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The acoustic feedback control performance of adaptive feedback cancellation in sound reinforcement systems

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  - nonlinear processing
  - forward path delay
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  - adaptive filter delay
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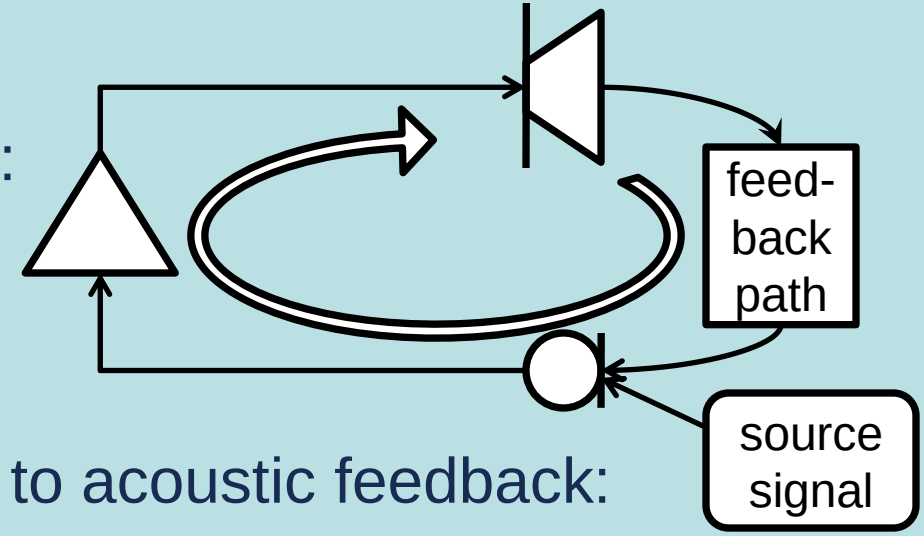
- Conclusion



Introduction: acoustic feedback control problem statement

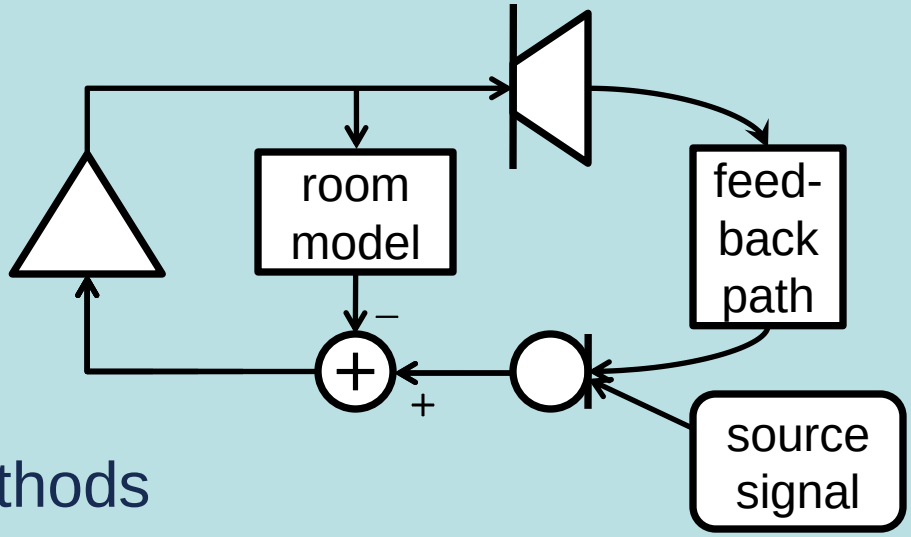
- acoustic feedback problem:
  - acoustic coupling between loudspeaker & microphone
  - closed signal loop
- performance limitation due to acoustic feedback:
  - limited achievable amplification (maximum stable gain)
  - poor sound quality (ringing, howling, reverberation)
- common applications:
  - public address/sound reinforcement systems
  - hands-free communications systems
  - hearing aids





