

# Active Noise Control of Speech in Headphones

using Linear Prediction

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Department of Electronic Systems  
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# Agenda

Active Noise Control of  
Speech in  
Headphones using  
Linear Prediction  
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## Introduction

What is Active Noise  
Control (ANC)  
Problem of ANC

## Methods

Feedforward FXLMS  
Linear Prediction  
Multirate Processing  
Combined system

## Simulations Results

Linear Prediction  
Parameters  
Attenuation Performance

## Discussion

Computational Cost

## Introduction

What is Active Noise Control (ANC)  
Problem of ANC

## Methods

Feedforward FXLMS  
Linear Prediction  
Multirate Processing  
Combined system

## Simulations Results

Linear Prediction Parameters  
Attenuation Performance

## Discussion

Computational Cost

# Introduction

## What is ANC

Active Noise Control of  
Speech in  
Headphones using  
Linear Prediction

Group 761

Introduction

What is Active Noise  
Control (ANC)

Problem of ANC

Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

Simulations Results

Linear Prediction  
Parameters

Attenuation Performance

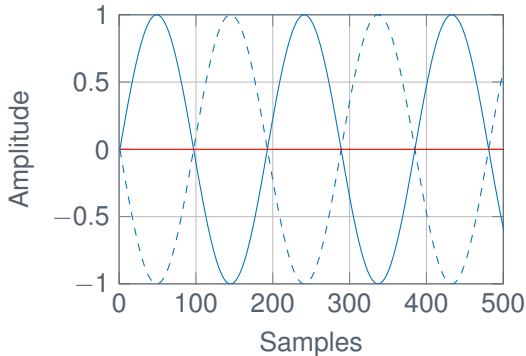
Discussion

Computational Cost

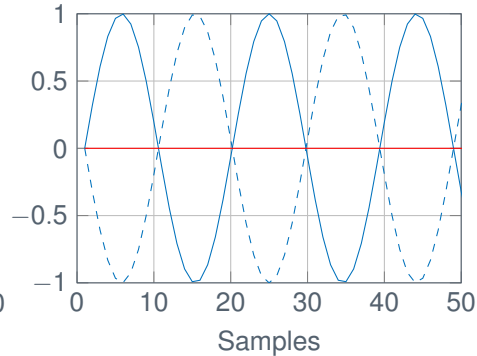
2

### ► The basic theory of ANC

- 250 Hz
- 2500 Hz



- Original signal
- - Counterphase signal
- Error



# Introduction

## How does ANC work

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Speech in  
Headphones using  
Linear Prediction  
Group 761

Introduction

What is Active Noise  
Control (ANC)

Problem of ANC

Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

Simulations Results

Linear Prediction  
Parameters

Attenuation Performance

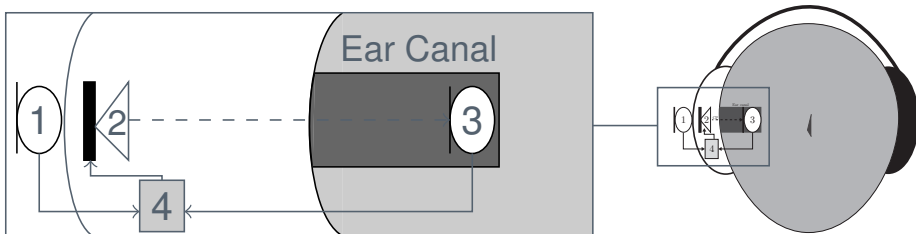
Discussion

Computational Cost

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3

- ▶ 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)



20

# Introduction

## Problem of ANC

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

Introduction

What is Active Noise  
Control (ANC)

Problem of ANC

4

Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

Simulations Results

Linear Prediction

Parameters

Attenuation Performance

Discussion

Computational Cost

- ▶ 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

## Problem of ANC

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

Introduction

What is Active Noise  
Control (ANC)

Problem of ANC

Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

Simulations Results

Linear Prediction  
Parameters

Attenuation Performance

Discussion

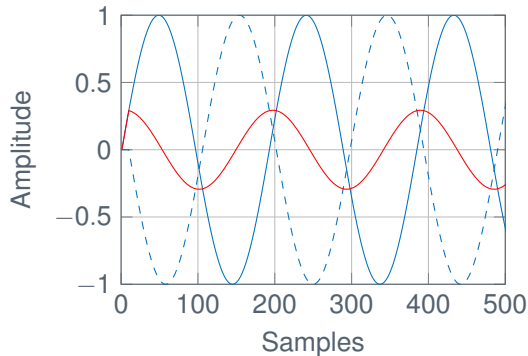
Computational Cost

5

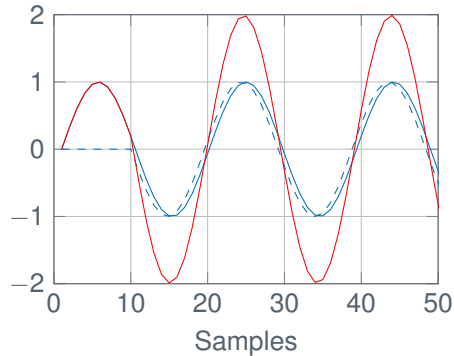
20

- ▶ Counter phase signal delayed 10 samples

- ▶ 250 Hz
- ▶ 2500 Hz



- Original signal
- - - Counterphase signal
- Error





# Introduction

## Speech vs Periodic Noise

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Speech in  
Headphones using  
Linear Prediction  
Group 761

