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Mapping the sound field of a 400 seat theatre

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ABSTRACT

Acoustic parameters of a 400 seat theatre were mapped as a function of position. The impulse response function was acquired by exciting the room from the stage with a mechanical source and measuring the response at each seat. A 1:20 scale model was constructed and comparisons between measurements of the scale model, a computer model (CATT-Acoustic), and the measured data were made. It was found that the acoustic parameters extracted from the measured data (reverberation time and strength) showed large spatial variations. Some of these variations were captured by the models.

Keywords: Room Acoustics, Spatial Variation, Computer Modeling, Scale Modeling

I. INTRODUCTION

The Lyric Theatre in Blacksburg, Virginia has a main room that seats 400 in a volume of approximately 3,000 cubic meters. It is shoebox shaped, approximately 20 meters long, 15 meters wide and 10 meters high with a balcony along the rear wall. It has been recently restored to its original circa 1929 condition. While numerous authors have studied room acoustics parameters of performance spaces, the variation within a single hall has been largely ignored, with few exceptions[1,2]. This paper reports on experiments conducted to compare the spatial distribution of measured acoustic parameters with those predicted by a scale model and CATT-Acoustic[3] computer model.

The individual location of each listener in a room can have a profound impact on what is heard.[4] Prediction of this variation is important, as the consistency of the acoustic response within a hall is indicative of its perceived quality.[5]

To study this spatial variation in parameters, the impulse response of the Lyric Theatre has been measured. The data is post-processed to obtain reverberation time, T_{60}, and a modified strength, G_m, at a one seat resolution. These results are compared to measurements made on a 1:20 scale model and to the output from the CATT-Acoustics software package.

II. METHOD

Because the room is nearly symmetric about its longitudinal axis, the impulse response was measured in the house-left seats only.

A. Data collection in the Lyric theatre

A simple mechanical impulsive source was used. Made from two boards of medium density fibreboard spring loaded to clap together when remotely triggered, the source was measured in an anechoic chamber and found to be sufficiently omnidirectional and broadband. To quickly measure the response at multiple locations within the main room, a 16 meter linear microphone array was assembled. Omnidirectional Acousticel TMS-130A and TMS-130B microphones were used at a spacing of just over 1 meter. This spacing corresponds to the distance between rows of seats. Fifteen microphones and a trigger channel from the mechanical source were acquired using National Instruments hardware.

The source was set on the proscenium stage; vibration isolation was used to prevent structural excitation of the stage. The microphone array was suspended along the length of the theatre. In this way, a data set could be collected for an entire column of seats. Data was also collected along the aisles.

For each measurement, four seconds of data were simultaneously recorded at a rate of 16kHz. Three measurements were taken at each position for a total of six hundred and seventy-five measurements at two hundred and twenty-five positions.

A nonlinear model of an exponential decay with a stationary noise floor[6] was used to estimate the reverberation time. A simple linear fit was also performed.[7] The time histories of data sets that yielded reverberation times far from the mean value were plotted and compared visually to their calculated decay curves to ensure an accurate fit. Modified relative strength, G_m [4], was evaluated for each position. Note this parameter is labeled “modified” as the source reference level was measured at a distance of 1 meter as opposed 10 meters in an anechoic chamber. While there is some deviation of this method from ISO standard 3382, the authors believe the results presented here remain valid because they focus on inter-seat variances as opposed to absolute parameters or comparisons across multiple performance spaces.

B. Data collection in the scale model

Prediction of the acoustic response of a space using scaled architectural models is common practice. Fundamental rules derived from the reduced wavelength in the model sound field have been formulated[8] and applications of modeling continue to be explored.[9] The model of the Lyric Theatre was built at one-twentieth scale. Considering absorption coefficients at the scaled frequencies, medium density fibreboard was used for the reflective surfaces, felt was used for the absorptive surfaces, and golf tees represented the seats. Using an AcoPacific 7016 1/4” microphone and type 4016 preamp, the impulse response was measured at every seat. A fabric dome tweeter was used as the source and was placed on the stage. Using WinMLS software,[10] two hundred and twenty one measurements were taken over a scaled bandwidth from 40Hz to 250Hz.

