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
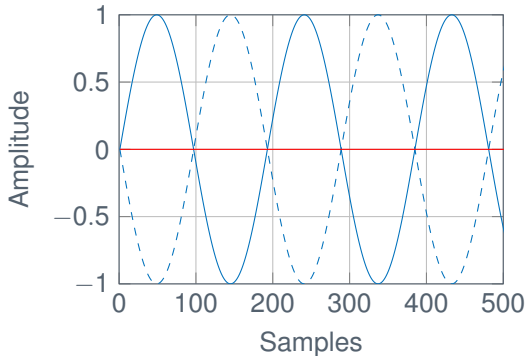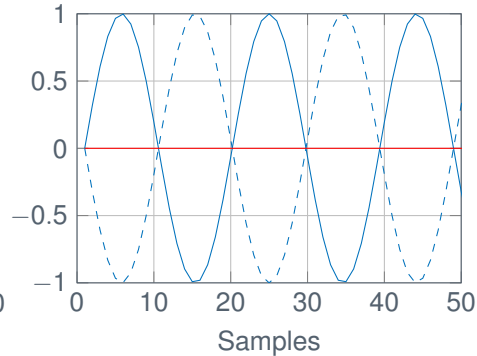   Attenuation Performance

Discussion
    Computational Cost

► The basic theory of ANC
  ► 250 Hz
  ► 2500 Hz

—— Original signal
- - - Counterphase signal
—— Error

▶ 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)
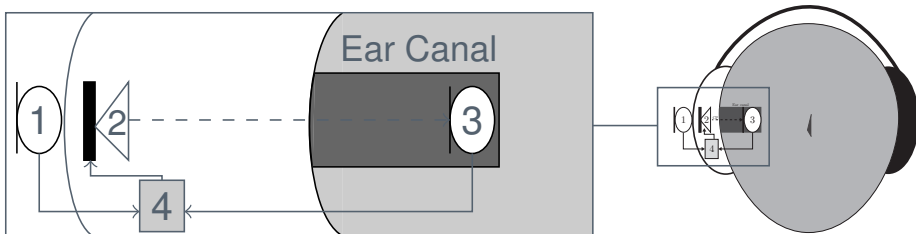
► Feedforward problem
► Sampling and reconstruction delay.
  ► Anti Aliasing filter
  ► Reconstructions filter
► The measured delay of a Sigma Delta converter TLV320AIC3204
► Spacing between microphones
  ► Min: 75.5 mm
  ► Max: 302 mm

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

▶ Counter phase signal delayed 10 samples
  ▶ 250 Hz
  ▶ 2500 Hz
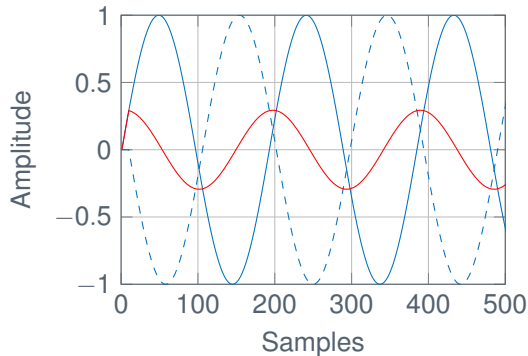
— Original signal
-- Counterphase signal
— Error
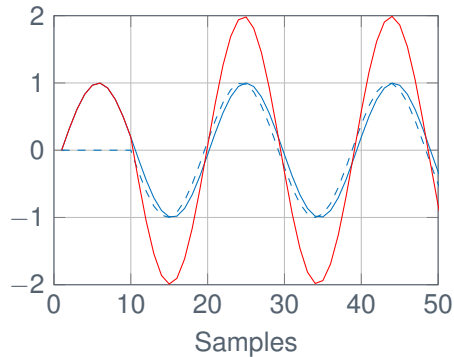
- ▶ Signal Characteristics
    - ▶ Periodic Signals
        - ▶ Periodic
        - ▶ Strict Sense Stationary (SSS)
    - ▶ Speech Signals
        - ▶ Quasiperiodic
        - ▶ 50 Hz – 4000 Hz
        - ▶ Can be assumed Wide Sense Stationary (WSS) for 20 ms – 30 ms
- ▶ Periodic noise is easy to cancel
- ▶ Speech noise is difficult to cancel

▶ 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)

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

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

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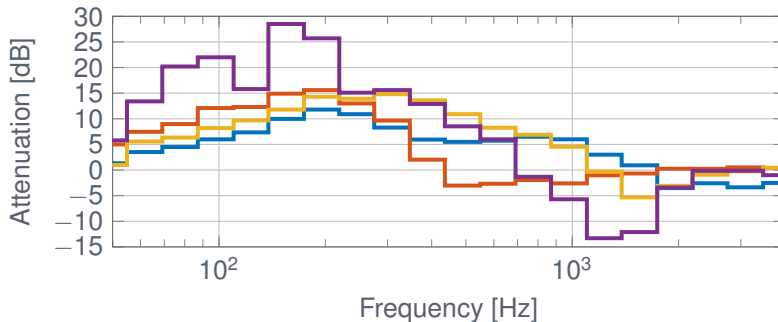
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▶ Control filter
  ▶ Transfer function from (1) to (2)
  ▶ Adaptive
▶ Cancelation path
  ▶ Transfer function from (2) to (3)
  ▶ Linear Time Invariant
▶ Adaptive FXLMS Algorithm
  ▶ Optimization problem

