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A Study on Combining Acoustic Echo Cancellers with Impulse Response Shortening

Stefan Goetze[1], Markus Kallinger[2], Karl-Dirk Kammeyer[1], Alfred Mertins[2]

[1]Dept. Of Communications Engineering
University of Bremen, Germany

[2]Signal Processing Group
University of Oldenburg, Germany

Outline

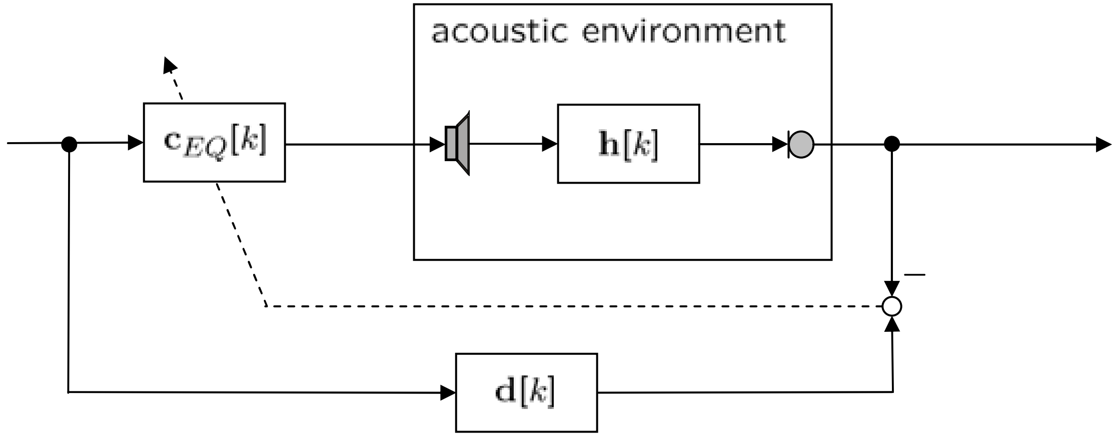
- Motivation
- Listening Room Compensation / Impulse Response Shortening
- Acoustic Echo Cancellation (AEC)
- Tail Effect for Acoustic Echo Cancellers
- Mutual influences of AEC and LRC
- Simulation Results / Conclusions

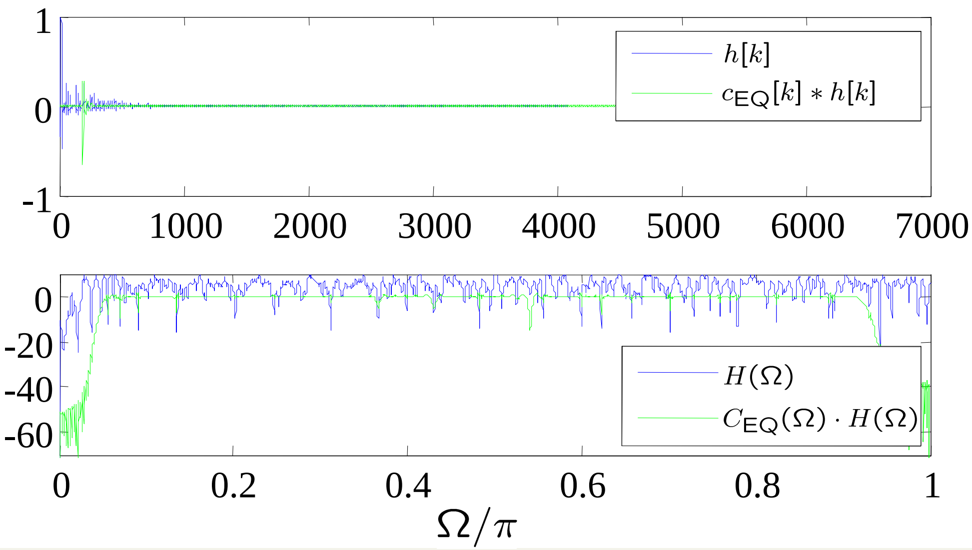
Motivation

- Hands-free systems should employ subsystems for
  - Noise Reduction (NR)
  - Acoustic Echo Cancellation (AEC) and
  - Dereverberation / Listening Room Compensation
- Listening Room Compensation / Impulse Response Shortening can increase speech intelligibility but needs an estimate of the RIR
- Acoustic Echo Canceller have to cope with very high order impulse responses
  - System identification may be insufficient
- Combination of both subsystems: Inner AEC or outer AEC
- What are the mutual influences of the two subsystems?

