

# Active Noise Control of Speech in Headphones

using Linear Prediction

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# Agenda

Active Noise Control of  
Speech in  
Headphones using  
Linear Prediction  
Group 761

## Introduction

What is Active Noise  
Control (ANC)  
Problem of ANC

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Feedforward FXLMS  
Linear Prediction  
Multirate Processing  
Combined system

## Simulations Results

Linear Prediction  
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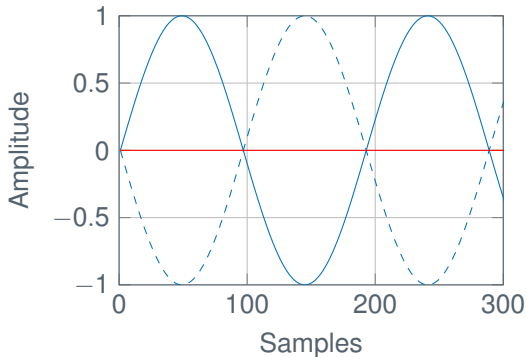
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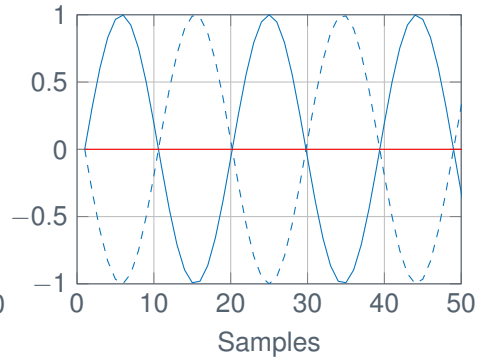
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### ► The basic theory of ANC

- 250 Hz
- 2500 Hz



- Original signal
- - Counterphase signal
- Error



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# Introduction

## How does ANC work

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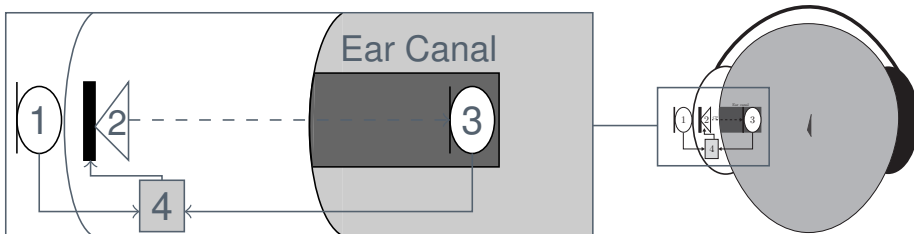
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- ▶ Headphone cups attenuate high frequencies passively
- ▶ Lower frequencies must be attenuated actively
- ▶ Feedforward system
  - ▶ 1: Reference microphone
  - ▶ 2: Headphone loudspeaker
  - ▶ 3: Error microphone
  - ▶ 4: Digital signal Processor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



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# Introduction

## Problem of ANC

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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 mm
  - ▶ Max: 302 mm

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

# Introduction

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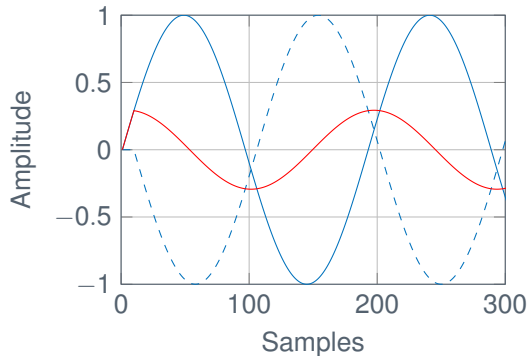
Computational Cost

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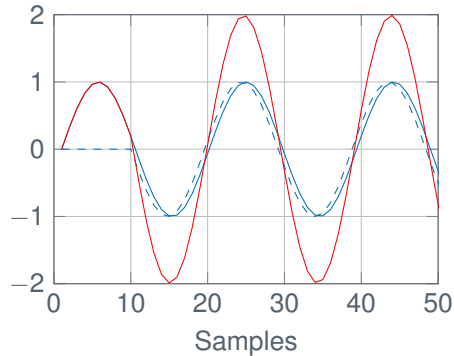
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### ▶ Counterphase signal delayed 10 samples