Introduction: acoustic feedback control state of the art

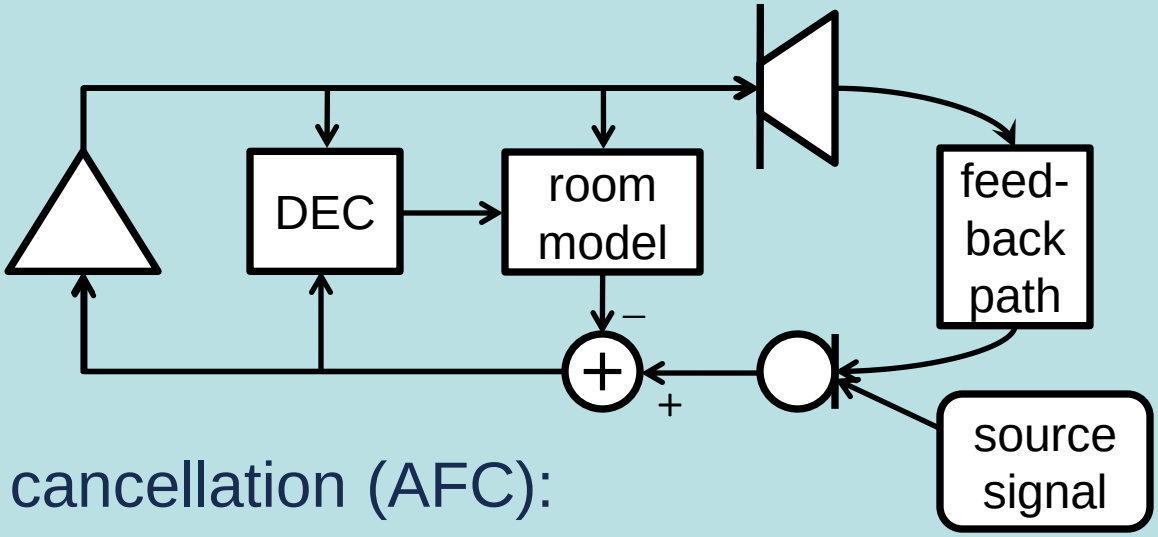
Classification of state-of-the-art acoustic feedback control methods:
[van Waterschoot and Moonen, “50 years of acoustic feedback control: state of the art and future challenges”, submitted for publication, Feb. 2009]



- phase modulation (PM) methods
  - smoothing of “loop gain” (= closed-loop magnitude response)
  - phase/frequency/delay modulation, frequency shifting
- gain reduction methods
  - (frequency-dependent) gain reduction after howling detection
- spatial filtering methods
  - (adaptive) microphone beamforming for reducing direct coupling
- room modeling methods
  - adaptive feedback cancellation (AFC), adaptive inverse filtering



Introduction: AFC concept & fundamental problem



- adaptive feedback cancellation (AFC):
  - estimate room model (impulse response/frequency response)
  - subtract feedback signal estimate from microphone signal
- fundamental problem in AFC:
  - correlation of source and loudspeaker signal leads to biased and high-variance room model
- two approaches to AFC decorrelation:
  - decorrelation in the closed signal loop
  - decorrelation in the adaptive filtering circuit



Introduction: research objectives & performance measures

- research objectives:
  - to quantify adaptive feedback cancellation (AFC) performance in terms of acoustic feedback control performance measures
  - to compare and evaluate different decorrelation methods
  - to study the influence of decorrelation parameters
- performance measures:
  - traditional performance measure = adaptive filter misadjustment
  - acoustic feedback control performance measures:

achievable amplification → maximum stable gain increase (ΔMSG)

$$\Delta\mathrm{MSG}(t)\ [\mathrm{dB}] = -20\log_{10}\left[\frac{\max_{\omega\in\mathcal{P}}|J(\omega,t)[F(\omega,t)-\hat{F}(\omega,t)]|}{\max_{\omega\in\mathcal{P}}|J(\omega,t)F(\omega,t)|}\right]$$

