



## 6th MCRTN “Smart Structures” Workshop

# *Active Noise Control System Development and Algorithm Implementation in a Passenger Car*

*15 – 16 Dec 2009, Paris, France*



Business from technology

ESR Fellow: Guangrong Zou

Host Supervisor: Marko Antila

# Table of Contents

- Introduction
- The Active Noise Control (ANC) system
- Implementation of the algorithm
- First experimental results
- Conclusion
- Future work



# Introduction

## o Cars, EVERYWHERE

✓ How many cars are there in the world currently?

Over **600,000,000**, about **87%** of the total motor vehicles.

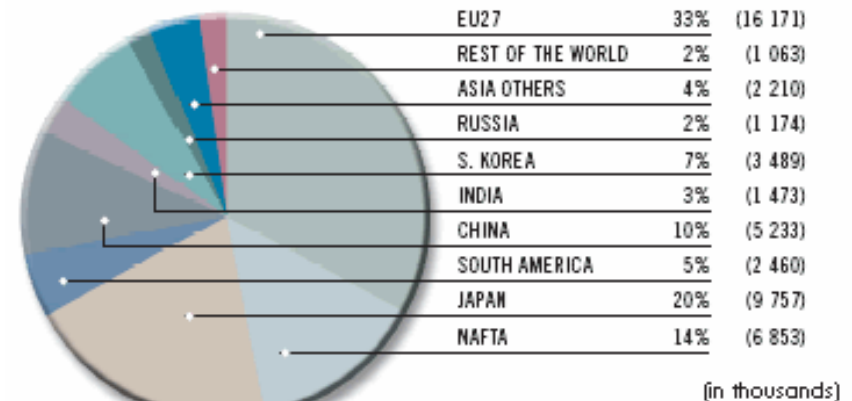
✓ How many cars produced yearly ?

✓ Which country produces most cars ?

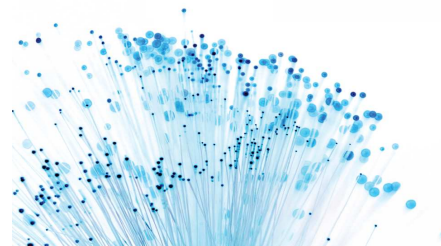
| year              | cars produced<br>in the world |
|-------------------|-------------------------------|
| 2009 (projection) | 51,971,328                    |
| 2008              | 52,940,559                    |
| <b>2007</b>       | <b>54,920,317</b>             |
| 2006              | 49,886,549                    |
| 2005              | 46,862,978                    |
| 2004              | 44,554,268                    |

World passenger car production (% share)» 2006

source: ACEA - European Automobile Manufacturers' Association



(Data Source: <http://www.worldometers.info/cars> )



# Introduction

o Everyday, drivers and passengers suffer from the **noise and vibration** inside cars



