International Telecommunication Union

Speech Enhancement Methods for Vehicle Applications

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TEMIC Speech Dialog Systems

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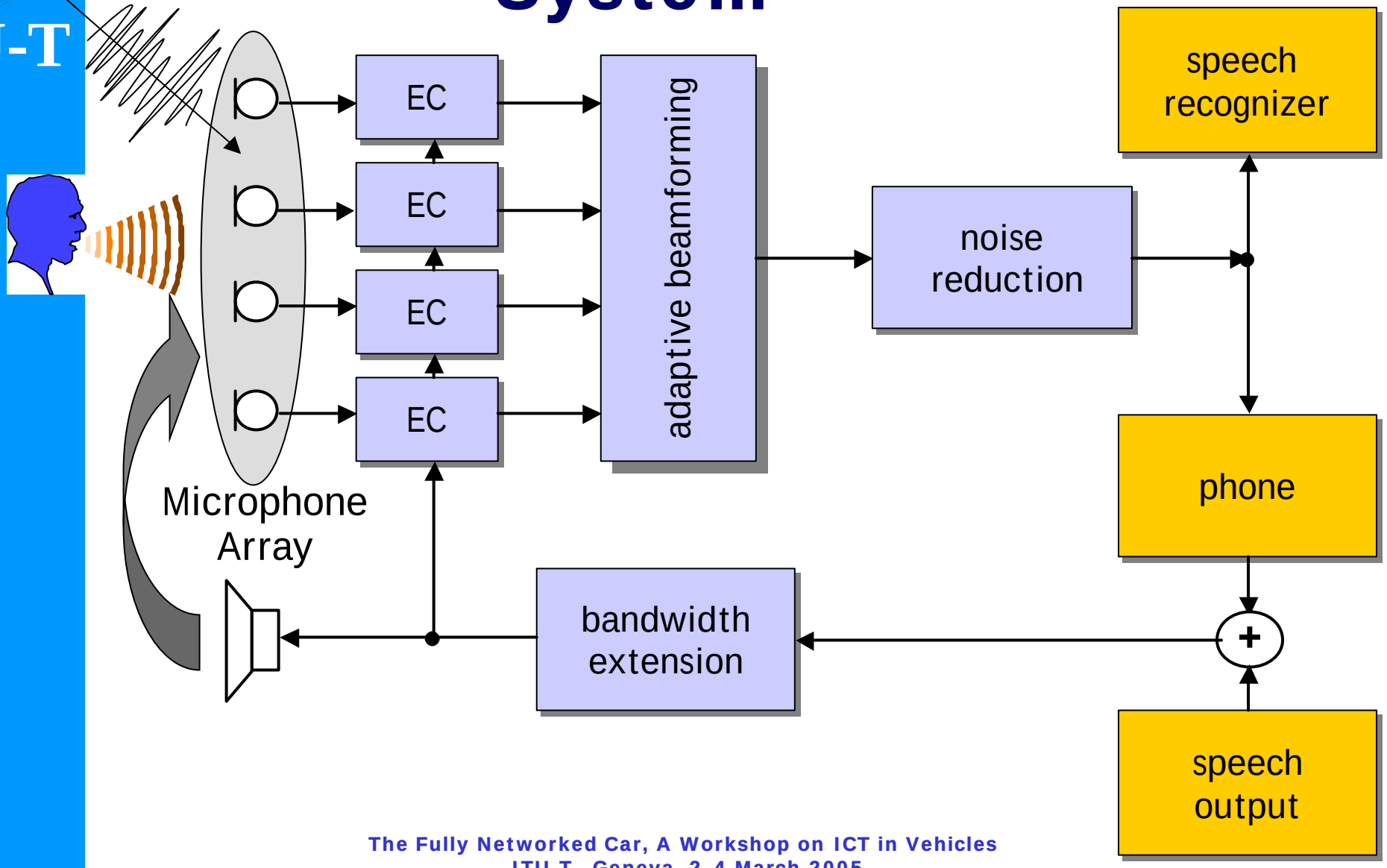
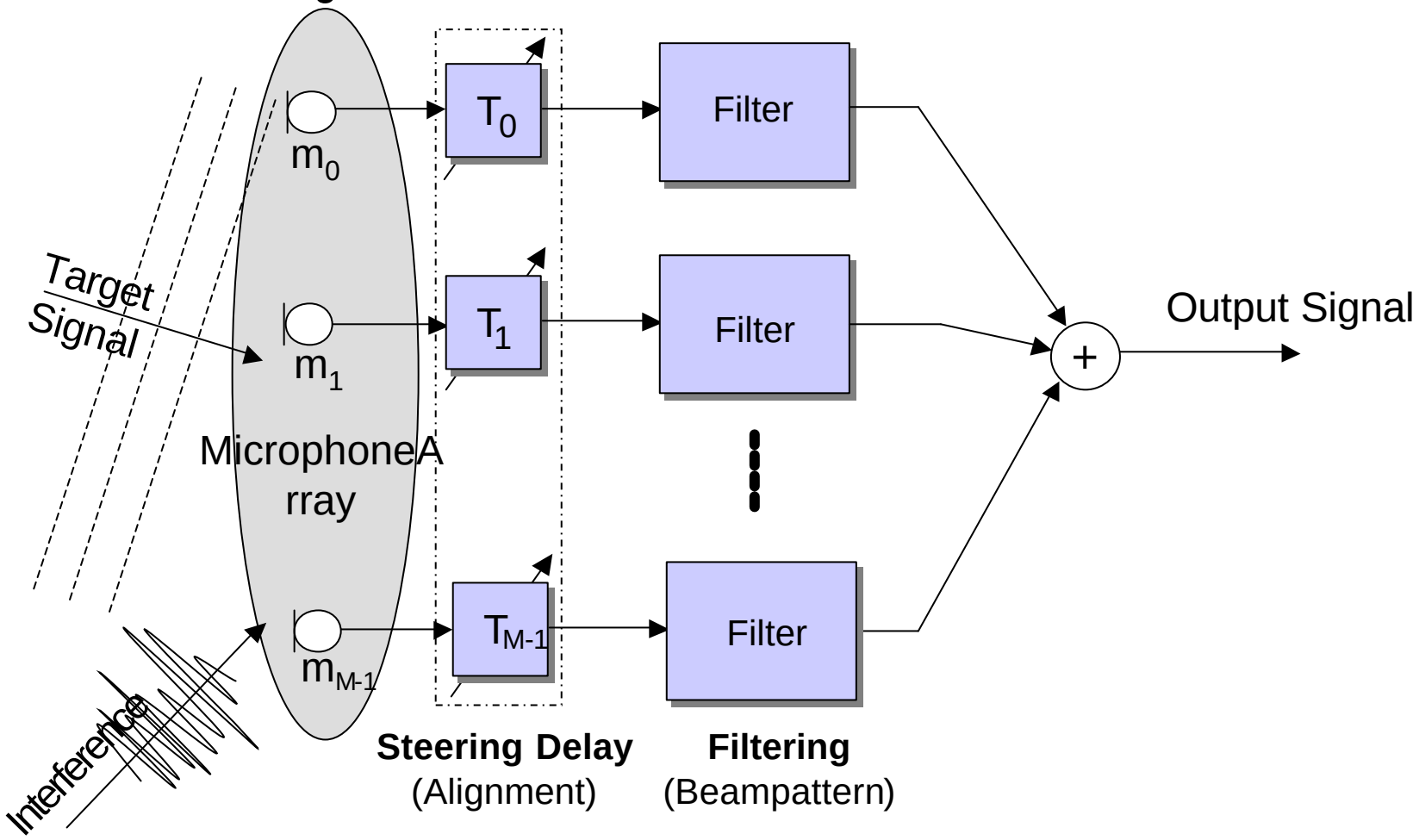
Integrated Hands-Free System

