HRTF measurements Cochlear SP 15 devices

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February 26, 2010

1 Devices

1.1 SP 19 Devices

- xPC19
- xPC20

1.2 Measurement of devices xPC19 and xPC20 using B&K4222

1.2.1 Equipment

- Date: 16/02/2010
- Reference microphone: BK4189, 0 V polarization
  Amplifier for reference microphone: BK2610, IG30dB, OG0dB, HP22Hz

1.2.2 Procedure:

- Calibrate loudspeaker such that level of 1kHz sinusoid at reference microphone equals 75 dB SPL
  - Output BK4189 for 94 dB SPL: -10 dB -> 3 dBu = 0.78 dBV
  - Output BK4189 for 75 dB SPL: -28,8 dB-> -18 dBV
- Record microphone outputs of xPC19 and xPC20, together with the reference microphone output

1.2.3 Results for 75 dB SPL:

- xPC19:
  - Front: -35.2 dB (1st meas.); -35.3 dB (2nd meas.)
  - Rear: -35.0 dB (1st meas.); -35.2 dB (2nd meas.)
- xPC20:
  - Front: -34.9 dB (1st meas).; -34.9 dB (2nd meas.)
  - Rear: -35.3 dB (1st meas.); -35.3 dB (2nd meas.)
- Conversion to dBV
  - RME: 0 dBFS = 13 dBu -> -35 dB = -22 dBu
  - dBu: reference voltage = 0.7746 V; dBV: reference = 1V -> Conversion to dB V means adding 20*log10(0.7746)=-2.2185 dB.

- Results in dBV
  - xPC19 (connected to channel 1 and 2 of preamp):
    - Front: -24.4 dBV (1st meas.); -24.5 dBV (2nd meas.)
    - Rear: -24.2 dBV (1st meas.); -24.4 dBV (2nd meas.)
  - xPC20 (connected to channel 3 and 4 of preamp):
    - Front: -24.1 dBV (1st meas.); -24.1 dBV (2nd meas.)
    - Rear: -24.5 dBV(1st meas.); -24.5 dBV (2nd meas.)
- Results new battery:
  - xPC19 (ch 1&2):
    - Front: -35.4 dB = -24.6 dBV
    - Rear: -35.1 dB = -24.3 dBV
  - xPC19 (ch 3 &4):
    - Front: -35.5 dB =-24.7 dBV
    - Rear: -35.4 dB = -24.6 dBV
  - xPC20 (ch 1 & 2):
    - Front: -34.9 dB = -24.1 dBV
    - Rear: -34.9 dB = -24.1 dBV
  - xPC20 (ch 3 & 4)
    - Front: -35.2 dB = -24.4 dBV
    - Rear: -35.5 dB = -24.7 dBV

2 Test room O&N2, 07.4018

2.1 Test conditions

- Low reverberation: Option 1 + one and a half curtain in middle (to shield test set-up in right half of the room)
  - Curtains around the room, 1.5 curtain in middle (opposite side of door).
  - Acoustical ceiling in right half of the room
  - 4 triangular damping elements on ground to put cables on (to avoid that cables are touched by the moving loudspeaker set-up 'TheFly')
- Mid reverberation: Option 11
  - No acoustic ceiling in right half of the room
  - Only 6 curtains in the middle (border between left and right half)
- Dates of the measurements
  - Low reverb:
    - first HRTF data set on 11/02/2010
      - head positioned 6 cm more to the right (positive angles) than to the left

        - Only recordings of ITE with CI devices present
        - Left device xPC19, right device xPC20
        - RME: Channel 1 to 4: CI devices; Channel 5 to 6: ITE; Channel 7: signal sent to loudspeaker
    * second HRTF data set on 22/02/2010
        - head positioned in the middle
        - Includes recordings of ITE without CI devices
        - Set 1: Left device xPC19 (ch 1 & 2 pre-amp), right device xPC20 (ch 3 & 4 pre-amp)
        - Set 2: Left device xPC20 (connected to ch3 & 4 of pre-amp), right device xPC19 (ch1 & 2)
        - RME: Ch 1: signal sent to loudspeaker; Ch 2&3: ITE; Chan 4 to 7: CI devices(left, right)
- Mid reverb: data set on 23/02/2010
    * HRTF data set on 23/02/2010
        - head positioned in the middle
        - Left device xPC19, right device xPC20

2.2 Reverberation time and critical distance

File: CriticalDistance\ComputeReverbTime.m

2.2.1 Measurement procedure (cf. HearCom project)

Reverberation time

- Present a stationary speech weighted noise signal (VUman noise) consisting of 20 segments with a 4 s noise burst followed by 4 s of silence
  Sampling frequency: 48kHz
- Speaker: Fostex, positioned at 20 degrees; SPL level: 85 dB SPL at 1 meter and/or 91 dB SPL at 1 meter
- Recorded at a distance far enough from speaker: recordings available at 1, 2 and 3 meter (Example: 2 meter, 91 dB SPL)
- Microphone: BK4189 (0V polarization) with pre-amp B&K 2619
- Amplifier: BK2610: output gain 0 dB; input gain 20 dB
- Measure average energy over 20 segments; apply time-averaging filter (1000 taps @ 48kHz). Determine the slope of the energy decay after the burst using linear regression (on non-time-averaged data); Same procedure is also applied to one-third octave bands

