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STUDY GROUP 12 – CONTRIBUTION 293

Source: Brüel & Kjær

Title: HRTF measurements on HATS

During the recent work relating to the update of P.58 it has become apparent that the original documentation for the HATS free field and diffuse field measurements – on which the original P.58 was developed – is only partially available today. Furthermore the format used at that time (paper hardcopy) will not accommodate modern requirements for electronic data filing and data processing.

In order to establish an updated set of measurements that fulfil today's requirements Brüel & Kjær contacted a number of independent sites - calibration laboratories as well as universities - and asked if they were able to conduct an updated set of measurements. It turned out that The Technical University of Denmark (DTU), Department of Electrical Engineering, Acoustic Technology facilitating a large 1000m^3 anechoic chamber and several reverberation chambers was an optimal choice for the task. A comprehensive set of HRTF measurements was thus conducted at DTU in first quarter of 2011. A subset of these data - relevant for updating P.58 have been enclosed in this contribution in the following.

HRTF measurements of the Brüel & Kjær HATS Type 4128 and the Head Acoustic Artificial Head HMS.II both equipped with a Type 3.3 Right and Left ear simulator are presented.
First graphs of the free field and diffuse field results for both HATS are shown on pages 3-7 containing both Left Ear and Right Ear.
Then tables are combined so that the free field results for Brüel & Kjær HATS Type 4128-C Left Ear and Right Ear are displayed on page 8, 9, 10, 11 and respective page 12, 13, 14, 15. The free field table results for HSM II.3 Left Ear and Right Ear are displayed on page 16, 17, 18, 19 and respective page 20, 21, 22, 23. The diffuse field table results for Right Ear of both HATS are displayed on page 24.
Finally the table on page 25 illustrates the reproducibility of the measurements setup showing two repeated measurements with the same HATS removed from the room between each measurement.

Brüel & Kjær suggests that these new measurements results could form the basis for an update of P.58. The data acquired support a higher frequency resolution than the current free-field corrections, hence it would be relevant to consider to take this into considerations when reviewing the general performance specifications as currently outlined in P.58. In addition it could be relevant to consider to include measurement uncertainties – a factor currently lacking in P.58.

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TECHNICAL UNIVERSITY OF DENMARK

Measuring HRTFs of Head and Torso Simulators

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3.3.2 Sine sweep measurements

- **Brüel & Kjær Type 4128-C HATS model nr. 1**

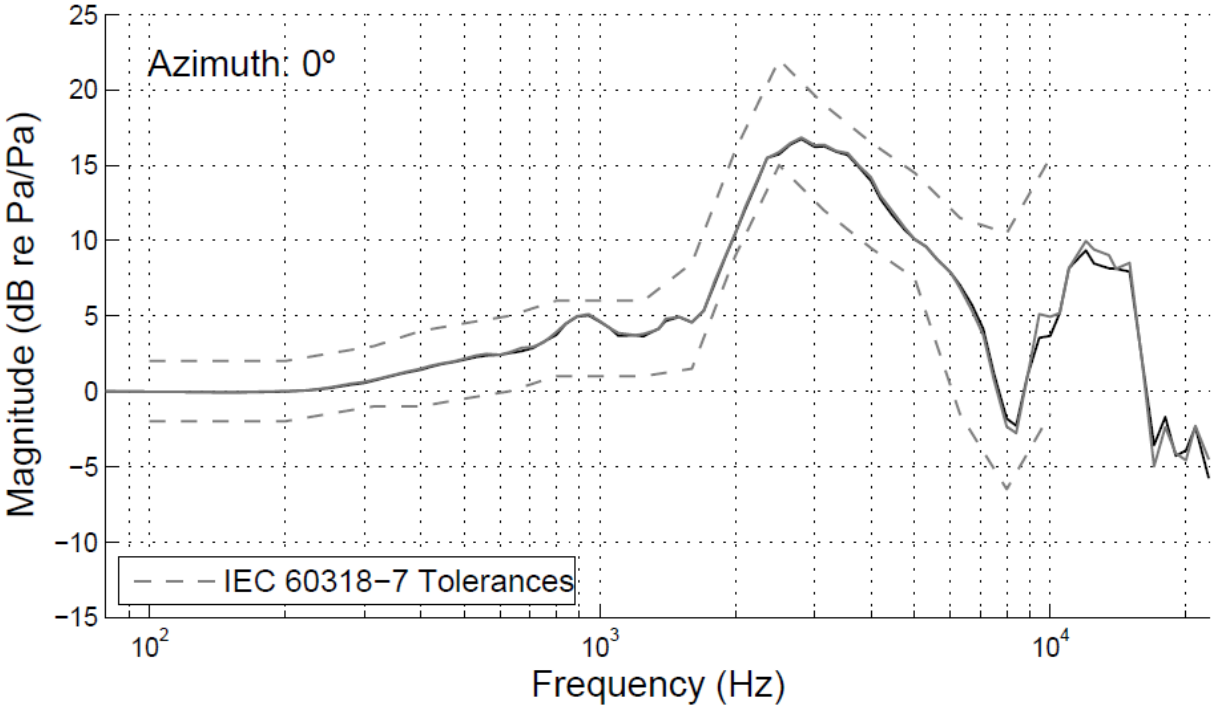

Figure 20: *Sine sweep HRTF measurement of Brüel & Kjær Type 4128-C HATS model nr. 1 at 0° azimuth. Black curve is left ear. 1/12th octave bands.*

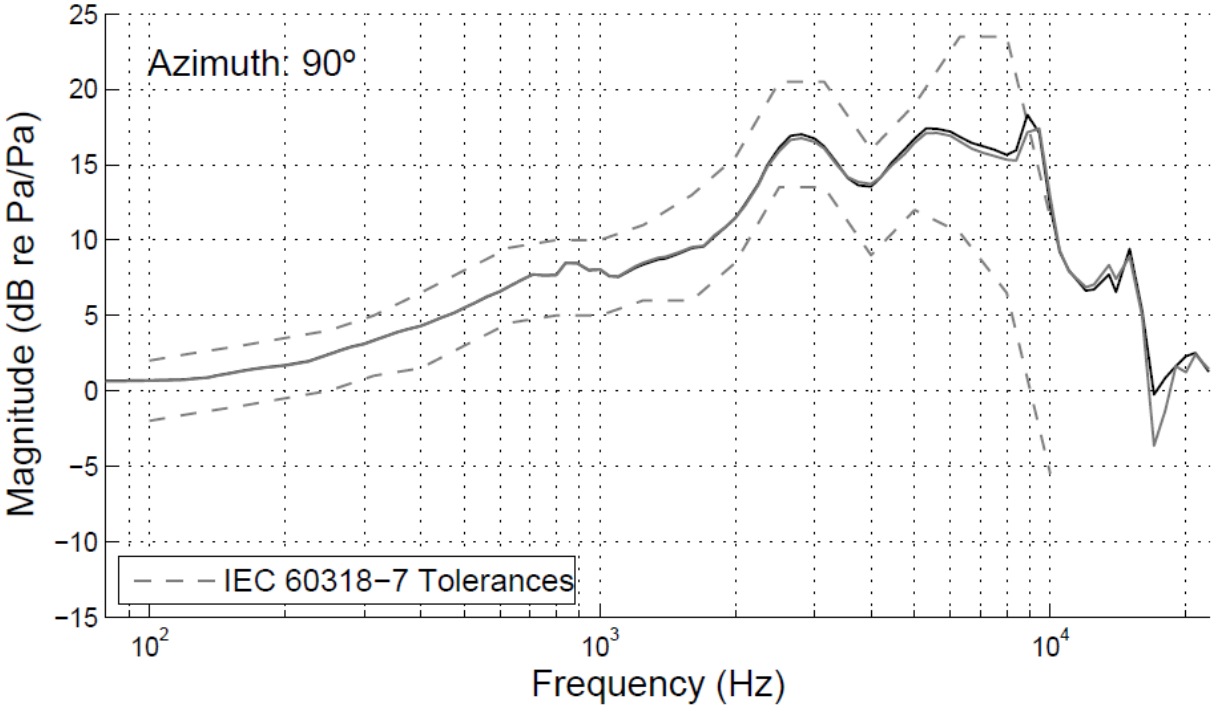

Figure 21: *Sine sweep HRTF measurement of Brüel & Kjær Type 4128-C HATS model nr. 1 at 90° azimuth. Black curve is left ear. 1/12th octave bands.*

