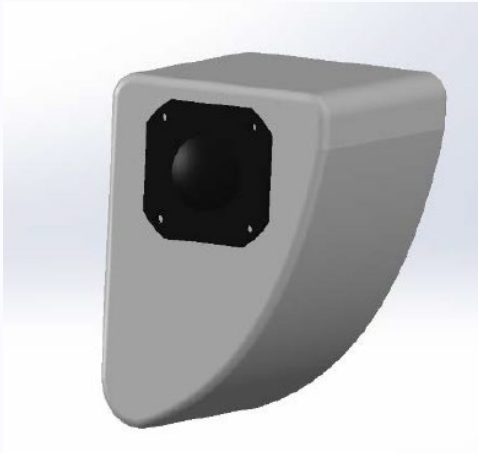


Flat response
Low frequency roll off

High Variability
Poor low frequency response
Poor design
Poor installation

Loudspeaker performance

- For local control space constraints require a small speaker.
- Achieving adequate low frequency performance from a small speaker requires careful design.

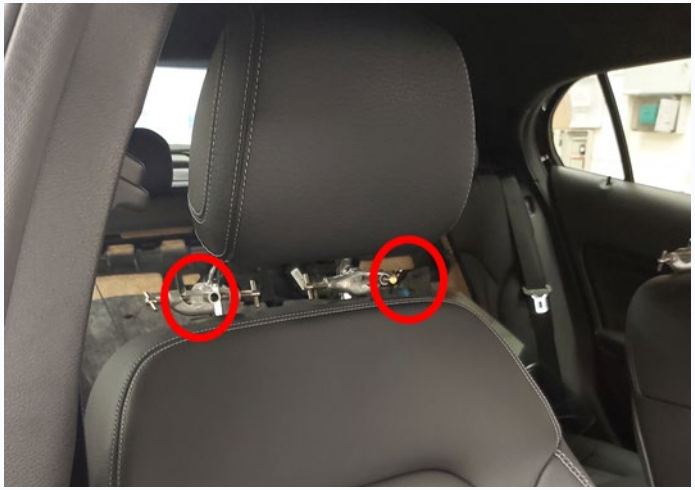


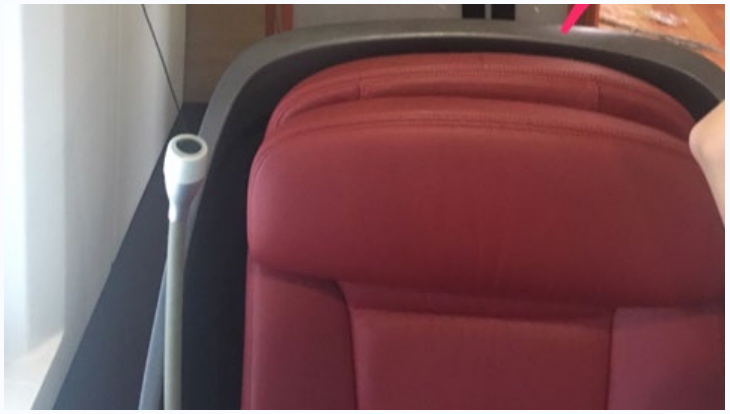
Loudspeakers - Global vs Local

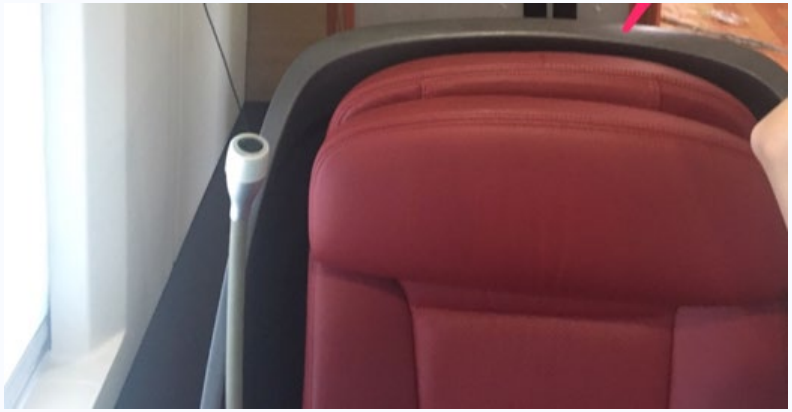
- Can use the standard vehicle audio system – 4 or 5 loudspeakers in a typical car
- Installation / design critical
- Secondary path varies with occupancy etc
- Greater delay between loud speaker and targets
- Secondary path is more stable
- Very short delay
- Packaging can be challenging
- Low Frequency control

Microphone Location

- Adaptive ANC reduces the noise at the location of the microphones.
- The microphones are inevitably some distance from the occupants ears.
- Virtual or remote microphone techniques can improve performance.
- If distance is too great performance badly impacted







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Conclusions

- Active Noise Control can be very effective at reducing low frequency noise
- Global control system is generally less effective but can use existing hardware
- Local control is most effective but requires loudspeakers very local to occupant
- It is difficult to address all noise issue ie road & wind etc
- Convergence speed is critical but can lead to instability

- Main take away
  - Turn it off to demonstrate it!

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