A Sound Reproduction System for Spatial Audio in a Driving Simulator

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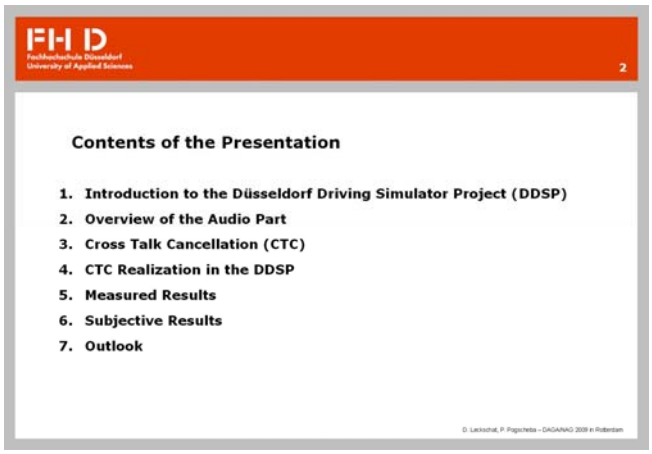
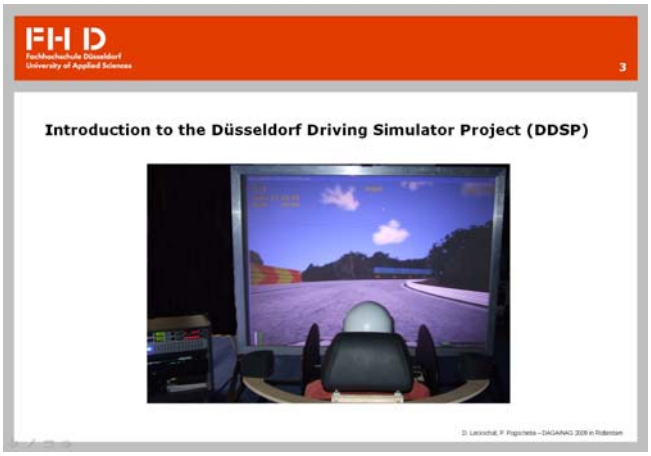
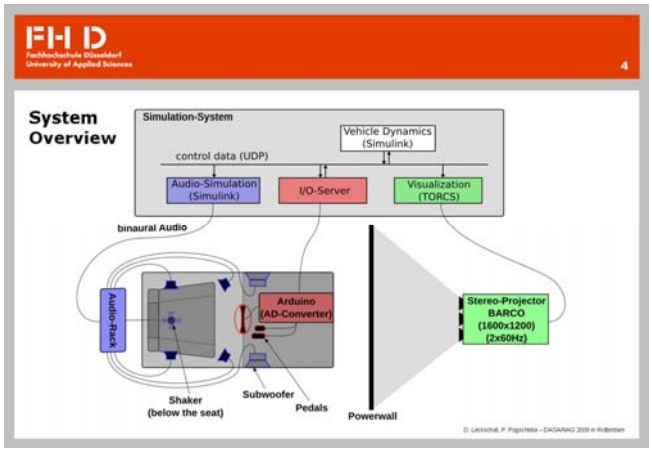
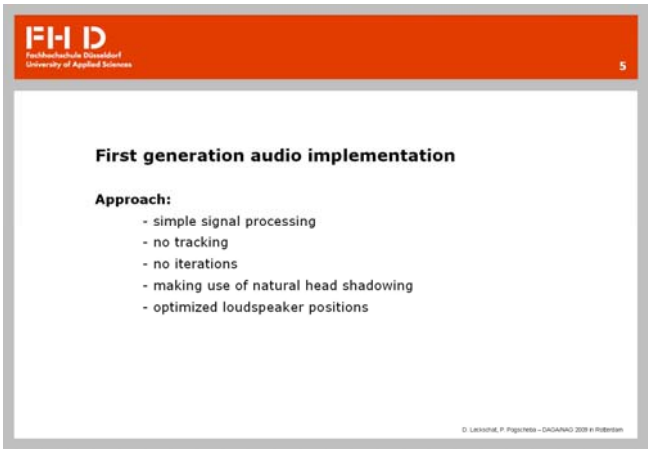
Abstract

