Determination of
Sound absorption in a reverberation room according to
ISO 354:2003 and ISO 20189:2018

<u>Object:</u>
Abstracta Agile

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Customer	Horda Stans Contact person: Anders Edin
Report author:	Lars Wester, LW decibel ab
Signature:	Stefan Jacob (May 9, 2023 08:26 GMT+2)
Report reviewed:	Stefan Jacob, KTH
Signature:	
Measurements carried out by:	Lars Wester, LW decibel ab
Measurement results reviewed by:	Stefan Jacob, KTH
Number of pages Report	7
Number of Appendixes	4 (s.8-13)

LW decibel offers custom solutions and products for improved acoustic and climate comfort. Through a network of reputable specialists, we offer help with everything from acoustic calculations, concept development and testing to delivery, installation, and documentation.
LW decibel cooperate with **Horda Stans** and, markets the best acoustic materials available in terms of quality and value. From these materials, we then manufacture customer-specific items and products. Everything from drawing up designs for an order to production and delivery follows quality assured processes.
We work with the Marcus Wallenberg Laboratory for Sound and Vibration Research (**MWL**) at KTH Royal Institute of Technology in Stockholm. This collaboration involves laboratory measurements and analyses, development of materials and products, and acoustic training for sales staff and product developers.

1) **Measurement date**
2021-12-21

2) **Measurement method**,
The measurements of reverberation times and calculations of **Equivalent Sound Absorption Area, A_{obj}** have been carried out according to ISO 354:2003. The measurement procedure is described in appendix 4.
Reverberation times T1 and T2 were measured using 4 different microphones and one omni directional loudspeaker in 3 different positions according to Drawing 1 below.
Evaluation range of the decays: T is derived from the time at which the decay curve first reaches 5 dB and 25 dB below the initial level (T_{20}).
Additionally, the result as **N_{10} -value** as defined by Kammarkollegiet for the measured product is presented.

3) **Test room and environment**
The test room meets the requirements on diffusion of sound field according to ISO 354:2003 6.1.3 and Annex A. Controlled December 2020.
For the measurements performed here, set 9 was used, see Appendix 1.
The Sound Absorption Area for the empty test room meets the requirements according to ISO 354:2003 6.1.4. Controlled December 2020, see Appendix 1.

Test room nr	81
Room dimensions	L:7.82 x B:6.00 x H:5.20 m
Room Volume	244 m^3
Room surface area	235 m^2

4) Instrumentation, calibration and linearity

	Model	Serial no.	Calibration date	Next calibration
Software	Spectra Plus DT			
Dynamic signal analyser	Data Translation DT9837A	1F1FB33	System calibration	
Microphone 1	B&K 4942-A-021	2360828		
Microphone 2	B&K 4942-A-021	2360829		
Microphone 3	B&K 4942-A-021	2360830		
Microphone 4	B&K 4942-A-021	2360845		
Acoustic Calibrator	Bedrock BAC1 Class1	86065	2019-08-26	2023-08
Power Amplifier	B&K Type 2706	1697904		
Climate sensor	Klima Series			
Omni directional loudspeaker	Norsonic Nor276			

<u>Calibration:</u>

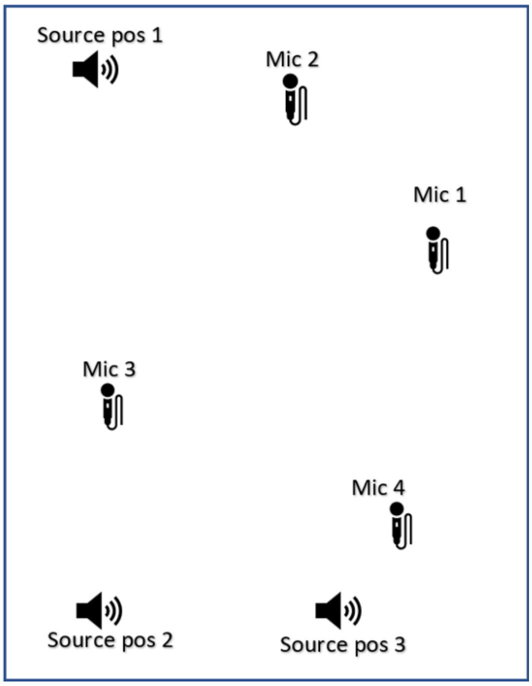
a) System calibration is performed before and after each measurement day using the acoustic calibrator.
b) Acoustic calibrator is calibrated each 2nd year.

