# Active Noise Control of Speech in Headphones

## using Linear Prediction

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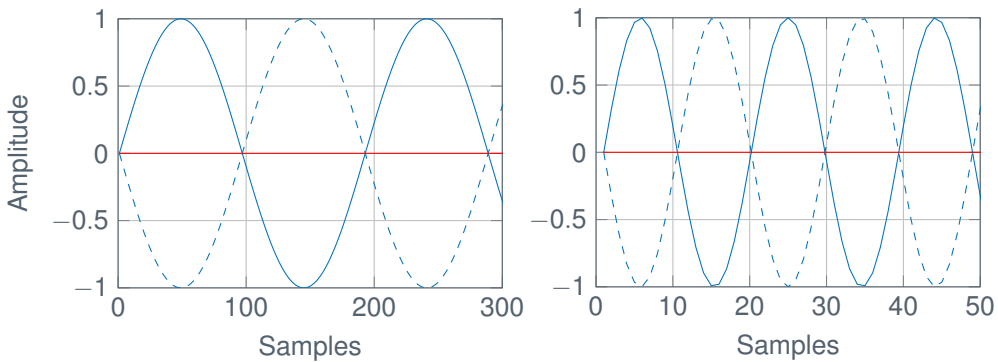
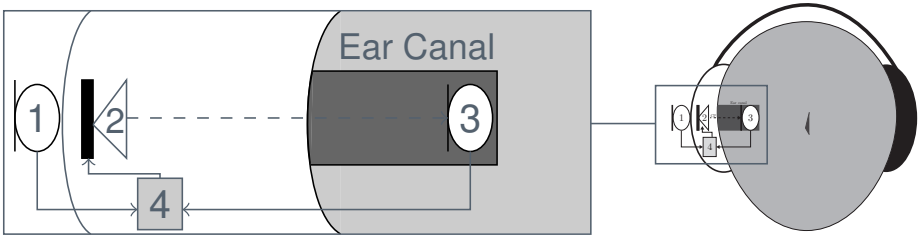
# Agenda

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



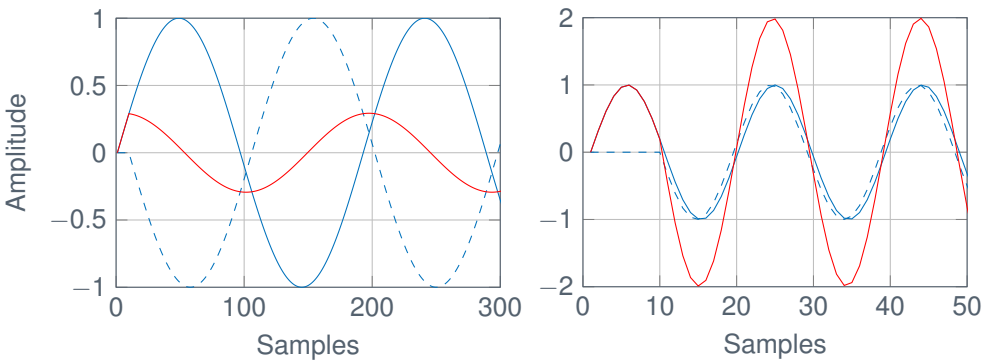
- Headphone cups attenuate high frequencies passively
- Lower frequencies must be attenuated actively
- Feedforward system
  - 1: Reference microphone
  - 2: Headphone loudspeaker
  - 3: Error microphone
  - 4: Digital signal Processor (DSP)



- Problem with feedforward
- 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

