TIME DOMAIN ACOUSTIC CONTRAST CONTROL IMPLEMENTATION OF SOUND ZONES FOR LOW-FREQUENCY INPUT SIGNALS

Daan H. M. Schellekens[a,b], Martin B. Møller[a,c], and Martin Olsen[d]

d.h.m.schellekens@student.tudelft.nl

INTRODUCTION

Sound zones are two or more regions within a listening space where listeners are provided with personal audio. Acoustic contrast is a measure of the acoustical separation between two zones, given as

$$C(\mathcal{Z}_B, \mathcal{Z}_D) = 10\log_{10}\left(\frac{\int_{\mathcal{Z}_B}\int |p(\mathbf{x},t)|^2 \mathrm{d}t\mathrm{d}\mathbf{x}}{\int_{\mathcal{Z}_D}\int |p(\mathbf{x},t)|^2 \mathrm{d}t\mathrm{d}\mathbf{x}}\right)$$

EXISTING SOUND ZONING METHODS

- Pressure matching (PM) [1],
  both amplitude and phase of a sound field are controlled.
- Acoustic contrast control (ACC) [2],
  average squared sound pressure in the two zones is controlled.
  - Traditional acoustic contrast control (TACC)
  - Broadband acoustic contrast control (BACC)
    - BACC-RV
    - BACC-RD [3]

Assumption: The target frequency range is restricted to low frequencies. Therefore, the phase of the reproduced sound field is not of concern.
Result: ACC is used.

PROBLEM STATEMENT

State-of-the-art BACC methods, often investigated under anechoic conditions, are not able to realize a flat frequency response in a limited frequency range within a reverberant environment.

ACOUSTIC CONTRAST CONTROL MODEL

Sampled output of the k-th microphone in the bright zone

$$y_{B,k}(n) = \sum_{l=1}^{L}\sum_{i=0}^{I-1} h_{B,lk}(i) \sum_{m=0}^{M-1} w_l(m) x_s(n-m-i)$$