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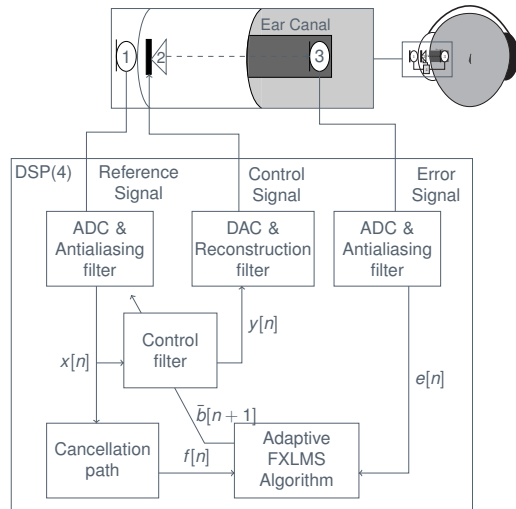Parameters
Attenuation Performance
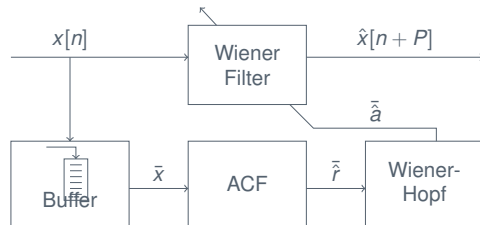
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► Auto Correlation Function estimation
  ► Frame length N
  ► Overlap O
► Wiener hopf equation: $\hat{R}\bar{a} = -\bar{\hat{r}}_x$
  ► Inverting matrix
  ► Levinson Durbin
► Wiener filtering in cascade
  ► Prediction order P

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

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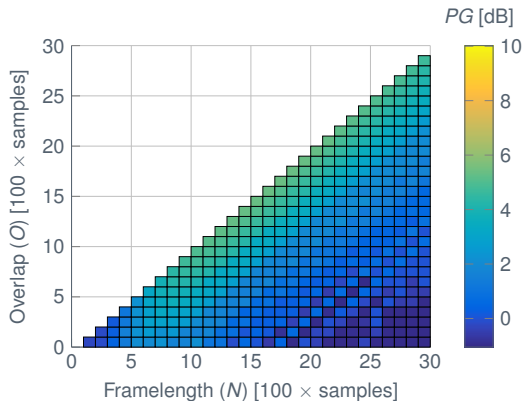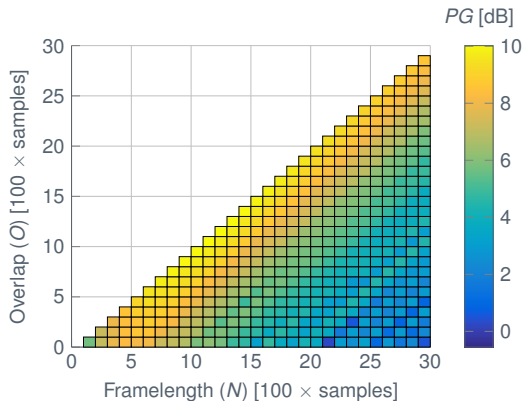Linear Prediction
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▶ Input for control filter and CP

   ▶ $x[n]$
   ▶ $\hat{x}[n+P]$
▶ CP delayed for
   compensation of error
   microphone delay
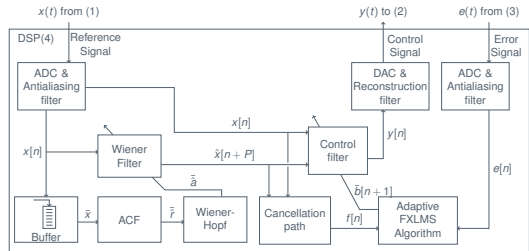
► Delays are introduced due to sampling and reconstruction
► Delays are reduced using multirate processing
► Compensation by Linear Prediction using Wiener filtering
► Noise cancelling using a feedforward FXLMS algorithm

► Simulink

► Prediction Gain

► Cross correlations

► Not entirely sure what to put here

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

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

- ANC attenuation with varying system delay
  - Feedforward FXLMS
  - Feedforward LP FXLMS
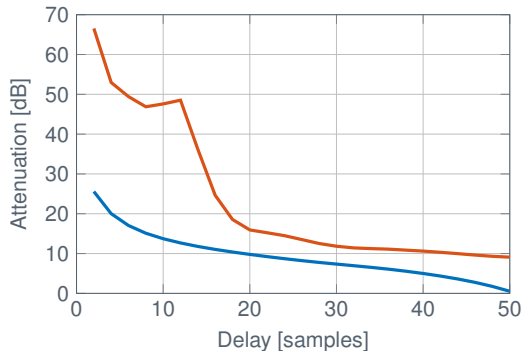
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▶ Frequency response
  ▶ Feedforward FXLMS
  ▶ Feedforward LP FXLMS
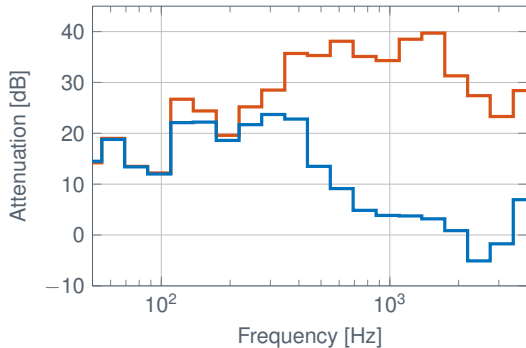
► Computational cost of System (instructions pr. sample)
  ► Linear Prediction: 55000
  ► Feedforward FXLMS: 4000
  ► Multirate: ≤ 100
► Figure missing of different DSP maximum instruction pr sample at 48 kHz

Questions?