Critical distance

- Present a 30 seconds VUman noise segment; 85 dB SPL at 1 meter
- Record noise segment at different distances r (0.1 m, 0.2 m, 0.4 m, 0.8 m, 1 m, 1.6 m, 2m, 3m, 3.5 m
- Compute energy of last 20 seconds;
- Perform linear regression on energy P(linear) and $\frac{1}{r^2}$:
  - Model: $P = \frac{a}{r^2} + b$
  - Critical distance $d_c = \sqrt{\frac{a}{b}}$
- Apply method in different one-third octave bands

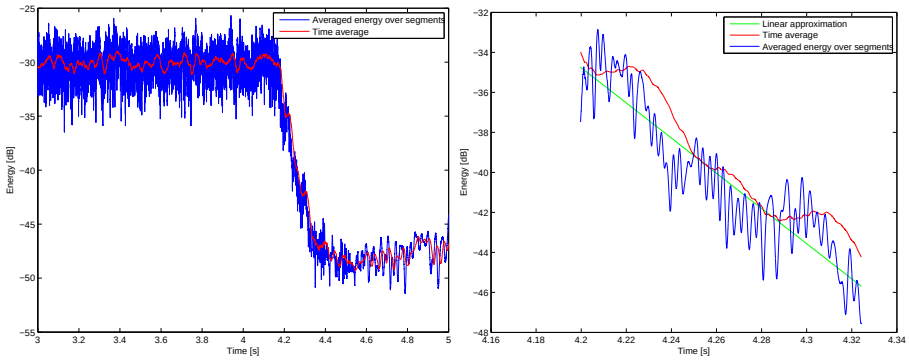


Figure 1: Energy decay curve

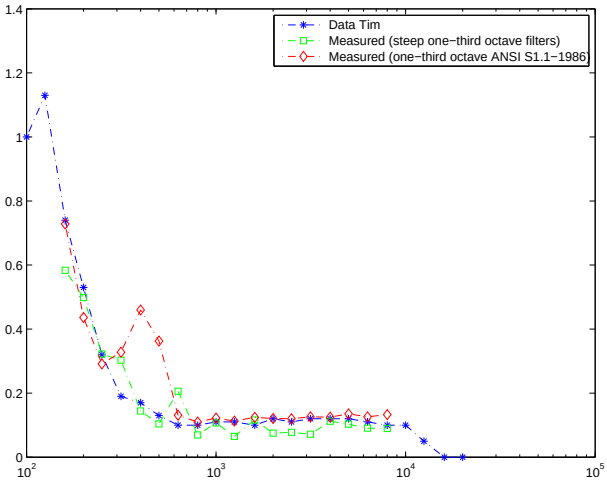


Figure 2: T60dB in one-third octave bands

2.2.2 Option 1: low reverberation

Reverberation time

- Data 2 meter distance (91 dB SPL)
  - T60dB_broad[1]: 0.682 sec
  - T60dB intelligibility weighted (160Hz to 8kHz): 0.168 sec (one third octave band ANSI S1.1-1986), 0.12 sec (steep one-third filter)
  - T60dB intelligibility weighted (data Tim): 0.13 sec
  - Data one-third octave bands and comparison with data Tim:
    - Remark: deviation in data around 400 Hz -> frequency band with bandwidth of 40Hz around center frequency: two reverberation curves visible: first fast decay (T60dB=0.185 s), followed by slow decay (T60dB 0.6 s). For more narrow filter: fast slope continues longer -> due to low frequency energy leakage
      T60dB has been recomputed using steep one-third filter banks and only considering the first energy drop of 10 dB in the determination of the linear approximation.

[1]Remark: VU noise was not equalized for loudspeaker characteristics

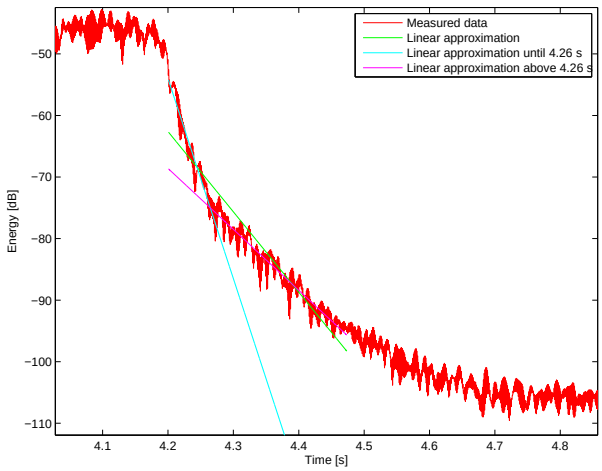


Figure 3: Energy decay curve around 400 Hz

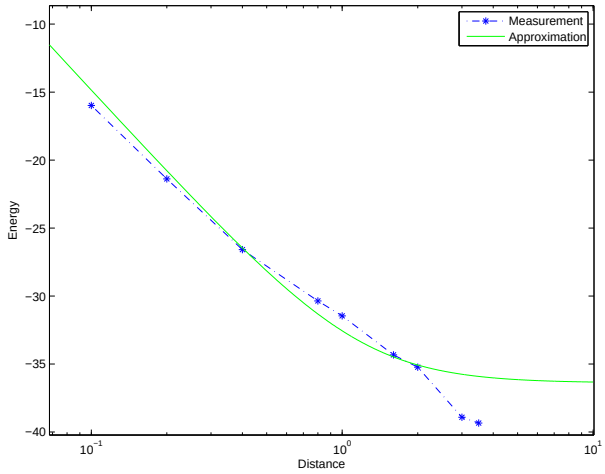


Figure 4: Critical distance (based on broadband energy)