Listening Room Compensation

- An equalizer precedes the acoustic channel
- Common design method: Least Squares Equalizer $\mathbf{c}_{\mathrm{EQ}} = \mathbf{H}^{+}\mathbf{d}$
- Problem: Channel $\mathbf{h}[k]$ is needed!





- The desired system $\mathbf{d}[k]$ is approximated by the overall system of $\mathbf{c}_{\mathrm{EQ}}[k] * h[k]$

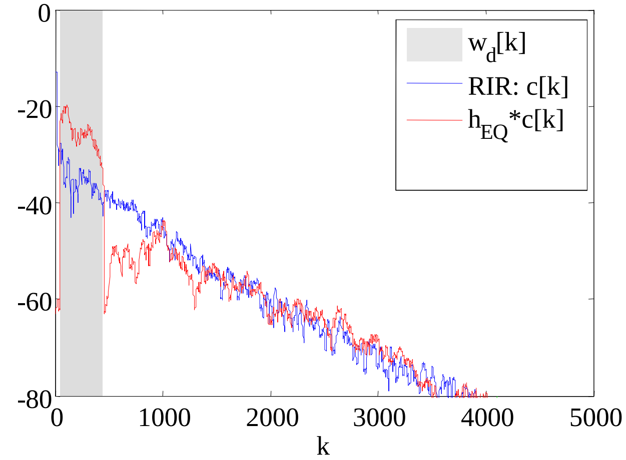
$$\mathrm{var}\{H(200..3700\mathrm{Hz})\} = 14.365$$

$$\mathrm{var}\left\{C_{\mathrm{EQ}}(200..3700\mathrm{Hz}) \cdot H(200..3700\mathrm{Hz})\right\} = 1.0379$$

Impulse Response Shortening (I)

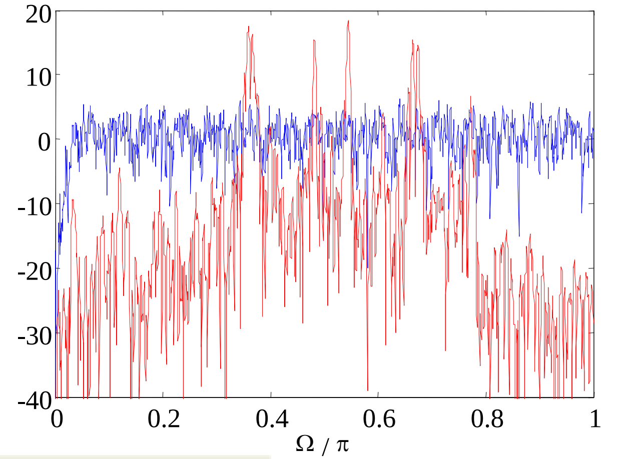
- The goal is not spectral flatness of the overall system but a concentration of the energy at the beginning (desired area $\mathbf{d}_d$).

$$\mathbf{d}_d = \text{diag}\{\mathbf{w}_d\}\mathbf{H}\mathbf{c}_{\text{EQ}}$$
$$\mathbf{d}_u = \text{diag}\{\mathbf{1} - \mathbf{w}_d\}\mathbf{H}\mathbf{c}_{\text{EQ}}$$



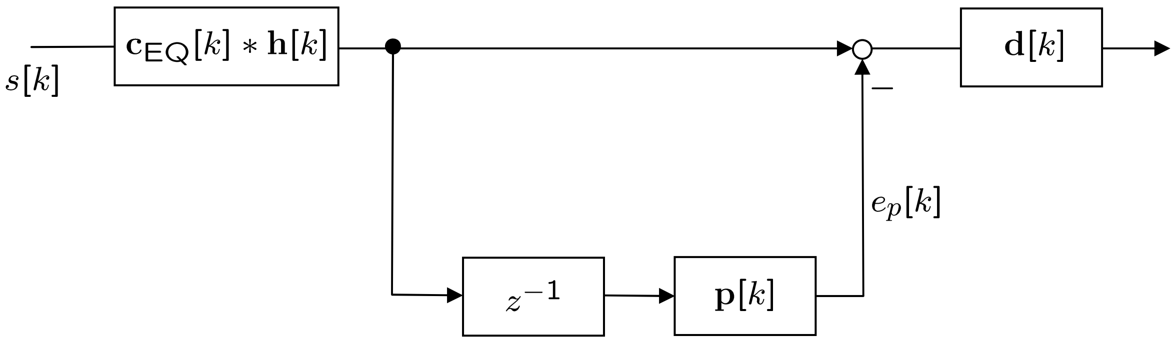
- Maximization the energy of $\mathbf{d}_d$ while keeping the energy of $\mathbf{d}_u$ constant leads to the impulse response shortener after Melsa:

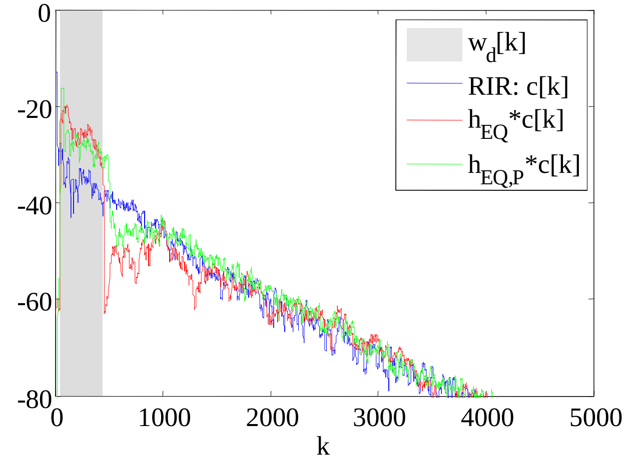
$$\mathbf{B}_{\text{BP}} \cdot \mathbf{c}_{\text{EQ,opt}} = \mathbf{A} \cdot \mathbf{c}_{\text{EQ,opt}} \cdot \lambda_{\text{max}}$$
$$\mathbf{A} = \mathbf{H}^H \text{diag}\left\{\mathbf{w}_{\text{BP,d}}\right\}^2 \mathbf{H}$$
$$\mathbf{B}_{\text{BP}} = \mathbf{H}_{\text{BP}}^H \text{diag}\left\{\mathbf{w}_{\text{BP,d}}\right\}^H \text{diag}\left\{\mathbf{w}_{\text{BP,d}}\right\} \mathbf{H}_{\text{BP}}$$

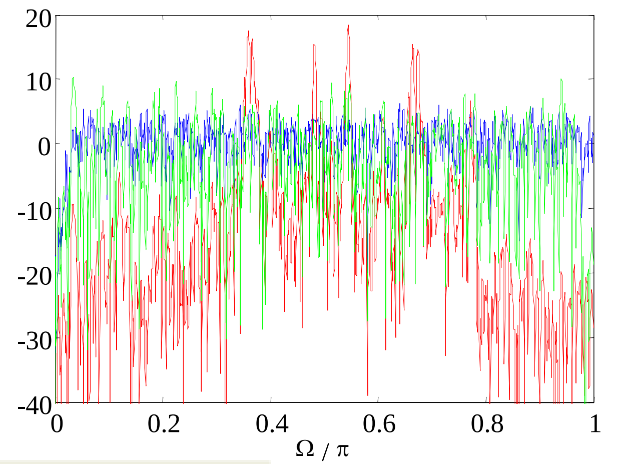


Impulse Response Shortening (II)

- Post processing by a linear prediction filter can reduce the spectral overshoots.

