

Active Noise Control of Speech in Headphones

using Linear Prediction

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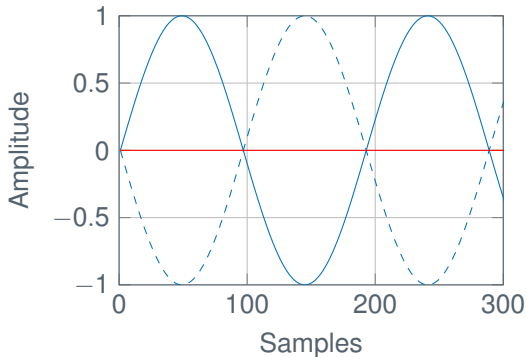
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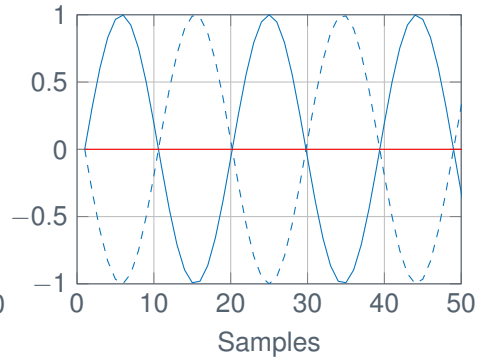
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► The basic theory of ANC

- 250 Hz
- 2500 Hz



- Original signal
- - Counterphase signal
- Error



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How does ANC work

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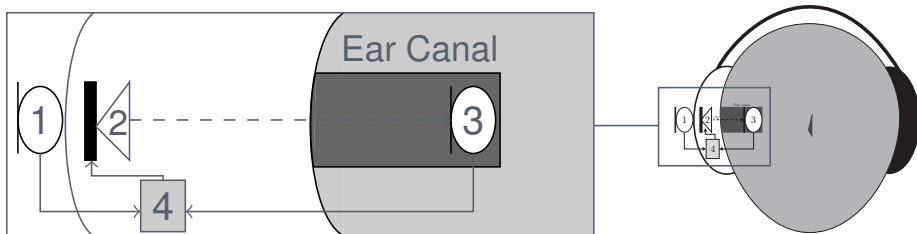
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- ▶ Headphone cups attenuate high frequencies passively
- ▶ Lower frequencies must be attenuated actively
- ▶ Feedforward system
 - ▶ 1: Reference microphone
 - ▶ 2: Headphone loudspeaker
 - ▶ 3: Error microphone
 - ▶ 4: Digital signal Processor (DSP)



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- ▶ 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 [μ s]	900	450	225
Delay [samples]	43	43	43

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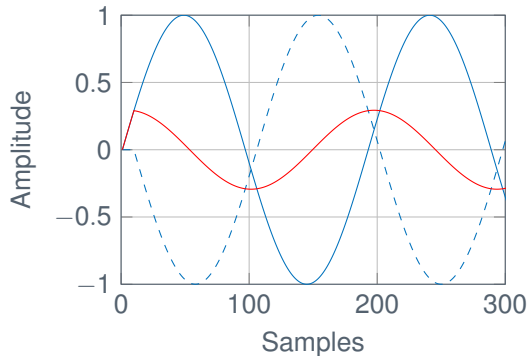
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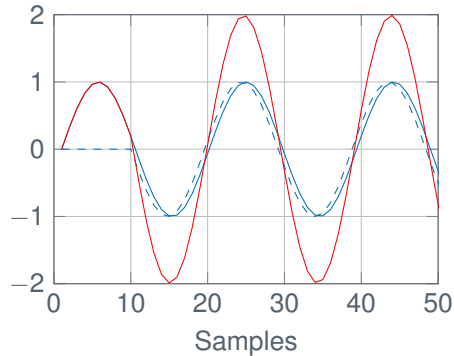
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▶ Counterphase signal delayed 10 samples

- ▶ 250 Hz
- ▶ 2500 Hz



- Original signal
- - Counterphase signal
- Error





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Speech vs Periodic Noise

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- ▶ 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 *ms* – 30 *ms*
- ▶ Speech noise is difficult to cancel

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Present consumer headphones

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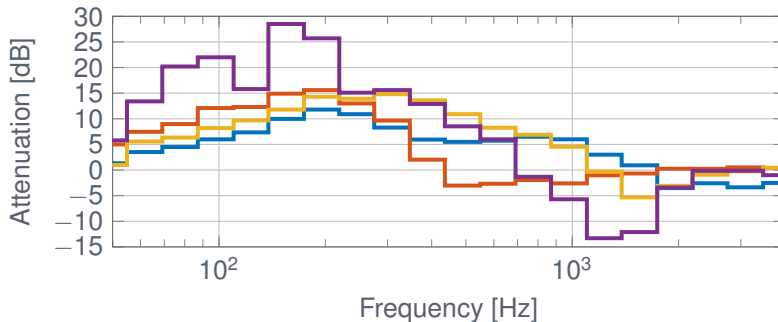
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► How well does the consumer headphones attenuate?