<u>Linearity</u>

The linearity for DT8737A is performed 2023-02-14 by Stefan Jacob KTH.
The result is presented in Appendix 2.

5) **Test object Abstracta Agile**

Mounting condition:
E.1.1 Type I mounting according to ISO20189:2018 Annex E.

Units: 2 # +z {k{g#þ p ,=# 4288{4;67{46;# Surface test object: 8,79m^2 Ref. ISO 20189:2018 Annex B4 Object position >1.2m from nearest surface.	 Picture 1 Test Object mounted in the test room.
Positions of microphones, Loudspeaker and Test object in the test room. Loudspeaker Height 0.3m Pos1 1.0/6.7/0.3 Pos2 1.0/1.2/0.3 Pos3 4.2/1.2/0.3 Mic1 4.5/4.0/2.1 Mic2 2.8/6.4/1.2 Mic3 1.3/2.9/1.6 Mic4 4.8/1.2/4.0	 Drawing 1

6) Measurement Results

Equivalent Sound Absorption Area

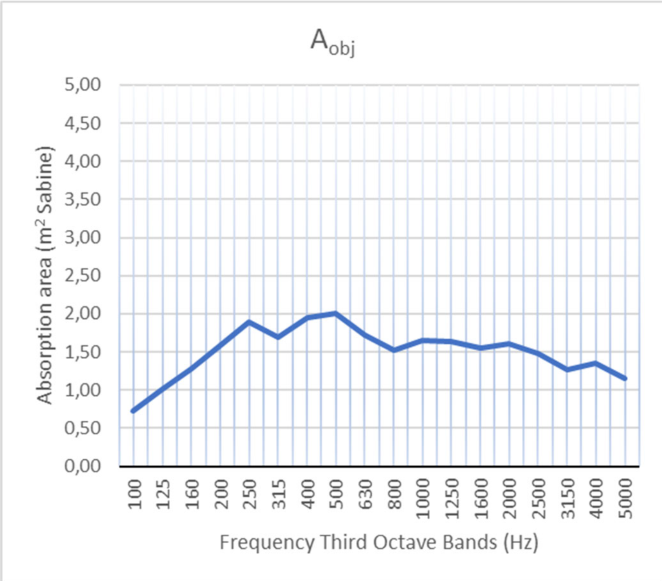


Diagram 1.
The scaling deviates from ISO 354:2003 to increase readability.

Equivalent Sound Absorption Area and N_{10}

N_{10} = 6,24

Frequency, Hz	Sound Absorption Area per object A_{obj} (m² Sabine)	
	A_{obj} Third Octave bands	A_{obj} Octave bands
100	0.73	
125	1.02	1.0
160	1.28	
200	1.57	
250	1.89	1.7
315	1.70	
400	1.96	
500	2.01	1.9
630	1.72	
800	1.53	
1000	1.64	1.6
1250	1.64	
1600	1.56	
2000	1.60	1.5
2500	1.48	
3150	1.26	
4000	1.35	1.3
5000	1.15	

Table 1

Measured Reverberation Times

Temperature 19.1°C
(Empty 19,0°C)

Relative humidity 41.1%
(Empty 41.6%)

Air pressure 997.22 hPa
(Empty 997.02 hPa)

Frequency, Hz	Empty room	Plenty Pod Medium
100	4.47	3.84
125	3.86	3.22
160	4.08	3.23
200	5.49	3.82
250	5.99	3.80
315	5.85	3.89
400	5.33	3.49
500	5.07	3.36
630	4.60	3.28
800	4.48	3.33
1000	4.34	3.19
1250	3.71	2.83
1600	3.39	2.66
2000	2.93	2.36
2500	2.51	2.09
3150	2.01	1.75
4000	1.63	1.44
5000	1.27	1.16

Table 2

Measurement uncertainty

To estimate the uncertainties in the measured sound absorption area, repeated measurements for empty room and with an absorber reference has been carried out together with Stefan Jacob at KTH.
The widths of the 95% confidence intervals are presented in Appendix 3.