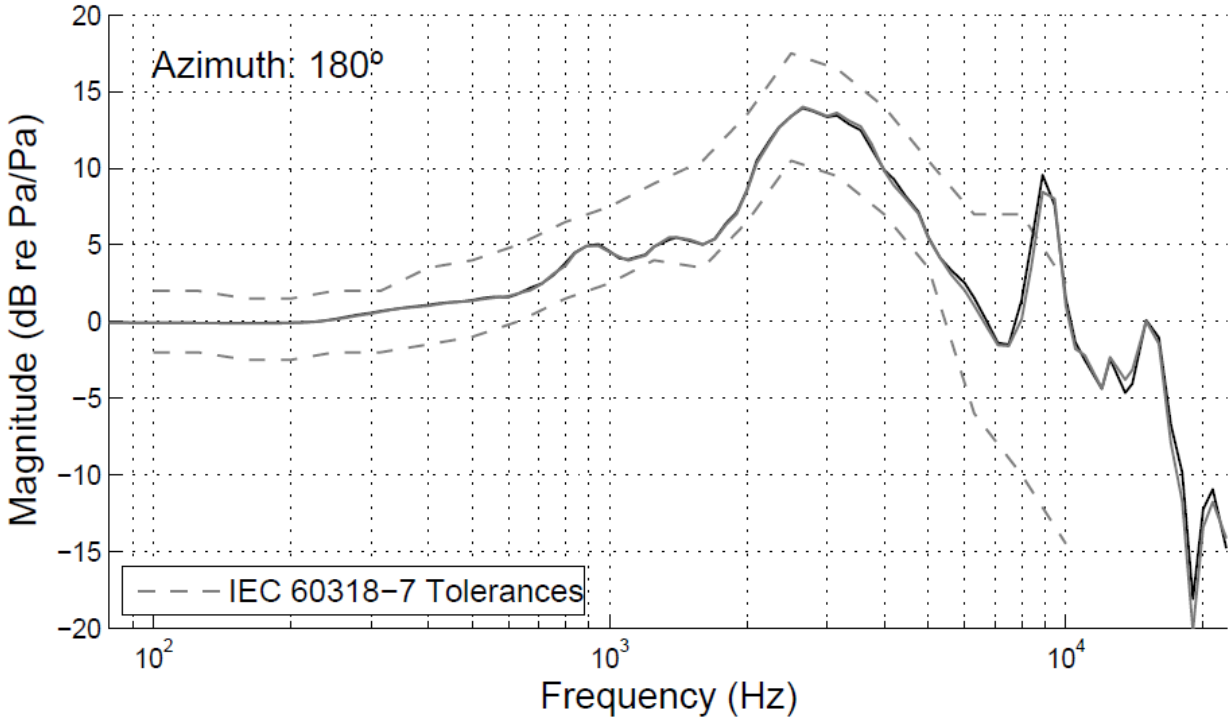

Figure 22: *Sine sweep HRTF measurement of Brüel & Kjær Type 4128-C HATS model nr. 1 at 180° azimuth. Black curve is left ear. 1/12th octave bands.*

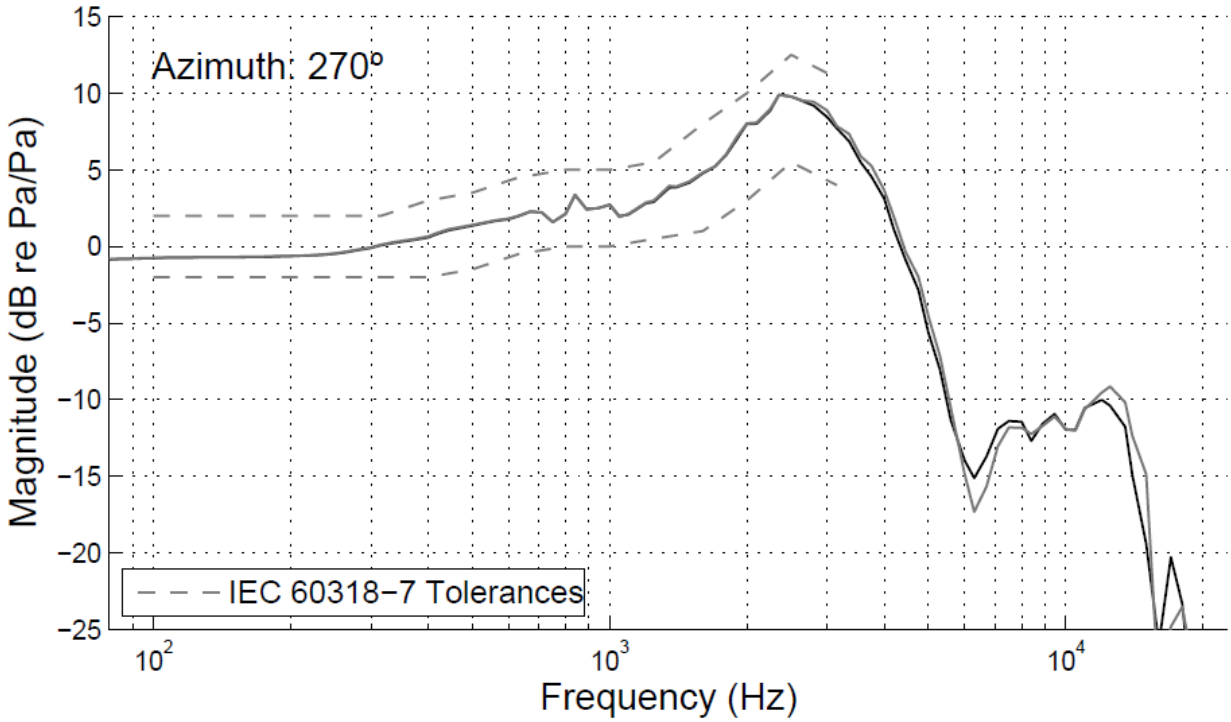

Figure 23: *Sine sweep HRTF measurement of Brüel & Kjær Type 4128-C HATS model nr. 1 at 270° azimuth. Black curve is left ear. 1/12th octave bands.*

