Active Noise Control of Speech in Headphones

using Linear Prediction

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► The basic theory of ANC

▶ 250 Hz

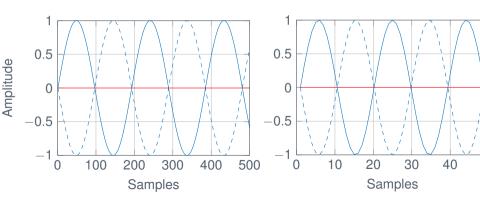
▶ 2500 Hz

Original signal

- - Counterphase signal

50

Error





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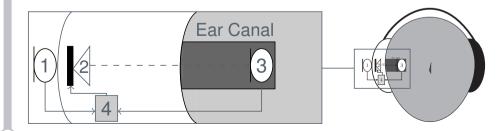
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- Headphone cups attenuate high frequencies passively
- ► Lower frequencies must be attenuated actively
- ▶ Feedforward system
 - ► 1: Reference microphone
 - ► 2: Headphone loudspeaker
 - ► 3: Error mirophone
 - ► 4: Digital signal Processor (DSP)





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Feedforward problem

- Sampling and reconstruction delay.
 - ► Anti Aliasing filter
 - Reconstructions filter
- ► The measured delay of a Sigma Delta converter TLV320AIC3204
- ► Spacing between microphones

► Min: 75.5 *m*m

► Max: 302 *m*m

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

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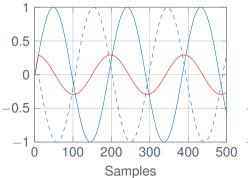
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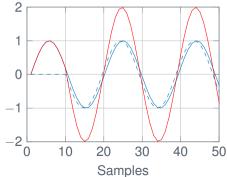
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Counter phase signal delayed 10 samples

- ▶ 250 Hz
- ► 2500 Hz

- Original signal
- -- Counterphase signal
- Error







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► Signal Characteristics

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

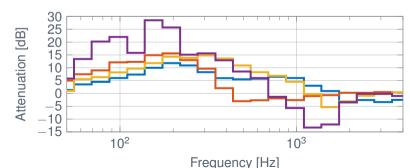
2.799 kr (2016)

► Bose QC15

2.696 kr (2011)

▶ BeoPlay H8

3.495 kr (2016)





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Problem of ANC

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► ANC attenuate infinitely ideally

- 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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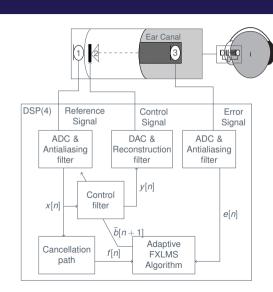
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► Control filter

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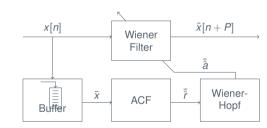
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Acoustics and Audio Technology Dept. of Electronic Systems Aalborg University ► Auto Correlation Function estimation

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





Multirate Processing

Simulations Results

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► Multirate Processing for reducing conversion delay

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

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

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Annual Continue

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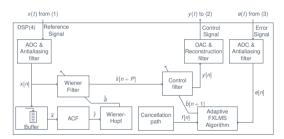
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Acoustics and Audio Technology Dept. of Electronic Systems Aalborg University ► Input for control filter and CP

- ▶ x[n]
- $\hat{x}[n+P]$
- ► CP delayed for compensation of error microphone delay





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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



Combined system

Simulations Results

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► Simulink

- ▶ Prediction Gain
- Cross correlations
- ► Not entirely sure what to put here

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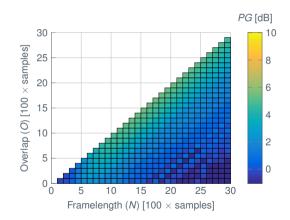
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- ▶ Optimal parameters
 - ► Frame length N = 1600
 - ► Overlap O = 1500
- ► Prediction Gain PG = 5.4 dB





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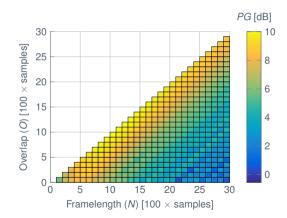
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- ► Optimal parameters
 - ► Frame length N = 1200
 - ► Overlap O = 1100
- ► Prediction Gain PG = 10 dB





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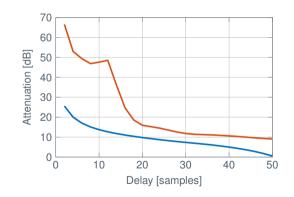
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 ANC attenuation with varying system delay

- ► Feedforward FXLMS
- ► Feedforward LP FXLMS



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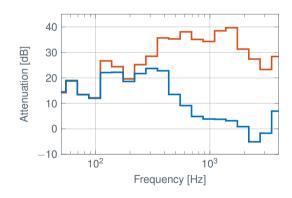


Simulations Results

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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

▶ Figure missing of different DSP maximum instruction pr sample at 48 kHz

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Questions?