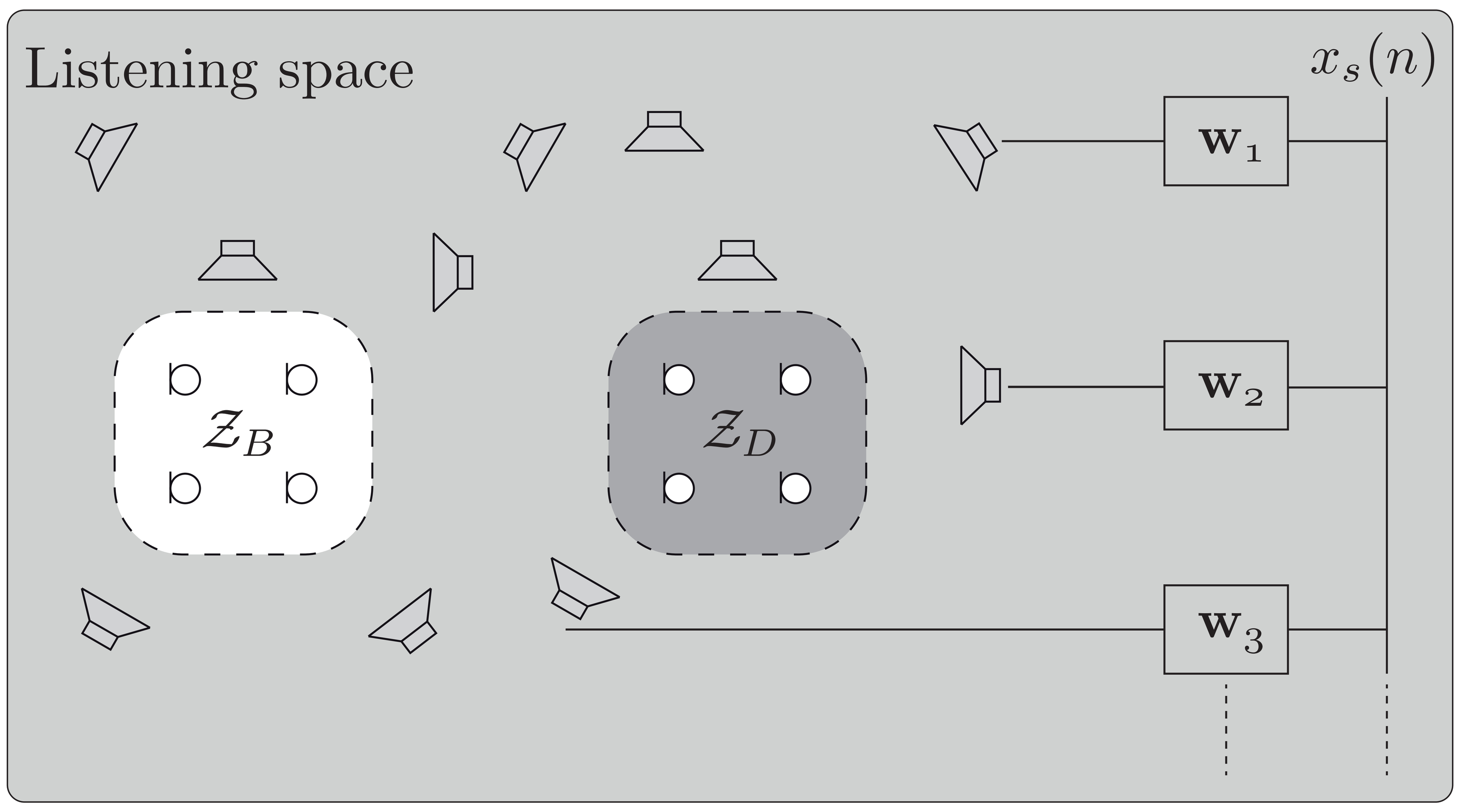

Fig. 1. Setup in a dampened room with $L = 11$ woofers and a square grid of 2 by 2 microphones per zone.

Assumption: the source signal is spectrally white and thus only the filters will affect the input to the loudspeakers.

Sampled output

$$y_{B,k}(n) = \mathbf{w}^T \mathbf{r}_{B,k}(n)$$

with

$$\mathbf{r}_{B,k}(n) = [h_{B,1k}(n), \ldots, h_{B,1k}(n-M+1), \ldots \\ \ldots, h_{B,Lk}(n), \ldots, h_{B,Lk}(n-M+1)]^T$$

Total energy in the bright zone, can be defined as

$$e_B = \sum_{k=1}^{K_B}\sum_{n=0}^{M+I-2} y^2_{B,k}(n)/K_B = \mathbf{w}^T\mathbf{R}_B\mathbf{w}$$

PROPOSED BACC-RTE METHOD

Frequency response of the k-th microphone in the bright zone

$$p_{B,k}(f) = \sum_{n=0}^{M+I-2} y_{B,k}(n)e^{-j2\pi f n T_s}$$

Minimization term

$$RTE = \frac{C_0}{\Delta f}\sum_{k=1}^{K_B}\sum_{j=1}^{J-2a+1} |p_{B,k}(f_{j+a}) - p_{B,k}(f_j) + \ldots \\ \ldots + p_{B,k}(f_{j+2a-1}) - p_{B,k}(f_{j+a-1})|^2$$

This term is used to define the optimization for the BACC-RTE method by

$$\mathbf{w}_{RTE} = \arg\max_{\mathbf{w}} \frac{\mathbf{w}^T\mathbf{R}_B\mathbf{w}}{(1-\beta)\mathbf{w}^T\mathbf{R}_D\mathbf{w} + \beta RTE + \delta\mathbf{w}^T\mathbf{w}}$$