o Noise inside a passenger car

## ✓ Sources

- Engine
- Rolling
- Wind
- etc

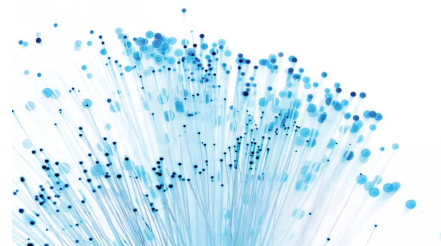
❖ dominant

$$f_p < 500\text{Hz}$$

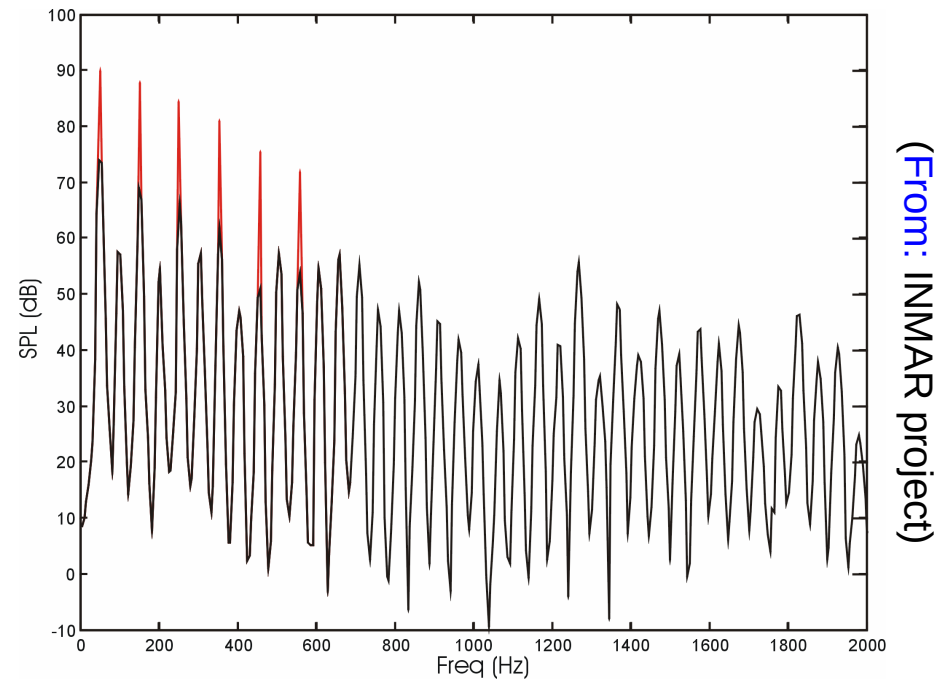
Effective  
Active Noise Control  
(ANC)