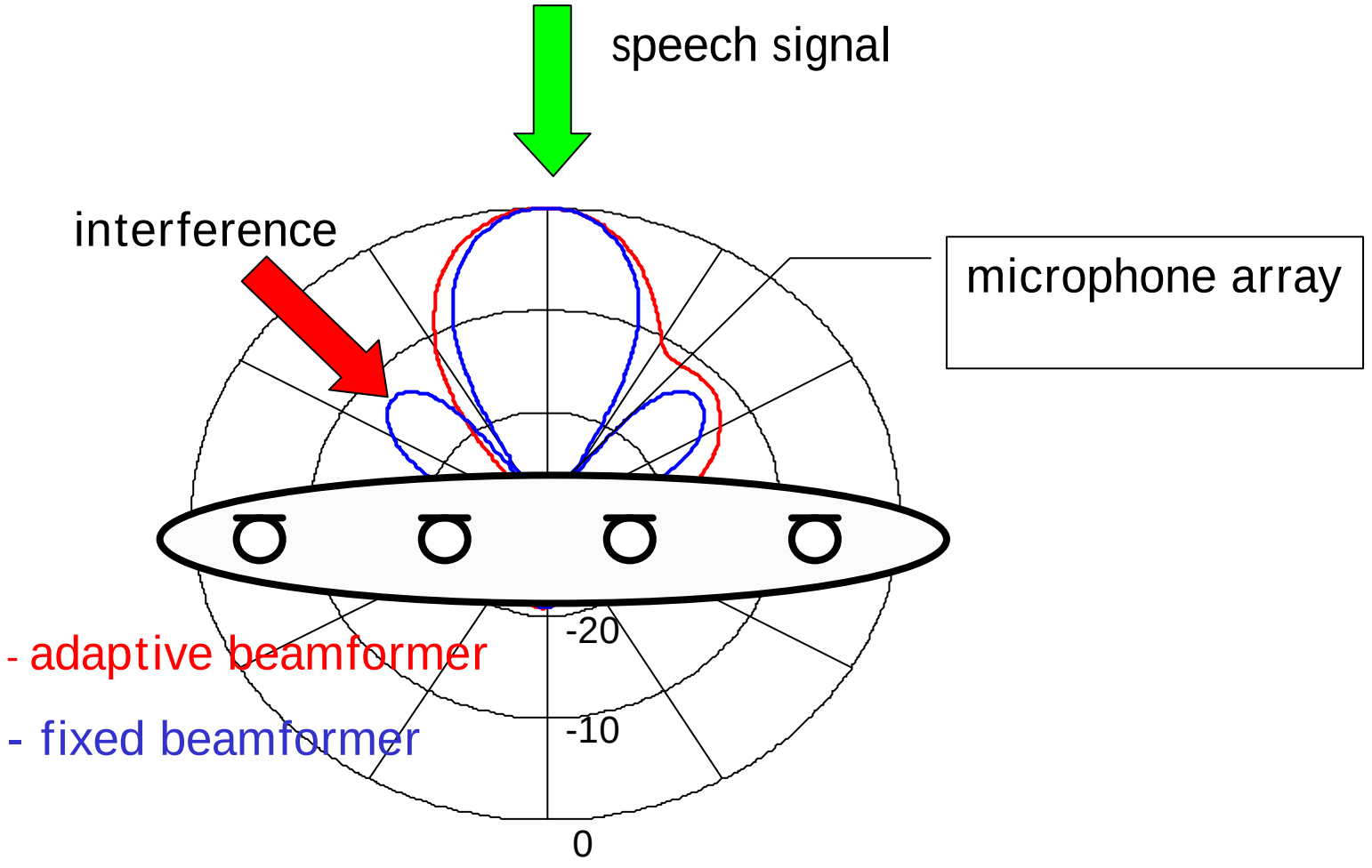


Beamforming

Structure of a generalized beamformer



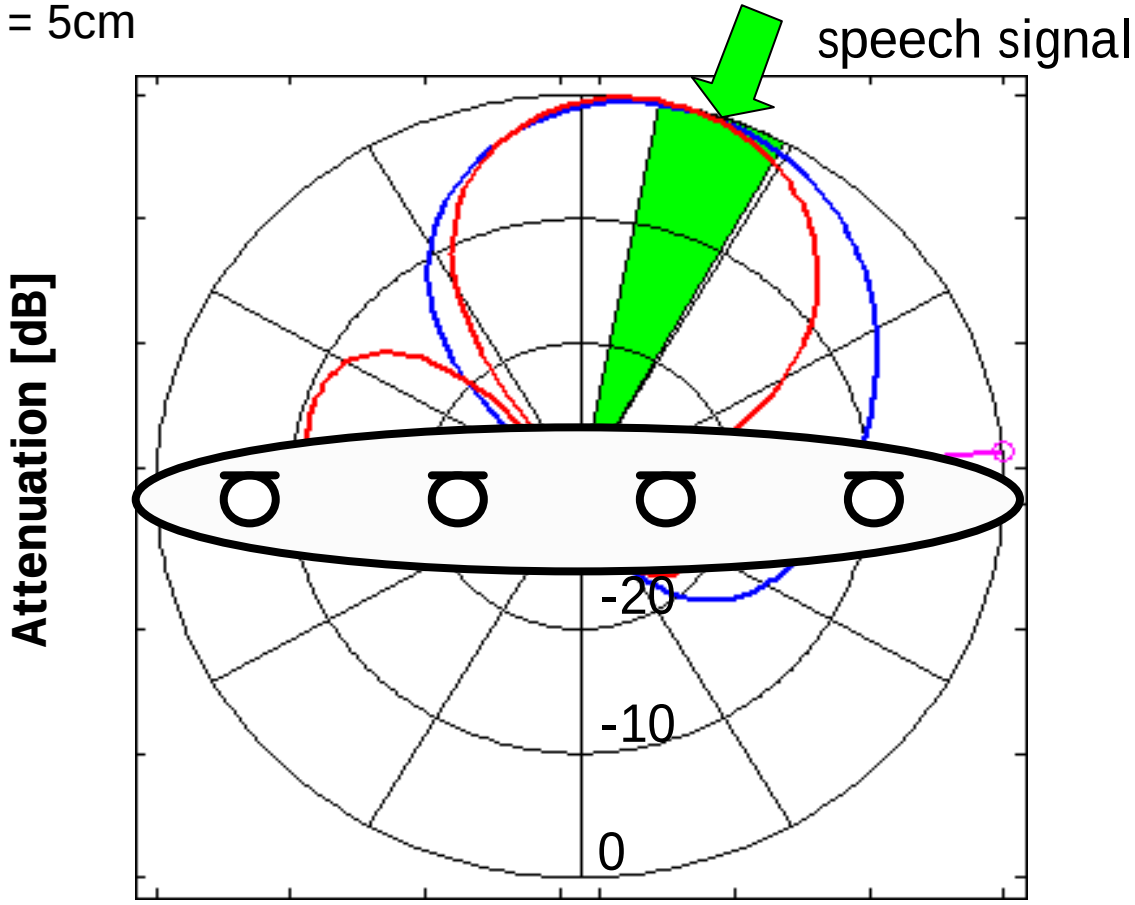
Beamforming



Beamforming

Beampattern at 1500Hz for a rotating noise source

4 Microphones, d = 5cm

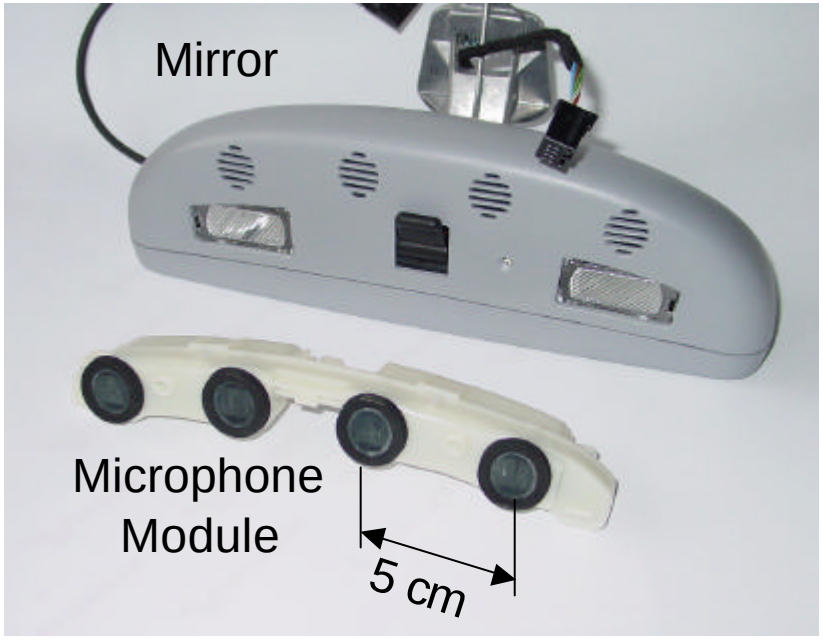


blue – fixed beamformer

red – adaptive beamformer

Beamforming
Microphone Array Integration

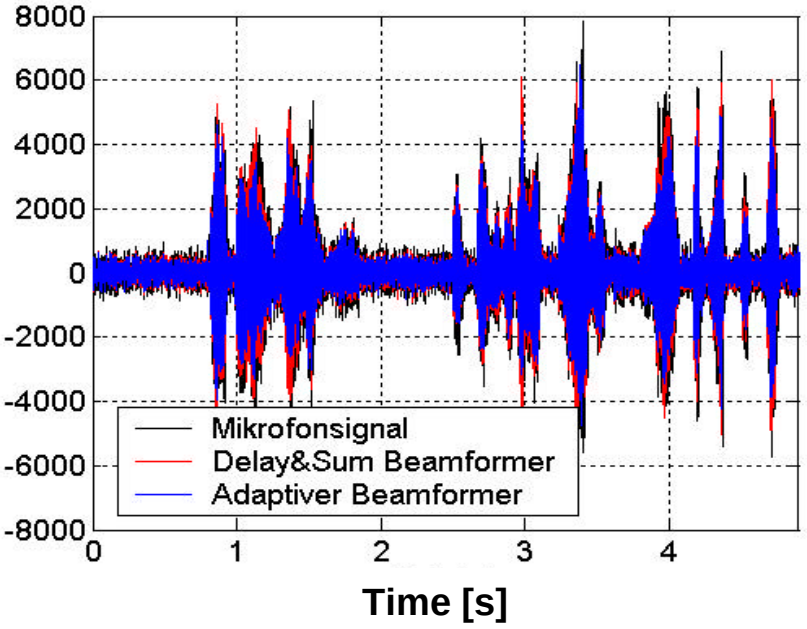
4 Microphone Array Integrated in Interior Mirror

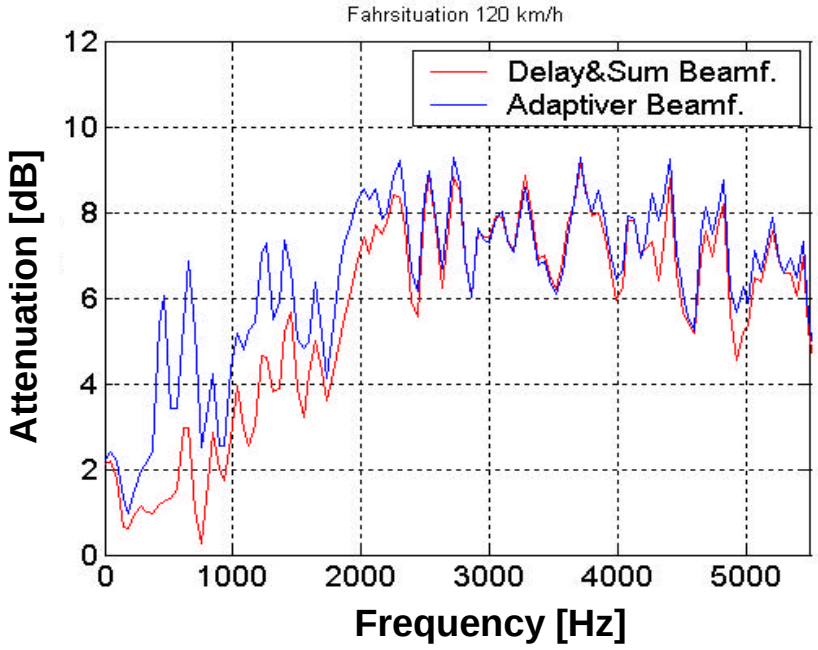