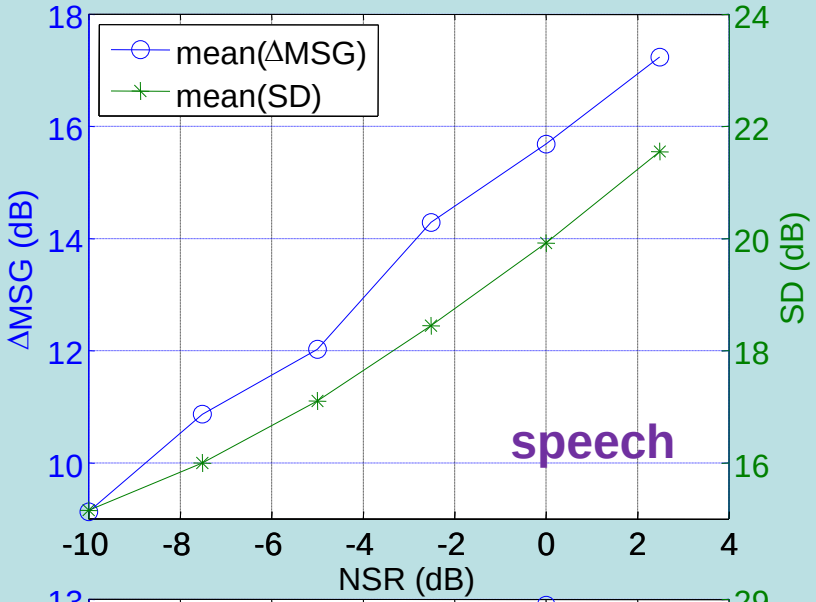
sound quality → frequency-weighted log-spectral signal distortion (SD)

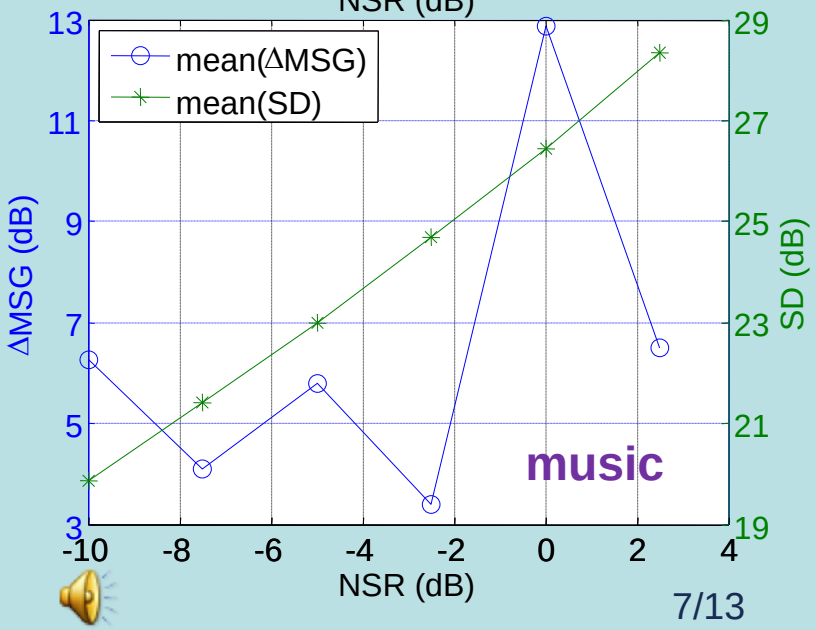
$$\mathrm{SD}(t) = \sqrt{\int_0^{f_s/2} w_{\mathrm{ERB}}(f)\left(10\log_{10}\frac{S_d(f,t)}{S_v(f,t)}\right)^2 df}$$



Decorrelation in the closed signal loop: (1) Noise injection [Goertz, '95],[Janse et al., '05],[Schmidt et al., '06]