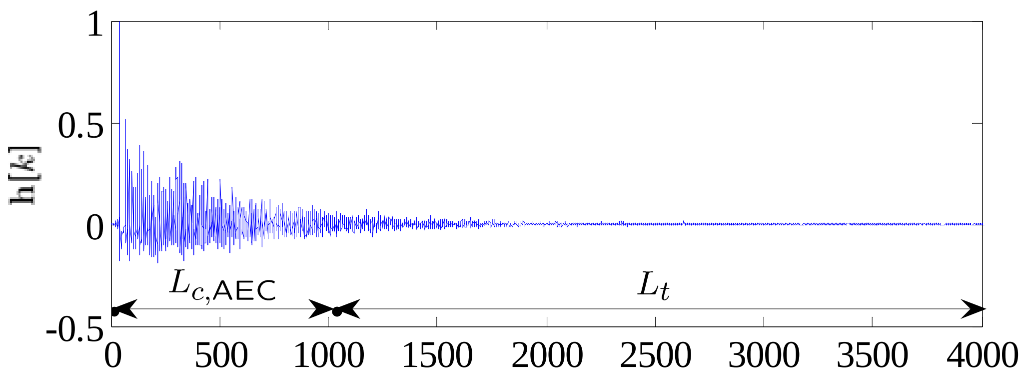


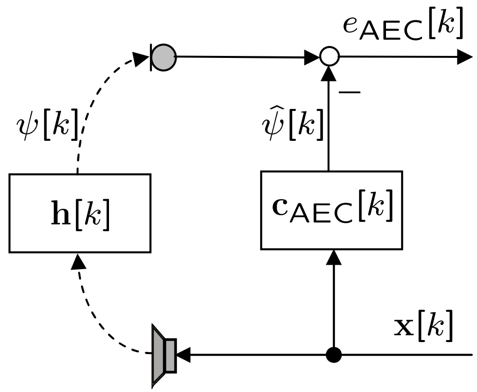




Tail Effect of Acoustic Echo Compensation (I)

- Echo cancellation is done by system identification

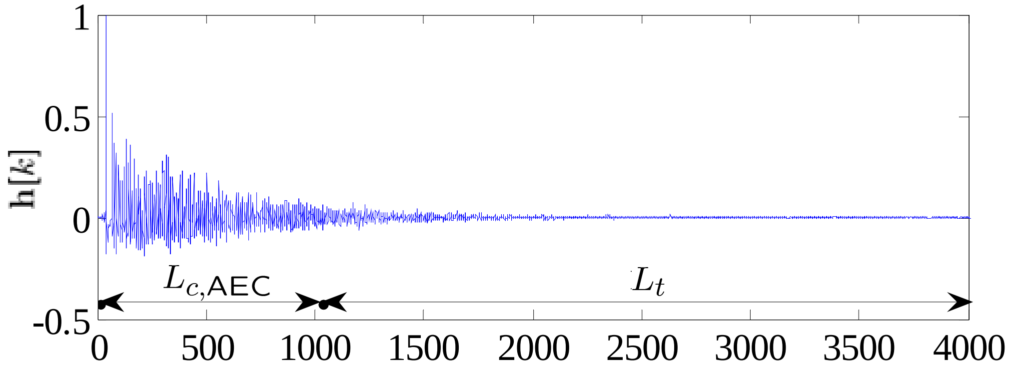


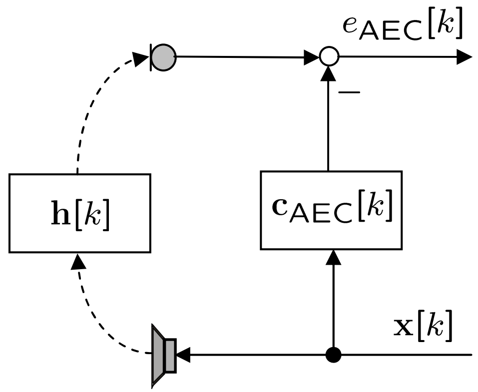


- The room impulse response (RIR) $\mathbf{h}[k]$ can be split up in two parts
- The first part ($L_{c,\mathsf{AEC}}$ samples) can be modelled by the AEC while the *tail* (L_t samples) can not.

Tail Effect of Acoustic Echo Compensation (II)

- Echo cancellation is done by system identification





$$e_{\mathsf{AEC}}[k] = \mathbf{h}_c^T[k]\mathbf{x}_c[k] - \mathbf{c}_{\mathsf{AEC}}^T[k]\mathbf{x}_c[k] + \mathbf{h}_t^T[k]\mathbf{x}_t[k]$$

$$\mathbf{h}[k] = \left[\mathbf{h}_c^T[k]\,,\, \mathbf{h}_t^T[k]\right]^T$$

$$\mathbf{h}_c[k] = \left[h_0[k]\,,\, h_1[k]\,,\, \ldots\,,\, h_{L_{c,\mathsf{AEC}}-1}[k]\right]^T$$

$$\mathbf{h}_t[k] = \left[h_{L_{c,\mathsf{AEC}}}[k]\,,\, h_{L_{c,\mathsf{AEC}}+1}[k] \ldots h_{L_h-1}\right]^T$$

$$\mathbf{x}_c[k] = \left[x[k]\,,\, x[k-1]\,,\, \ldots\,,\, x[k-L_{c,\,\mathsf{AEC}}+1]\right]^T$$

$$\mathbf{x}_t[k] = \left[x[k-L_{c,\,\mathsf{AEC}}]\,,\, \ldots\,,\, x[k-L_{c,\,\mathsf{AEC}}-L_t+1]\right]^T$$