- ▶ 250 Hz
- ▶ 2500 Hz



- Original signal
- - Counterphase signal
- Error





# Introduction

## Speech vs Periodic Noise

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- ▶ Signal Characteristics
  - ▶ Periodic Signals
    - ▶ 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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# Introduction

## Present consumer headphones

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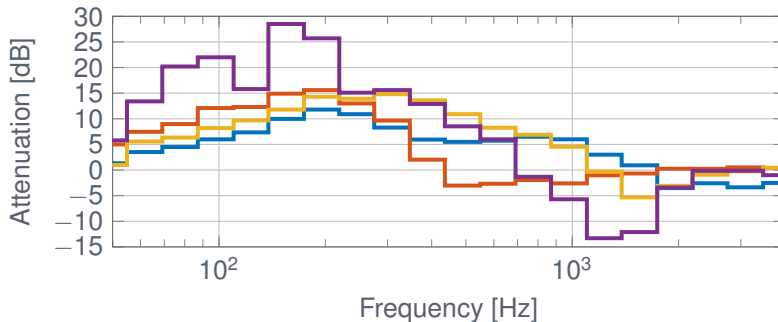
Attenuation Performance

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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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- ▶ 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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# Introduction

A solution for the problem

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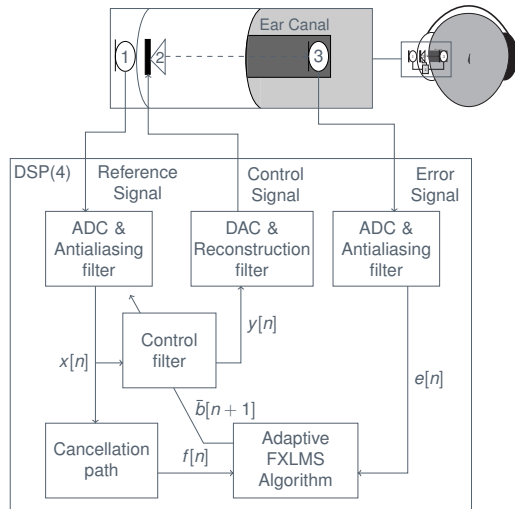
## Discussion

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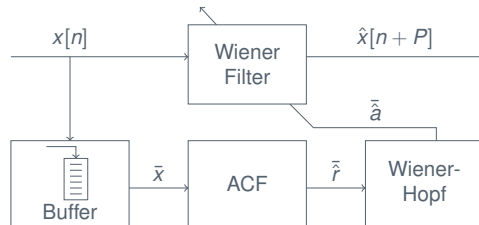
Combining a feedforward ANC algorithm with a Linear prediction (LP) scheme to compensate for delay.

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- ▶ Control filter
  - ▶ Transfer function from (1) to (2)
  - ▶ Adaptive
- ▶ Cancellation path
  - ▶ Transfer function from (2) to (3)
  - ▶ Linear time-invariant
- ▶ Adaptive FXLMS-Algorithm
  - ▶ Optimization problem



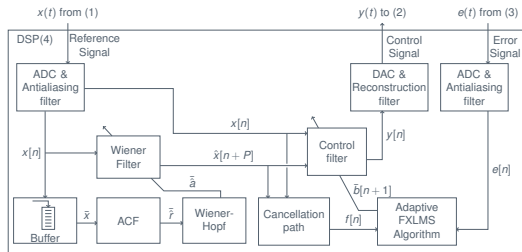
- ▶ Auto Correlation Function estimation
  - ▶ Framelength N
  - ▶ Overlap O
- ▶ Wiener-hopf equation:  $\hat{R}\bar{\bar{a}} = -\bar{\bar{r}}$ 
  - ▶ Inverting matrix
  - ▶ Levinson-Durbin
- ▶ Wiener filtering in cascade
  - ▶ Prediction length P



- ▶ 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 [ $\mu$ s]	900	450	225
Delay [samples]	43	43	43

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





# Methods

## Summary

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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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# Simulation Results

## How to test

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- ▶ Simulink
- ▶ Prediction Gain
- ▶ Filter banks vs Fourier transform
- ▶ Not entirely sure what to put here