- **Head Acoustics HMS II.3**

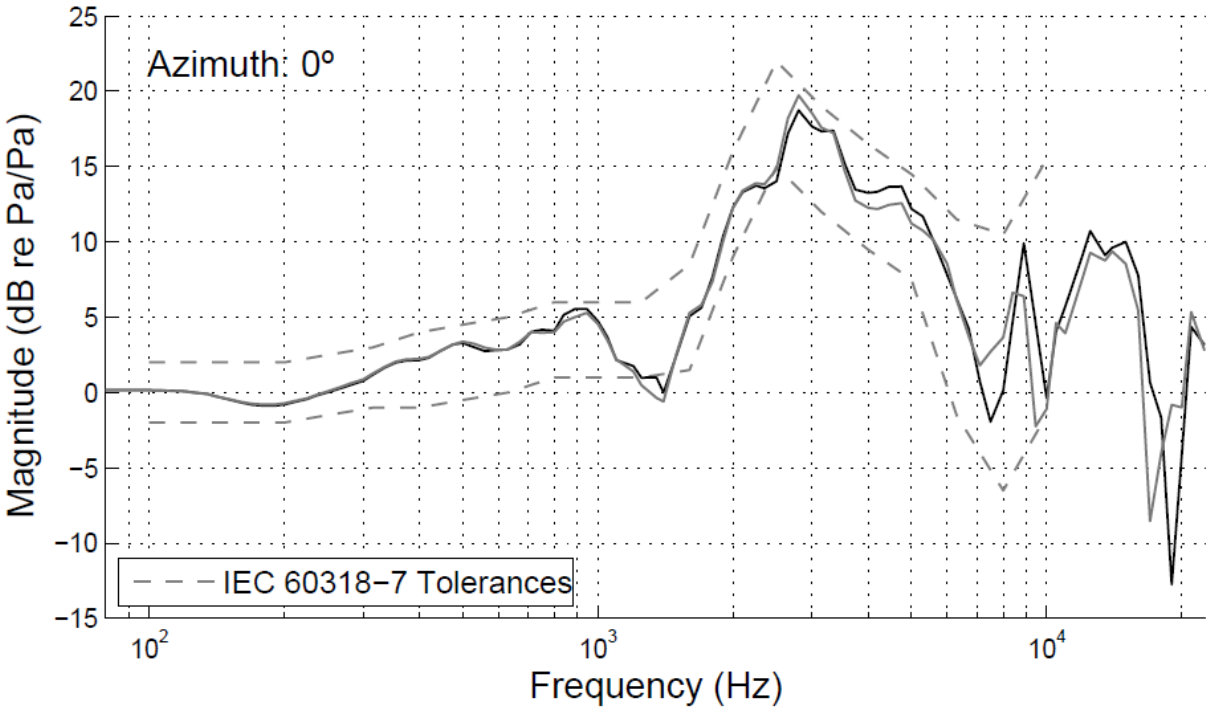

Figure 28: *Sine sweep HRTF measurement of Head Acoustics HMS II.3 at 0° azimuth. Black curve is left ear. 1/12th octave bands.*

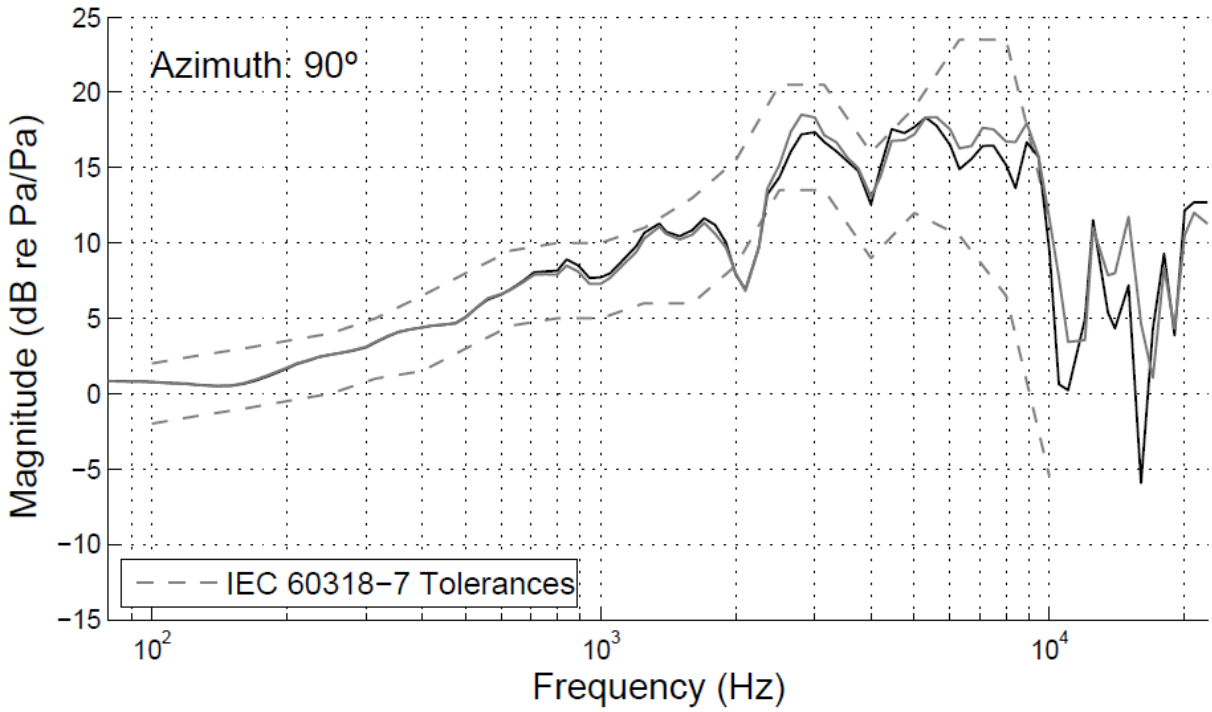

Figure 29: *Sine sweep HRTF measurement of Head Acoustics HMS II.3 at 90° azimuth. Black curve is left ear. 1/12th octave bands.*

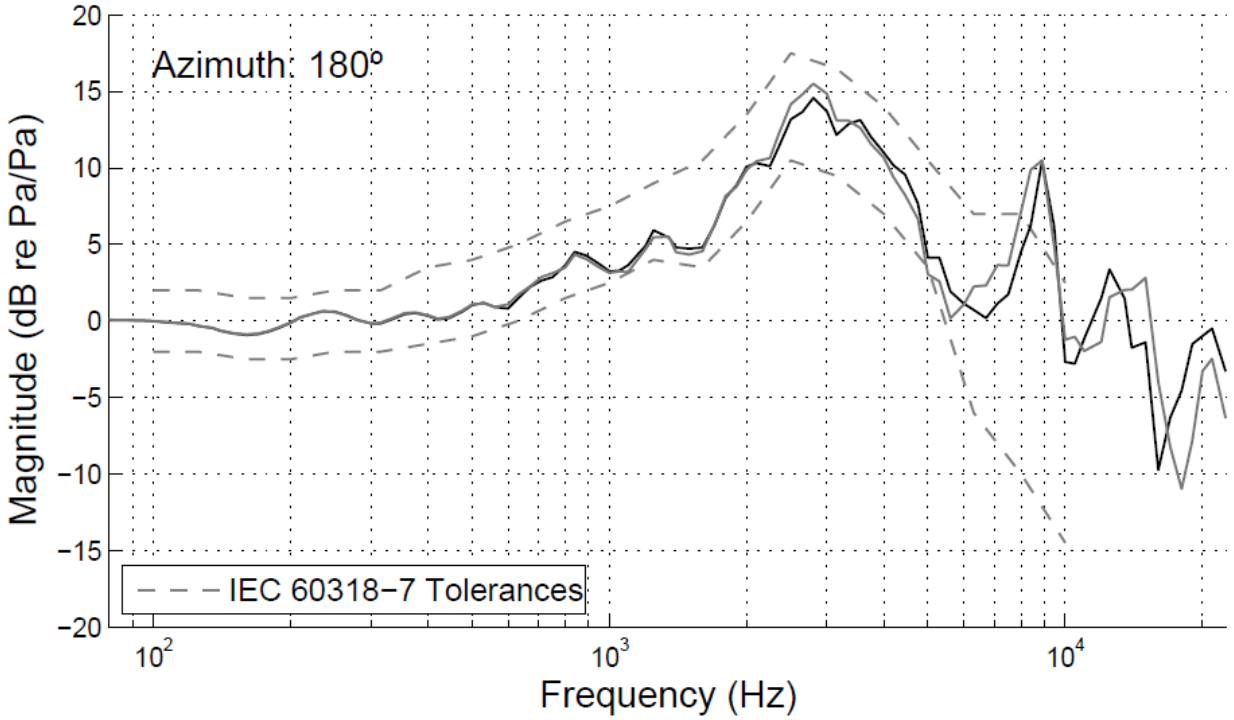

Figure 30: *Sine sweep HRTF measurement of Head Acoustics HMS II.3 at 180° azimuth. Black curve is left ear. 1/12th octave bands.*