Critical distance

- dc_broad: 1.2 m
- dc intelligibility weighted (160Hz to 8kHz): 2.39 m
- dc one-third octave bands:

2.2.3 Option 2: mid reverberation

Reverberation time

- Data 1 meter distance (85 dB SPL)
  - T60dB_broad: 0.74 s
  - T60dB intelligibility weighted: 0.47 s

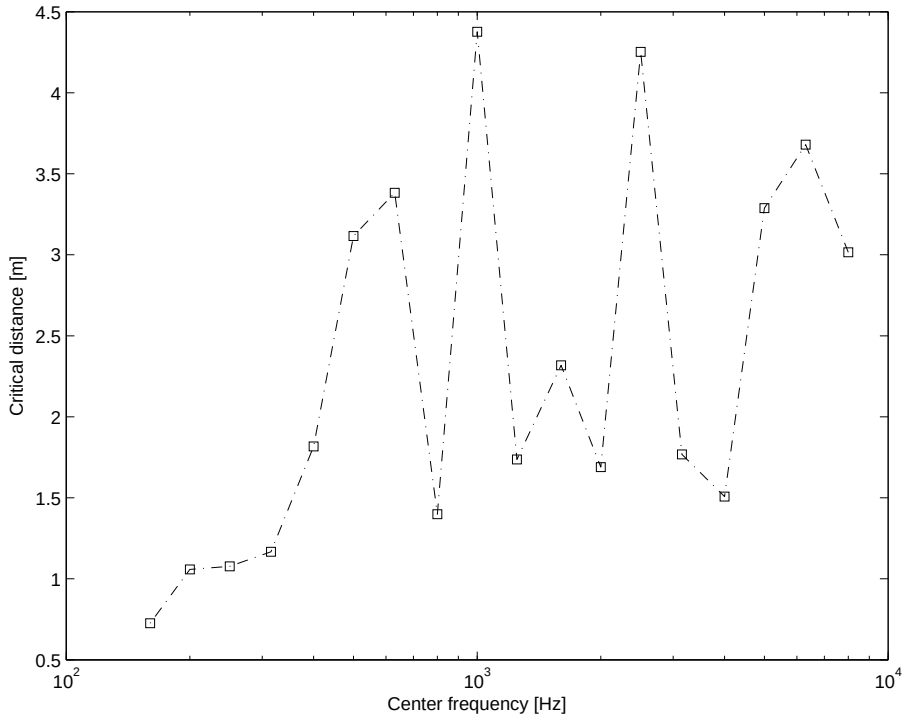


Figure 5: Critical distances in one-third octave bands

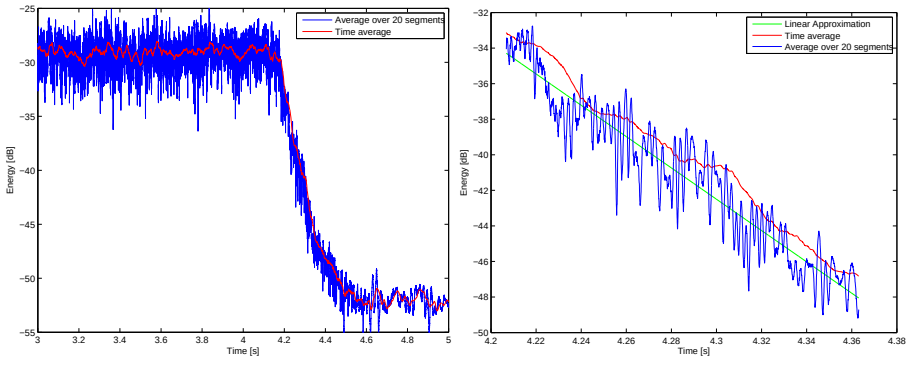


Figure 6: Energy decay curve

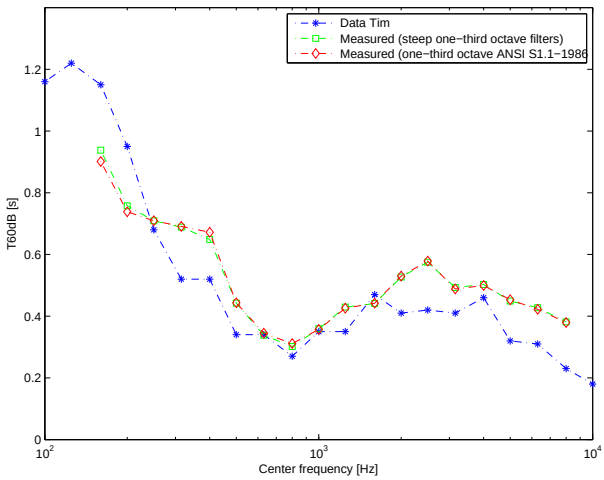


Figure 7: T60dB in one-third octave bands

  - T60dB intelligibility weighted (data Tim): 0.4 s

- Data one-third octave bands

Critical distance

- dc_broad: 0.68 m
- dc intelligibility weighted (160Hz to 8kHz): 1.4 m
- dc one-third octave bands:

3 HRTF measurements

3.1 Procedure

- Signal: 48kHz white noise signal (Whitenoise48kHz.wav), generated in Matlab.
- Program: TheFly.exe (max speed ring = 1)
- Procedure:
  - Calibrate Fostex speaker at 85 dB SPL
  - Speaker positions: -180:5:180
  - Measurement background noise:
    * Microphone in the middle, pointed towards speaker at 0 degrees
    * Recordings 12/02/2010: 1: microphone; 2: signal sent to loudspeaker (zeros in this case)
      Recordings 22-23/02/2010: 1: signal sent to loudspeaker (zeros in this case), 2: microphone
    * Mic: B&K 4189 (0V polarization) with pre-amp B&K 2619
    * Amplifier BK2610: output gain 0 dB; input gain 30 dB
    * Files: CenterNoHeadBK4189_quiet.raw (12/02/2010), CritDistLow/CenterNoHead_Quiet(SpOff).raw (22/02/2010)
      SpOff: loudspeaker was powered off during measurement

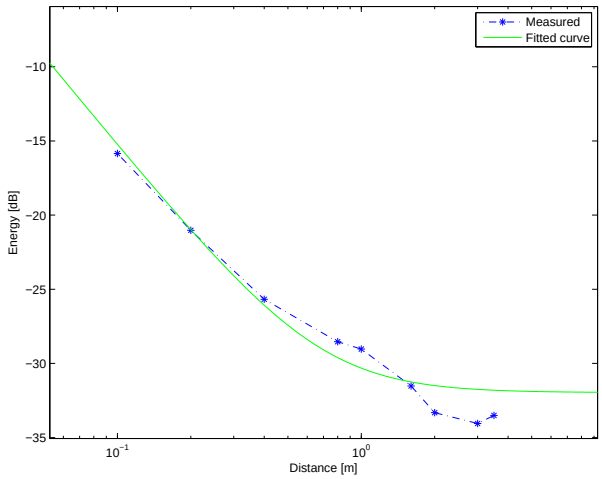


Figure 8: Critical distance (based on broadband energy)

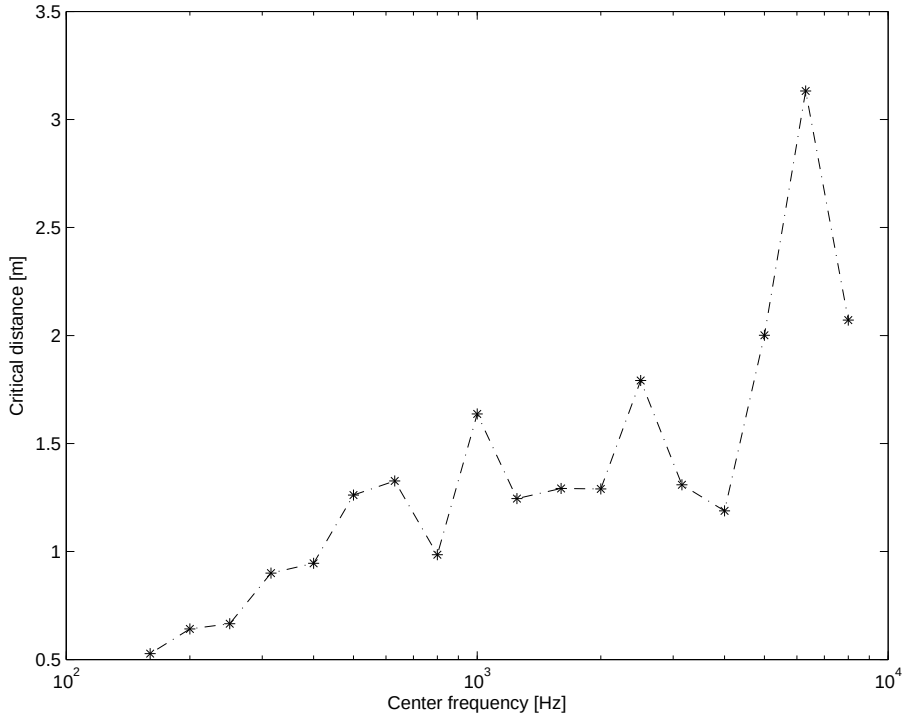


Figure 9: Critical distances in one-third octave bands

    - Calibrator recordings at IG 20 and 30 dB: Calibrator20dB.raw; Calibrator30dB.raw
- Measurement white noise signal (85 dB SPL) at center of the head (IG 30 dB, OG 0 dB)
    - File: CenterNoHeadBK4189_85dBSPL (12/02/2010), CritDistLow/CenterNoHead_85dBSPL.raw (22/02/2010)
- Measurement loudspeaker characteristics (IG 20 dB!!)
    - Microphone at 2 cm, 5 cm and 10 cm from speaker, pointed towards speaker
    - File: D5(10)cmNoHeadBK4189_85dBSPL.raw (12/02/2010), D2cmNoHead_85dBSPL.raw (22/02/2010)
    - Ch1: microphone; Ch2: signal sent to loudspeaker (12/02/2010), Ch1: signal sent to speaker; Ch2: microphone (22 and 23/02/2010)
- Measurement HRTFs 12/02/2010:
    - Setting OPUS pre-amp: 20 dB gain, 10 Hz HP filter
    - Ch1: Front mic SP15 19 (left)
    - Ch2: Rear mic SP15 19
    - Ch3: Front mic SP15 20 (right)
    - Ch4: Rear mic SP15 20
    - Ch5: ITE left
    - Ch6: ITE right
    - Ch7: signal sent to speaker (measured via 2nd channel MONACOR splitter)