- Concept:
  - injection of noise signal that is uncorrelated with source signal (e.g., white noise)
- Decorrelation parameter:
  - noise-to-signal ratio (NSR)
- Performance:
  - largest MSG increase of all decorrelation methods (→17 dB)
  - very poor sound quality
  - trade-off NSR value hard to find
- Note:
  - perceptually weighted noise does not seem to improve performance





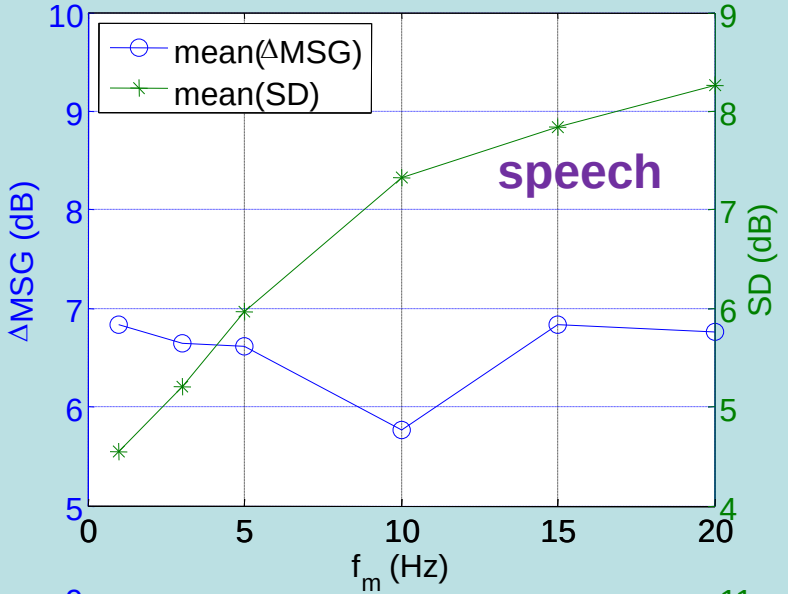
source signal

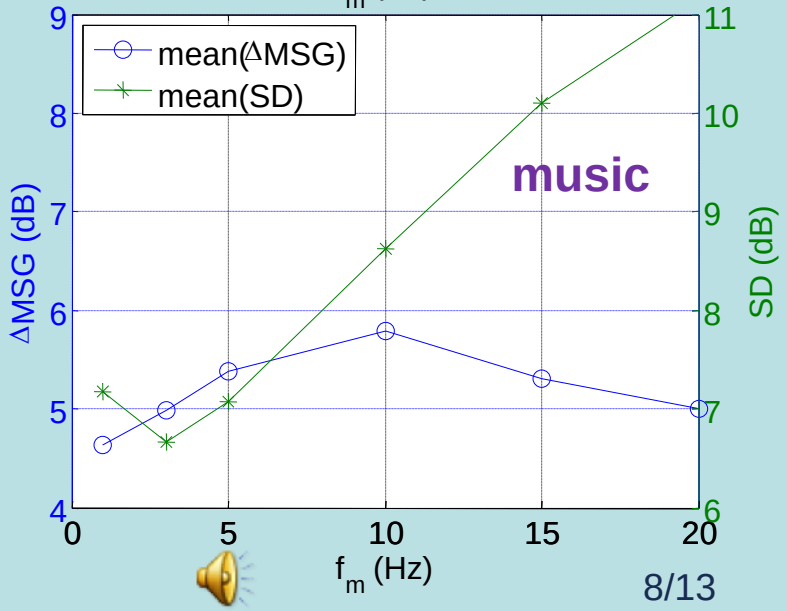


Decorrelation in the closed signal loop: (2) Time-varying processing

[Janse et al.,'98], [Schmidt et al., '06]

- Concept:
  - include time-varying signal operation in forward path (e.g., frequency shifting)
- Decorrelation parameter:
  - frequency shift (f_m)
- Performance:
  - reasonable MSG increase (~6 dB)
  - reasonable sound quality (vibrato effect in stationary signal portions)
  - preferably $f_m \leq 10$dB
- Note:
  - time-varying processing also stabilizes closed-loop system