## ✓ Components

- Periodic
- Stochastic



# The Active Noise Control (ANC) system

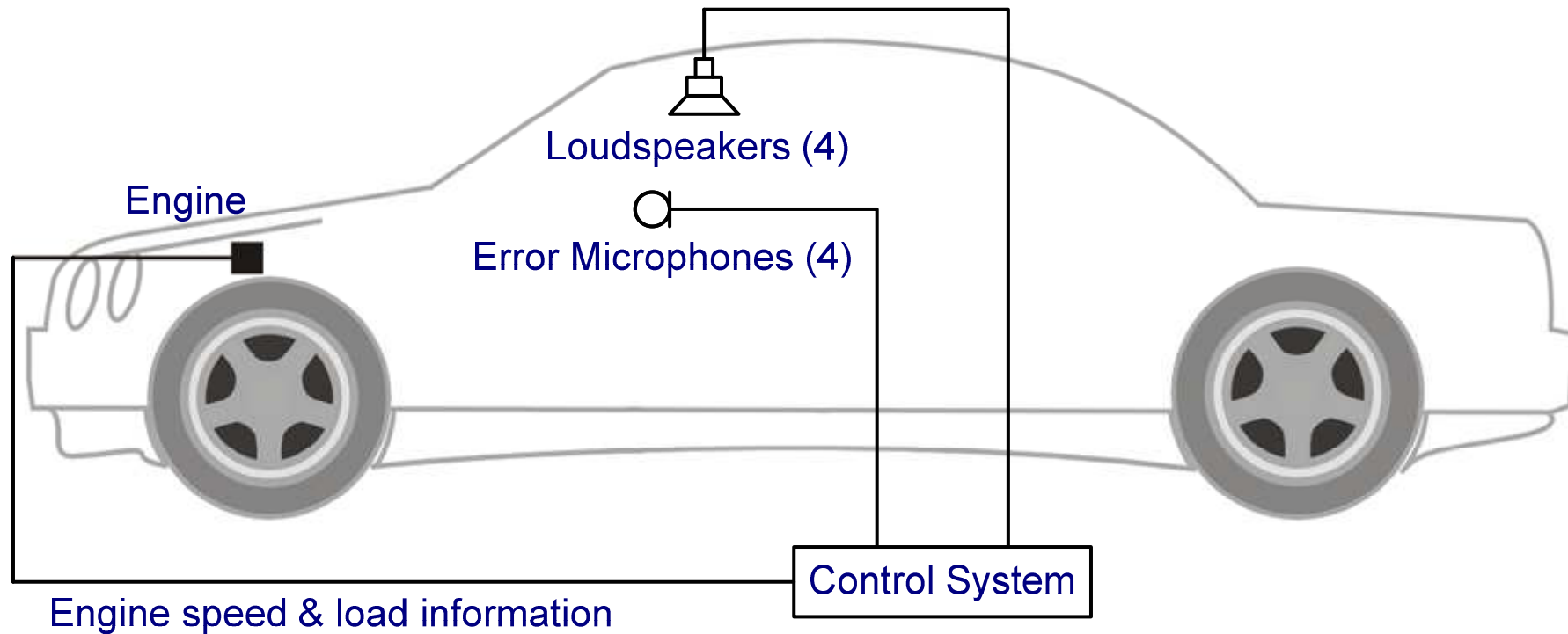


**Target:** To reduce the engine-related noise harmonics of the interior of the Ford C-MAX, specifically the 2nd-order harmonic.