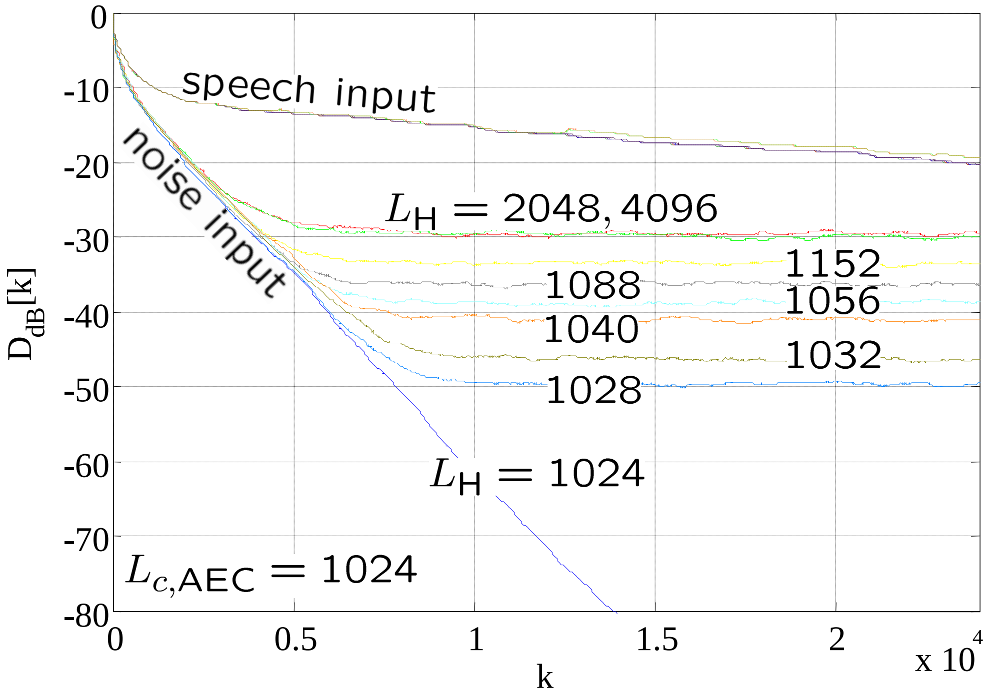
$$\mathbf{c}_{\mathsf{AEC}}[k] = \left[c_{\mathsf{AEC},0}[k],\, c_{\mathsf{AEC},1}[k],\, \ldots,\, c_{\mathsf{AEC},L_{c,\mathsf{AEC}}-1}[k]\right]^T$$

$$\boxed{\mathbf{c}_{\mathsf{AEC}}[k] = \mathbf{h}_c[k] + \mathsf{E}\left\{\mathbf{x}_c[k]\mathbf{x}_c^T[k]\right\}^{-1}\mathsf{E}\left\{\mathbf{x}_c[k]\mathbf{x}_t^T[k]\right\}\mathbf{h}_t[k]}$$

➔ A bias is introduced for a non white input signal!

Tail Effect of Acoustic Echo Cancellation (III)

- Echo cancellation is done by system identification



- Evaluation by means of system misalignment:

$$D_{dB}[k] = \frac{\|\mathbf{h}[k] - \mathbf{c}_{AEC}[k]\|^2}{\|\mathbf{h}[k]\|^2}$$