C. Simulation of the theatre response using CATT-Acoustic

CATT-Acoustic uses geometric acoustics to predict octave-band echograms based on a 3D CAD model of a room.[2] A simple model of the Lyric Theatre was programmed; absorption coefficients from reference texts were used.[4] The source location was the same as that used for the full scale tests.

III. RESULTS

Reverberation time, T_{60}, and modified strength, G_m, were obtained for each position at octave bands from 63Hz to 4000Hz. Figure 1 shows the reverberation time mapped to the seats in the main room. The general trend is the decrease in reverberation time with frequency, from 3.4s in the 63Hz band to 2.2s in the 250Hz. The CATT-Acoustic model underestimates the reverberation time. It can be seen from Figure 1(a,b,e,f) that at lower frequencies there is a significant inter-seat variation and that the scale-model is able to predict that variation.

As the modal density increases, the room response becomes increasingly uniform until a single reverberation time can be used to describe the entire room, as in Figure 1(c,d). The impulse responses in the 63Hz band at three seats are shown in Figure 2. Figure 2(a,b), reveals uniform (though unequal) decay rates in two seats. Figure 2(c) shows a fast initial decay followed by late-arriving reflections, at approximately 0.5s. This type of response yields a short T_{60}, a single number that does not capture the effect of the distinct echoes. Figure 3 illustrates the unpredictability of the spatial characteristics of a sound field when measured in the lower frequencies. The top graph overlays the similar impulse responses of two adjacent seats; the bottom graph overlays the dissimilar impulse responses of two nearby adjacent seats. This inter-seat variation reinforces that a single parameter, T_{60}, is not adequate to describe the response below the Schroeder cut–off frequency.[4]

The CATT-Acoustic model predicts shorter reverberation times than the measured data and the scale model. The inter-seat variability of the CATT-Acoustic result is also much less than that of the experimental results. This underscores geometric acoustics ineffectiveness in representing a modal sound field. Note that the software does not model below the 125Hz octave band. This is consistent with acknowledged limitations of the validity of ray-tracing based numerical models.

Maps of modified strength in the 1000Hz and 4000Hz octave bands for the theatre and computer model are shown in Figure 4. The high strength region near the top of Figure 4(a,b) clearly indicates the source position and defines the extent of the dominance of the direct field. The acoustic shadow created by the large overhang of the balcony at the rear of the room is easily discernable in the in-situ measurement maps and is also well predicted by the CATT model. The contrast between the aisle and seating areas in Figure 4(a) indicates a measurable increase of sound field strength in the aisles. The reduced absorption in the aisles is presumably responsible for this. Most striking is the presence of alternating distinct bands of high and low strength across entire rows of seats in the middle of the room and the ability of the CATT model to predict them. The researchers are unable at this time to explain the presence of these alternating bands.

IV. CONCLUSION

The response maps of the Lyric Theatre reveal the spatial variation of acoustic parameters in the room. At low frequencies, the maps show significant variation in reverberation time between seats. This can be greater than the difference between the average value of reverberation time in two different rooms. At middle and high frequencies, the inter-seat variation in reverberation time diminishes while distinct regions of low strength levels become more pronounced.

The results suggest that that computer and scale models are limited in their ability to accurately predict the response of a room in fine detail. Lack of detail in the models is often due to simplistic modeling of the geometry and boundaries.[11] The scale model predicted the inter-seat variation in T_{60} better than the ray tracing model. However the ray tracing model produced acceptable estimations of modified strength at high frequencies.

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LIST OF FIGURES

REFERENCES

[1] Chiles, S., and Barron, M. (2004) "Sound level distribution and scatter in proportionate spaces," *J. Acoust. Soc. Am.* Vol. 116, pp. 1585–1595.

[2] Siebein, G. W., Chiang, W., Cervone, R. P., Doddington, H. W. , and Schwab, W. K. (1992). "Acoustical measurements in lecture halls, theaters, and multi-use rooms," *J. Acoust. Soc. Am.* Vol. 92, pp. 2469.

[3] anon., CATT Acoustics Software for room acoustic consulting and virtual reality.

[4] Cremer, L. , and Müller, H. (1982). *Principles and aplications of room acoustics,* Applied Science Publishers, London.

[5] Beranek, L. (1996). *Concert and opera halls; How they sound,* Acoustical Society of America, Woodbury, NY.