**Strategy:** Multi-channel narrowband feedforward ANC

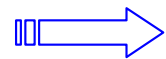


# The Active Noise Control (ANC) system



✓ 4 secondary sources

✓ 4 error sensors



**4x4 Multi-Input/Multi-Output (MIMO) system**



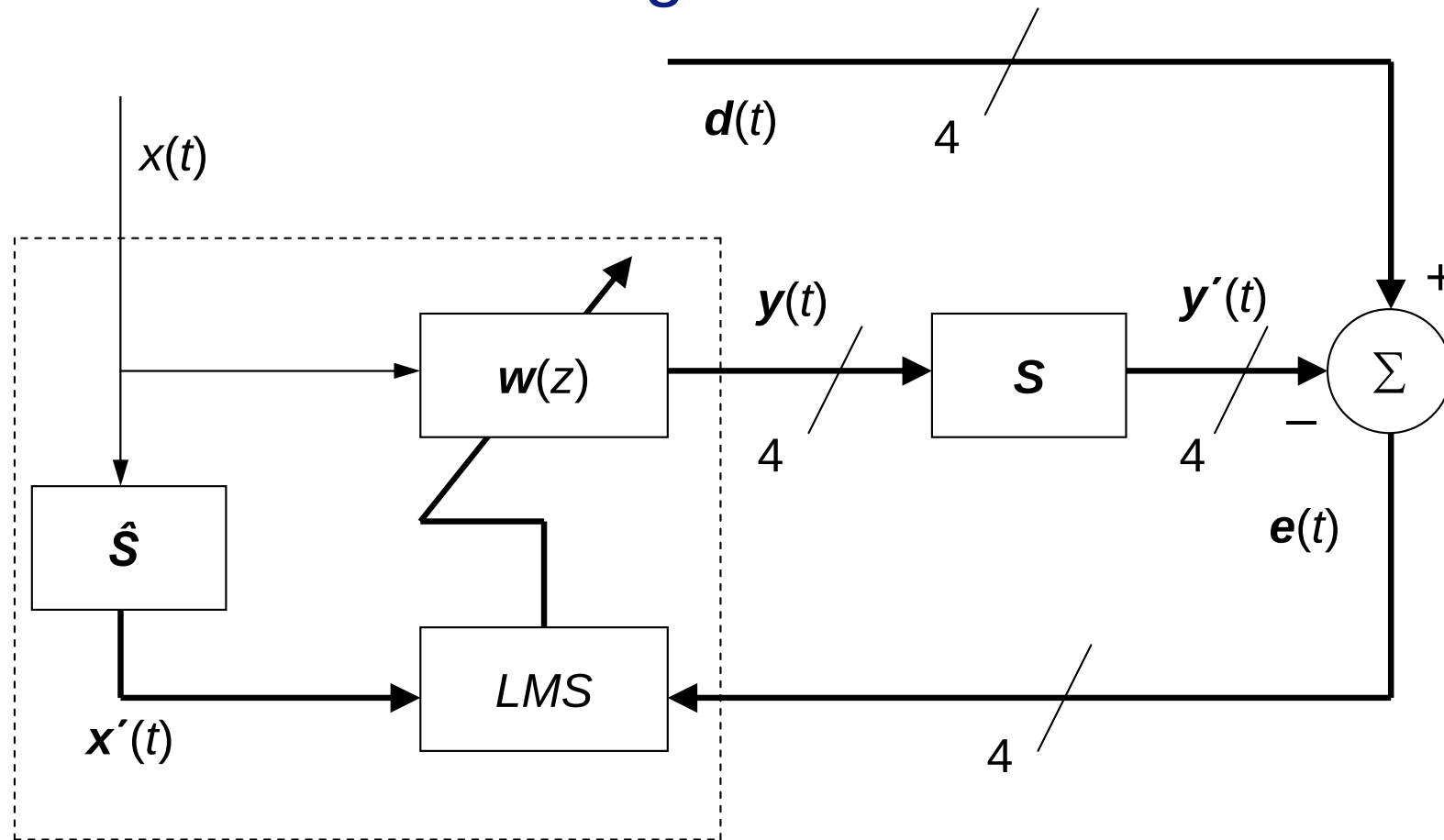


# The Active Noise Control (ANC) system



- ✓ The control system with remote controller
- ✓ 4 loudspeakers mounted on the front roof of the car
- ✓ 4 error microphones attached to the both sides of driver's and co-driver's headrests

# Implementation of the algorithm

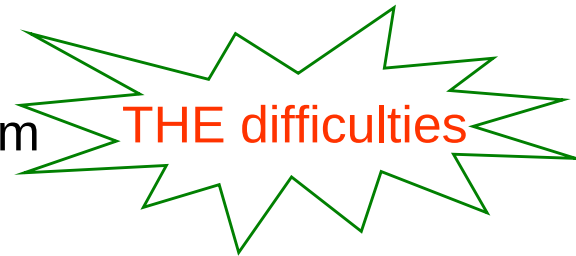


**Figure.** Simplified block diagram of the 4-channel ANC system



# Implementation of the algorithm

- o In practice, the performance of the ANC system will be affected mainly by
  - ✓ the accuracy of the plant estimate
  - ✓ the convergence speed of the ANC algorithm
  - ✓ the robustness of the ANC algorithm
- o An ideal ANC system, can reduce the noise level of the main orders efficiently, with high convergence speed and good robustness of the ANC algorithm.

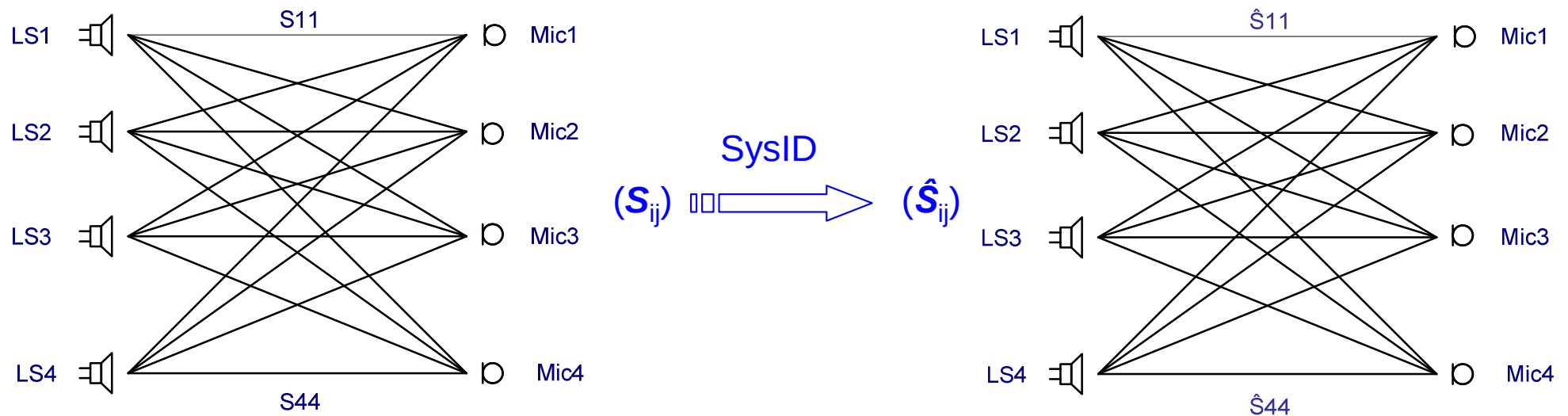


In INMAR project, Prof. Elliott and Lewis E. Rees have already developed a high-performance ANC algorithm for the same noise environment



# Implementation of the algorithm – The Plant

- One difficulty in implementing the FXLMS algorithm is that the plant is unknown and also very difficult to obtain. In practice, the common way is to use an estimate of the plant, which can be got by **System Identification**.