L_H : Considered length of RIR

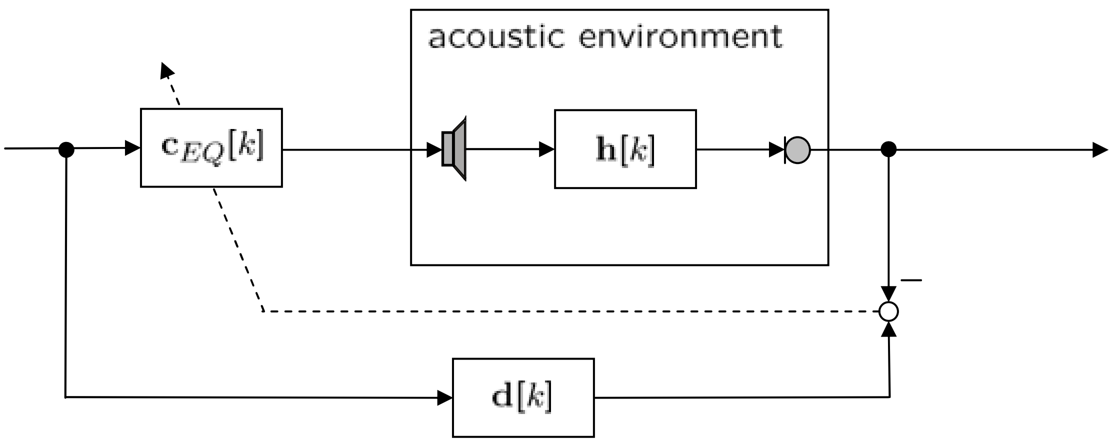
$L_{c,AEC} = 1024$: Order of AEC

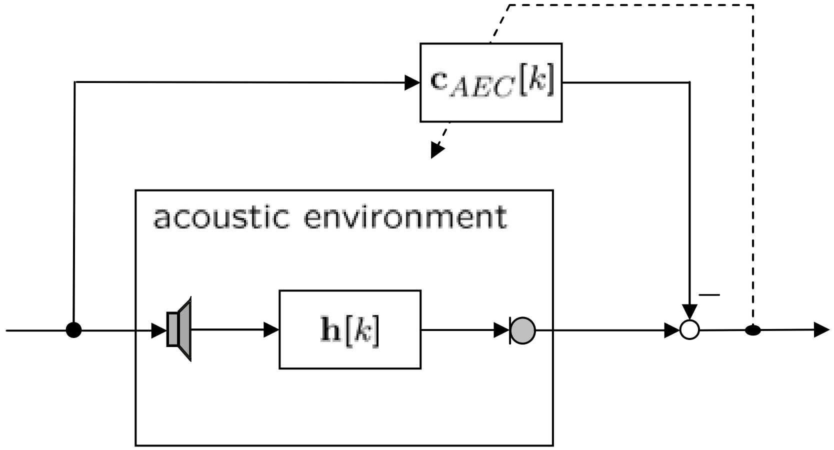
$$\mathbf{c}_{AEC}[k] = \mathbf{h}_c[k] + \mathrm{E}\left\{\mathbf{x}_c[k]\mathbf{x}_c^T[k]\right\}^{-1} \mathrm{E}\left\{\mathbf{x}_c[k]\mathbf{x}_t^T[k]\right\} \mathbf{h}_t[k]$$

➔ A bias is introduced for a non white input signal!

Possible Combinations of AEC and EQ

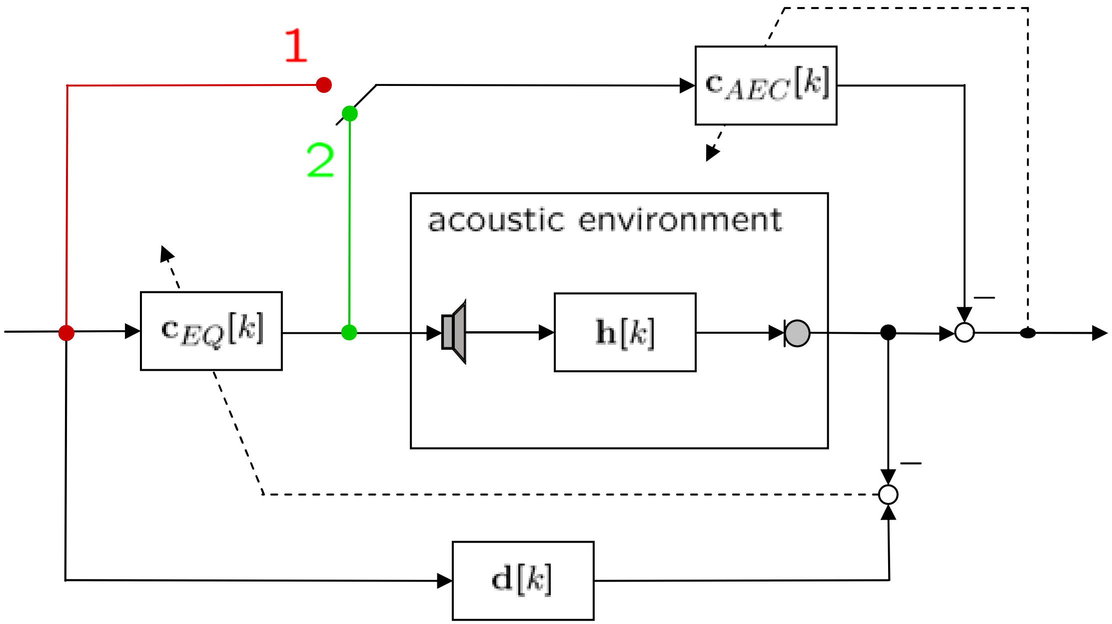
- Listening Room Compensation / Room Impulse Response Shortening
- Acoustic Echo Cancellation