- Cost-efficient integration due to integrated microphone module
- Fixed steered beamformer could be used as driver direction of arrival (DOA) varies only within a small range (62°-75°)
- Microphone array could be used by driver and co-driver

Beamforming Examples

Driving Situation 120 km/h

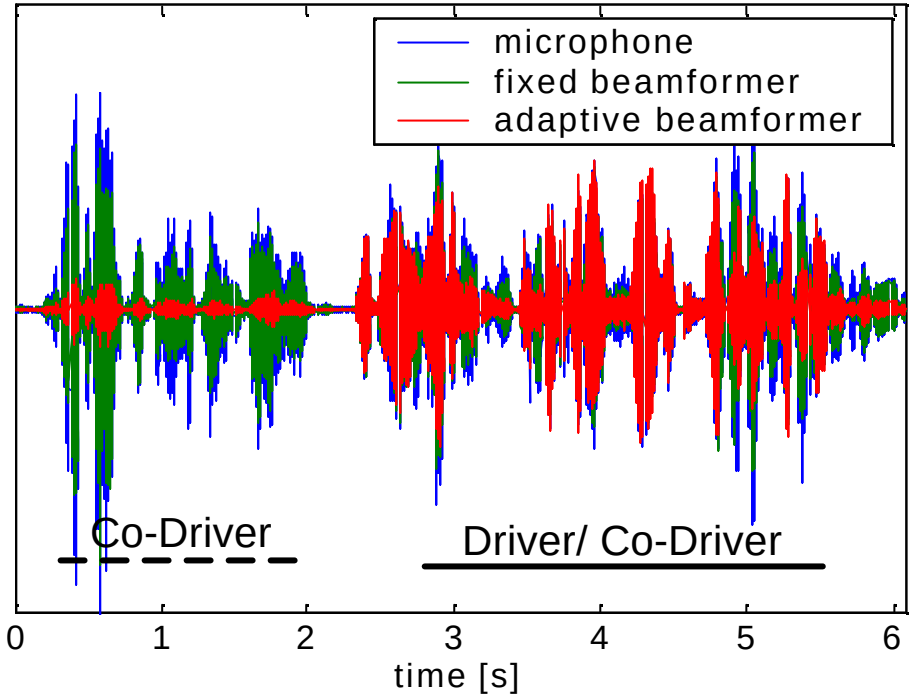




Significantly higher noise suppression in the low frequency range with the adaptive beamformer compared to the delay & sum beamformer