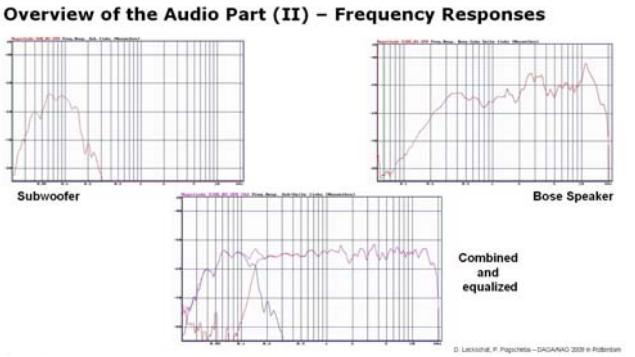
In the framework of the Driving Simulator at Duesseldorf University of Applied Sciences, the realization of the audio system will be performed in steps. The objective is to reproduce driving noise as well as the sounds of functional components, including their spatial position. In the first step a binaural, loudspeaker-based sound reproduction system was developed using a CTC (cross talk cancellation) system which is robust even without head tracking. The system is completed by subwoofers and an additional shaker. It is reported on how an optimized positioning of tweeters and woofers facilitates a relatively simple digital filter setup for CTC. Measurement results are shown, and subjective qualities of the system discussed. Moreover, we reveal some localization problems and discuss methods to solve them.



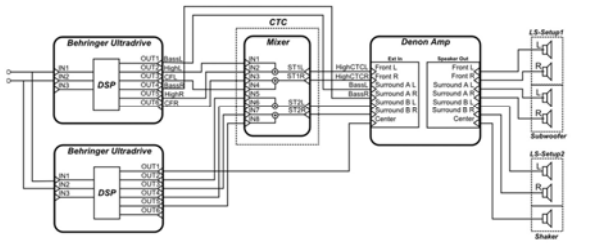




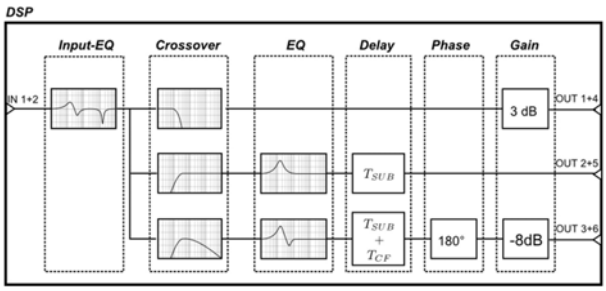




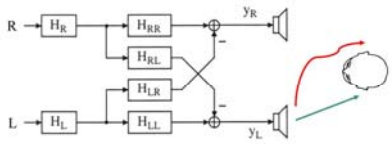
Audiosystem Overview



Signal Processing Overview



Cross Talk Cancellation (CTC)

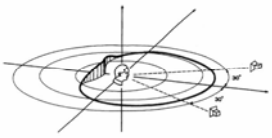


The undesired **crosstalk** signal (red) is attempted to be cancelled out by a **crossfeed** signal (via H_{LR}).

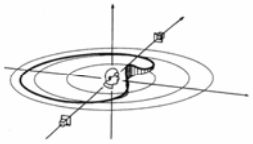
(after Gardner 1997)

Cross Talk Cancellation (CTC)

Limitations due to the Loudspeaker setup angle



±30°



±90°: „Napoleon´s Hat" effect

(A. Schmitz 1993)

Question:

How much crosstalk attenuation is needed for undisturbed localization?

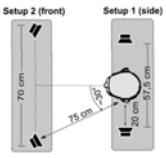
Postulate (experience from previous projects such as „binaural sky"):

-20 dB is perfect

-12 dB in all practical situations **is a good deal**

CTC Realization in the DDSP

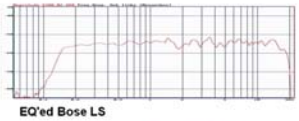
Simple approach for compensating crosstalk
- **take advantage of natural head shadowing**
- **support low/mid frequency separation by subtracting filtered, delayed signal on the opposite ear**



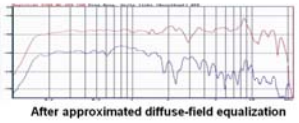
CTC Realization in the DDSP (2)

Artificial Head Measurements
- diffuse-field equalization

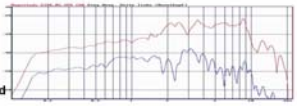
ipsilateral ear
contralateral ear



EQ'ed Bose LS



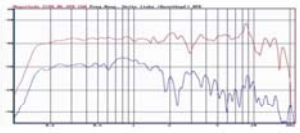
After approximated diffuse-field equalization



EQ'ed Bose LS
Measured by Artificial Head

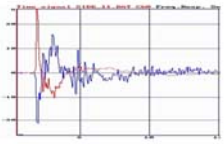
CTC Realization in the DDSP (3)