- 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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A solution for the problem

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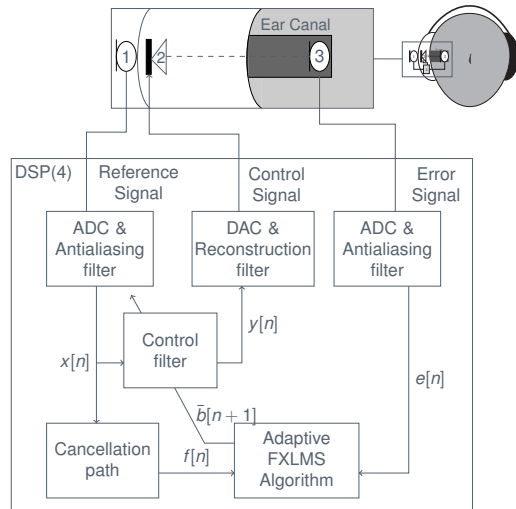
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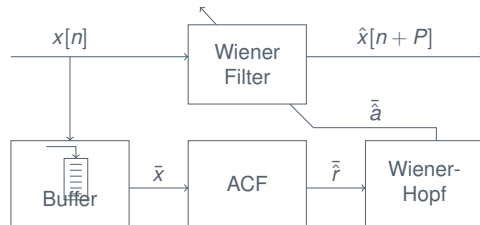
Combining a feedforward ANC algorithm with a Linear prediction (LP) scheme to compensate for delay.

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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

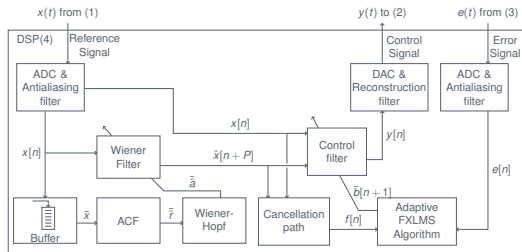


- ▶ Multirate Processing for reducing conversion delay
 - ▶ High sample rate
 - ▶ Low processing rate
- ▶ Smaller prediction length
 - ▶ 10 instead of 43

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

► Input for control filter and CP

- $x[n]$
- $\hat{x}[n + P]$





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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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How to test

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- ▶ Simulink
- ▶ Prediction Gain
- ▶ Filter banks vs Fourier transform
- ▶ Listening tests
 - ▶ Archimedes Project

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Optimal parameters

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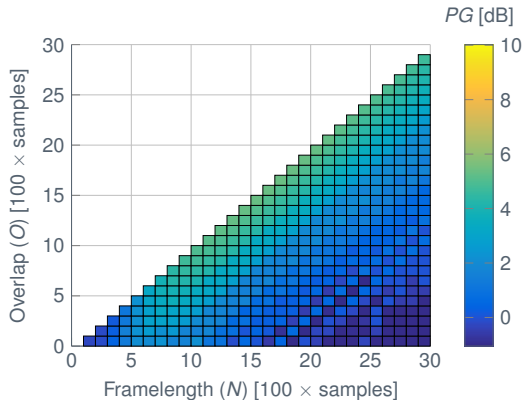
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- ▶ Prediction order $P = 43$
- ▶ Optimal parameters
 - ▶ Framelength $N = 1600$
 - ▶ Overlap $O = 1500$
- ▶ Prediction Gain $PG = 5.4$ dB



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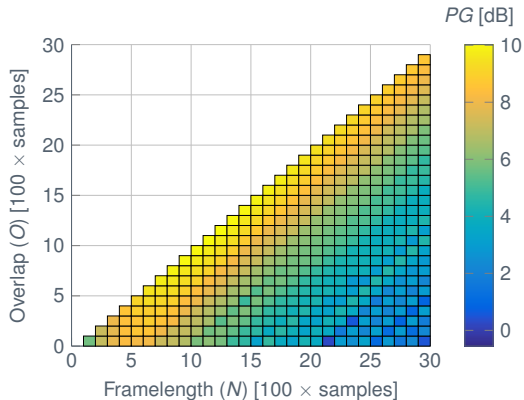
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- ▶ Prediction order $P = 10$
- ▶ Optimal parameters
 - ▶ Framelength $N = 1200$
 - ▶ Overlap $O = 1100$
- ▶ Prediction Gain $PG = 10$ dB



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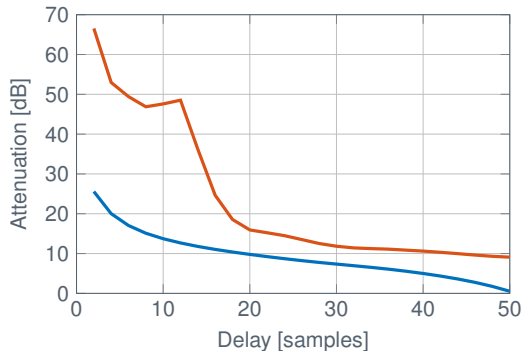
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- ▶ ANC attenuation with
varying system delay
 - ▶ Feedforward FXLMS
 - ▶ Feedforward LP FXLMS



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Frequency response

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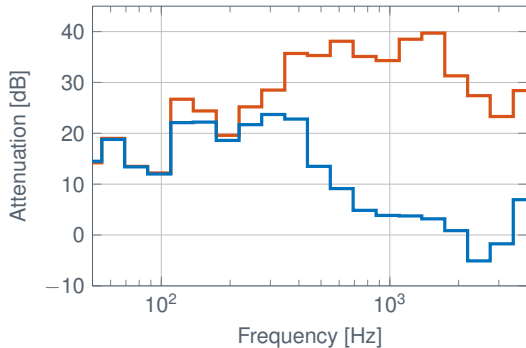
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- Frequency response
 - Feedforward FXLMS
 - Feedforward LP FXLMS





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► Computational cost of System (instructions pr. sample)

- Linear Prediction: 55000
- Feedforward FXLMS: 4000
- Multirate: ≤ 100

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Questions?



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