Introduction

What is Active Noise  
Control (ANC)

Problem of ANC

6

Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

Simulations Results

Linear Prediction  
Parameters

Attenuation Performance

Discussion

Computational Cost

### ► 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

20

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# Introduction

## Present consumer headphones

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Speech in  
Headphones using  
Linear Prediction  
Group 761

Introduction

What is Active Noise  
Control (ANC)

Problem of ANC

Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

Simulations Results

Linear Prediction

Parameters

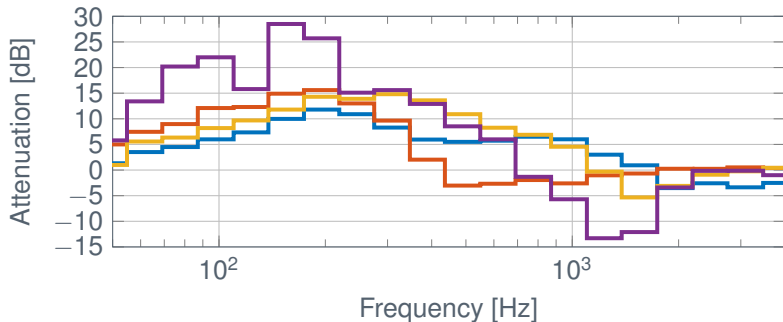
Attenuation Performance

Discussion

Computational Cost

### ► 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)







# Introduction

## Summary

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

### Introduction

What is Active Noise  
Control (ANC)

Problem of ANC

### Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

### Simulations Results

Linear Prediction

Parameters

Attenuation Performance

### Discussion

Computational Cost

8

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

20



# Introduction

A solution for the problem

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Speech in  
Headphones using  
Linear Prediction  
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## Introduction

What is Active Noise  
Control (ANC)

Problem of ANC

9

## Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

## Simulations Results

Linear Prediction

Parameters

Attenuation Performance

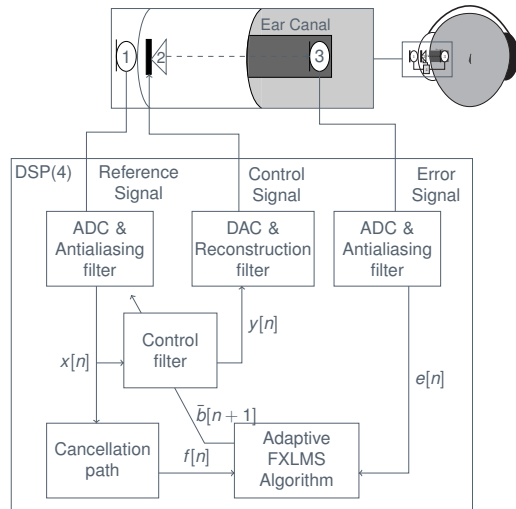
## Discussion

Computational Cost

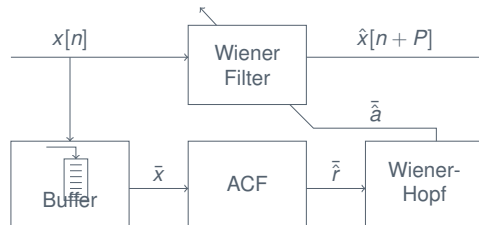
Combining a feedforward ANC algorithm with a Linear prediction (LP) scheme to compensate for delay.

20

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



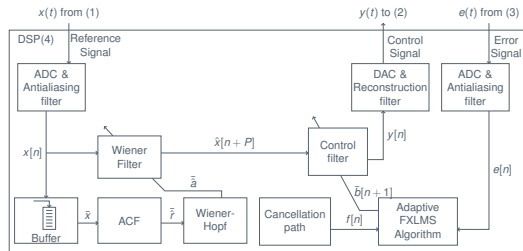
- ▶ Multirate Processing for reducing conversion delay
  - ▶ High sample rate
  - ▶ Low processing rate
- ▶ Smaller prediction order
  - ▶ 10 instead of 43

$f_s$ [kHz]	48	96	192
Delay [ $\mu$ 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

### Active Noise Control of Speech in Headphones using Linear Prediction

Group 761

#### Introduction

What is Active Noise  
Control (ANC)

Problem of ANC

#### Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

#### Simulations Results

Linear Prediction  
Parameters

Attenuation Performance

#### Discussion

Computational Cost

14

- ▶ 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

20



# Methods

## How to test

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Speech in  
Headphones using  
Linear Prediction  
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### Introduction