Improvement of natural head shadowing

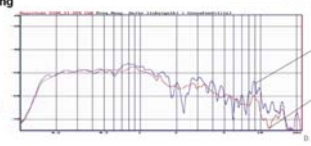


Natural head shadowing

Crosstalk and Compensation Signal

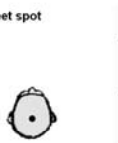


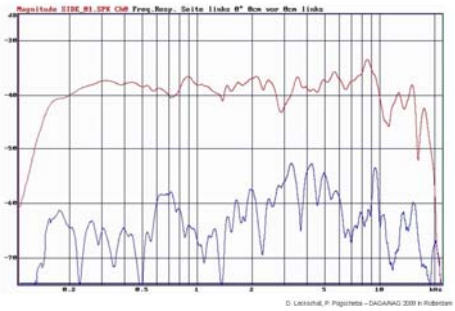
Crosstalk(blue)
+
filtered compensation spectrum (red)



Measured Results: Setup1 (side LS) → left ear

Sweet spot

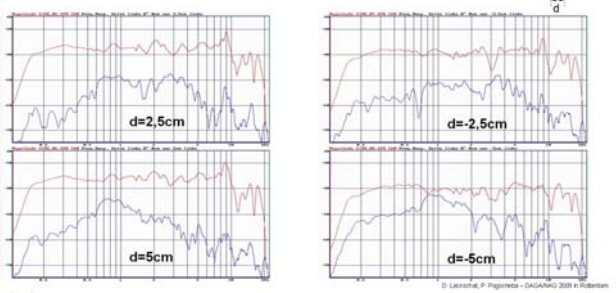




ipsilateral ear
contralateral ear

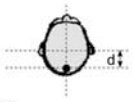
Measured Results: Setup1 (side LS) → left ear

Lateral head translation

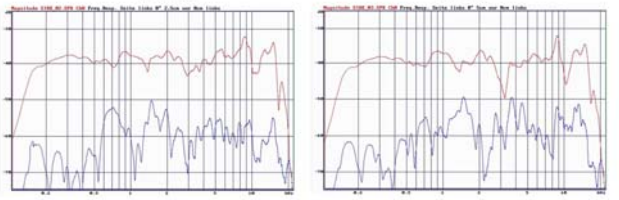


Measured Results: Setup1 (side LS) → left ear

Longitudinal head translation

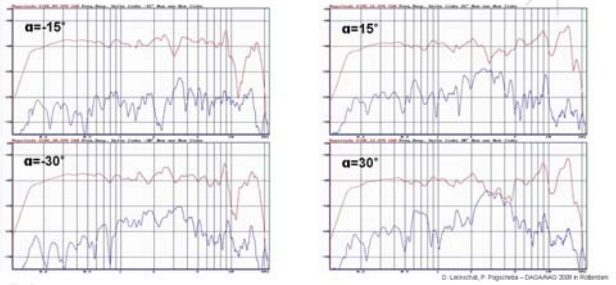


d=2,5cm d=5cm



Measured Results: Setup1 (side LS) → left ear

Head rotation



Measured Results: Setup1 (side)

Pros:

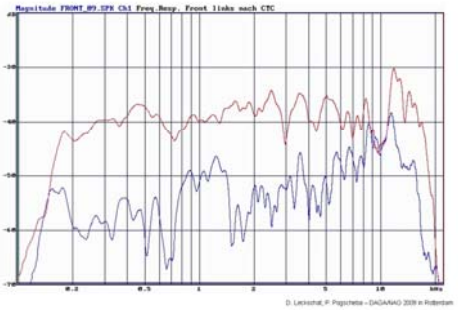
- high natural channel separation
- quite stable for head rotation

Cons:

- no good front localization
- Napoleon´s Hat effect

Measured Results: Setup2 (front LS) → left ear

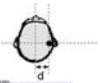
Sweet spot

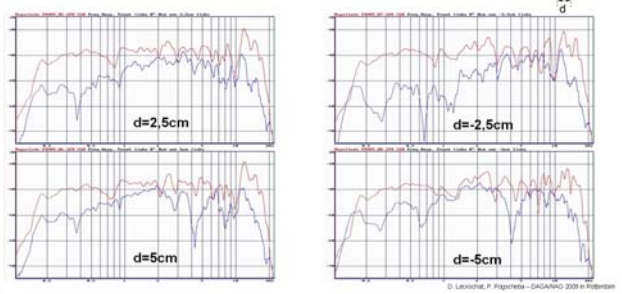


ipsilateral ear
contralateral ear

Measured Results: Setup2 (front LS) → left ear

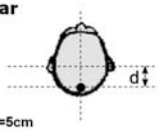
Lateral head translation



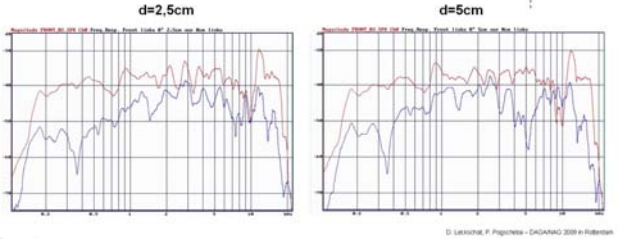


Measured Results: Setup2 (front LS) → left ear

Longitudinal head translation

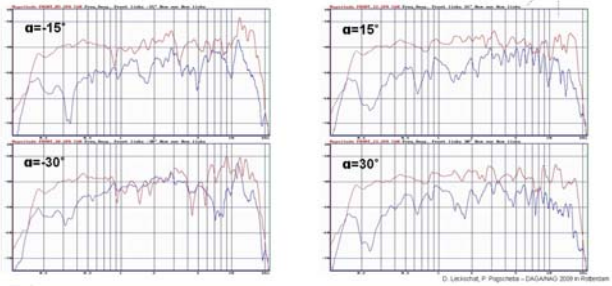


d=2,5cm d=5cm



Measured Results: Setup2 (front LS) → left ear

Head rotation



Measured Results: Setup2 (front)

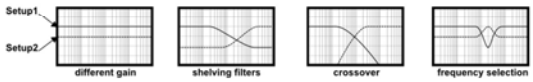
Pros:
- good front localization

Cons:
- significant crosstalk in midrange frequencies
- poor back localization
- insufficient natural separation

Measured Results: Setup3 (combination)

Different approaches to combine both setups
- separation by digital crossover
- mixing with different gains (also frequency-dependent)

Example:

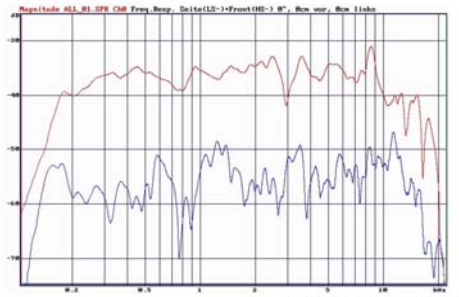


Possible Problems:
- phasing effects when moving
- comb-filter effects

Measured Results: Setup3 (combination) → left ear

Shelving approach (front: less treble, side: less bass)

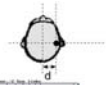
Sweet spot

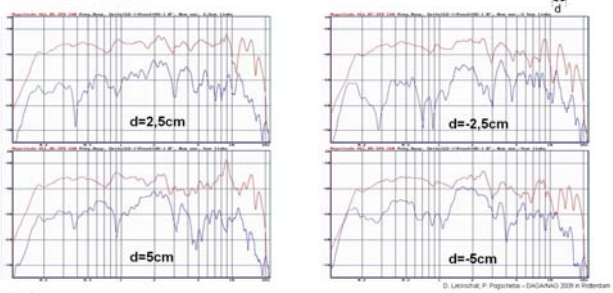


Measured Results: Setup3 (combination) → left ear

Shelving approach

Lateral head translation

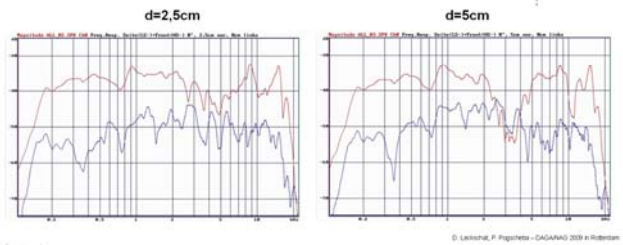




Measured Results: Setup3 (combination) → left ear

Shelving approach

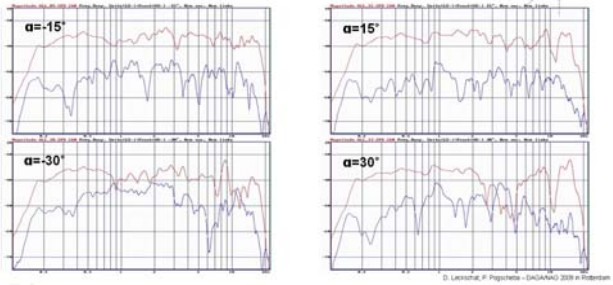
Longitudinal head translation



Measured Results: Setup3 (combination) → left ear

Shelving approach

Head rotation



Outlook

- Improvement of the combination of front and side loudspeakers
- Optimize channel separation
- Investigate movement stability and optimize for bigger sweet spot
- Formal Listening Tests