Possible Combinations of AEC and EQ

- Two Combinations are possible:

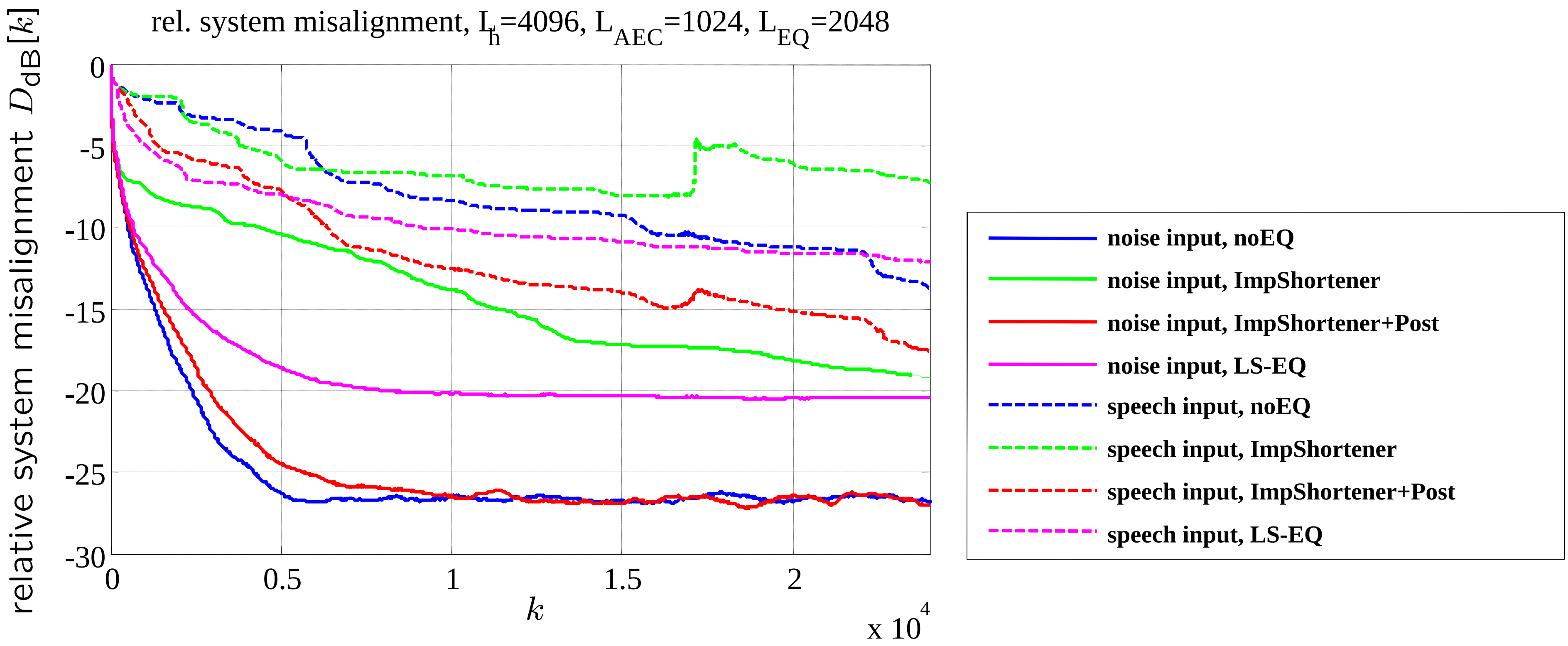


- Outer AEC
  - AEC has to identify shorter overall system $\mathbf{c}_{\mathrm{EQ}}[k] * \mathbf{h}[k]$.
- Inner AEC
  - AEC identifies RIR $\mathbf{h}[k]$ which can be used for equalizer.

- What are the mutual influences?