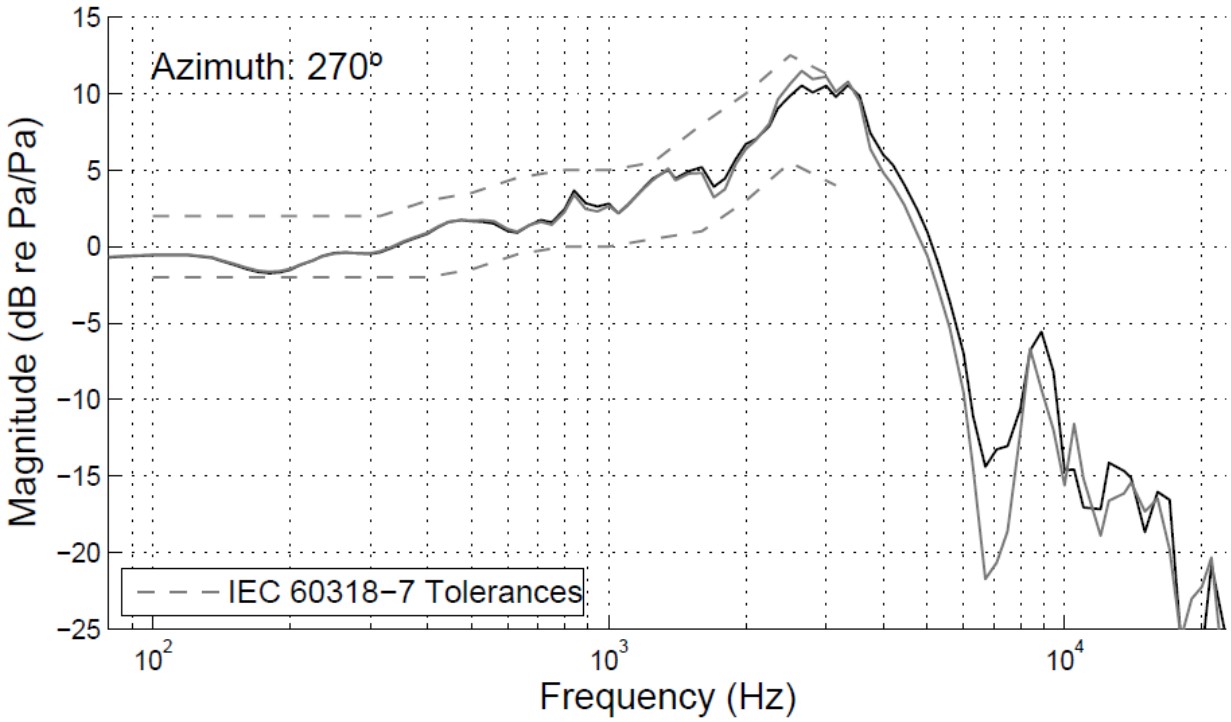

Figure 31: *Sine sweep HRTF measurement of Head Acoustics HMS II.3 at 270° azimuth. Black curve is left ear. 1/12th octave bands.*

3.4 HRTFs in the diffuse field

Figure 32 shows HRTF measurements in the diffuse field, made with pink noise. The solid curve represents the HRTF, while the dotted lines are tolerances set by ITU-T Rec. P.58[8]. All measurements and tolerances are shown in 1/3rd octave bands. The HRTFs are also an average of the five measured positions.

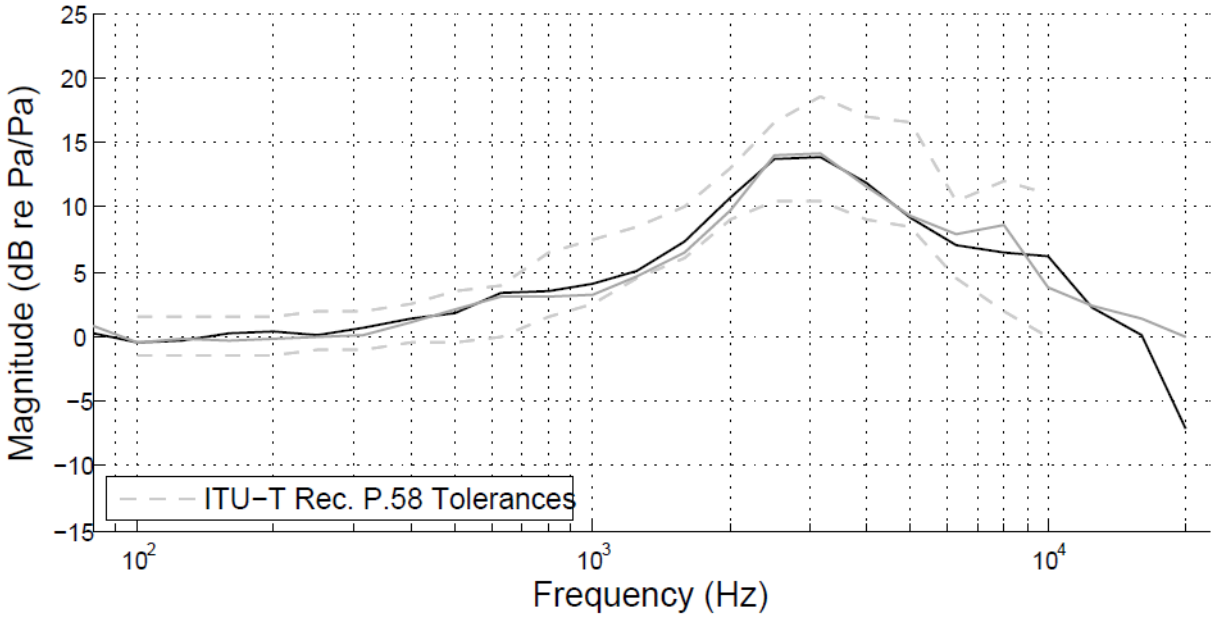

Figure 32: *Average of five positions for diffuse-field HRTF. ITU-T Rec. P.58 Tolerances in dashed lines, solid black curve is Brüel & Kjær Type 4128-C HATS model nr. 1, and solid grey curve is Head Acoustics HMS II.3. Right ear is presented. 1/3rd octave bands.*

5.4 Tables for free-field measurement results

Results are shown from the sine sweep method, in 1/12th octave bands.