What is Active Noise  
Control (ANC)  
Problem of ANC

### Methods

Feedforward FXLMS  
Linear Prediction  
Multirate Processing  
Combined system

### Simulations Results

Linear Prediction  
Parameters  
Attenuation Performance

### Discussion

Computational Cost

15

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

20



# Simulation Results

## Optimal parameters

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Speech in  
Headphones using  
Linear Prediction  
Group 761

### Introduction

What is Active Noise  
Control (ANC)  
Problem of ANC

### Methods

Feedforward FXLMS  
Linear Prediction  
Multirate Processing  
Combined system

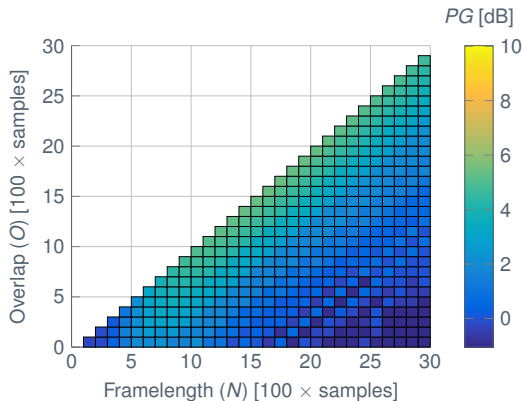
### Simulations Results

Linear Prediction  
Parameters  
Attenuation Performance

### Discussion

Computational Cost

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



16

20

# Simulation Results

## Optimal parameters

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

### Introduction

What is Active Noise  
Control (ANC)  
Problem of ANC

### Methods

Feedforward FXLMS  
Linear Prediction  
Multirate Processing  
Combined system

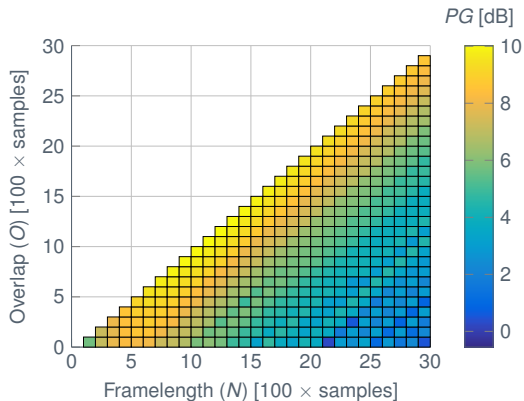
### Simulations Results

Linear Prediction  
Parameters  
Attenuation Performance

### Discussion

Computational Cost

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



17

20

# Simulation Results

## Attenuation Performance

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

### Introduction

What is Active Noise  
Control (ANC)  
Problem of ANC

### Methods

Feedforward FXLMS  
Linear Prediction  
Multirate Processing  
Combined system

### Simulations Results

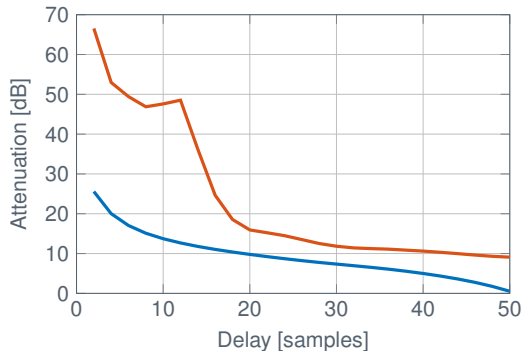
Linear Prediction  
Parameters  
Attenuation Performance

18

### Discussion

Computational Cost

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



20

# Simulation Results

## Frequency response

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Speech in  
Headphones using  
Linear Prediction  
Group 761

### Introduction

What is Active Noise  
Control (ANC)  
Problem of ANC

### Methods

Feedforward FXLMS  
Linear Prediction  
Multirate Processing  
Combined system

### Simulations Results

Linear Prediction  
Parameters  
Attenuation Performance

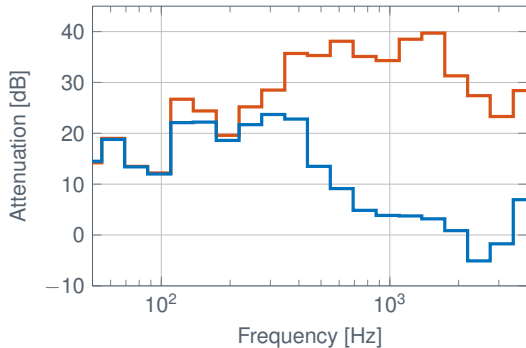
19

### Discussion

Computational Cost

20

- Frequency response
  - Feedforward FXLMS
  - Feedforward LP FXLMS





# Discussion

## Computational Cost

### Active Noise Control of Speech in Headphones using Linear Prediction

Group 761

#### Introduction

What is Active Noise  
Control (ANC)

Problem of ANC

#### Methods

Feedforward FXLMS

Linear Prediction

Multirate Processing

Combined system

#### Simulations Results

Linear Prediction  
Parameters

Attenuation Performance

#### Discussion

Computational Cost

20

- ▶ 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

20

Questions?



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