# Active Noise Control of Speech in Headphones

using Linear Prediction

22. december 2016

Christian Claumarch, Kasper Kiis Jensen Maxime Démurger, Mikkel Krogh Simonsen Oliver Palmhøj Jokumsen 16gr761@es.aau.dk

> Acoustics and Audio Technology - Fall 2016 Department of Electronic Systems Aalborg University Denmark





Group 761

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Feedforward FXL

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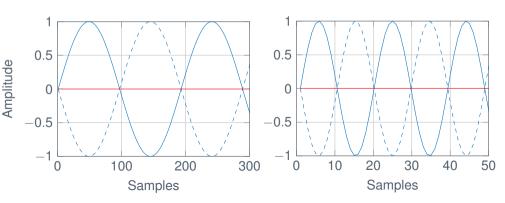
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► The basic theory of ANC

- ▶ 250 Hz
- ▶ 2500 Hz

- Original signal
- - Counterphase signal
- Error





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Feedforward FXLM Linear Prediction

Multirate Processis Combined system

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- Headphone cups attenuate high frequencies passively
- ► Lower frequencies must be attenuated actively
- ▶ Feedforward system
  - ► 1: Reference microphone
  - ► 2: Headphone loudspeaker
  - ► 3: Error microphone
  - ► 4: Digital signal Processor (DSP)





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Control (ANC)

Problem of ANC

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► Problem with feedforward

- Sampling and reconstruction delay
  - ► Anti Aliasing filter
  - ► Reconstructions filter
- ► The measured delay of a Σ/Δ-converter - TLV320AIC3204
- ► Spacing between microphones

► Min: 75.5 *m*m

► Max: 302 mm

$f_s$ [kHz]	48	96	192
Delay [ $\mu$ s]	900	450	225
Delay [samples]	43	43	43

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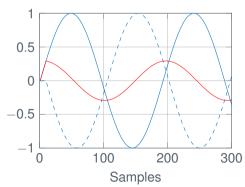
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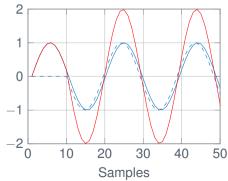
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► Counterphase signal delayed 10 samples

- ▶ 250 Hz
- ► 2500 Hz

- Original signal
- - Counterphase signal
- Error







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- ► Periodic noise is easy to cancel
- ► Signal Characteristics
  - ► Periodic Signals
    - ► Strict Sense Stationary (SSS)
  - ► Speech Signals
    - Quasiperiodic
    - ► 50 Hz 4000 Hz
    - ► 50 Hz 4000 Hz
    - ▶ Can be assumed Wide Sense Stationary (WSS) for 20 ms 30 ms
- Speech noise is difficult to cancel



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▶ How well does the consumer headphones attenuate?

► Denon AH-GC20

2.200 kr (2016)

Bose QC25

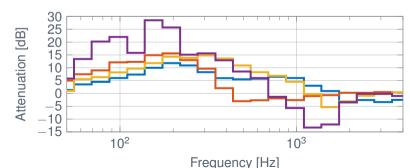
2.799 kr (2016)

► Bose QC15

2.696 kr (2011)

▶ BeoPlay H8

3.495 kr (2016)





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Problem of ANC

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- ► ANC ideally attenuate infinitely
- Delays are introduced by sampling and reconstruction
- ► Periodic signals can be attenuated infinitely
- ► Speech signals are not attenuated very well



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Acoustics and Audio Technology Dept. of Electronic Systems Aalborg University Combining a feedforward ANC algorithm with a Linear prediction (LP) scheme to compensate for delay.



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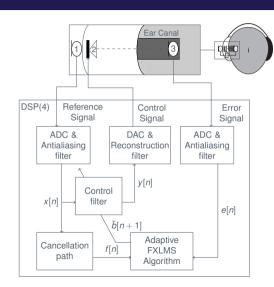
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► Control filter

- ► Transfer function from (1) to (2)
- Adaptive
- Cancelation path
  - ► Transfer function from (2) to (3)
  - ▶ Linear time-invariant
- ► Adaptive FXLMS-algorithm
  - ► Optimization problem





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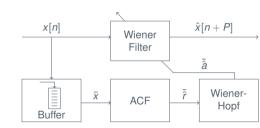
Attenuation Performan

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Acoustics and Audio Technology Dept. of Electronic Systems Aalborg University ► Auto Correlation Function estimation

- ► Framelength N
- ▶ Overlap O
- Wiener-hopf equation:  $\hat{R}\bar{\hat{a}} = -\bar{\hat{r}}$ 
  - ► Inverting matrix
  - ► Levinson-Durbin
- ► Wiener filtering in cascade
  - ► Prediction length P





Multirate Processing

# Simulations Results

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► Multirate Processing for reducing conversion delay

- ► High sample rate
- ► Low processing rate
- ► Smaller prediction length
  - ▶ 10 instead of 43

$f_s$ [kHz]	48	96	192
Delay [μs]	900	450	225
Delay [samples]	43	43	43

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Combined system

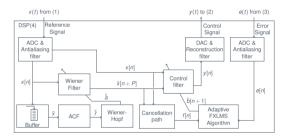
# Simulations Results

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► Input for control filter and CP

x[n]
 x̂[n+P]





Combined system

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Delays are introduced due to sampling and reconstruction

- Delays are reduced using multirate processing
- ► Compensation by Linear Prediction using Wiener filtering
- ► Noise cancelling using a feedforward FXLMS-algorithm



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- ► Simulink
- ► Archimedes Project
- Prediction Gain
- ► Filter banks vs Fourier transform
- Listening tests



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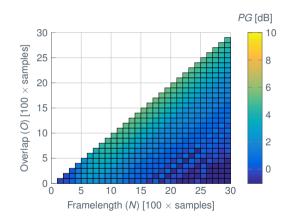
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- ▶ Optimal parameters
  - ► Framelength N = 1600
  - ► Overlap O = 1500
- ► Prediction Gain PG = 5.4 dB





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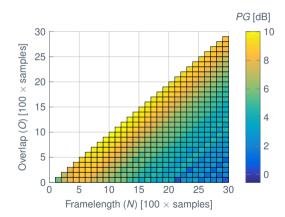
Acoustics and Audio Technology Dept. of Electronic Systems Aalborg University ► Prediction order P = 10

► Optimal parameters

► Framelength N = 1200

► Overlap O = 1100

► Prediction Gain PG = 10 dB





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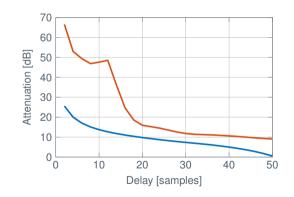
Attenuation Performance

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 ANC attenuation with varying system delay

- ► Feedforward FXLMS
- ► Feedforward LP FXLMS



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Simulations Results

Attenuation Performance

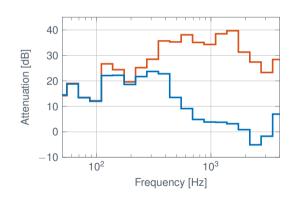
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► Frequency response

- ► Feedforward FXLMS
- ► Feedforward LP FXLMS





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Computational Cost

► Computational cost of System (instructions pr. sample)

► Linear Prediction: 55000

► Feedforward FXLMS: 4000

► Multirate: ≤ 100

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# Questions?