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	-0.03	600	2.42	3550	15.67
105	-0.03	630	2.53	3750	14.92
110	-0.04	670	2.66	4000	13.95
120	-0.04	710	2.86	4200	12.75
125	-0.05	750	3.28	4450	11.72
135	-0.06	800	3.74	4750	10.72
140	-0.07	840	4.46	5000	10.09
150	-0.07	890	4.95	5300	9.60
160	-0.07	945	5.03	5600	8.76
170	-0.06	1000	4.61	6000	7.89
180	-0.05	1050	4.21	6300	7.04
190	-0.04	1100	3.68	6700	5.73
200	-0.02	1200	3.71	7100	4.15
210	0.01	1250	3.65	7500	1.16
225	0.05	1350	4.15	8000	-1.82
235	0.11	1400	4.67	8400	-2.28
250	0.21	1500	4.92	8900	1.02
265	0.31	1600	4.57	9450	3.54
280	0.43	1700	5.34	10000	3.68
300	0.55	1800	7.14	10500	5.20
315	0.72	1900	8.93	11000	8.17
335	0.92	2000	10.48	12000	9.34
355	1.10	2100	12.05	12500	8.47
375	1.26	2250	14.09	13500	8.15
400	1.42	2350	15.48	14000	8.13
420	1.61	2500	15.73	15000	7.93
445	1.80	2650	16.39	16000	2.02
475	1.95	2800	16.74	17000	-3.57
500	2.09	3000	16.21	18000	-1.70
530	2.26	3150	16.26	19000	-4.29
560	2.38	3350	15.89	20000	-3.92

Table 1: *HRTF at 0° azimuth angle, left ear - Brüel & Kjær Type 4128 HATS*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	0.70	600	6.58	3550	14.11
105	0.71	630	6.93	3750	13.63
110	0.73	670	7.35	4000	13.55
120	0.75	710	7.72	4200	14.17
125	0.81	750	7.66	4450	15.16
135	0.89	800	7.69	4750	16.03
140	1.00	840	8.49	5000	16.73
150	1.16	890	8.47	5300	17.40
160	1.32	945	7.99	5600	17.39
170	1.46	1000	8.04	6000	17.20
180	1.56	1050	7.60	6300	16.85
190	1.63	1100	7.57	6700	16.44
200	1.70	1200	8.17	7100	16.23
210	1.81	1250	8.39	7500	16.01
225	1.96	1350	8.73	8000	15.66
235	2.16	1400	8.77	8400	15.96
250	2.43	1500	9.11	8900	18.31
265	2.69	1600	9.46	9450	17.12
280	2.92	1700	9.58	10000	12.22
300	3.12	1800	10.25	10500	9.22
315	3.35	1900	10.85	11000	7.97
335	3.63	2000	11.47	12000	6.65
355	3.90	2100	12.38	12500	6.73
375	4.10	2250	13.76	13500	7.73
400	4.30	2350	14.95	14000	6.56
420	4.55	2500	16.14	15000	9.42
445	4.86	2650	16.92	16000	5.31
475	5.18	2800	17.03	17000	-0.25
500	5.51	3000	16.74	18000	0.85
530	5.86	3150	16.21	19000	1.63
560	6.22	3350	15.17	20000	2.30

Table 2: *HRTF at 90° azimuth angle, left ear - Brüel & Kjær Type 4128 HATS*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	-0.08	600	1.58	3550	12.49
105	-0.08	630	1.81	3750	11.30
110	-0.09	670	2.19	4000	9.89
120	-0.09	710	2.48	4200	9.29
125	-0.10	750	3.00	4450	8.19
135	-0.10	800	3.82	4750	7.16
140	-0.11	840	4.51	5000	5.51
150	-0.11	890	4.92	5300	4.18
160	-0.10	945	5.05	5600	3.38
170	-0.10	1000	4.57	6000	2.52
180	-0.09	1050	4.13	6300	1.54
190	-0.09	1100	4.06	6700	0.06
200	-0.08	1200	4.37	7100	-1.39
210	-0.06	1250	4.89	7500	-1.50
225	-0.02	1350	5.34	8000	1.40
235	0.05	1400	5.48	8400	5.07
250	0.16	1500	5.26	8900	9.57
265	0.30	1600	5.02	9450	7.58
280	0.44	1700	5.40	10000	1.51
300	0.56	1800	6.41	10500	-1.36
315	0.68	1900	7.16	11000	-2.50
335	0.80	2000	8.57	12000	-4.40
355	0.90	2100	10.51	12500	-2.44
375	0.99	2250	11.90	13500	-4.66
400	1.08	2350	12.69	14000	-4.06
420	1.17	2500	13.41	15000	0.08
445	1.25	2650	13.94	16000	-1.05
475	1.30	2800	13.72	17000	-6.74
500	1.39	3000	13.35	18000	-9.86
530	1.54	3150	13.45	19000	-18.12
560	1.61	3350	12.89	20000	-12.25

Table 3: *HRTF at 180° azimuth angle, left ear - Brüel & Kjær Type 4128 HATS*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	-0.76	600	1.77	3550	5.50
105	-0.74	630	1.96	3750	4.56
110	-0.73	670	2.26	4000	3.11
120	-0.72	710	2.22	4200	1.10
125	-0.72	750	1.59	4450	-0.86
135	-0.71	800	2.11	4750	-2.84
140	-0.71	840	3.36	5000	-5.63
150	-0.71	890	2.42	5300	-8.03
160	-0.70	945	2.51	5600	-11.35
170	-0.69	1000	2.74	6000	-13.97
180	-0.68	1050	1.98	6300	-15.12
190	-0.66	1100	2.08	6700	-13.71
200	-0.64	1200	2.80	7100	-11.90
210	-0.61	1250	2.91	7500	-11.40
225	-0.58	1350	3.83	8000	-11.44
235	-0.54	1400	3.86	8400	-12.69
250	-0.47	1500	4.17	8900	-11.57
265	-0.37	1600	4.77	9450	-10.93
280	-0.24	1700	5.20	10000	-11.96
300	-0.10	1800	5.94	10500	-11.97
315	0.07	1900	7.00	11000	-10.54
335	0.23	2000	8.00	12000	-10.02
355	0.34	2100	8.01	12500	-10.39
375	0.43	2250	8.87	13500	-11.77
400	0.59	2350	9.90	14000	-14.92
420	0.83	2500	9.79	15000	-19.39
445	1.07	2650	9.48	16000	-25.98
475	1.23	2800	9.20	17000	-20.28
500	1.36	3000	8.43	18000	-23.32
530	1.51	3150	7.71	19000	-30.13
560	1.66	3350	6.87	20000	-28.83

Table 4: *HRTF at 270° azimuth angle, left ear - Brüel & Kjær Type 4128 HATS*

5.5 Tables for free-field measurement results - right ear from figure 20 to 31

All results are shown from the sine sweep method, in 1/12th octave bands.

