

Active Noise Control of Speech in Headphones

using Linear Prediction

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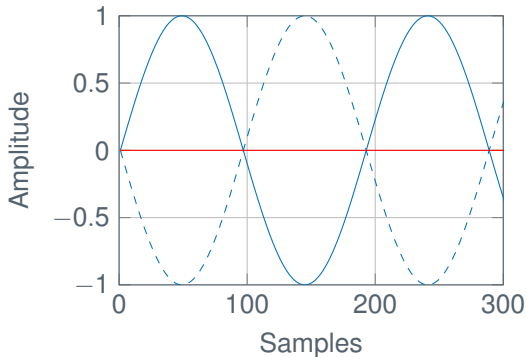
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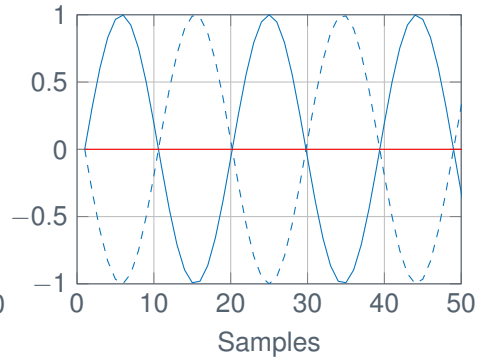
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► The basic theory of ANC

- 250 Hz
- 2500 Hz



- Original signal
- - Counterphase signal
- Error



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How Does ANC Work?

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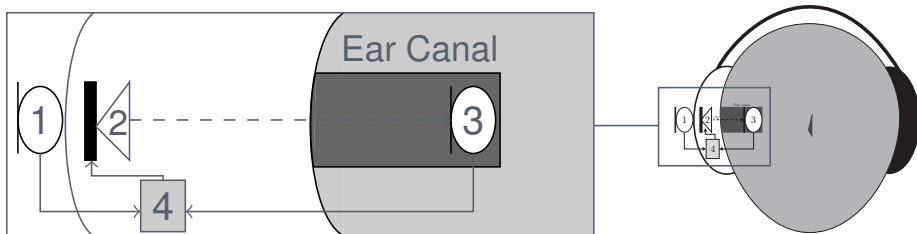
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- ▶ Headphone cups attenuate high frequencies passively
- ▶ Lower frequencies must be attenuated actively
- ▶ Feedforward system
 - ▶ 1: Reference microphone
 - ▶ 2: Headphone loudspeaker
 - ▶ 3: Error microphone
 - ▶ 4: Digital Signal Processor (DSP)



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- ▶ Problem with feedforward
- ▶ Sampling and reconstruction delay
 - ▶ Anti Aliasing filter
 - ▶ Reconstructions filter
- ▶ The measured delay of a Σ/Δ -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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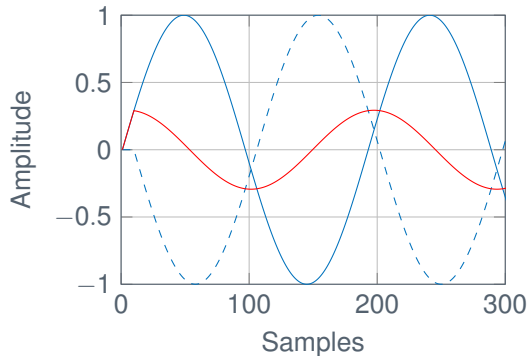
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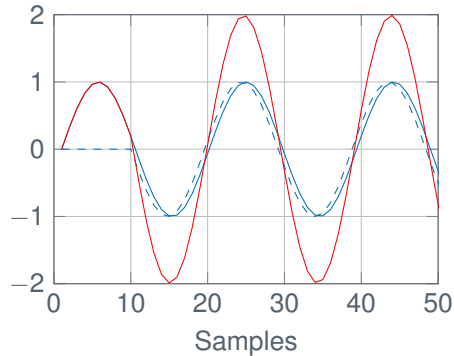
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▶ Counterphase signal delayed 10 samples