Beamforming Examples

Interfering Co-Driver



Single Microphone

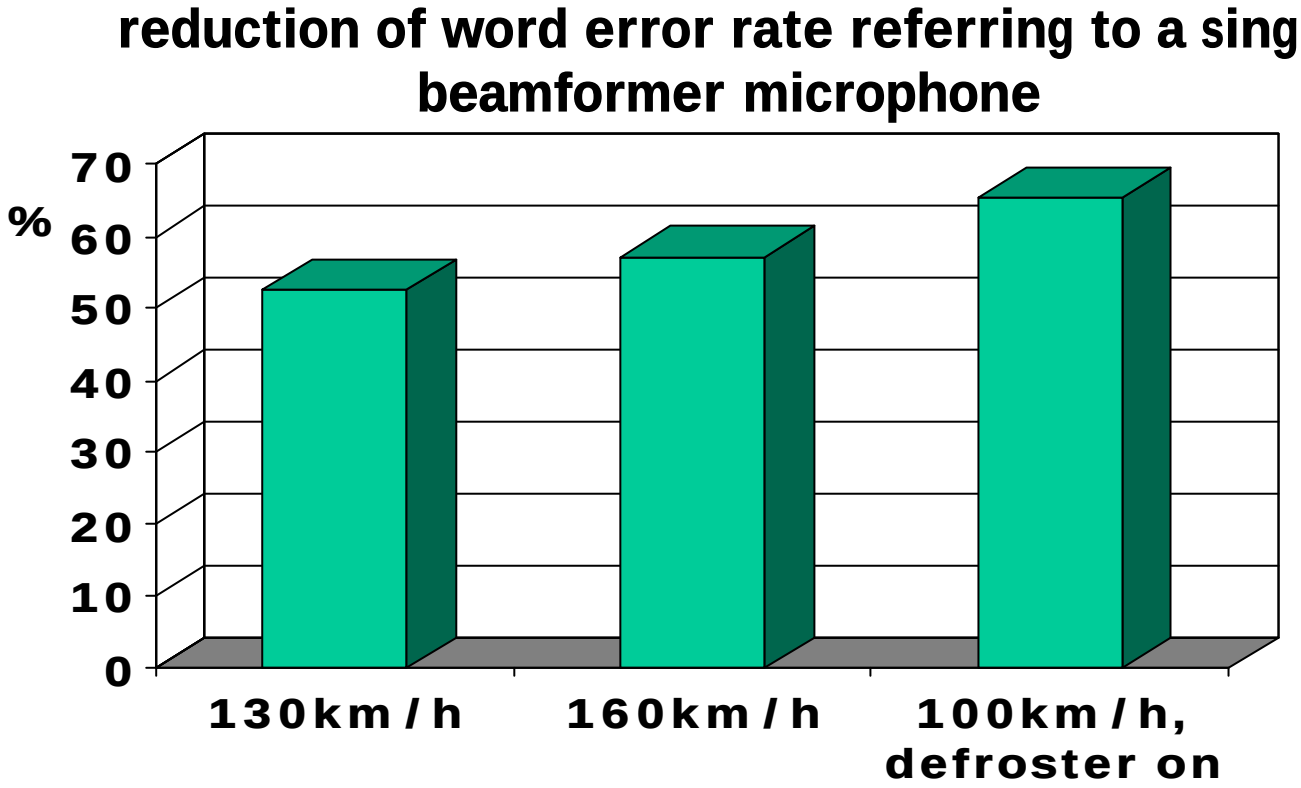
Fixed Beamformer

Adaptive Beamformer

Suppression of interferer >15dB by adaptive beamformer

Beamforming Examples

Speech recognition tests: 50 speakers, 1000 digits strings with in sum 9000 digits per situation



Reduction of word error rate by adaptive beamformer is significantly higher than 50%!

Beamforming

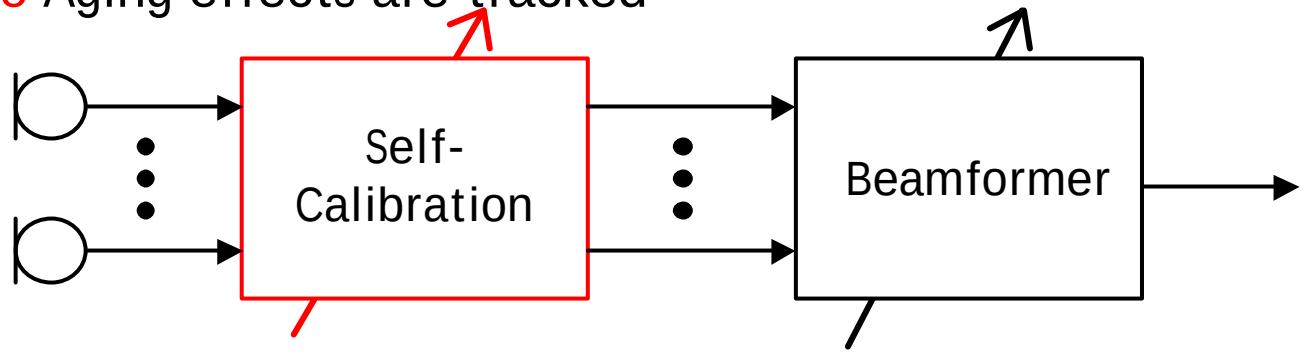
Adaptive Self-Calibration

Problem: Beamformers are very sensitive to a mismatch of the microphones. Mutual deviations of the individual microphones may provoke a significant distortion of the beamformer output signal. Deviations inevitably occur due to fabrication tolerances and aging of the microphones.

Solution: The mutual deviations of the microphones are compensated in a preprocessing unit which adjusts itself adaptively without being noticed by the driver.

Benefits:

- A costly calibration of the beamformer can be saved
- Aging effects are tracked