  File: LowReverb.raw_x_(angle)_y_0.raw

  Positive angle corresponds to right-hand side.
- Measurement HRTFs 22/02/2010:
    - Setting OPUS pre-amp: 20 dB gain, 10 Hz HP filter
    - Ch1: signal sent to speaker (measured via 2nd channel MONACOR splitter)
    - Ch2: ITE left
    - Ch3: ITE right
    - Ch4: Front mic SP15 19 (left)
    - Ch5: Rear mic SP15 19
    - Ch6: Front mic SP15 20 (right)
    - Ch7: Rear mic SP15 20

  Files:
    - SP15_LowReverb.raw_x_(angle)_y_0.raw: xPC19 (amp. ch 1&2) on left ear; xPC 20 (amp. ch 3&4) on right ear
    - ITE_LowRever.raw_x_(angle)_y_0.raw: contains ITE signals in absence of CI devices
        - Ch1: signal sent to speaker; Ch2: ITE left; Ch3: ITE right
    - SP15swap_LowReverb.raw_x_(angle)_y_0.raw: xPC20 (amp. ch3&4) on left ear; xPC19 (amp. ch1&2) on right ear

  Positive angle corresponds to right-hand side.
- Measurement HRTFs 23/02/2010: cf. HRTFs 22/02/2010

  Files:
    - SP15_MidReverb.raw_x_(angle)_y_0.raw: xPC19 (amp. ch 1&2) on left ear; xPC 20 (amp. ch 3&4) on right ear
    - ITE_LowRever.raw_x_(angle)_y_0.raw: contains ITE signals in absence of CI devices

3.2 Results (mfiles: CalcHrtfs_(date).m)

- HRTFs 12/02/2010:
  - HRTF_SP15_GHB/HRTF_SP15_19_LeftCortex_GHB_074018lowreverb_11-Feb-2010.mat
    - HRTF_SP15_GHB/HRTF_SP15_20_RightCortex_GHB_074018lowreverb_11-Feb-2010.mat
    - HRTFs 22/02/2010 (data 12/02 used for loudspeaker equalization):
      - HRTFSP15_220210/HRTF_ITE_left_LeftCortex_GHB_074018lowreverb_22-Feb-2010.mat
      - HRTFSP15_220210/HRTF_ITE_right_RightCortex_GHB_074018lowreverb_22-Feb-2010.mat
      - HRTFSP15_220210/HRTF_SP15_19_LeftCortex_GHB_074018lowreverb_22-Feb-2010.mat
      - HRTFSP15_220210/HRTF_SP15_20_RightCortex_GHB_074018lowreverb_22-Feb-2010.mat
      - HRTFSP15_220210/HRTF_SP15_20_LeftCortex_GHB_074018lowreverb_22-Feb-2010.mat
      - HRTFSP15_220210/HRTF_SP15_19_RightCortex_GHB_074018lowreverb_22-Feb-2010.mat