EXPERIMENTAL RESULTS

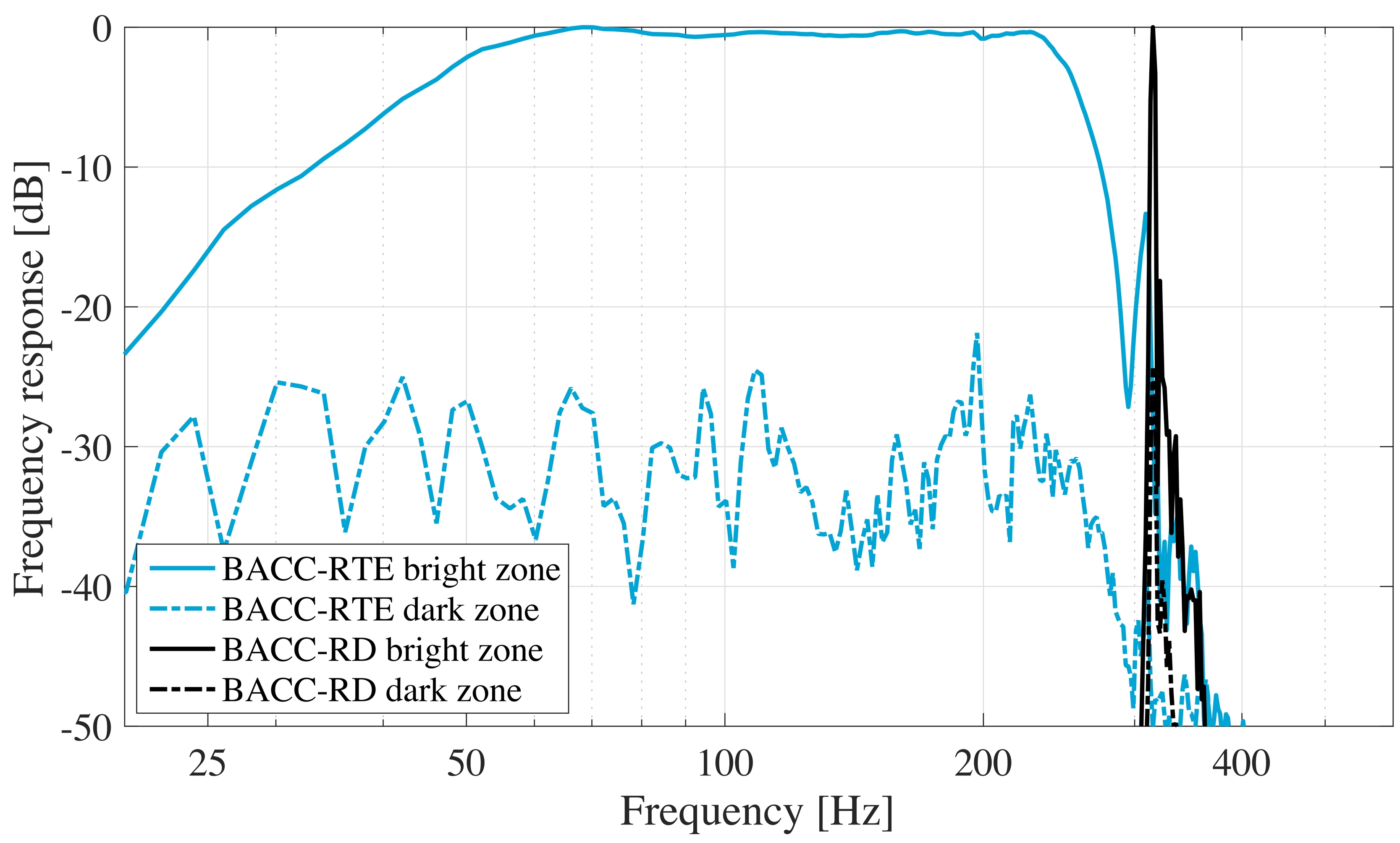

Fig. 2. Averaged frequency responses for BACC-RTE and BACC-RD method in bright and dark zone with $f_1 = 10$ Hz and $f_J = 310$ Hz.

CONCLUSION

Contrary to BACC-RD it is possible to attain high contrast and low variation across frequency in the target frequency range using the proposed BACC-RTE method.

[1] M. Poletti, "An investigation of 2-d multizone surround sound systems," in Audio Engineering Society Convention 125. Audio Engineering Society, 2008.
[2] J.-W. Choi and Y.-H. Kim, "Generation of an acoustically bright zone with an illuminated region using multiple sources," Journal of the Acoustical Society of America, vol. 111, no. 4, pp. 1695–1700, 2002.
[3] Y. Cai, M. Wu, L. Liu, and J. Yang, "Time-domain acoustic contrast control design with response differential constraint in personal audio systems," The Journal of the Acoustical Society of America, vol. 135, no. 6, pp. EL252–EL257, 2014.

BANG & OLUFSEN
TU Delft
AALBORG UNIVERSITET
HARMAN

[a]Bang & Olufsen A/S, Struer, Denmark
[b]Circuits and Systems, Delft University of Technology, Delft, The Netherlands
[c]Department of Electronic Systems, Aalborg University, Aalborg, Denmark
[d]HARMAN Lifestyle Division, Struer, Denmark