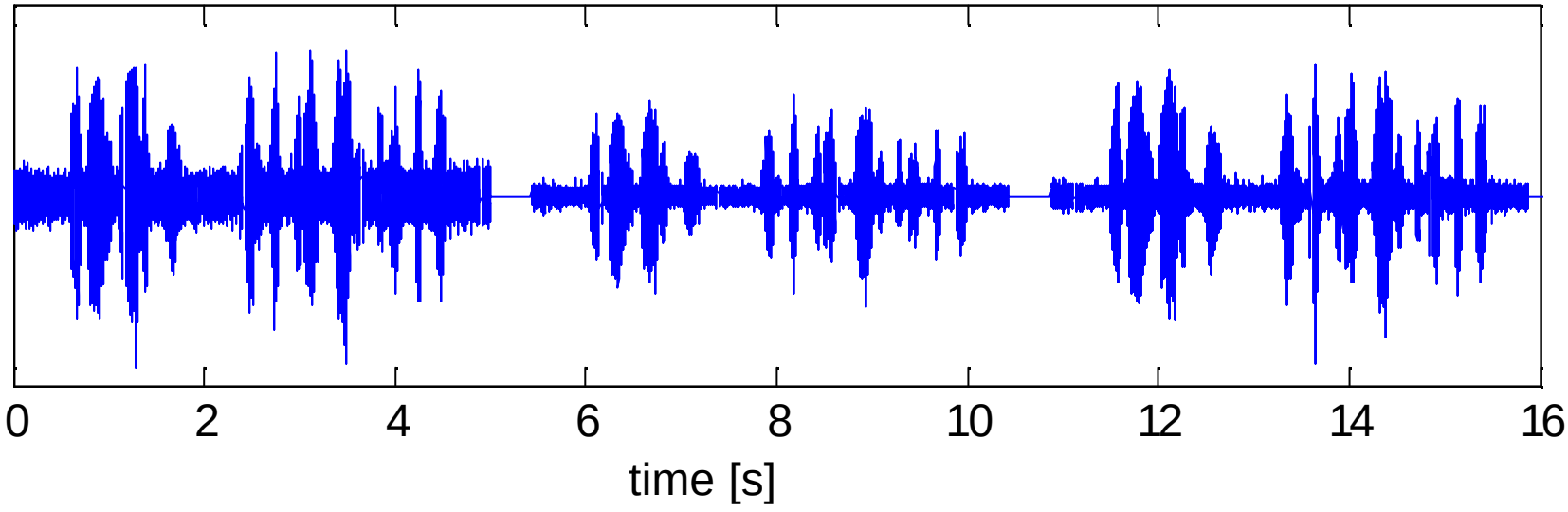


Beamforming
Adaptive Self-Calibration

microphone signal

adaptive beamformer

adaptive beamformer with self-calibration

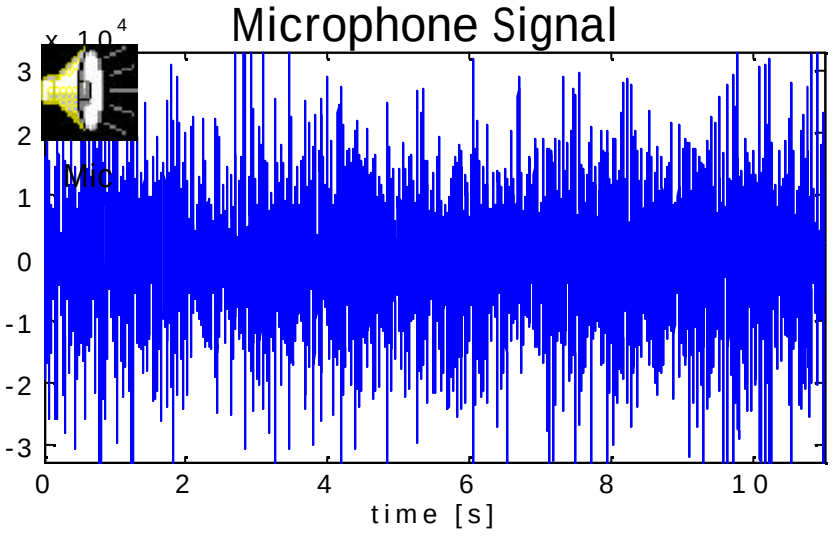


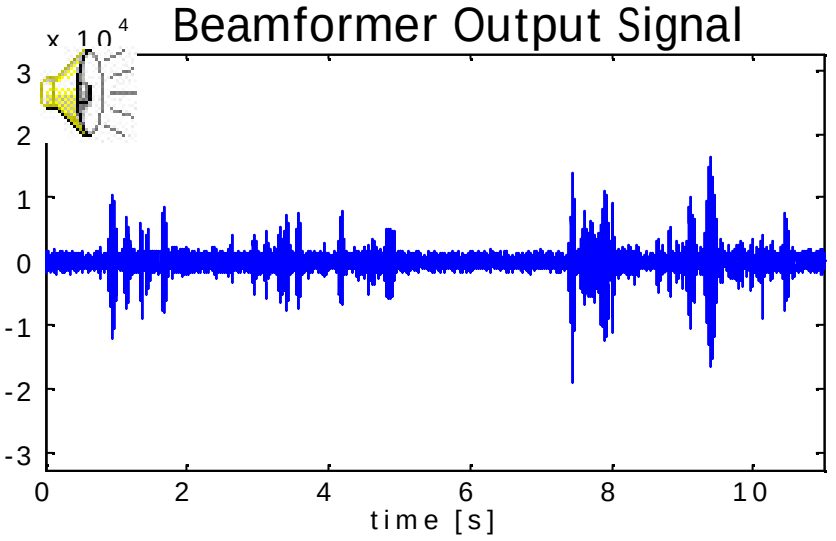
Beamforming
Wind Noise Suppression

Problem: Wind noise can provoke strong pulse-like disturbances of the microphone signals. In cars, this problem is mainly caused by the fan or an open top of a convertible.

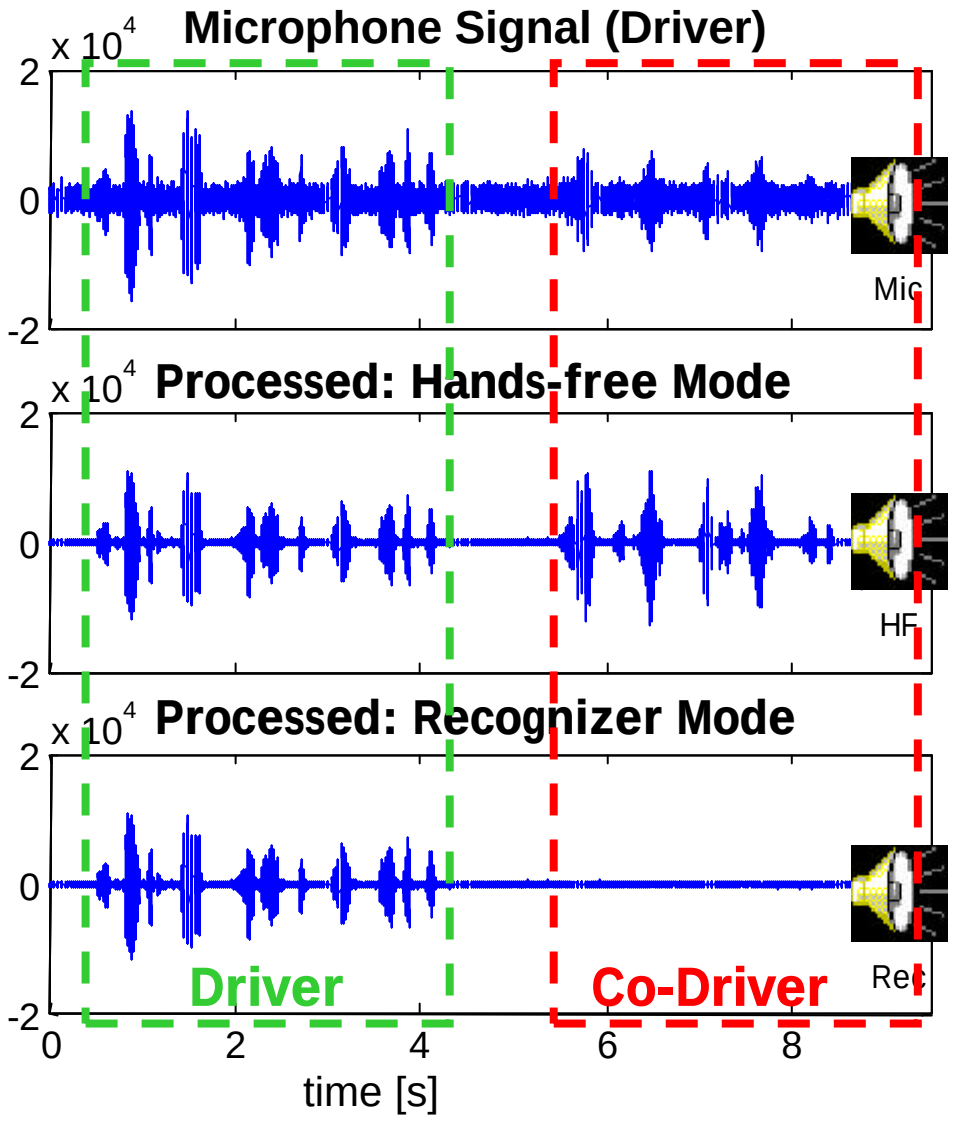
Due to design reasons or lack of space the standard wind shield of the microphones is often insufficient.