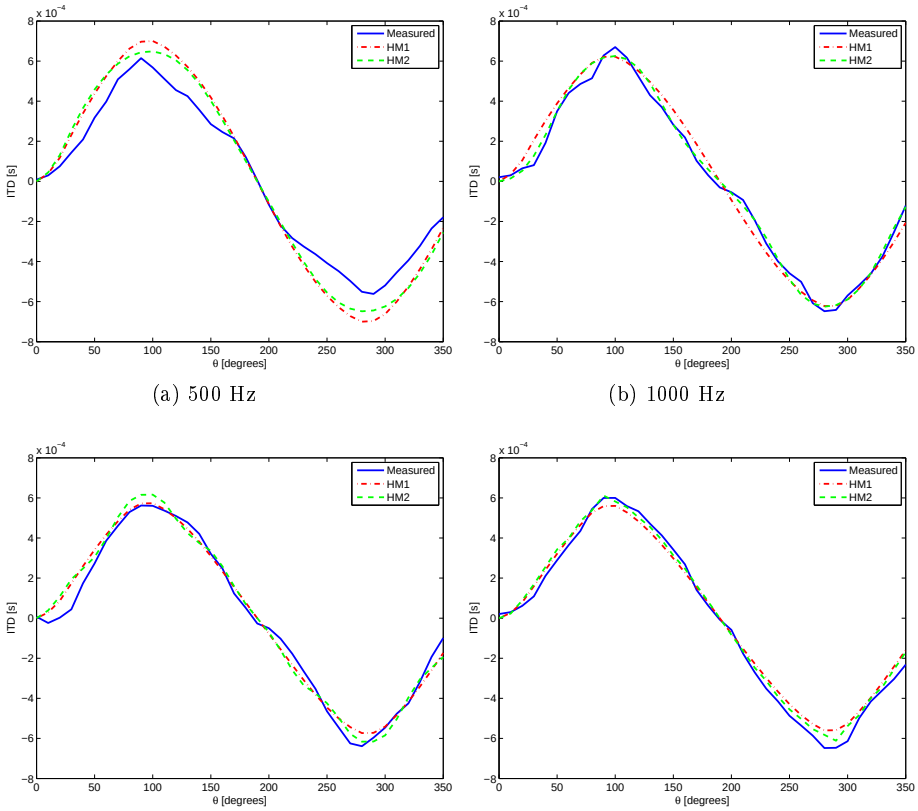
      Remark: IRs ITE and SP15_ITE are different due to presence CI device: largest differences above 2kHz and for angles around 90 degrees (in case of left device)
    - HRTFs 23/02/2010 (data 12/02 used for loudspeaker equalization):
      - HRTFSP15_230210/HRTF_SP15_19_LeftCortex_GHB_074018midreverb_23-Feb-2010.mat
      - HRTFSP15_230210/HRTF_SP15_20_RightCortex_GHB_074018midreverb_23-Feb-2010.mat
      - HRTFSP15_230210/HRTF_ITE_left_LeftCortex_GHB_074018midreverb_23-Feb-2010.mat
      - HRTFSP15_230210/HRTF_ITE_right_RightCortex_GHB_074018midreverb_23-Feb-2010.mat

3.3 Comparison with head models (d=0.082)

- Low reverb data 22/02/2010
  - ITD between front left and right mic CI device
  - ILD between front left and right mic CI device
  - Level difference rear to front microphone CI device
- Mid reverb data 23/02/2010:
  - ITD between front left and right mic CI device
  - ILD front left and right mic CI device
  - Level difference rear and front microphone CI device
  - Remark: strong reflection in HRIR left device for angles around 90-110: to compute ITD only crosscorrelation between -800 and + 800 microseconds is considered
  - ILD lower due to reverberation; for mid reverberation better match with head models
- Remark: In [1], good accordance betweeen the true and modeled ITD was found at 250 and 500 Hz, at higher frequencies, a larger ITD was found for the measured data. Here, for the low reverberation case, true ITD at 500 Hzlower than the modeled one and below 4kHz, true ILD lower than modeled ILD; Note that head size in the models was not optimized for the data set.

References

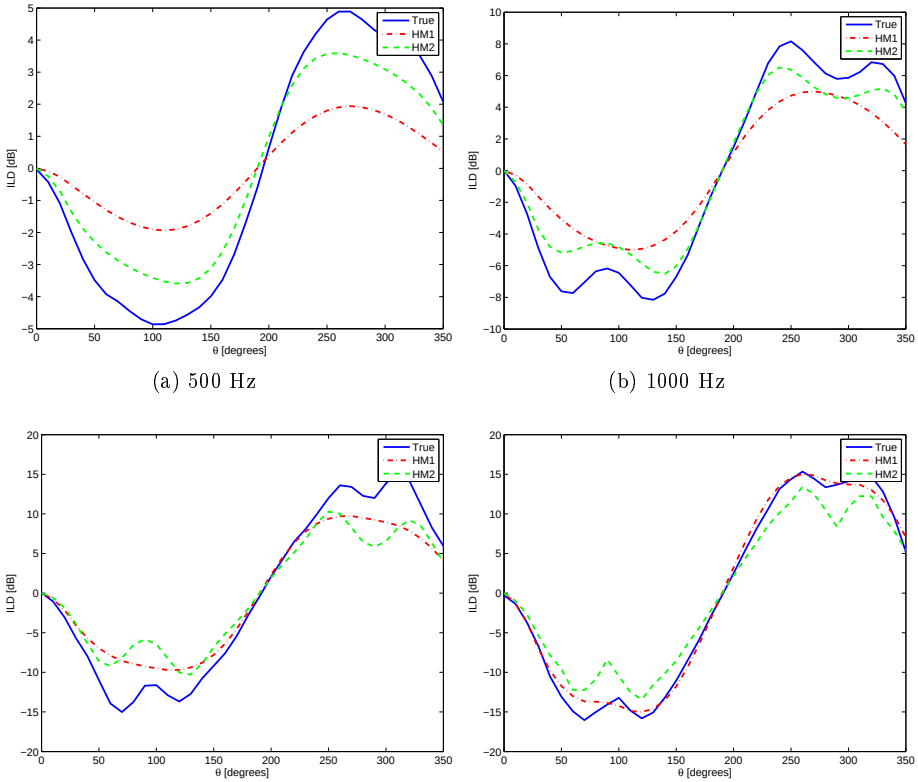
[1] H. Kayser, S. Ewert, J. Annemueller, T. Rohdenburg, V. Hohmann, and B. Kollmeier, "Database of multichannel in-ear and behind-the-ear head-related and binaural room impulse responses," *EURASIP journal on Advances in Signal Processing*, pp. 1–10, 2009.