[6] Karjalainen, M., Antsalo, P., Mäkivirta, A., Peltonen, T., and Välimäki, V. (2001). "Estimation of modal decay parameters from noisy response measurements," *AES 110th Convention*, Amsterdam, The Netherlands, May.

[7] Bies, D. A., and Hansen, C. H. (2003). *Engineering Noise Control*, Spon Press, NY.

[8] Spandöck, F. (1934). "Akustische modellversuche," *Ann. Der Phsyik* Vol. 20, pp. 345–360.

[9] Xiang, N. and Blauert, J. (1993). "Binaural scale modeling for auralisation and prediction in auditoria," *Applied Acoustics*, Vol. 38, pp. 267–290.

[10] anon., Win MLS, Measurement tool for audio, acoustics and vibrations.

[11] Lisa, M., Rindel, J. H., and Christensen, C. L. (2004) "Predicting the acoustics of ancient open-air theaters: The importance of calculation methods and geometrical details.," *Joint Baltic Nordic Acoustics Meeting,* Mariehamn Aland.


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b
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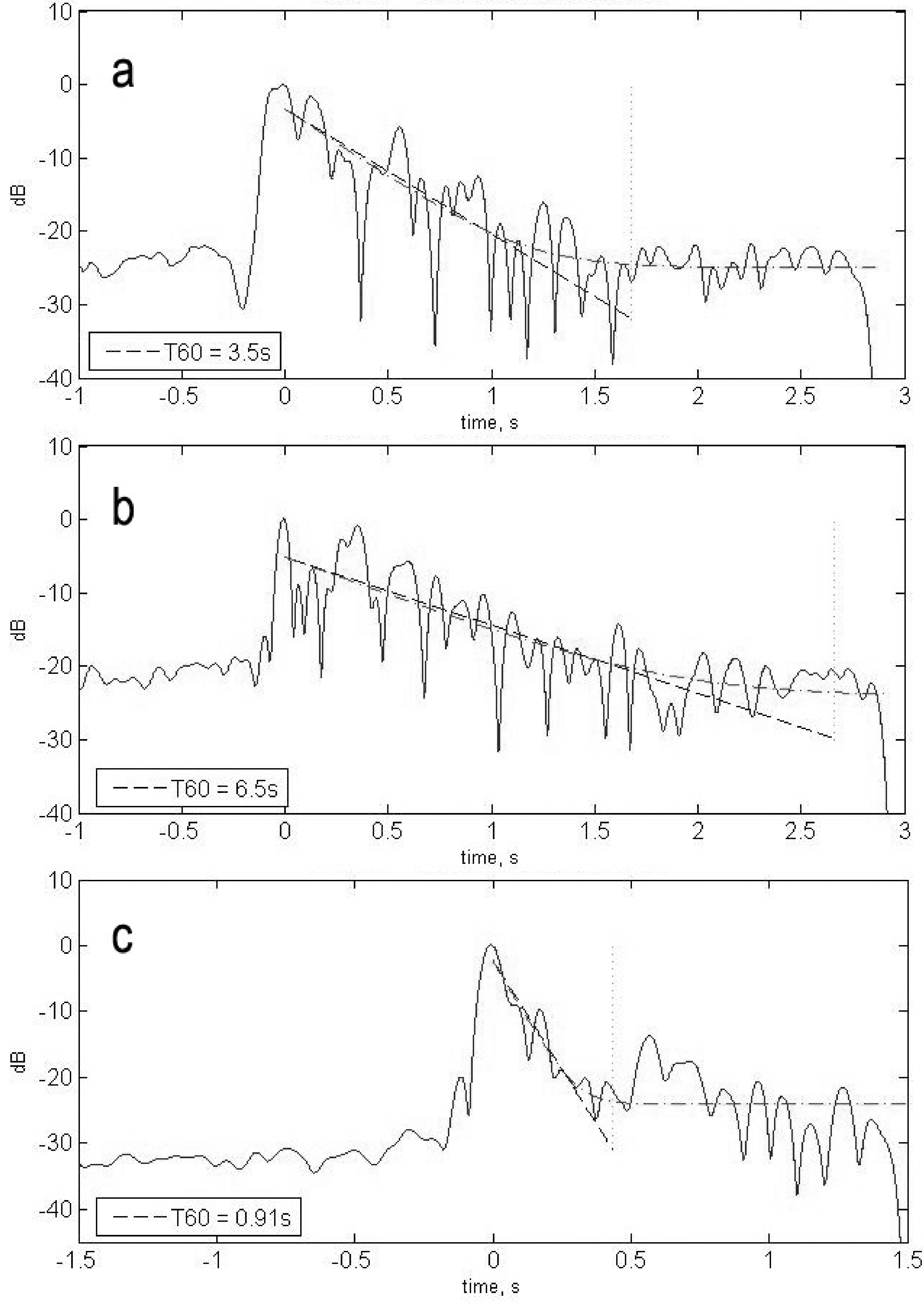
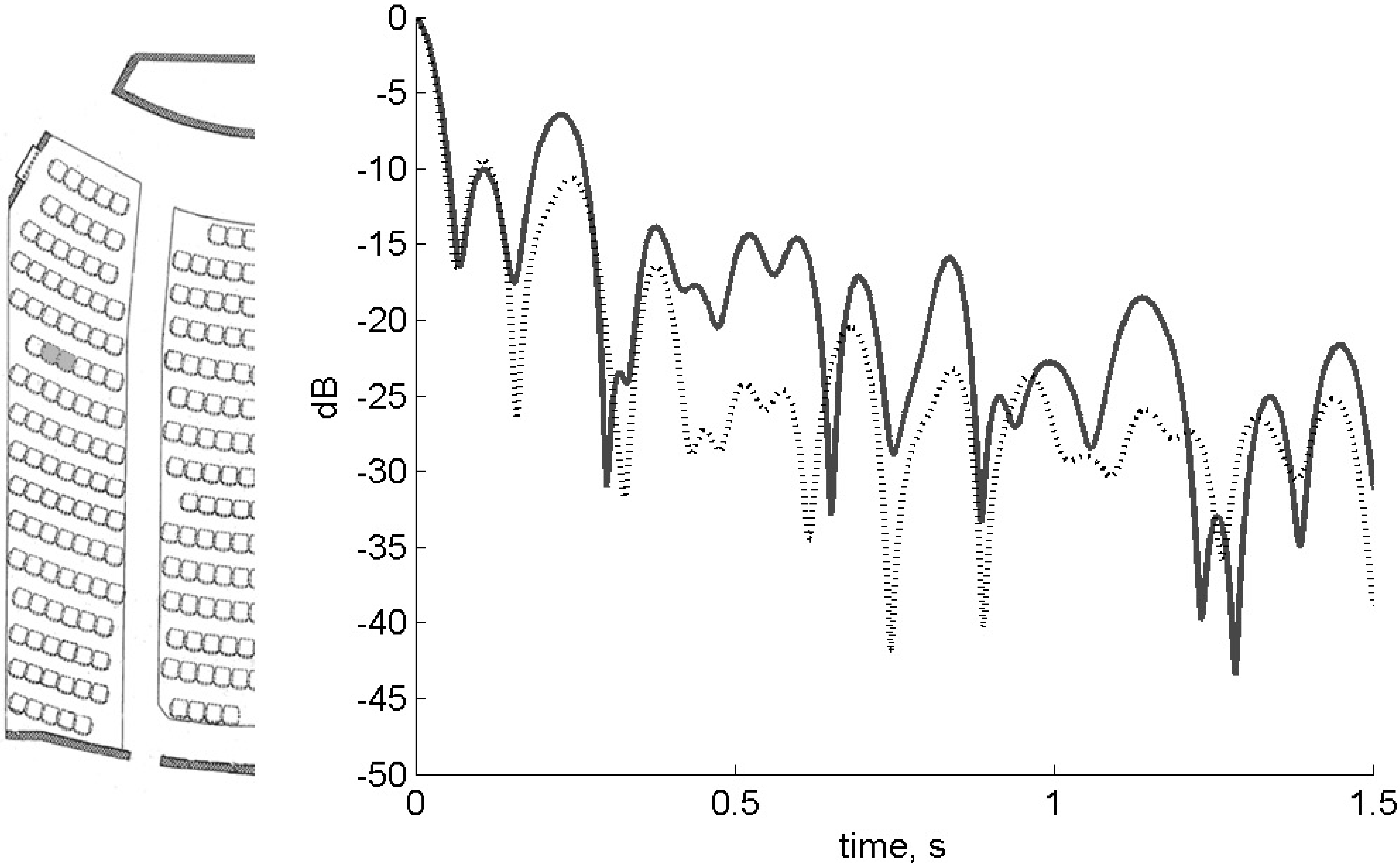
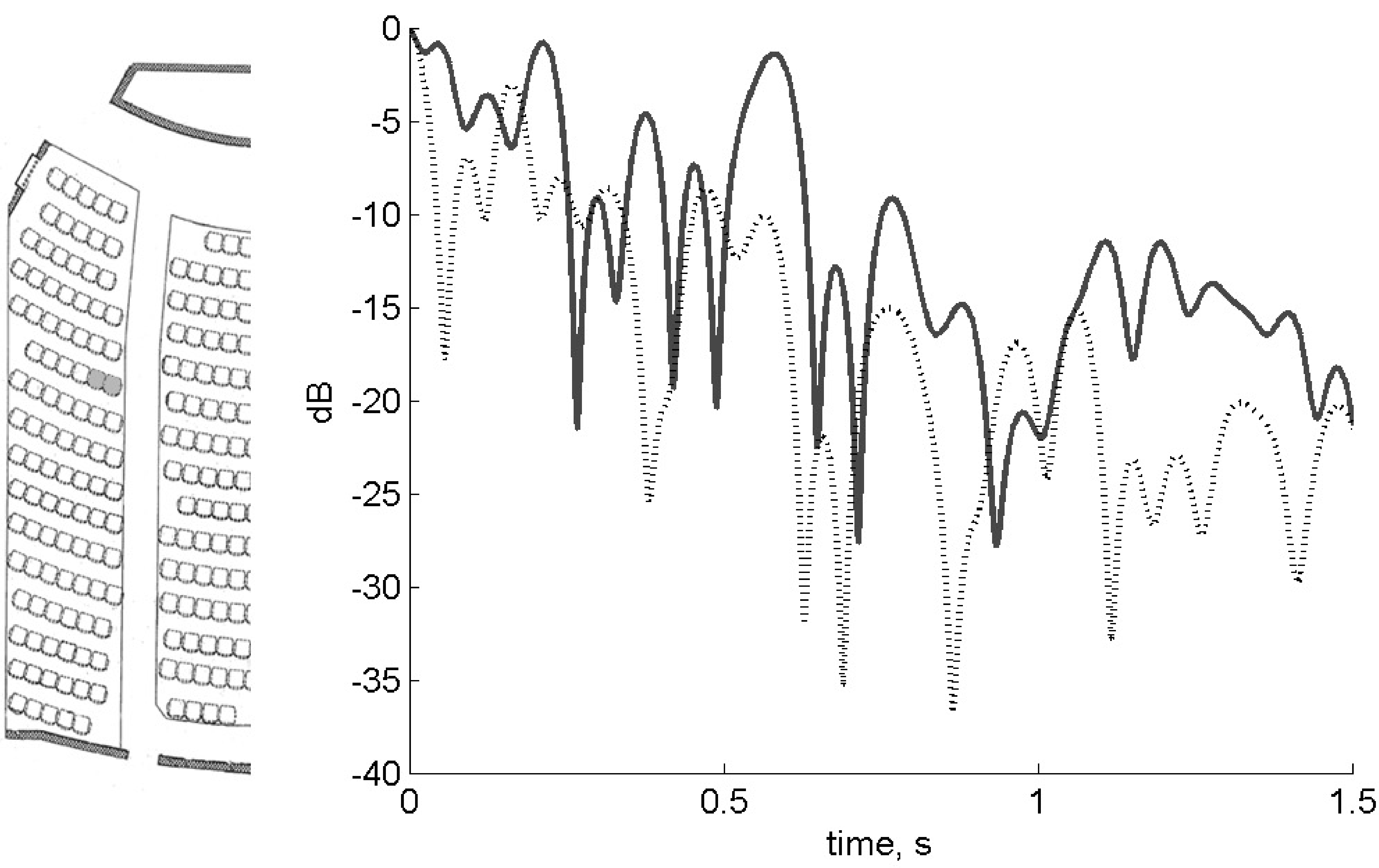