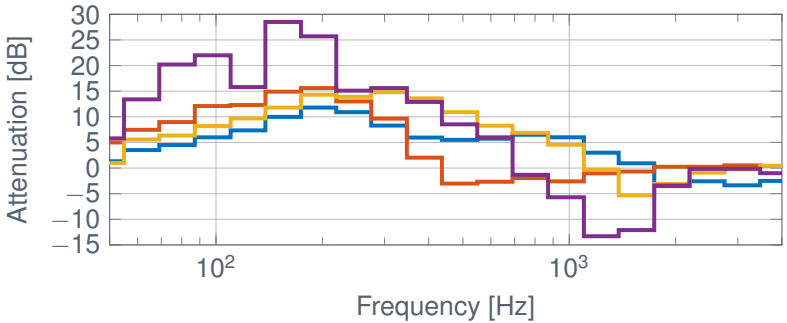
| $f_s$ [$k$Hz] | 48 | 96 | 192 |
|---|---|---|---|
| Delay [$\mu$s] | 900 | 450 | 225 |
| Delay [samples] | 43 | 43 | 43 |

- Counterphase signal delayed 10 samples
  - 250 Hz
  - 2500 Hz



- Periodic noise is *easy* to cancel
- Signal characteristics
  - Periodic signals
    - Strict Sense Stationary (SSS)
  - Speech Signals
    - Quasiperiodic
    - 50 Hz – 4000 Hz
    - Can be assumed Wide Sense Stationary (WSS) for 20 *m*s – 30 *m*s
- Speech noise is *difficult* to cancel

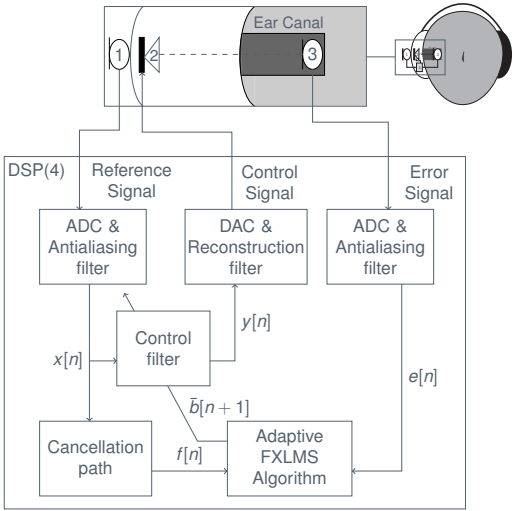
- How well does the consumer headphones ANC attenuate?
  - Denon AH-GC20 2.200 kr (2016)
  - Bose QC25 2.799 kr (2016)
  - Bose QC15 2.696 kr (2011)
  - BeoPlay H8 3.495 kr (2016)



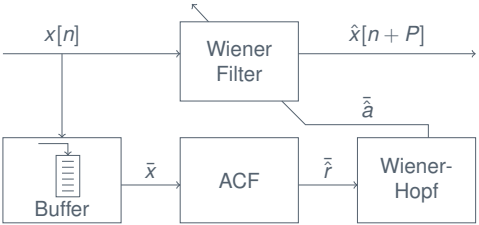
- ANC ideally attenuate infinitely
- Delays are introduced by sampling and reconstruction
- Periodic signals can be attenuated infinitely
- Speech signals are not attenuated very well

Combining a Feedforward ANC Algorithm With a Linear Prediction (LP) Scheme to Compensate for Delay.

- 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



- 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 for reducing conversion delay
  - High sample rate
  - Low processing rate
- Smaller prediction length
  - 10 instead of 43

| $f_s$ [$k$Hz] | 48 | 96 | 192 |
|---|---|---|---|
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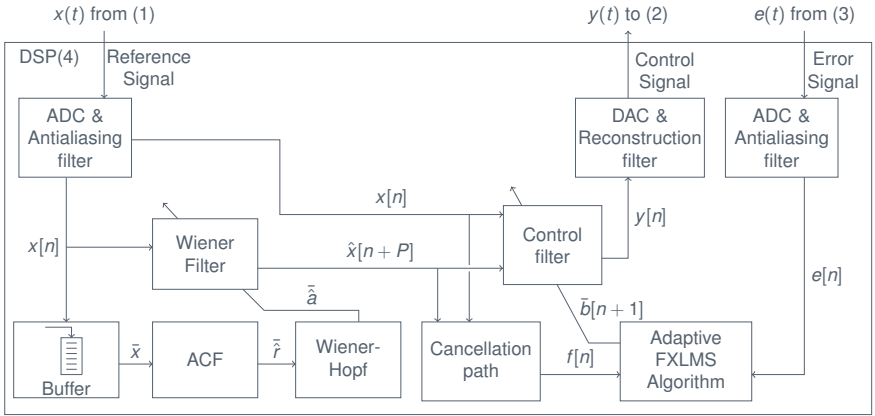
| Delay [samples] | 43 | 43 | 43 |