- ▶ 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
 - ▶ Wide Sense Stationary (WSS)
 - ▶ Speech Signals
 - ▶ Quasiperiodic
 - ▶ 50 Hz – 4000 Hz
 - ▶ Can be assumed WSS for 20 *ms* – 30 *ms*
- ▶ Speech noise is *difficult* to cancel

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Present Consumer Headphones

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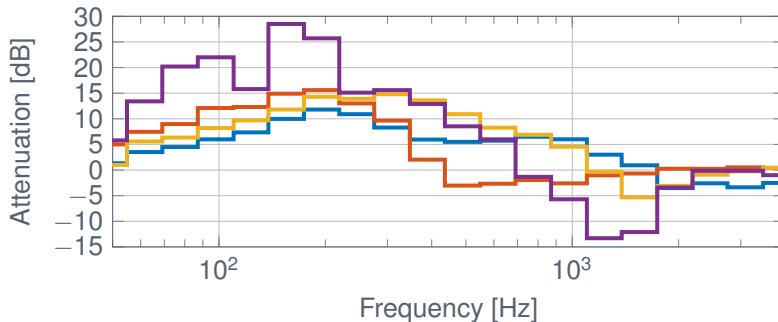
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► How well does the consumer headphone's ANC attenuate?

- 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)





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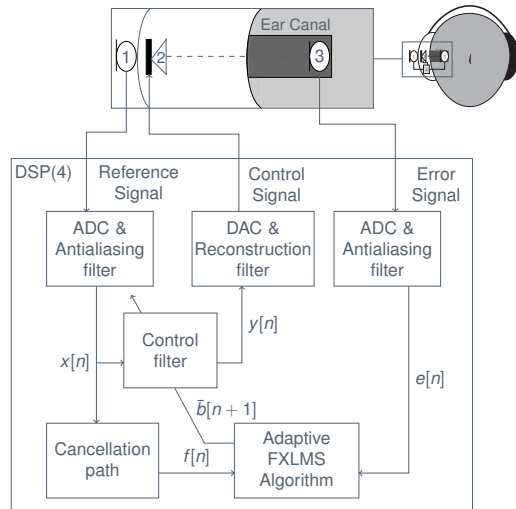
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Combining a Feedforward ANC Algorithm With a Linear Prediction (LP) Scheme to
Compensate for Delay.

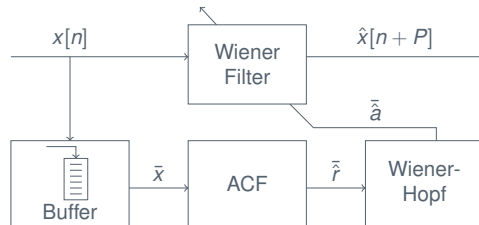
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- ▶ Control filter
 - ▶ Transfer function from (1) to (2)
 - ▶ Adaptive
- ▶ Cancellation path
 - ▶ Transfer function from (2) to (3)
 - ▶ Linear time-invariant
- ▶ Adaptive FXLMS-algorithm
 - ▶ Optimization problem



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

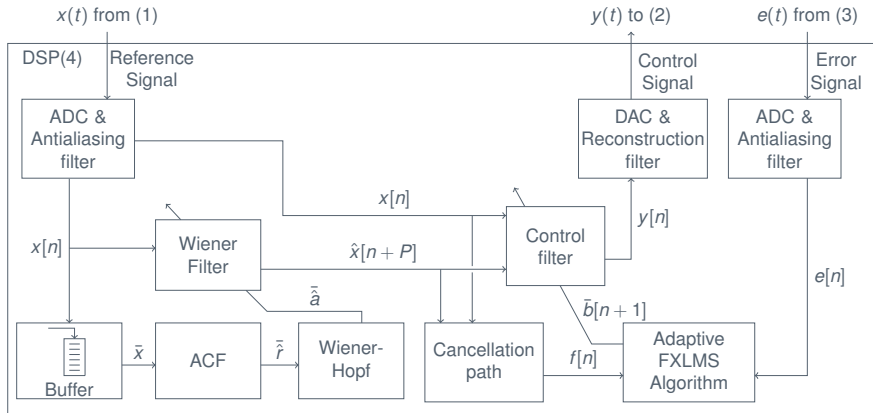


- ▶ Multirate processing for reducing conversion delay
 - ▶ High sample rate
 - ▶ Low processing rate
- ▶ Smaller prediction length
 - ▶ 10 instead of 43