(a) 500 Hz (b) 1000 Hz

(c) 2000 Hz (d) 4000 Hz

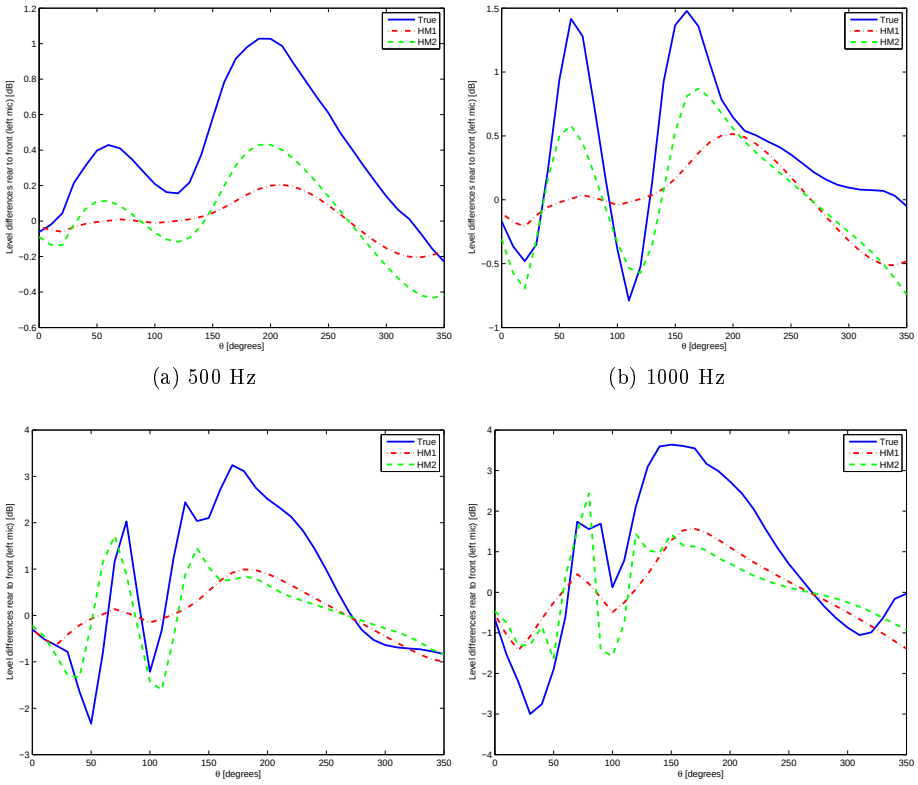
Figure 10: ITD - HRTFs GHB - low reverberation