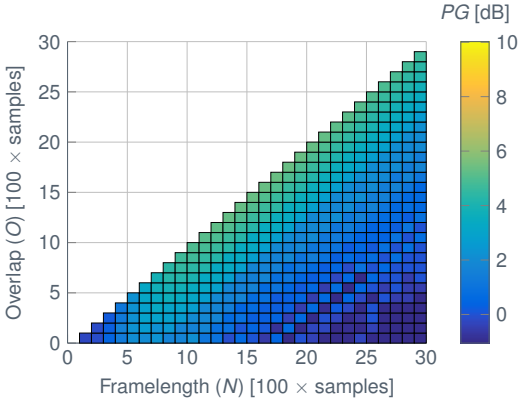
- Input for control filter and CP
  - $x[n]$
  - $\hat{x}[n+P]$



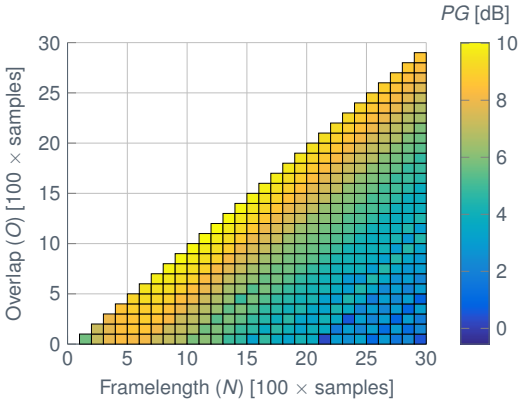
- Delays are introduced due to sampling and reconstruction
- Delays are reduced using multirate processing
- Compensation by Linear Prediction using Wiener filtering
- Noise cancelling using a feedforward FXLMS-algorithm

- Simulink
- Archimedes Project
- Prediction Gain
- Filter-banks vs. Fourier transform
- Listen to results

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



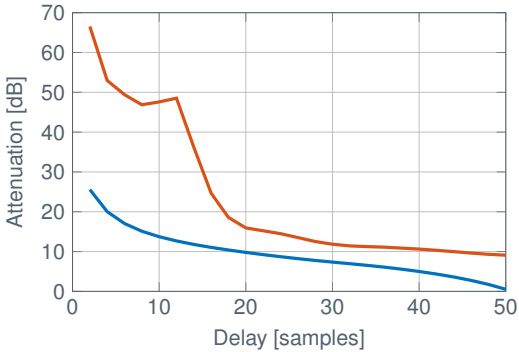
- Prediction order P = 10
- Optimal parameters
  - Framelength N = 1200
  - Overlap O = 1100
- Prediction Gain PG = 10 dB



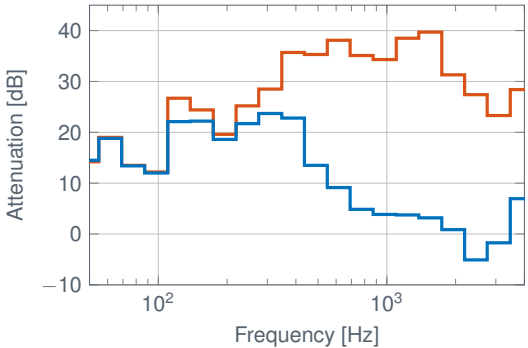
# Simulation Results
## Attenuation Performance



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



- Frequency response
  - Feedforward LP FXLMS
  - Feedforward FXLMS



- Proof of concept
- Computational cost of system (instructions per sample)
  - Linear Prediction: > 50,000
  - Feedforward FXLMS: > 4,000
  - Multirate: < 100

Questions?

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