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	-0.03	600	2.42	3550	15.80
105	-0.03	630	2.59	3750	15.01
110	-0.04	670	2.88	4000	14.19
120	-0.05	710	2.95	4200	12.96
125	-0.05	750	3.25	4450	11.98
135	-0.06	800	3.92	4750	10.86
140	-0.06	840	4.48	5000	10.09
150	-0.06	890	4.98	5300	9.61
160	-0.04	945	5.12	5600	8.79
170	-0.03	1000	4.64	6000	7.89
180	-0.02	1050	4.21	6300	6.86
190	-0.01	1100	3.87	6700	5.35
200	0.00	1200	3.72	7100	3.73
210	0.03	1250	3.81	7500	0.75
225	0.06	1350	4.12	8000	-2.34
235	0.13	1400	4.82	8400	-2.78
250	0.24	1500	4.94	8900	0.94
265	0.37	1600	4.59	9450	5.12
280	0.50	1700	5.33	10000	4.94
300	0.63	1800	7.33	10500	5.19
315	0.78	1900	9.00	11000	8.17
335	0.95	2000	10.51	12000	9.98
355	1.14	2100	12.21	12500	9.40
375	1.32	2250	14.19	13500	9.02
400	1.50	2350	15.47	14000	8.13
420	1.68	2500	15.87	15000	8.52
445	1.85	2650	16.47	16000	1.92
475	1.99	2800	16.84	17000	-4.99
500	2.16	3000	16.33	18000	-2.37
530	2.37	3150	16.35	19000	-4.12
560	2.48	3350	15.96	20000	-4.59

Table 14: *HRTF at 0° azimuth angle, right ear - Brüel & Kjær Type 4128 HATS model nr.1*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	0.66	600	6.60	3550	14.18
105	0.68	630	6.94	3750	13.86
110	0.70	670	7.36	4000	13.73
120	0.73	710	7.73	4200	14.16
125	0.79	750	7.67	4450	14.97
135	0.87	800	7.67	4750	15.72
140	0.97	840	8.47	5000	16.46
150	1.13	890	8.47	5300	17.10
160	1.29	945	8.04	5600	17.11
170	1.42	1000	8.08	6000	16.93
180	1.52	1050	7.63	6300	16.55
190	1.60	1100	7.61	6700	16.07
200	1.67	1200	8.27	7100	15.79
210	1.78	1250	8.51	7500	15.59
225	1.93	1350	8.84	8000	15.34
235	2.12	1400	8.90	8400	15.27
250	2.39	1500	9.20	8900	17.16
265	2.66	1600	9.54	9450	17.40
280	2.89	1700	9.62	10000	12.85
300	3.09	1800	10.34	10500	9.32
315	3.33	1900	10.87	11000	7.93
335	3.62	2000	11.49	12000	6.88
355	3.88	2100	12.28	12500	7.05
375	4.09	2250	13.66	13500	8.35
400	4.29	2350	14.84	14000	7.41
420	4.55	2500	15.91	15000	8.91
445	4.86	2650	16.64	16000	4.96
475	5.18	2800	16.76	17000	-3.64
500	5.51	3000	16.52	18000	-1.31
530	5.87	3150	16.08	19000	1.62
560	6.25	3350	15.03	20000	1.23

Table 15: *HRTF at 90° azimuth angle, right ear - Brüel & Kjær Type 4128 HATS model nr.1*

2

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	-0.08	600	1.65	3550	12.73
105	-0.08	630	1.84	3750	11.62
110	-0.09	670	2.04	4000	9.82
120	-0.09	710	2.46	4200	8.88
125	-0.10	750	3.08	4450	8.04
135	-0.11	800	3.63	4750	7.04
140	-0.11	840	4.46	5000	5.43
150	-0.12	890	4.92	5300	4.18
160	-0.13	945	4.94	5600	3.09
170	-0.13	1000	4.53	6000	2.04
180	-0.12	1050	4.22	6300	1.03
190	-0.12	1100	3.98	6700	-0.32
200	-0.10	1200	4.32	7100	-1.54
210	-0.07	1250	4.88	7500	-1.60
225	-0.03	1350	5.50	8000	0.15
235	0.03	1400	5.49	8400	3.54
250	0.13	1500	5.35	8900	8.47
265	0.25	1600	5.05	9450	8.01
280	0.38	1700	5.36	10000	1.02
300	0.50	1800	6.31	10500	-1.79
315	0.64	1900	7.04	11000	-2.20
335	0.78	2000	8.51	12000	-4.36
355	0.88	2100	10.32	12500	-2.32
375	0.94	2250	11.76	13500	-3.79
400	1.02	2350	12.63	14000	-3.15
420	1.13	2500	13.39	15000	0.01
445	1.23	2650	14.02	16000	-1.46
475	1.29	2800	13.77	17000	-7.93
500	1.35	3000	13.41	18000	-11.73
530	1.47	3150	13.62	19000	-20.18
560	1.56	3350	13.10	20000	-13.43

Table 16: *HRTF at 180° azimuth angle, right ear - Brüel & Kjær Type 4128 HATS model nr.1*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	-0.74	600	1.82	3550	5.89
105	-0.72	630	2.00	3750	5.27
110	-0.71	670	2.28	4000	3.67
120	-0.71	710	2.22	4200	1.93
125	-0.70	750	1.59	4450	-0.34
135	-0.69	800	2.14	4750	-1.97
140	-0.69	840	3.37	5000	-4.56
150	-0.68	890	2.41	5300	-7.15
160	-0.67	945	2.51	5600	-10.55
170	-0.66	1000	2.71	6000	-14.88
180	-0.64	1050	1.92	6300	-17.32
190	-0.63	1100	2.12	6700	-15.67
200	-0.61	1200	2.87	7100	-13.05
210	-0.59	1250	3.00	7500	-11.81
225	-0.56	1350	3.96	8000	-11.84
235	-0.52	1400	3.91	8400	-12.24
250	-0.45	1500	4.27	8900	-11.72
265	-0.34	1600	4.83	9450	-11.11
280	-0.20	1700	5.22	10000	-11.91
300	-0.05	1800	6.00	10500	-12.02
315	0.12	1900	7.16	11000	-10.63
335	0.27	2000	8.04	12000	-9.54
355	0.39	2100	8.09	12500	-9.14
375	0.49	2250	8.99	13500	-10.17
400	0.66	2350	9.88	14000	-12.35
420	0.90	2500	9.77	15000	-14.86
445	1.13	2650	9.52	16000	-28.85
475	1.29	2800	9.43	17000	-24.81
500	1.41	3000	8.87	18000	-23.54
530	1.56	3150	7.86	19000	-27.25
560	1.70	3350	7.34	20000	-28.93

Table 17: *HRTF at 270° azimuth angle, right ear - Brüel & Kjær Type 4128 HATS model nr.1*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	0.16	600	2.81	3550	15.18
105	0.15	630	2.87	3750	13.48
110	0.12	670	3.19	4000	13.25
120	0.09	710	4.02	4200	13.33
125	0.01	750	4.17	4450	13.66
135	-0.09	800	4.11	4750	13.69
140	-0.23	840	5.16	5000	12.19
150	-0.45	890	5.56	5300	11.69
160	-0.66	945	5.56	5600	10.06
170	-0.81	1000	4.73	6000	7.82
180	-0.88	1050	3.70	6300	6.26
190	-0.87	1100	2.15	6700	4.25
200	-0.79	1200	1.76	7100	0.75
210	-0.64	1250	0.99	7500	-1.93
225	-0.44	1350	1.00	8000	0.15
235	-0.23	1400	-0.01	8400	4.73
250	0.02	1500	2.56	8900	9.92
265	0.25	1600	5.07	9450	4.59
280	0.48	1700	5.62	10000	-0.37
300	0.77	1800	7.65	10500	4.05
315	1.17	1900	10.36	11000	5.71
335	1.65	2000	12.28	12000	9.02
355	1.99	2100	13.30	12500	10.73
375	2.13	2250	13.73	13500	9.11
400	2.15	2350	13.56	14000	9.60
420	2.31	2500	14.03	15000	10.00
445	2.75	2650	17.20	16000	7.78
475	3.18	2800	18.73	17000	0.67
500	3.29	3000	17.66	18000	-1.66
530	3.01	3150	17.35	19000	-12.74
560	2.74	3350	17.38	20000	-4.13