The measurement results are only valid for the measured samples.
This report can only be reproduced in its entirety.

Appendix 1

Diffusivity of the Test room according to ISO 354:2003 Annex A

Report – Diffusivity of MWL room 81
Date: 20201203
Author: Stefan Jacob

Aim
The aim was the measure diffusivity of the reverberation chamber located at MWL, KTH (room 81) using the method described in ISO 354:2003 Annex A.

Materials
B&K microphone type 4942-A-24; SN 2360828,2360829,2360830,2360845
Data Translation DT8837; SN 0004F301A59F
B&K noise generator type 1405; SN 601337
B&K power amplifier type 2706; SN 1697904
Look Line D302; SN AM 14051
Driesen & Kern DKP2021-STD-0-24-1-1-0-SDT; SN K-10342
Parafon Buller White; Product Code 295778
Room 81 at MWL; KTH; L:7.82 x B:6.00 x H:5.20 = 244 m^3

Setup
Sample was put on the floor in the configuration of 2.5x3 plates yielding a total continuous surface of 2.975x3.57m (10.62m^2), which was tightly enclosed by wooden beams of the same height as the sample. The position of the sample, speaker and microphones was in accordance with ISO 354:2003, with the only notable difference that the max height of the microphone position with respect to the rooms floor was 2.5m. Bandwidth-limited white noise (f<20kHz) was generated and amplified to yield a noise level in the reverberation chamber, which was at least 20dB above the background.

Procedure
Measurements were taken on two different days, with slightly improved methodology on the second measurement occasion. According to ISO 354:2003, all removeable diffusors were taken away for the first campaign. Three measurements were taken before mounting 4 diffusor plates back into the reverberation chamber. Each measurement consisted of four random microphone positions and orientations, acquired simultaneously and lasted 10 seconds. Data was acquired at 52KS/s per channel and stored as waveform for further analysis. Noise generation was turned on before data acquisition, to obtain a steady sound field, during data acquisition noise generation was stopped (button at B&K 1405). Speaker, microphone position and orientation were changed after each measurement in accordance with ISO 354:2003. The above outlined procedure was repeated by mounting more and more diffusor plates back into the room (Set 1 to 5 in Figure 1). During the
measurements ambient air temperature, pressure and humidity was continuously monitored. On a second day more diffusers were introduced (Set 6 to 9 in Figure 1). To increase low frequency resolution (<1kHz) every measurement was repeated 10 times and averaged before decay characteristics were computed. To facilitate automatic data analysis the B&K 1405 was replaced by software generated white noise from DT8837. The rest of the procedure was identical to the first measurement campaign.

Analysis
Analysis was done in Matlab and included the following steps. Data was filtered into active bands from 500Hz – 5KHz, each band was background corrected and decay times were estimated according to ISO 354:2003. Statistical difference of the decay times between Set 9 and 8 was tested by Wilcoxon rank sum test.

Results
One set of three measurements were done for 0,4,8,12 and 17 diffusor plates mounted in the room on measurement occasion one. During the second campaign 4 fractal diffusors were placed in the room plus additional plates. All data is represented as equivalent sound absorption area (e.s.a Area / m^2)

Set	1	2	3	4	5	6	7	8	9
T / C	20.48	20.64	20.70	20.77	20.83	20.22	20.26	20.24	20.34
relH / %	55.63	53.14	52.76	52.80	52.81	45-50	45-50	45-50	45-50
P / Pa	100509	100499	100490	100486	100489	100440	100410	100386	100395

Table 1 Environmental Parameters during the measurements.