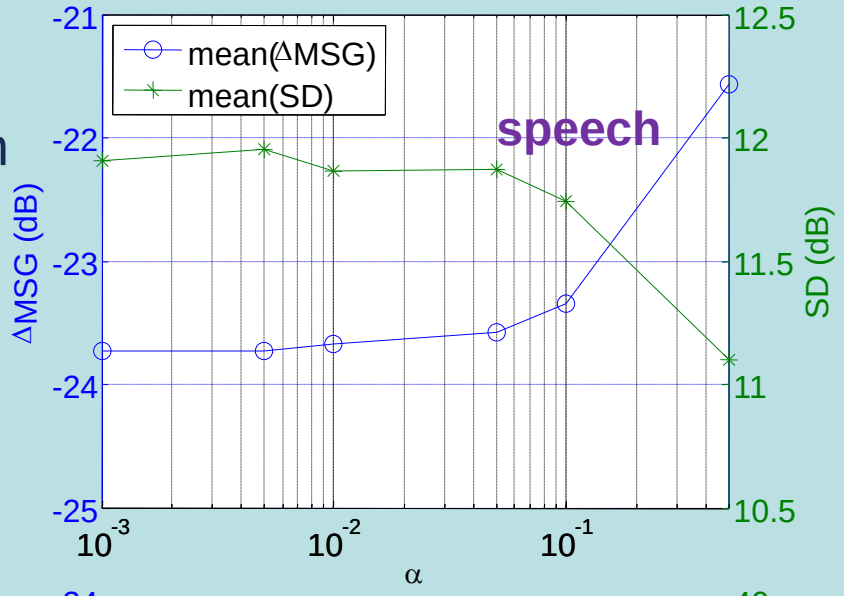


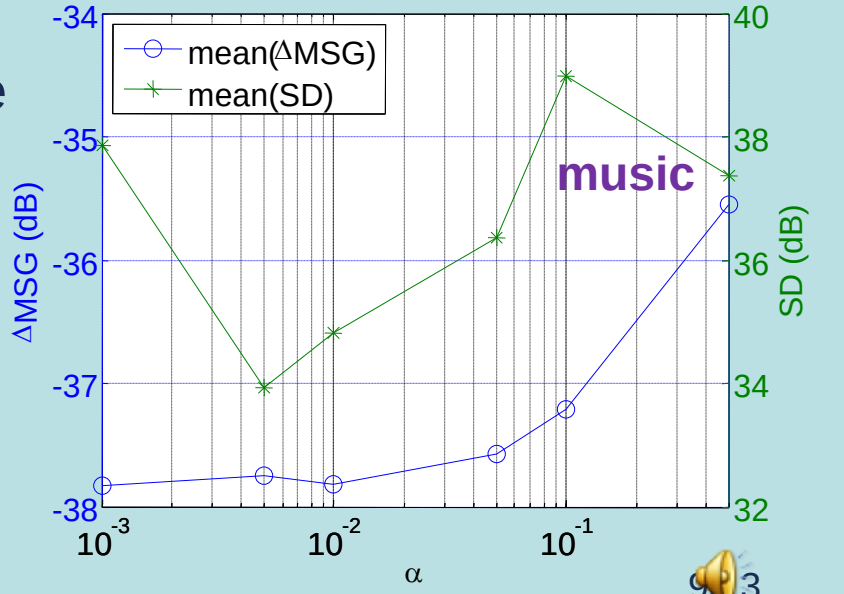
source signal



Decorrelation in the closed signal loop: (3) Nonlinear processing [Schmidt et al., '06]

- Concept:
  - include nonlinear signal operation in forward path (e.g., mix half-wave rectified signal with original signal), cf. stereo AEC
- Decorrelation parameter:
  - mixing parameter α
- Performance:
  - MSG decrease i.o. MSG increase
  - very poor sound quality