Table 9: *HRTF at 0° azimuth angle, left ear - Head Acoustics HMS II.3*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	0.78	600	6.58	3550	15.40
105	0.74	630	6.94	3750	14.79
110	0.71	670	7.46	4000	12.56
120	0.67	710	8.05	4200	14.98
125	0.60	750	8.11	4450	17.57
135	0.54	800	8.16	4750	17.31
140	0.51	840	8.91	5000	17.70
150	0.53	890	8.52	5300	18.33
160	0.65	945	7.68	5600	17.80
170	0.86	1000	7.72	6000	16.51
180	1.12	1050	7.99	6300	14.90
190	1.40	1100	8.60	6700	15.58
200	1.66	1200	9.80	7100	16.44
210	1.97	1250	10.68	7500	16.47
225	2.23	1350	11.30	8000	15.18
235	2.43	1400	10.74	8400	13.65
250	2.59	1500	10.46	8900	16.68
265	2.71	1600	10.85	9450	15.72
280	2.85	1700	11.64	10000	9.44
300	3.06	1800	11.20	10500	0.62
315	3.40	1900	10.05	11000	0.24
335	3.79	2000	7.90	12000	4.96
355	4.09	2100	6.91	12500	11.52
375	4.27	2250	9.69	13500	5.38
400	4.39	2350	13.23	14000	4.33
420	4.50	2500	14.37	15000	7.18
445	4.57	2650	16.07	16000	-5.94
475	4.68	2800	17.22	17000	4.30
500	5.09	3000	17.36	18000	9.30
530	5.73	3150	16.70	19000	3.87
560	6.25	3350	16.09	20000	12.17

Table 10: *HRTF at 90° azimuth angle, left ear - Head Acoustics HMS II.3*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	-0.02	600	0.81	3550	13.14
105	-0.07	630	1.46	3750	12.04
110	-0.12	670	2.23	4000	11.00
120	-0.19	710	2.65	4200	10.18
125	-0.32	750	2.86	4450	9.57
135	-0.47	800	3.63	4750	7.68
140	-0.64	840	4.52	5000	4.13
150	-0.83	890	4.27	5300	4.13
160	-0.91	945	3.78	5600	1.93
170	-0.86	1000	3.25	6000	1.12
180	-0.67	1050	3.28	6300	0.72
190	-0.41	1100	3.64	6700	0.18
200	-0.12	1200	4.91	7100	1.13
210	0.23	1250	5.94	7500	1.75
225	0.50	1350	5.46	8000	4.55
235	0.64	1400	4.81	8400	6.26
250	0.62	1500	4.73	8900	10.45
265	0.39	1600	4.81	9450	6.19
280	0.07	1700	6.25	10000	-2.67
300	-0.17	1800	8.06	10500	-2.80
315	-0.16	1900	8.88	11000	-1.16
335	0.13	2000	10.08	12000	1.50
355	0.44	2100	10.33	12500	3.37
375	0.52	2250	10.12	13500	1.47
400	0.33	2350	11.35	14000	-1.75
420	0.11	2500	13.19	15000	-1.40
445	0.19	2650	13.67	16000	-9.75
475	0.59	2800	14.58	17000	-6.30
500	1.04	3000	13.71	18000	-4.54
530	1.19	3150	12.17	19000	-1.52
560	0.92	3350	12.88	20000	-0.97

Table 11: *HRTF at 180° azimuth angle, left ear - Head Acoustics HMS II.3*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	-0.57	600	1.02	3550	9.85
105	-0.55	630	0.91	3750	7.43
110	-0.55	670	1.40	4000	6.01
120	-0.57	710	1.73	4200	5.35
125	-0.63	750	1.58	4450	4.04
135	-0.73	800	2.45	4750	2.42
140	-0.90	840	3.67	5000	0.97
150	-1.17	890	2.84	5300	-1.20
160	-1.45	945	2.62	5600	-3.58
170	-1.66	1000	2.81	6000	-6.96
180	-1.74	1050	2.16	6300	-11.09
190	-1.69	1100	2.70	6700	-14.39
200	-1.52	1200	3.92	7100	-13.25
210	-1.23	1250	4.46	7500	-13.05
225	-0.90	1350	5.01	8000	-10.58
235	-0.62	1400	4.45	8400	-6.80
250	-0.42	1500	4.94	8900	-5.56
265	-0.38	1600	5.19	9450	-8.18
280	-0.44	1700	3.92	10000	-14.61
300	-0.48	1800	4.45	10500	-14.58
315	-0.37	1900	5.73	11000	-17.05
335	-0.07	2000	6.70	12000	-17.17
355	0.27	2100	7.03	12500	-14.13
375	0.54	2250	7.86	13500	-14.67
400	0.83	2350	9.04	14000	-15.13
420	1.23	2500	9.86	15000	-18.67
445	1.60	2650	10.53	16000	-16.03
475	1.73	2800	10.07	17000	-16.56
500	1.66	3000	10.51	18000	-25.76
530	1.61	3150	9.79	19000	-33.09
560	1.49	3350	10.55	20000	-26.66

Table 12: *HRTF at 270° azimuth angle, left ear - Head Acoustics HMS II.3*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	0.16	600	2.82	3550	14.69
105	0.14	630	2.87	3750	12.75
110	0.12	670	3.37	4000	12.28
120	0.08	710	4.02	4200	12.19
125	0.01	750	3.96	4450	12.46
135	-0.10	800	4.02	4750	12.57
140	-0.23	840	4.70	5000	11.22
150	-0.42	890	5.02	5300	10.76
160	-0.61	945	5.30	5600	10.12
170	-0.74	1000	4.54	6000	8.55
180	-0.79	1050	3.47	6300	6.17
190	-0.78	1100	2.19	6700	3.75
200	-0.71	1200	1.39	7100	1.80
210	-0.57	1250	0.49	7500	2.72
225	-0.38	1350	-0.34	8000	3.66
235	-0.18	1400	-0.60	8400	6.63
250	0.08	1500	2.66	8900	6.39
265	0.33	1600	5.29	9450	-2.25
280	0.59	1700	5.81	10000	-1.10
300	0.88	1800	7.34	10500	4.61
315	1.26	1900	10.03	11000	3.94
335	1.72	2000	12.26	12000	7.52
355	2.06	2100	13.40	12500	9.27
375	2.21	2250	13.90	13500	8.77
400	2.24	2350	13.82	14000	9.38
420	2.37	2500	14.83	15000	8.54
445	2.75	2650	18.21	16000	5.45
475	3.18	2800	19.73	17000	-8.53
500	3.38	3000	18.55	18000	-4.03
530	3.24	3150	17.60	19000	-0.81
560	2.98	3350	17.23	20000	-0.99

Table 22: *HRTF at 0° azimuth angle, right ear - Head Acoustics HMS II.3*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	0.76	600	6.62	3550	15.65
105	0.72	630	6.89	3750	14.98
110	0.68	670	7.37	4000	13.09
120	0.64	710	7.89	4200	14.40
125	0.57	750	7.93	4450	16.78
135	0.52	800	7.91	4750	16.84
140	0.50	840	8.50	5000	17.21
150	0.54	890	8.11	5300	18.34
160	0.69	945	7.28	5600	18.36
170	0.92	1000	7.30	6000	17.55
180	1.19	1050	7.69	6300	16.29
190	1.47	1100	8.30	6700	16.45
200	1.73	1200	9.41	7100	17.64
210	2.01	1250	10.29	7500	17.55
225	2.25	1350	11.07	8000	16.73
235	2.43	1400	10.60	8400	16.70
250	2.59	1500	10.23	8900	17.96
265	2.72	1600	10.56	9450	15.75
280	2.88	1700	11.34	10000	11.57
300	3.11	1800	10.61	10500	7.72
315	3.44	1900	9.70	11000	3.43
335	3.82	2000	7.99	12000	3.56
355	4.10	2100	6.81	12500	10.99
375	4.26	2250	9.70	13500	7.86
400	4.39	2350	13.61	14000	8.00
420	4.52	2500	15.18	15000	11.73
445	4.58	2650	17.39	16000	4.64
475	4.66	2800	18.52	17000	1.05
500	5.05	3000	18.33	18000	8.35
530	5.75	3150	17.16	19000	4.33
560	6.34	3350	16.69	20000	10.50