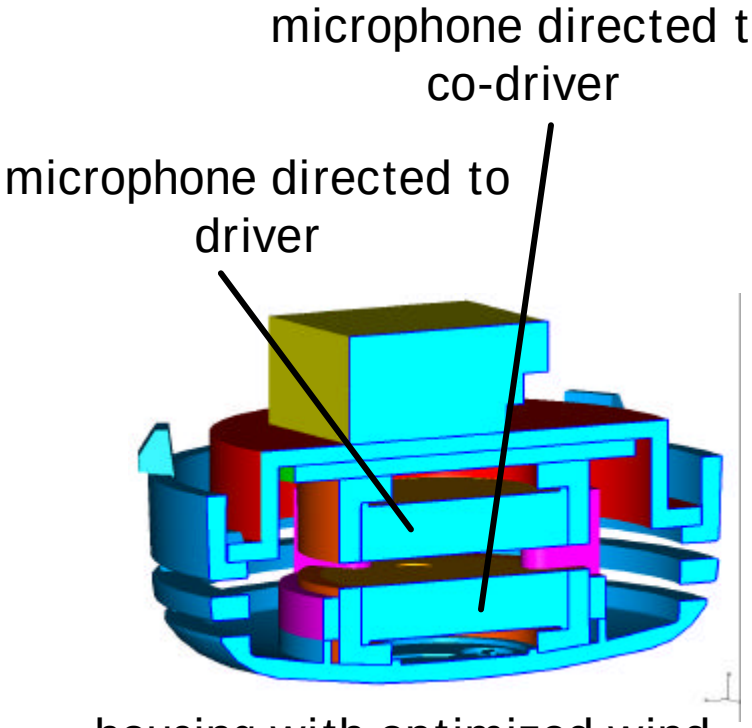
Solution: Suppression of wind buffets by a (multi-channel) wind-noise suppression algorithm





Compact Dual-Microphone-Array

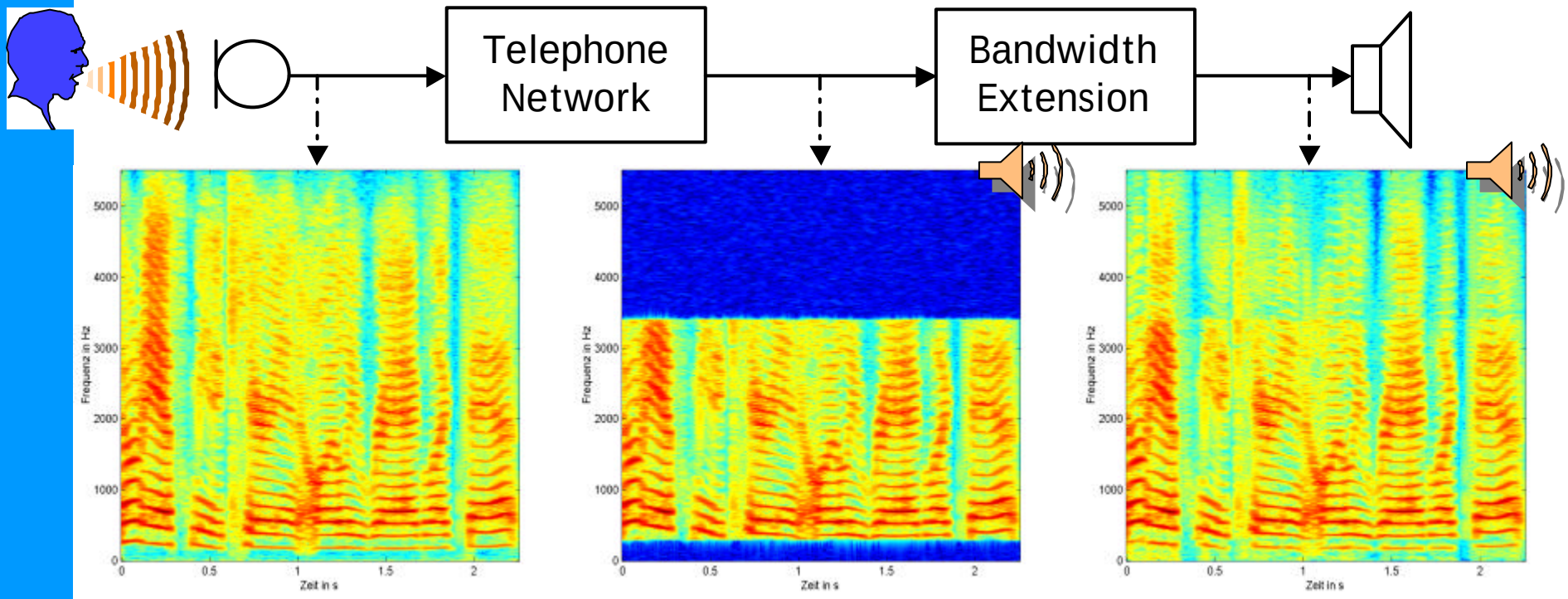




Bandwidth Extension

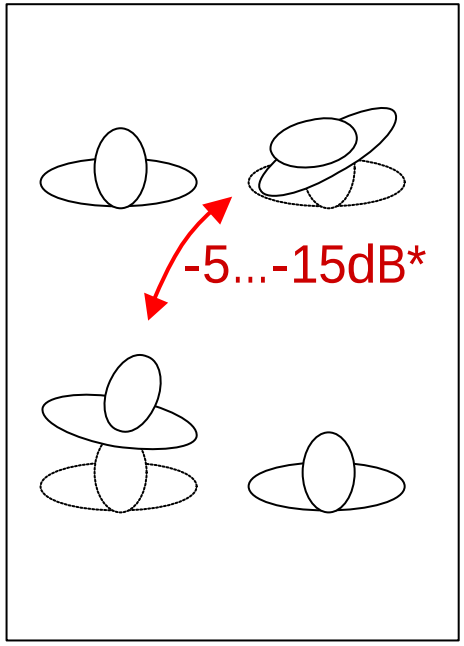
Problem: Degradation of speech quality due to the bandwidth limitation of the telephone network

Solution: Extrapolation of missing frequency components from the received speech signal



In-Car Communication

Passenger compartment



*Acoustic loss (referred to the ear of the driver)

Current Situation:

- Communication between passengers is difficult, because of the acoustic loss (especially front to back
- Front passengers have to speak louder than normal – longer conversations will be tiring
- Driver turns around – road safety is reduced

Solution:

- Improve the speech quality and intelligibility by means of an intercom system

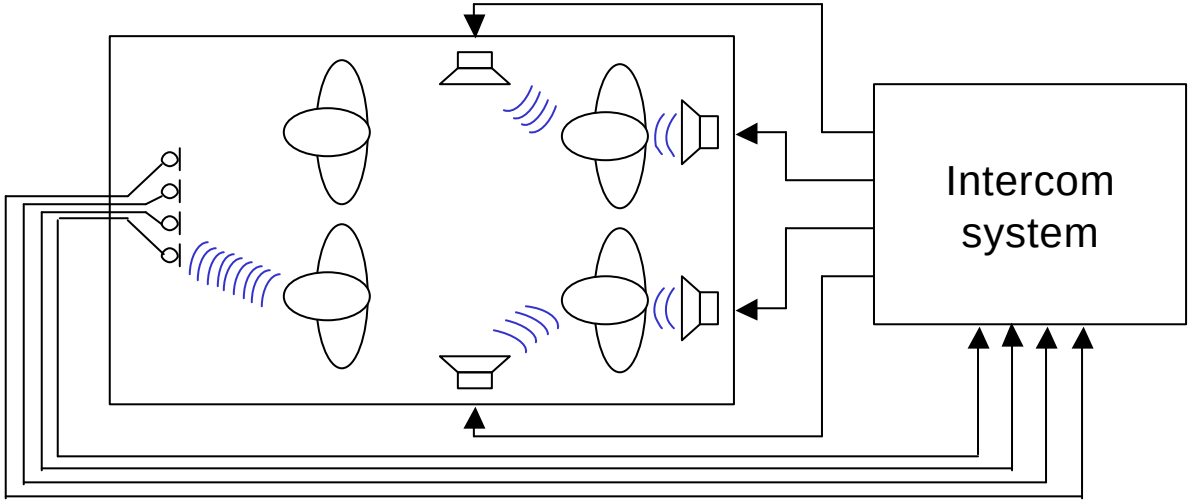
Application:

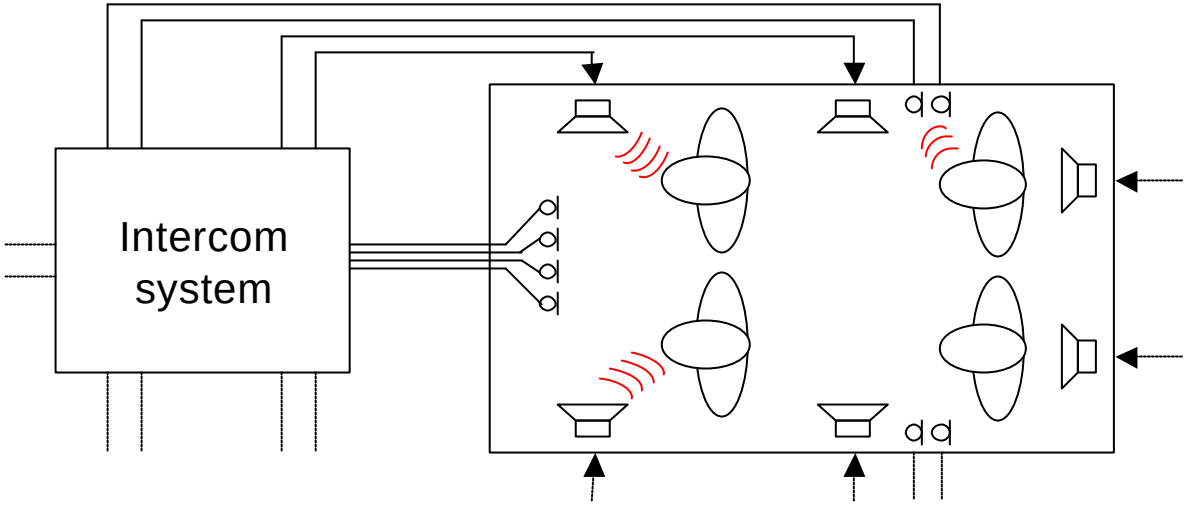
- Mid and high class automobiles, which are already equipped with the necessary audio and signal processing
- Vans, etc. → systems with reduced quality

In-Car Communication
Implementation

One-Way System

- 2-4 microphones
- 2-4 loudspeakers



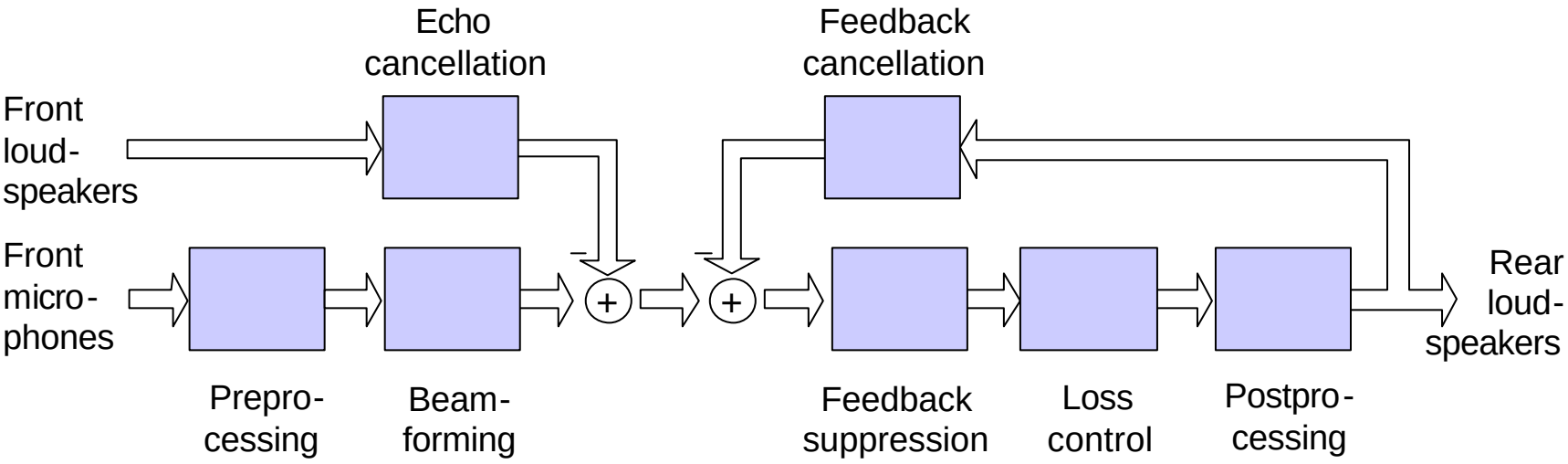


Two-Way System

- 4-8 microphones
- 6-8 loudspeakers

In-Car Communication
Signal Processing Components

Algorithmic Structure for One Direction (Front → Rear):



Problems and Challenges:

- Stability
- System delay
- Correlation of excitation and distortion

In-Car Communication
Demo System

4 microphones within
the front top control unit

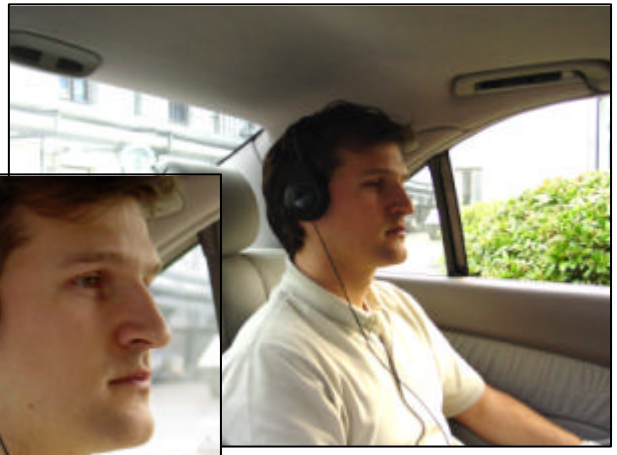
2x2 microphones (integrated
within the rear grab handles)

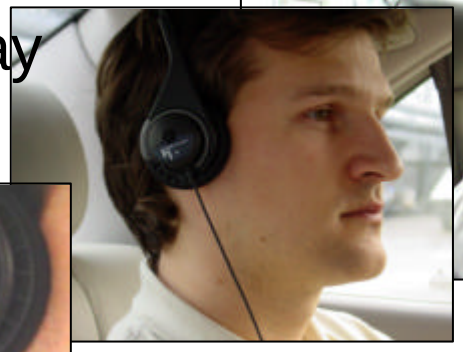
In-Car Communication
Subjective Tests

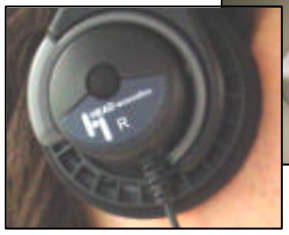
- Prerecorded speech examples with different Lombard levels were played back via an artificial mouth

- Binaural recordings were made by means of a HEADacoustics NoiseBook on the seat behind the driver