- Also, the greatest effect on the stability of the system is the accuracy of the plant estimate, especially the **phase** difference between the plant and the plant estimate.

# Implementation of the algorithm – Convergence behavior

- The convergence behavior of an ANC system is affected by
  - ✓ The stepsize of adaptive filters to reduce the different noise orders
  - ✓ The frequency dependent convergence behavior, which caused by the inclusion of the plant estimate
    - The different stepsizes at different frequency points,
    - The stepsize at one point might cause the system unstable at some other frequency points
    - The overall stepsize of each order is determined by the smallest of the optimum stepsizes at all frequency points
  - ✓ The delay associated with the plant estimate



# Implementation of the algorithm – Robustness

- The robustness of an ANC system is affected by
  - ✓ The accuracy of the plant estimate while system identification
    - the delay
    - the phase difference
    - the length of the adaptive filters
  - ✓ The length of the adaptive filters in the online adaptive process
  - ✓ The auto-adaptation ability to the dramatic changes of noise signal inputs, including the engine speed and load



# First experimental results

- Experimental system: 4-channel narrowband feedforward ANC system
- Adopted algorithms: modified FXLMS algorithm
- Noise to attenuate: the practical noise inside the car
  - engine speed: from around 700 rpm to 6000 rpm,
  - engine load: 0, (at the first phase)
- Orders to attenuate: 2nd, (3.5th, 4th, 5th, 5.5th and 6th)