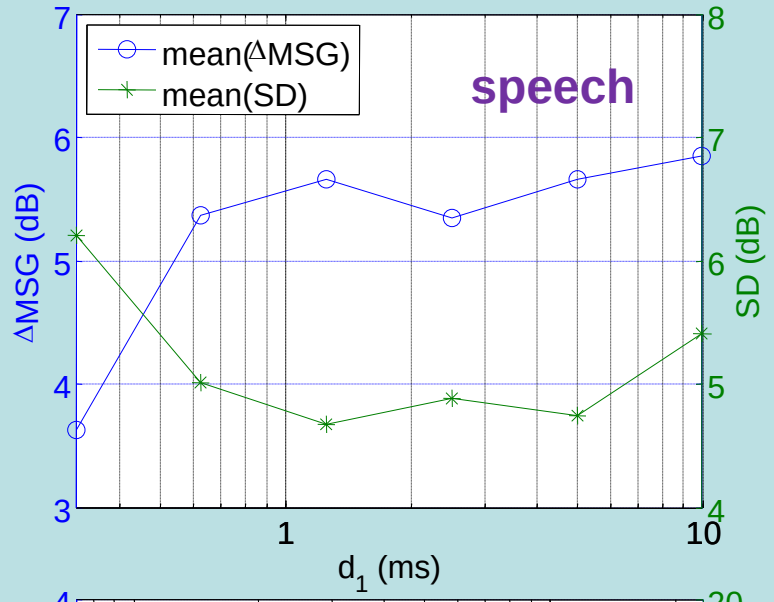
source signal

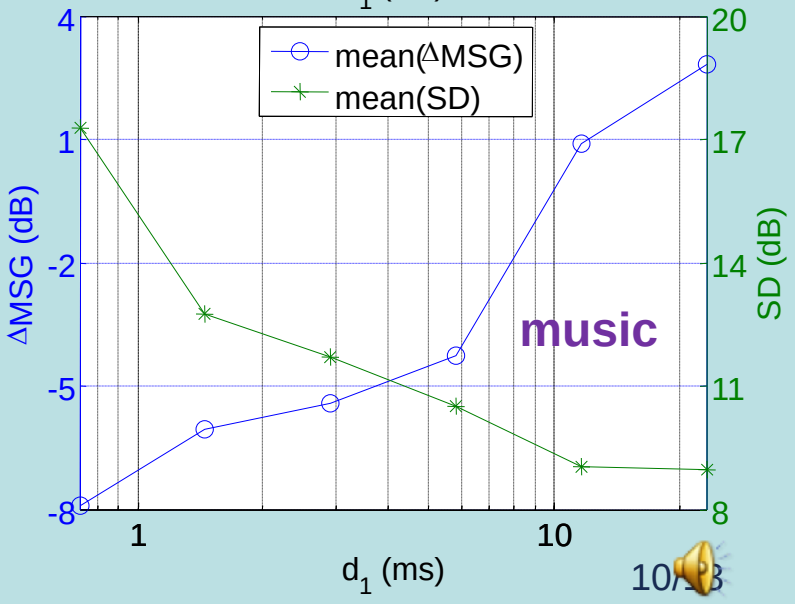


Decorrelation in the closed signal loop: (4) Forward path delay [Siqueira et al., '00 (hearing aid AFC)]

- Concept:
  - include delay in forward path
- Decorrelation parameter:
  - delay value (d_1)
- Performance:
  - reasonable MSG increase for speech (~5 dB),

    MSG decrease for music
  - little effect on sound quality
  - preferably d_1 = 1…5 ms (speech)
- Note:
  - delay is often already there due to buffering in A/D-D/A, DAFX, …
  - delay restrictions are weak compared to hearing aid AFC