- Driving-Situations
  - 0km/h beside motorway
  - 130km/h on motorway



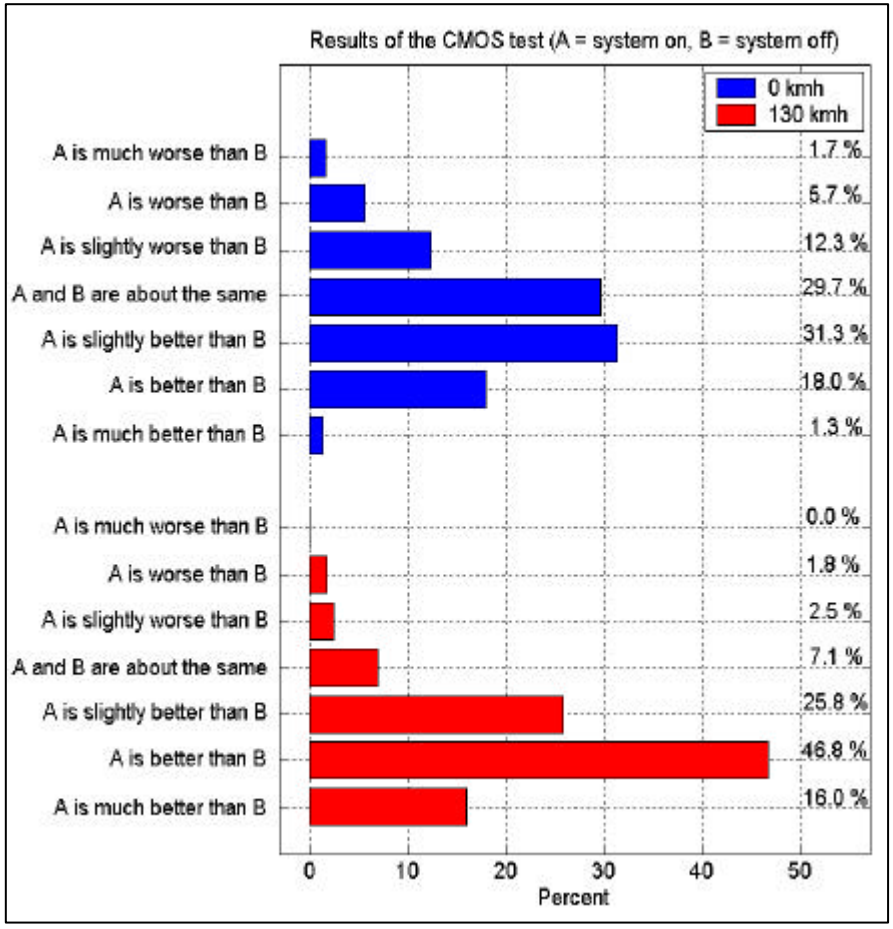




In-Car Communication
Results of Speech Quality Test (CMOS-Test)

25 signal pairs per driving situation (intercom on/off) /
15 listeners per scenario

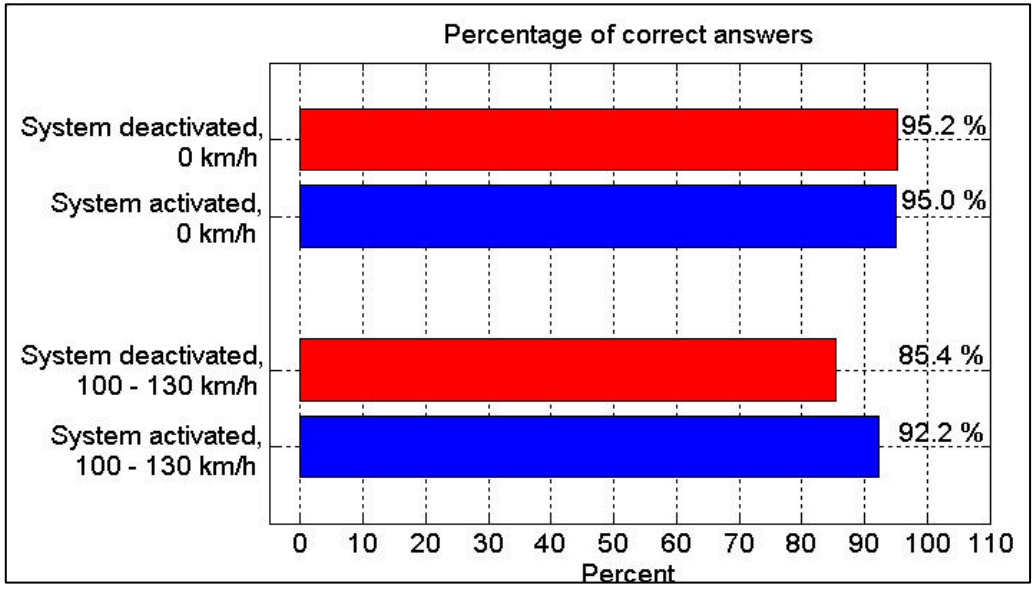
- **0 km/h, vehicle parked close to a motorway**
  - 19,7% prefer the system to be switched off
  - 29,7% have no preference
  - 50,7% prefer the system to be switched on
- **130 km/h, motorway**
  - 4,3% prefer the system to be switched off
  - 7,1% have no preference
  - 88,6% prefer the system to be switched on



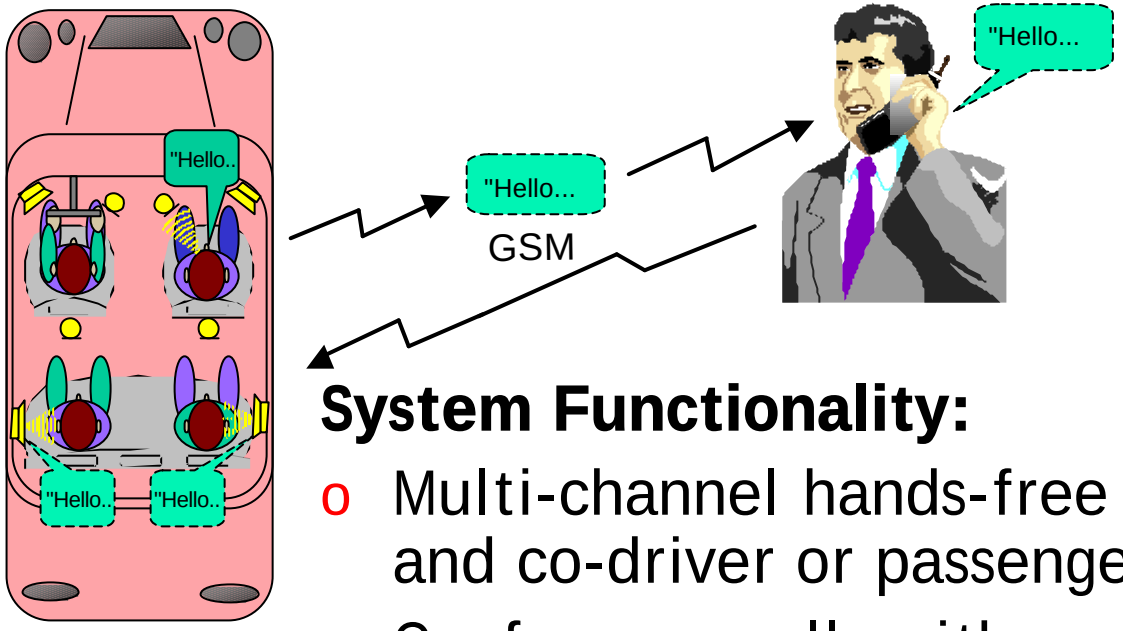
In-Car Communication
Results of Speech Intelligibility Test (MRT)

48 utterances were presented to each listener per driving situation

- **0 km/h, vehicle parked close to a motorway**
  - No significant difference (95.2% correct answers for system on versus 95.0% for system off)
  - Due to the automatic gain adjustment the intercom system operates with only very small gain at these noise levels
- **130 km/h, motorway**
  - Significant improvement of speech intelligibility by the intercom
  - Nearly 50% error reduction



Conference Calls / In-Car Communication



System Functionality:

- Multi-channel hands-free system for driver and co-driver or passengers on the back seats
- Conference calls with up to 4 partners with intercom functionality from the front to the back
- Intercom functionality between passengers in the front and in the back
- Speech recognition capabilities available for all seats

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Thank you for your attention!