Absorption of empty room

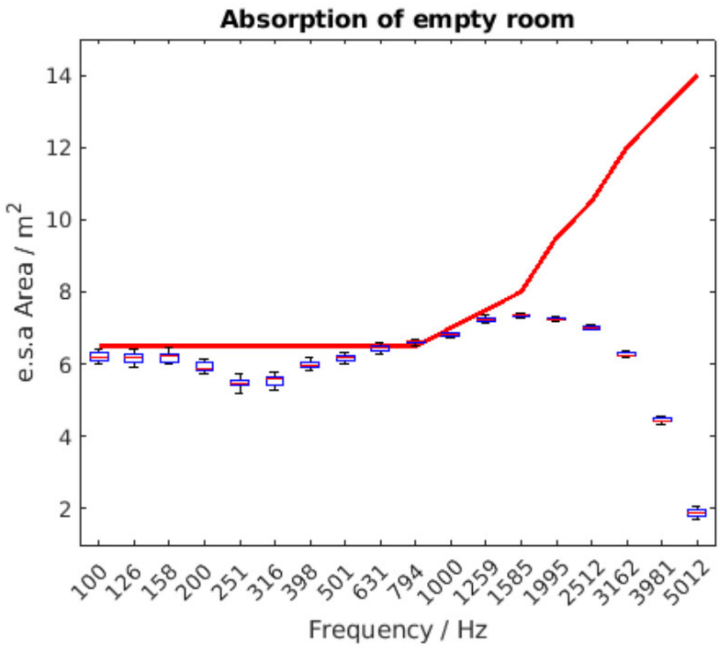


Figure 2 Equivalent sound absorption area (e.s.a Area) in third octave band of the empty room in Set 9 configuration (boxplot) and the ISO 354 limit (red line). The plot shows that the absorption of the empty room is below the limit given in ISO 354.