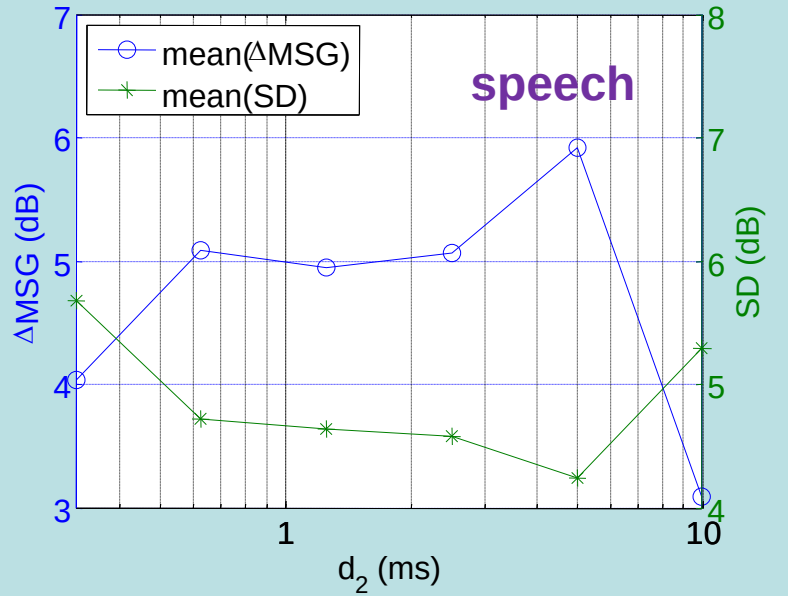
source signal

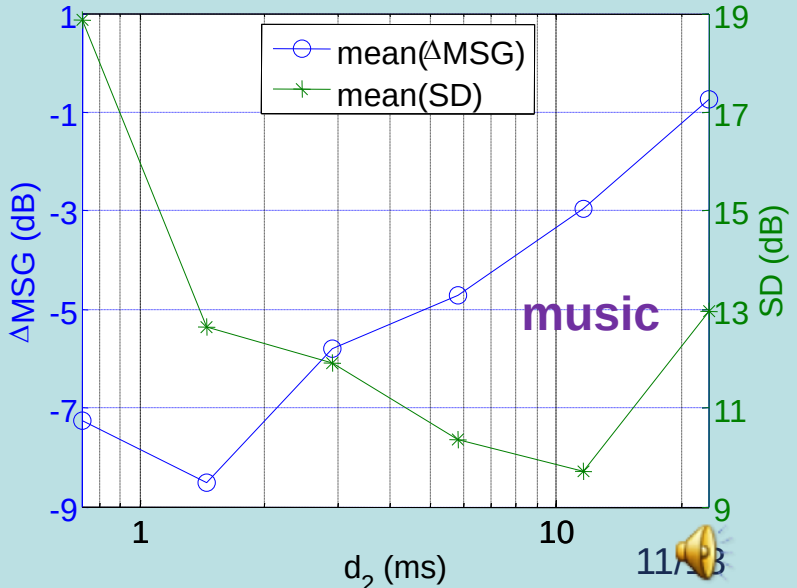


Decorrelation in adaptive filtering circuit: (5) Adaptive filter delay [Gallego et al., '02],[Ortega et al., '05]

- Concept:
  - include delay in adaptive filter path (before adaptive filter)
- Decorrelation parameter:
  - delay value (d_2)
- Performance:
  - reasonable MSG increase for speech (~5 dB),

    MSG decrease for music
  - little effect on sound quality
  - preferably d_2 = 1…5 ms (speech)
- Note:
  - the acoustic feedback path is assumed to have a propagation delay ≥ d_2