Table 23: *HRTF at 90° azimuth angle, right ear - Head Acoustics HMS II.3*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	0.00	600	1.09	3550	12.62
105	-0.05	630	1.70	3750	11.57
110	-0.11	670	2.27	4000	10.67
120	-0.17	710	2.88	4200	9.40
125	-0.30	750	3.12	4450	8.24
135	-0.45	800	3.49	4750	6.67
140	-0.62	840	4.35	5000	3.05
150	-0.80	890	4.05	5300	2.59
160	-0.88	945	3.55	5600	0.17
170	-0.81	1000	3.15	6000	1.10
180	-0.63	1050	3.24	6300	2.25
190	-0.37	1100	3.21	6700	2.32
200	-0.08	1200	4.70	7100	3.64
210	0.24	1250	5.46	7500	3.63
225	0.50	1350	5.51	8000	7.18
235	0.62	1400	4.49	8400	9.89
250	0.58	1500	4.34	8900	10.49
265	0.35	1600	4.57	9450	4.94
280	0.05	1700	6.31	10000	-1.22
300	-0.14	1800	8.16	10500	-1.03
315	-0.09	1900	8.78	11000	-1.97
335	0.21	2000	9.89	12000	-1.37
355	0.50	2100	10.45	12500	1.55
375	0.57	2250	10.66	13500	2.04
400	0.38	2350	12.20	14000	2.04
420	0.16	2500	14.18	15000	2.82
445	0.26	2650	14.82	16000	-3.99
475	0.67	2800	15.51	17000	-8.23
500	1.10	3000	14.87	18000	-10.97
530	1.17	3150	13.12	19000	-7.82
560	0.92	3350	13.09	20000	-3.27

Table 24: *HRTF at 180° azimuth angle, right ear - Head Acoustics HMS II.3*

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	-0.53	600	1.15	3550	9.52
105	-0.52	630	0.98	3750	6.38
110	-0.52	670	1.40	4000	4.84
120	-0.53	710	1.61	4200	4.00
125	-0.59	750	1.42	4450	2.72
135	-0.70	800	2.27	4750	0.83
140	-0.85	840	3.39	5000	-0.60
150	-1.11	890	2.46	5300	-2.94
160	-1.37	945	2.30	5600	-5.33
170	-1.56	1000	2.64	6000	-9.52
180	-1.64	1050	2.20	6300	-14.49
190	-1.60	1100	2.73	6700	-21.73
200	-1.45	1200	3.86	7100	-20.67
210	-1.19	1250	4.35	7500	-18.59
225	-0.90	1350	5.11	8000	-12.04
235	-0.65	1400	4.34	8400	-6.67
250	-0.46	1500	4.77	8900	-9.34
265	-0.41	1600	4.82	9450	-11.98
280	-0.43	1700	3.21	10000	-15.61
300	-0.44	1800	3.75	10500	-11.59
315	-0.30	1900	5.41	11000	-15.18
335	0.01	2000	6.38	12000	-18.90
355	0.35	2100	6.96	12500	-16.62
375	0.62	2250	8.04	13500	-16.14
400	0.90	2350	9.63	14000	-15.42
420	1.28	2500	10.65	15000	-17.32
445	1.62	2650	11.48	16000	-16.48
475	1.74	2800	10.95	17000	-19.82
500	1.71	3000	11.11	18000	-25.57
530	1.73	3150	10.12	19000	-23.03
560	1.65	3350	10.77	20000	-22.25

Table 25: *HRTF at 270° azimuth angle, right ear - Head Acoustics HMS II.3*

Value tables from noise measurements in the diffuse field, shown as 1/3th octave bands.

Freq. (Hz)	Ampli. (dB)
100	-0.49
125	-0.28
160	0.24
200	0.41
250	0.08
315	0.70
400	1.44
500	1.76
630	3.35
800	3.46
1000	4.13
1250	5.12
1600	7.36
2000	10.70
2500	13.66
3150	13.82
4000	11.88
5000	9.14
6300	7.01
8000	6.46
10000	6.23
12500	2.24
16000	0.04
20000	-7.10

Freq. (Hz)	Ampli. (dB)
100	-0.47
125	-0.23
160	-0.32
200	-0.12
250	0.03
315	0.17
400	1.08
500	2.03
630	3.08
800	3.06
1000	3.23
1250	4.68
1600	6.43
2000	9.79
2500	13.97
3150	14.10
4000	11.63
5000	9.39
6300	7.89
8000	8.65
10000	3.82
12500	2.36
16000	1.42
20000	-0.09

Table 13: *Measurements in the diffuse field, shown as 1/3th octave bands, right ear - Brüel & Kjær Type 4128 HATS and Head Acoustics HMS II.3 respectively*

5.7 Tables for free-field measurement results - repeatability from figure 7

Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)	Freq. (Hz)	Ampli. (dB)
100	0.00*	600	0.17	3550	0.34
105	0.00*	630	0.12	3750	0.20
110	0.01	670	0.10	4000	0.16
120	0.01	710	0.11	4200	0.18
125	0.01	750	0.21	4450	0.18
135	0.01	800	0.20	4750	0.21
140	0.02	840	0.23	5000	0.27
150	0.03	890	0.24	5300	0.38
160	0.03	945	0.21	5600	0.30
170	0.03	1000	0.24	6000	0.23
180	0.04	1050	0.21	6300	0.33
190	0.04	1100	0.23	6700	0.41
200	0.06	1200	0.14	7100	0.36
210	0.07	1250	0.12	7500	0.26
225	0.06	1350	0.13	8000	0.26
235	0.06	1400	0.12	8400	0.35
250	0.09	1500	0.04	8900	0.28
265	0.09	1600	0.10	9450	0.23
280	0.10	1700	0.16	10000	0.30
300	0.10	1800	0.24	10500	0.37
315	0.10	1900	0.28	11000	0.38
335	0.11	2000	0.29	12000	0.34
355	0.12	2100	0.28	12500	0.36
375	0.12	2250	0.27	13500	0.33
400	0.13	2350	0.22	14000	0.28
420	0.13	2500	0.22	15000	0.54
445	0.12	2650	0.26	16000	0.60
475	0.14	2800	0.25	17000	0.32
500	0.14	3000	0.25	18000	0.21
530	0.15	3150	0.27	19000	0.26
560	0.16	3350	0.22	20000	0.25

Table 30: *Two HRTF measurements divided by each other to show deviation between the two, to illustrate reproducibility. HRTFs are from the Brüel & Kjær Type 4128-C HATS model nr. 1, in the frontal direction.*

* At low frequencies, the wave length is very long (e.g. 3.43m at 100 Hz) and therefore the physical changes in the setup affects less on the HRTFs measurements. 0.00 dB happens since numbers are given to two decimal places, and differences are less than 0.01 dB.