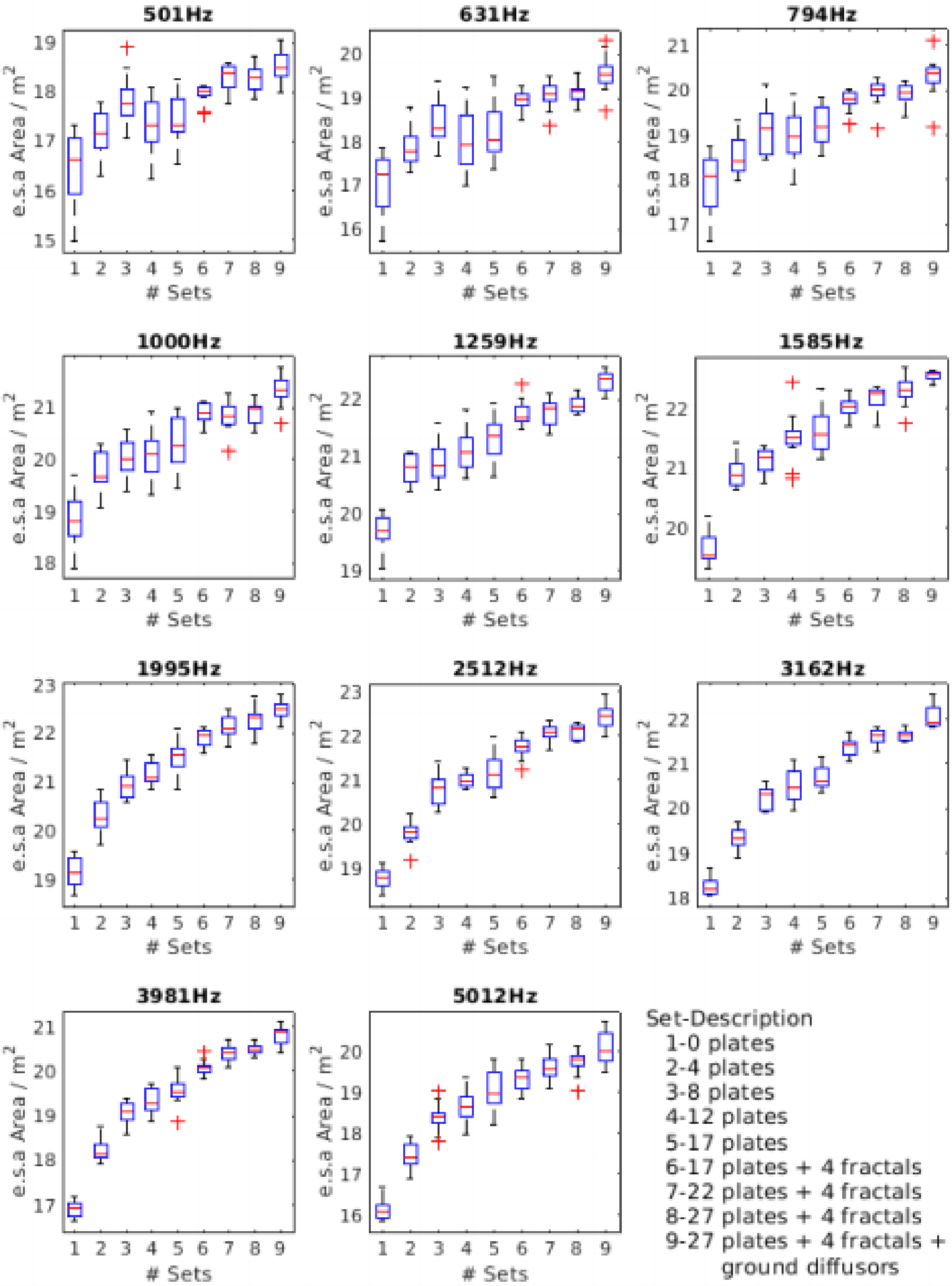


Figure 1 Equivalent sound absorption area (e.s.a Area) in third octave band and number of diffusors. E.s.a Area increases as expected for all octave bands with increasing number of diffusors. Subpanels show boxplot for the indicated third octave band. Red bar denotes the median value of the 12 microphone positions, blue box the interquartile range, whiskers the 95% data spread and red crosses the outliers.

Linearity

Measurement Report

20230214

Stefan Jacob; sjacob@kth.se; 0721486242

MWL

Abstract

Verify the amplitude linearity of ADC of an ac signal.

Materials

DUT : DT9837A; S/N 1F1FB33

Stanford Research Systems DS360; S/N 33005

Caltek Instruments CM3604; S/N H20116407

Laptop with MATLAB 2019

Method

Using a stabilized function generator and voltage dividers it is possible to check the linearity of the DUT ADCs over the entire amplitude range. For 0dB, 20dB and 40dB attenuation of the 20Vpp 983Hz sine signal the generators amplitude was decreased accordingly. The output of the generator was connected to a 99.7k Ω resistor and then to the ADC. For 60 to 160dB attenuation the generator was kept at the 0.2Vpp amplitude and second resistor (9800Ω, 813Ω, 98.1Ω, 10.5Ω, 1.4Ω and 0.05Ω) was put into series after the first one. Voltage drop over the second resistor was sampled by the ADC. The smallest voltage drop with the 0.05Ω resisor could not be resolved and was hidden in the noise floor. Fitting of the data revealed the following Gain, Confidence intervals (95%) and largest residuals.

	Gain (dB / 20dB)	Conf. Int 95%	Conf. Int. 95%	Max Residual (dB)
Ch 1	19.9879	19.7907	20.1850	0.8143
Ch 2	20.0061	19.7907	20.1850	0.9441
Ch 3	20.0030	19.7907	20.1850	0.8832
Ch 4	19.9821	19.7907	20.1850	0.7617

Results

Amplitude linearity is comparable for all 4 ADCs in the DUT and is very close to 20dB / 20dB (unity gain) for the ac signal tested. The largest residual from the linear fit is smaller than 1dB for all 4 channels.