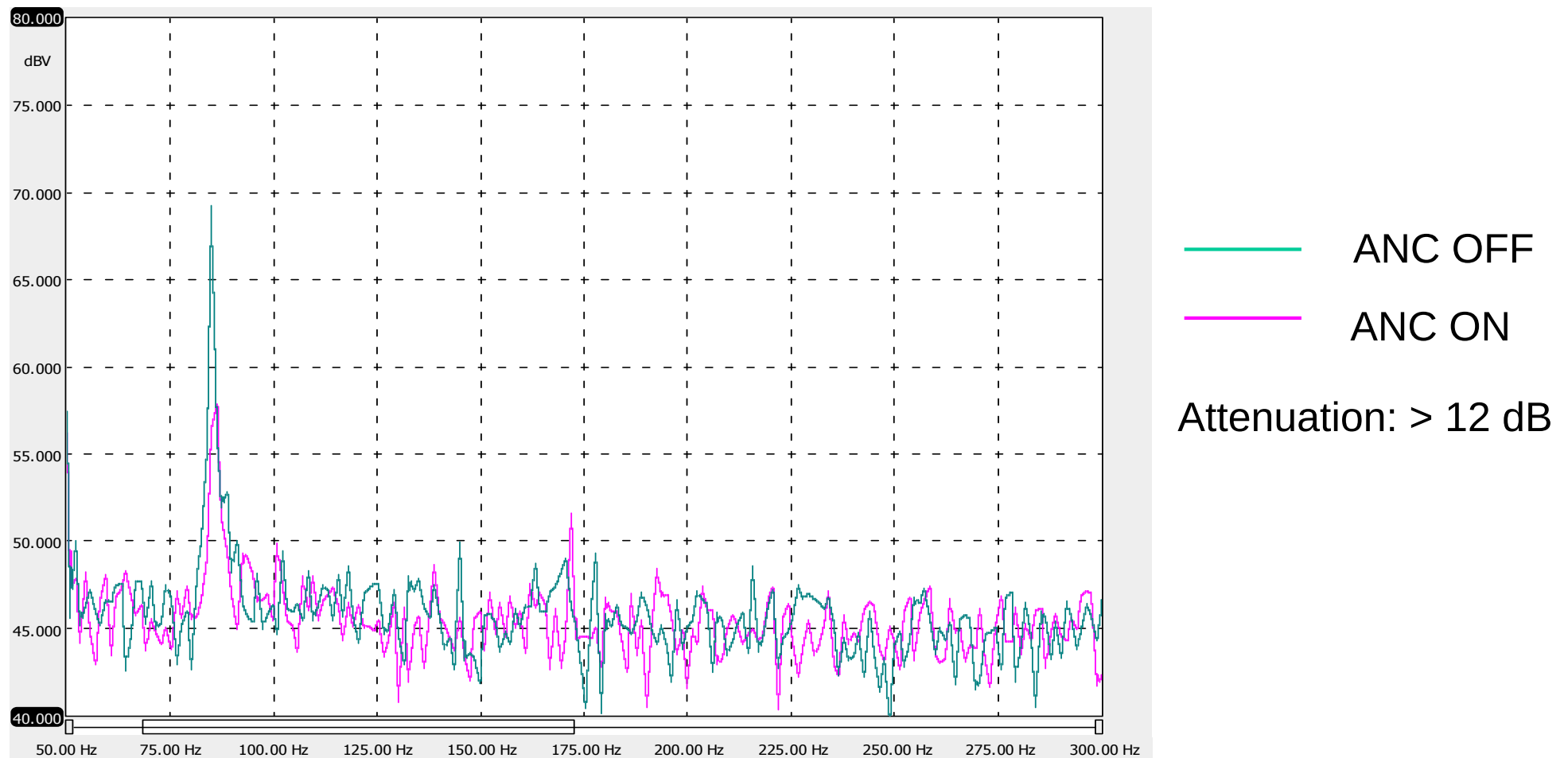


# First experimental results

- The most effective order: 2nd order
- The most effective speed range: from over 2000 rpm to below 4000 rpm, especially at around 2500 rpm and 3500 rpm, the 2nd order attenuation over 20 dB
- For the engine speed below 2000 rpm or over 4000 rpm, less effective specifically for over 5000 rpm, possible instability
- For other engine load, no test yet
- Reasons:
  - The complexity of acoustic environment inside the car
  - The frequency dependent convergence behavior of the algorithm



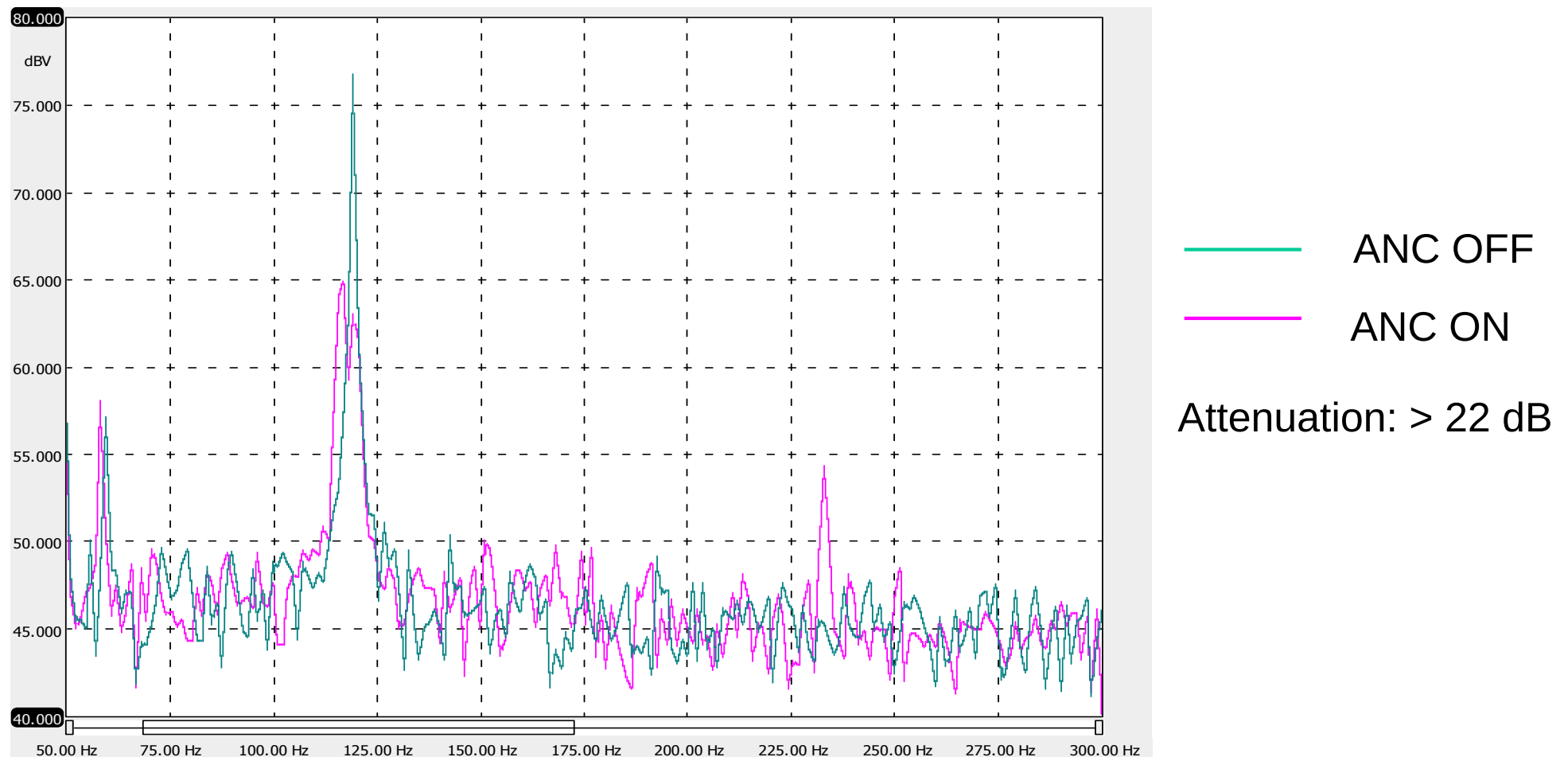
# First experimental results – Some figures