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

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Optimal parameters

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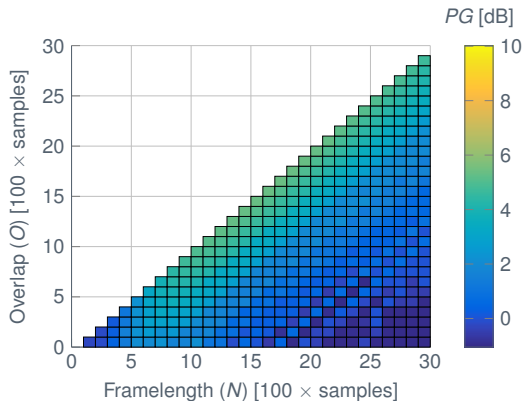
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- ▶ Prediction order $P = 43$
- ▶ Optimal parameters
 - ▶ Framelength $N = 1600$
 - ▶ Overlap $O = 1500$
- ▶ Prediction Gain $PG = 5.4$ dB



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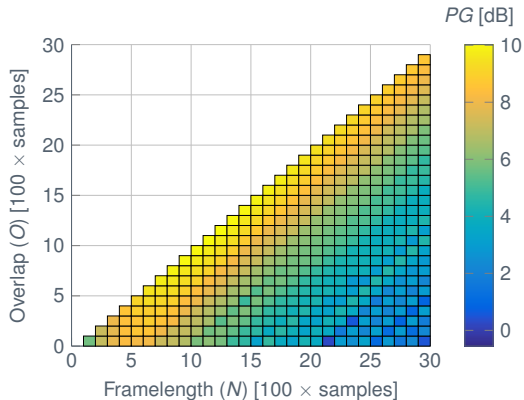
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- ▶ Prediction order $P = 10$
- ▶ Optimal parameters
 - ▶ Framelength $N = 1200$
 - ▶ Overlap $O = 1100$
- ▶ Prediction Gain $PG = 10$ dB



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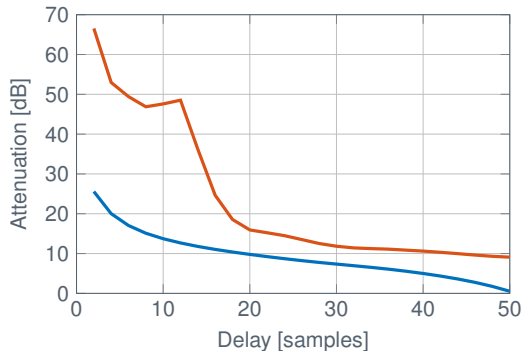
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- ANC attenuation with
varying system delay
 - Feedforward LP FXLMS
 - Feedforward FXLMS



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Frequency Response

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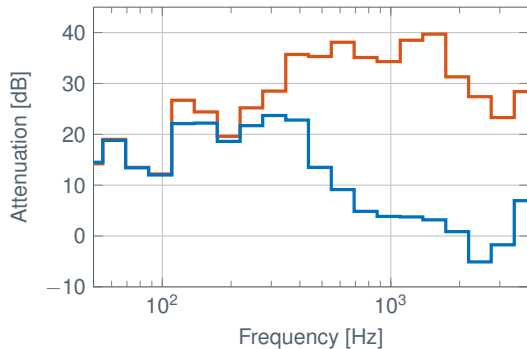
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- Frequency response
 - Feedforward LP FXLMS
 - Feedforward FXLMS





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

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Questions?



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