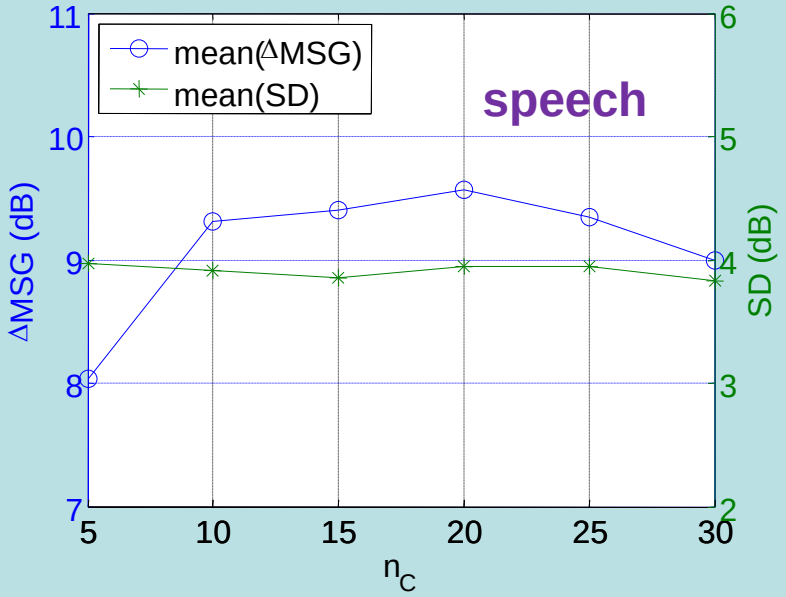
source signal

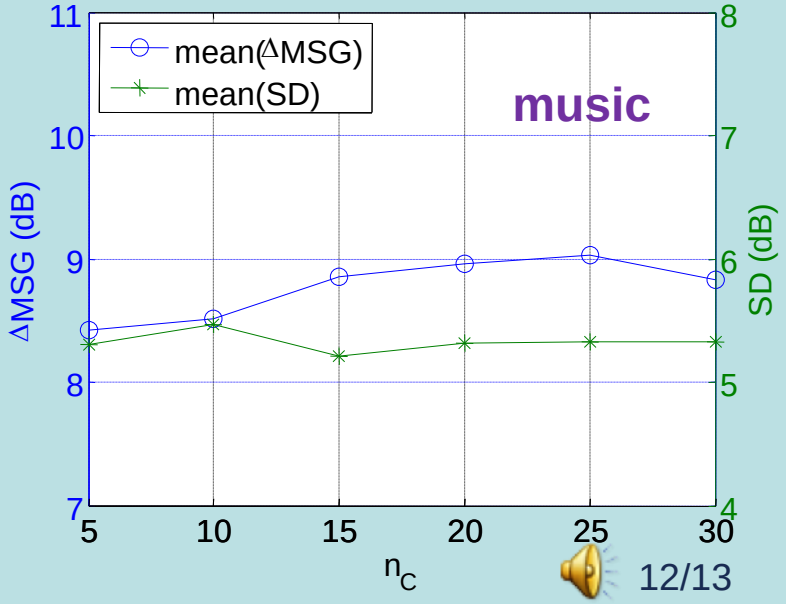


Decorrelation in adaptive filtering circuit: (6) Prefiltering

[van Waterschoot et al., '04],[Ortega et al., '05], [Rombouts et al., '06],[van Waterschoot et al., '09]

- Concept:
  - prefiltering of loudspeaker and microphone signal with inverse source signal model
- Decorrelation parameter:
  - source signal model order (n_C)
- Performance:
  - high MSG increase (→ 10 dB)
  - best sound quality of all decorrelation methods
  - preferably $n_C \geq 10$
- Note:
  - source signal model should be estimated concurrently with feedback path





source signal



Conclusion

Decorrelation in the closed signal loop:

- Decorrelation by noise injection delivers very high MSG (> 15 dB), but is inappropriate in terms of sound quality.
- Decorrelation by time-varying processing is a “fair compromise” approach that combines reasonable MSG and sound quality.
- Decorrelation by nonlinear processing is clearly unsuited for AFC applications (in contrast to stereo AEC).
- Decorrelation by forward path delay is suited only for speech signals, resulting in limited MSG but good sound quality.

Decorrelation in the adaptive filtering circuit:

- Decorrelation by adaptive filter delay does not outperform forward path delay yet relies on propagation delay assumption.
- Decorrelation by prefiltering is superior in terms of sound quality and moreover delivers high MSG values (up to 10 dB)

More sound? http://homes.esat.kuleuven.be/~tvanwate