a
T60 = 3.5s
b
T60 = 6.5s
c
T60 = 0.91s
dB
time, s



0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
dB
0
0.5
1
1.5
time, s



0
-5
-10
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-35
-40
dB
0
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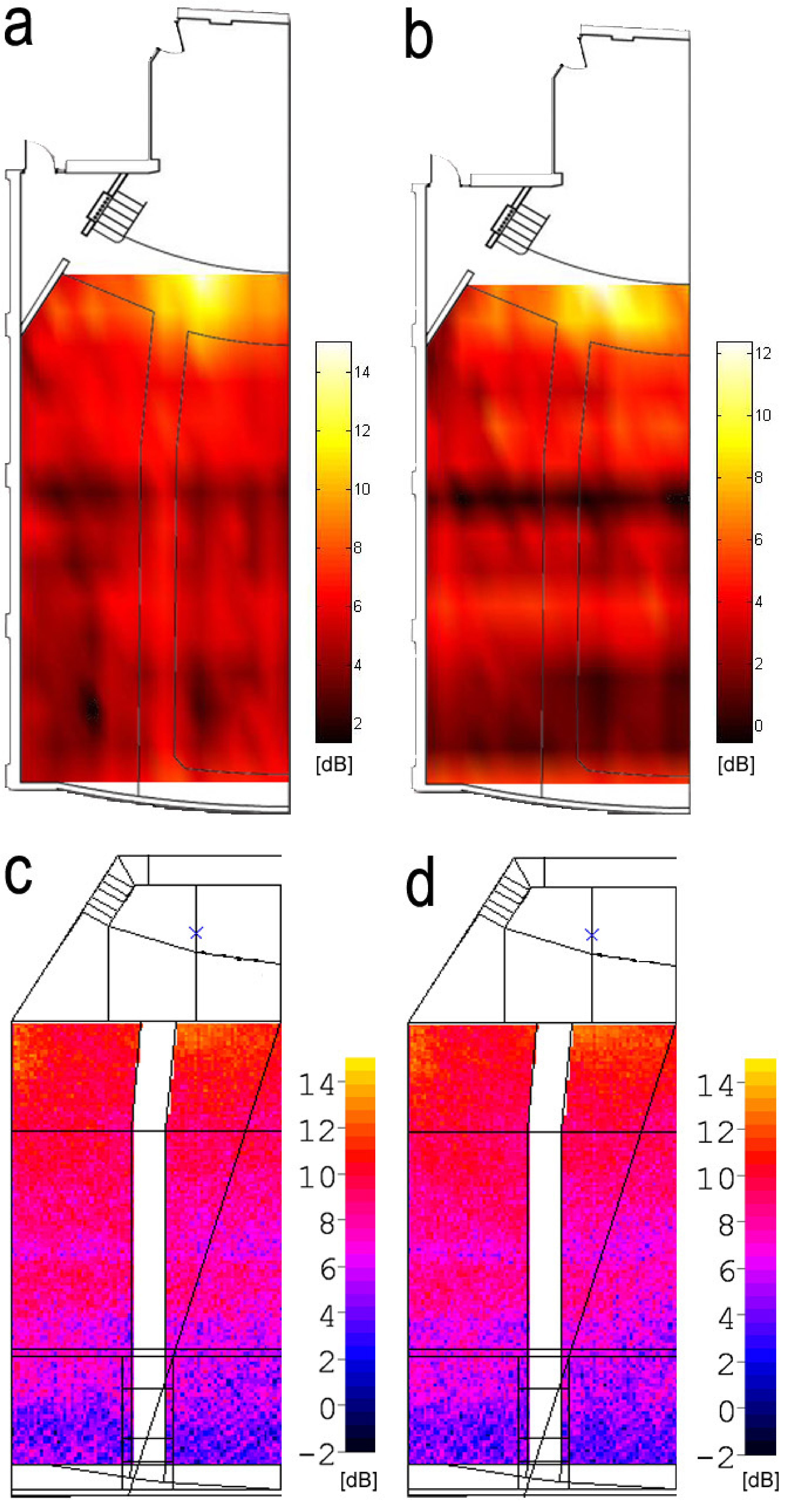
1.5
time, s



a
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14
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