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# Simulation Results

## Optimal parameters

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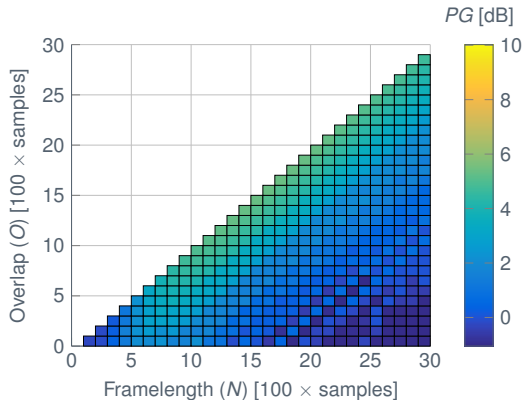
### Simulations Results

Linear Prediction  
Parameters  
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### Discussion

Computational Cost

- ▶ Prediction order  $P = 43$
- ▶ Optimal parameters
  - ▶ Framelength  $N = 1600$
  - ▶ Overlap  $O = 1500$
- ▶ Prediction Gain  $PG = 5.4$  dB



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# Simulation Results

## Optimal parameters

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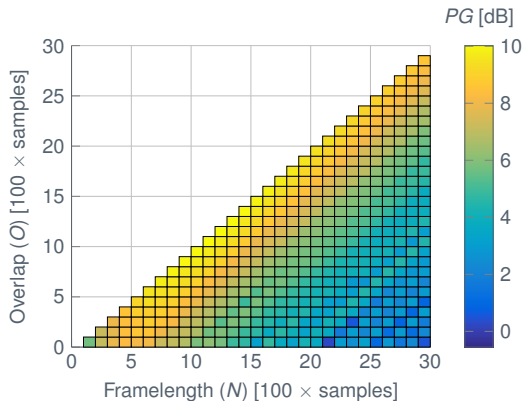
### Simulations Results

Linear Prediction  
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Computational Cost

- ▶ Prediction order  $P = 10$
- ▶ Optimal parameters
  - ▶ Framelength  $N = 1200$
  - ▶ Overlap  $O = 1100$
- ▶ Prediction Gain  $PG = 10$  dB



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# Simulation Results

## Attenuation Performance

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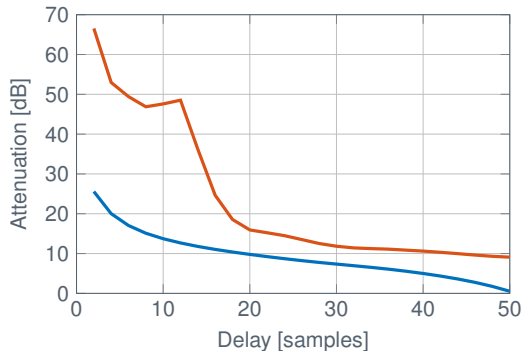
Linear Prediction  
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### Discussion

Computational Cost

- ▶ ANC attenuation with  
varying system delay
  - ▶ Feedforward FXLMS
  - ▶ Feedforward LP FXLMS



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# Simulation Results

## Frequency response

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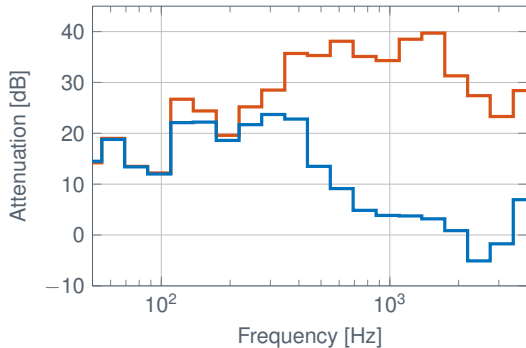
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- Frequency response
  - Feedforward FXLMS
  - Feedforward LP FXLMS





# Discussion

## Computational Cost

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- ▶ Computational cost of System (instructions pr. sample)
  - ▶ Linear Prediction: 55000
  - ▶ Feedforward FXLMS: 4000
  - ▶ Multirate:  $\leq 100$
- ▶ Figure missing of different DSP maximum instruction pr sample at 48 kHz

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Questions?



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