**Figure.** The attenuations of 2nd order harmonic at around 2500 RPM



# First experimental results – Some figures



**Figure.** The attenuations of 2nd order harmonic at around 3500 RPM



# Conclusion

- ✓ A 4-channel narrowband feedforward ANC system was constructed
- ✓ A modified FXLMS algorithm is firstly implemented to the ANC system
- ✓ In practice, the performance of the ANC system will be affected mainly by the accuracy of the plant estimate, the convergence speed and also the robustness of the ANC algorithm.
- ✓ The first experimental results were obtained, but not so effective for all the noise orders in the targeted frequency range

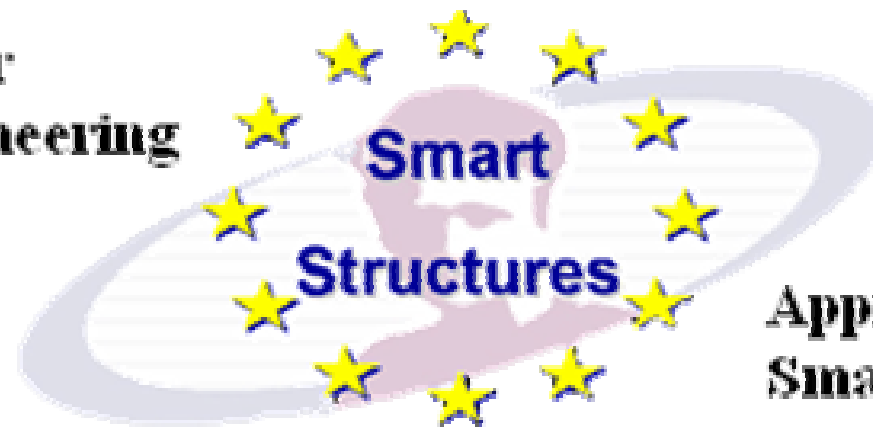


## Future work

- ✓ To improve the accuracy of the plant estimate
  - Look-Up Table (LUT)
  - Equalization process
  - The reduction of phase difference
- ✓ To optimize the ANC algorithm implementation
  - To increase the sampling rate of the system, *Nyquist rate*
  - Adaptive stepsizes for different orders
  - Other adaptive process?



**A Computer  
Aided Engineering**



**Approach to  
Smart Structures**