Influence of the EQ on the AEC

- Evaluation by means of the system misalignment: $D_{\mathrm{dB}}[k] = 10 \cdot \log_{10} \frac{||\mathbf{h}[k] - \mathbf{c}_{\mathrm{AEC}}[k]||^2}{||\mathbf{h}[k]||^2}$

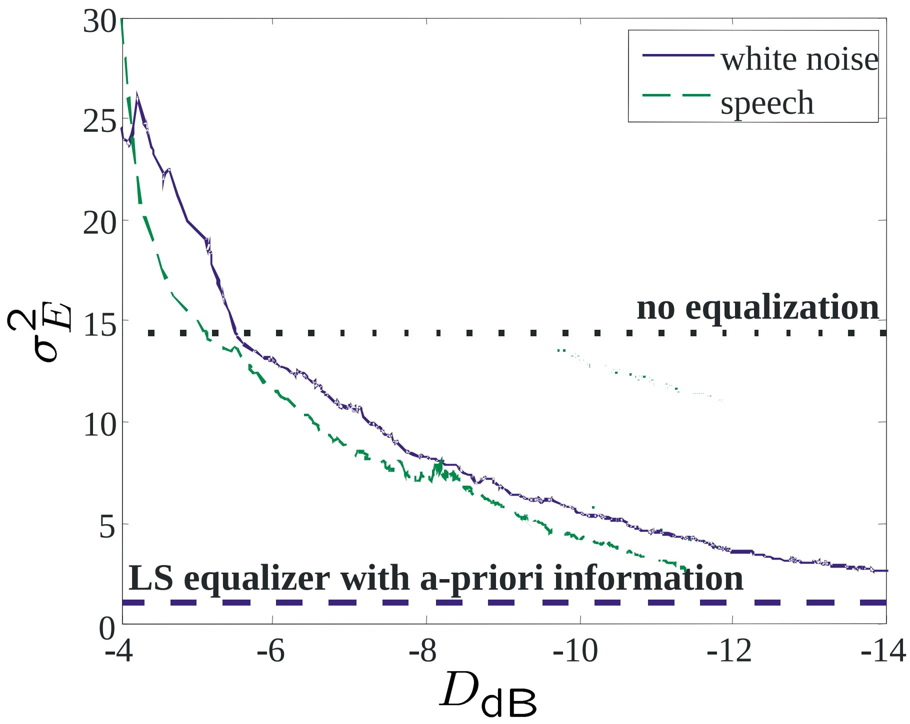


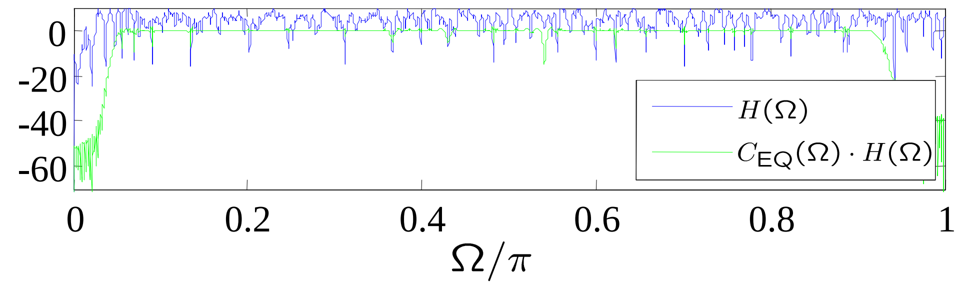
Influence of the system identification on the EQ

- Evaluation by means of the variance of the overall system:

$$\sigma_E^2 = \frac{1}{m_{max} - m_{min}} \sum_{m=m_{min}}^{m_{max}} \left(20 \cdot \log_{10}|E[m]| - \bar{E}_{\mathrm{dB}}\right)^2$$

$$\bar{E}_{\mathrm{dB}} = \frac{1}{m_{max} - m_{min}} \sum_{m=m_{min}}^{m_{max}} 20 \cdot \log_{10}|E[m]|$$





$$\mathrm{var}\left\{H(200..3700\mathrm{Hz})\right\} = 14.365$$

$$\mathrm{var}\left\{C_{\mathrm{EQ}}(200..3700\mathrm{Hz}) \cdot H(200..3700\mathrm{Hz})\right\} = 1.0379$$

Conclusion

- Coloration introduced by the Equalizer in front of an AEC leads to less accurate system identification.
- The Impulse Response Shortener with post-processing leads to the best results.
- Tail effect of the AEC leads to less accurate system identification.
- Equalizer needs reliable estimate of the RIR for LRC.

Thank you for your attention!

References

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