(a) 500 Hz (b) 1000 Hz

(c) 2000 Hz (d) 4000 Hz

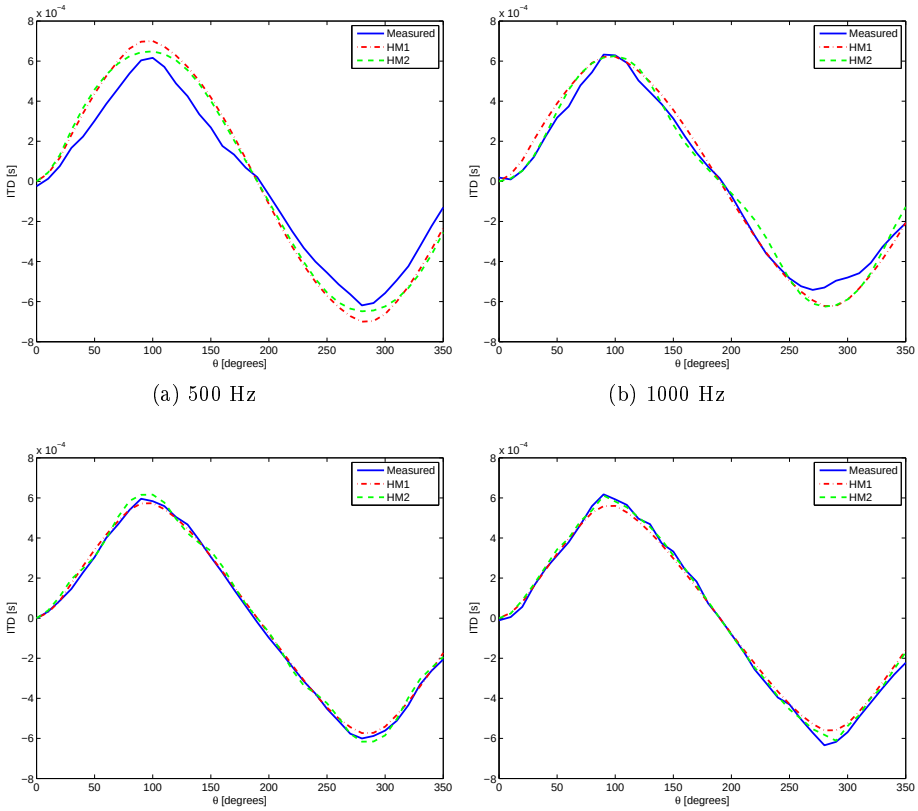
Figure 11: ILD - low reverberation



(a) 500 Hz (b) 1000 Hz

(c) 2000 Hz (d) 4000 Hz

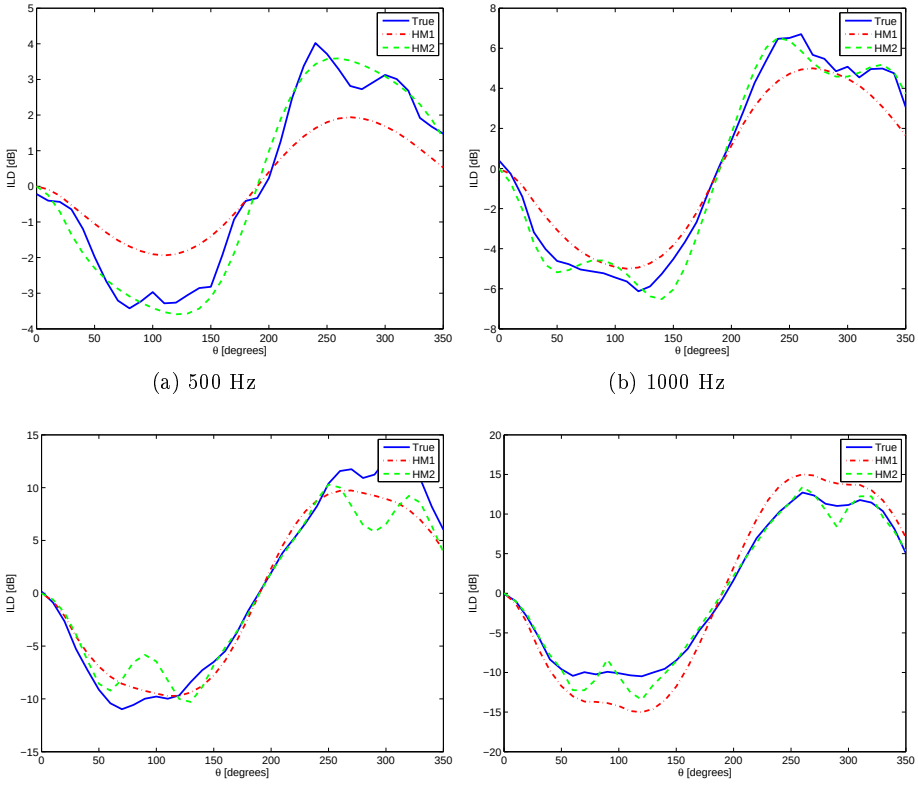
Figure 12: Level difference rear vs front mic - HRTF GHB - low reverberation



(a) 500 Hz (b) 1000 Hz

(c) 2000 Hz (d) 4000 Hz

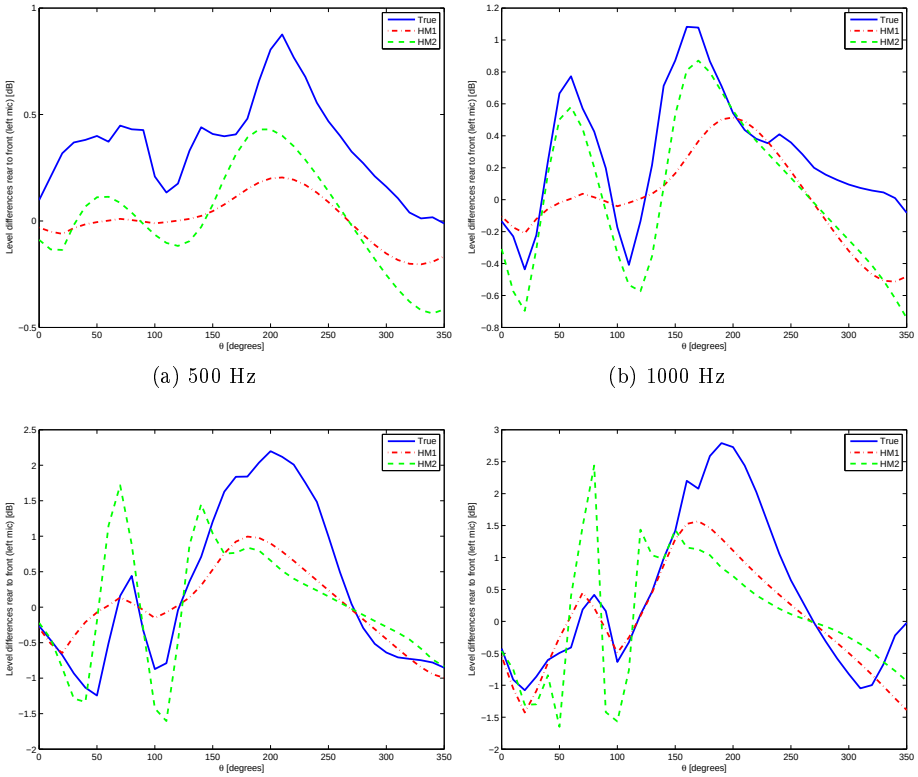
Figure 13: ITD - HRTFs GHB - mid reverberation



(a) 500 Hz (b) 1000 Hz

(c) 2000 Hz (d) 4000 Hz

Figure 14: ILD - mid reverberation



(a) 500 Hz (b) 1000 Hz

(c) 2000 Hz (d) 4000 Hz

Figure 15: Level difference rear vs front mic - HRTF GHB - mid reverberation