Measurement uncertainty

Analysis Report

20230214

Stefan Jacob; sjacob@kth.se; 0721486242

MWL

Abstract

To analyze the uncertainty of the equivalent absorption area obtained by reverberation decay.

Method

Compute equivalent absorption area based on ISO 354:2003 based on 12 microphone positions and 3 source positions and compensated for environmental parameters. These measurements are repeated on the same day or different day on the 95% confidence interval is computed. Unfortunately, only 4 dataset for the empty reverberation room and 3 data sets for the sample are currently available, which is not enough for a statistically secure conclusion. Hence, only preliminary data is shown.

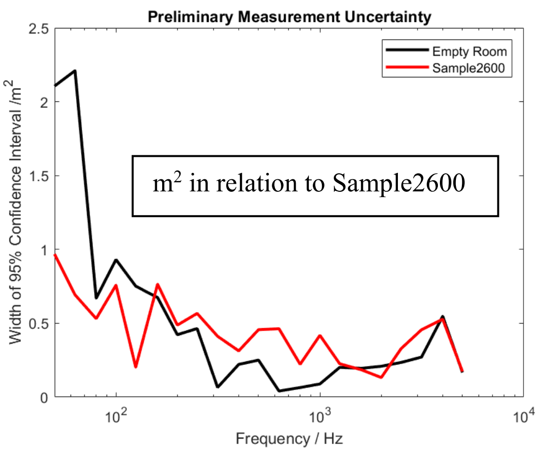
Material

Data obtained from LW decibel AB (Lars Wester), see his reports for measurement details.

Laptop with Matlab2019

Results

The width of the 95% confidence intervals is shown below for the empty room and for the sample (sample in room – sample). It can be seen that for low frequencies the confidence interval is quite large as the sound pressure produced by the speaker is very low. From 100Hz upwards the width is below 1m^2. The author does expect that the width of the confidence interval decreases as more measurements are taken.



Measurement procedure ISO 354:2003

1. Calibration of microphones.

2. Positioning of microphones (4 positions, minimum distance from any boundary surface d_{min}>1m) and sound source i.e., the omnidirectional loudspeaker (3 different positions, >3m apart) in the test room.

3. Connecting of microphones:
   Microphone1, DT3897A Channel 0, Test room connection 11A17
   Microphone2, DT3897A Channel 1, Test room connection 11A18
   Microphone3, DT3897A Channel 2, Test room connection 11A19
   Microphone4, DT3897A Channel 3, Test room connection 11A20

4. Connecting of sound source.

5. Configuration of Spectra Plus and adjustment of power amplifier gain and attenuation. (90°/30)

6. Documentation of background Sound pressure levels per third octave band in empty test room.

7. Documentation of Sound pressure levels per third octave band with broad band noise from the omnidirectional loudspeaker. Ref. ISO 354:2003 7.2.1

8. Documentation of temperature, relative humidity, and air pressure during measurements of T1.

9. Measurements of mean reverberation times T1, at each frequency 100Hz to 5kHz.
   T1 for each source position and microphone combination is measured 3 times. In total 36 measurements. (3 source positions x 4 microphone positions x 3 measurements per combination). Averaging according to ISO 354:2003 7.2.2.

10. Mounting of the test object into the test room.
    a. For plane absorbers:
       - $10m^2 < A_{object} < 12m^2$
       - Mounting type according to ISO 354:2003 Annex B
       - Not parallel to the nearest edge of the room
       - Not closer than 1m from any edge of the boundary of the room
    b. For screens, furniture and single objects intended for interior use, see ISO 20189:2018

11. Documentation of temperature, relative humidity, and air pressure during measurements of T2.

12. Measurements of mean reverberation times T2, at each frequency 100Hz to 5kHz.
    T2 for each source position and microphone combination is measured 3 times. In total 36 measurements. (3 source positions x 4 microphone positions x 3 measurements per combination). Averaging according to ISO 354:2003 7.2.2.

13. Calibration of microphones.

20220105.3 AGILE ISO354

Final Audit Report 2023-05-09

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