Investigation on acceptable reverberation time at various frequency bands in halls that present amplified music

Subjective ratings from 25 professional musicians and sound engineers were obtained to assess two Danish rock venues of similar size and similar low frequency reverberation times, but different high frequency reverberation times. The musicians judged one hall significantly better than the other, confirming a hypothesis that rock venues can have a longer reverberation time at mid to high frequencies at least in the empty condition. A fairly long reverberation time in the 63 Hz octave band is found to be acceptable, so the 125 Hz octave band is probably the single most important band to control for amplified music.

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A Measure Based on Beamforming Power for Evaluation of Sound Field Reproduction Performance

This paper proposes a measure to evaluate sound field reproduction systems with an array of loudspeakers. The spatially-averaged squared error of the sound pressure between the desired and the reproduced field, namely the spatial error, has been widely used, which has considerable problems in two conditions. First, in non-anechoic conditions, room reflections substantially deteriorate the spatial error, although these room reflections affect human localization to a lesser degree. Second, for 2.5-dimensional reproduction of spherical waves, the spatial error increases consistently due to the difference in the amplitude decay rate, whereas the degradation of human localization performance is limited. The measure proposed in this study is based on the beamforming powers of the desired and the reproduced fields. Simulation and experimental results show that the proposed measure is less sensitive to room reflections and the amplitude decay than the spatial error, which is likely to agree better with the human perception of source localization.
Bayesian inference of the flow resistivity of a sound absorber and the room's influence on the Sabine absorption coefficients

A Bayesian analysis is applied to determine the flow resistivity of a porous sample and the influence of the test chamber based on measured Sabine absorption coefficient data. The Sabine absorption coefficient measured in a reverberation chamber according to ISO 354 is influenced by the test chamber significantly, whereas the flow resistivity is a rather reproducible material property, from which the absorptive characteristics can be calculated through reliable models. Using Sabine absorption coefficients measured in 13 European reverberation chambers, the maximum a posteriori and the uncertainty of the flow resistivity and the test chamber’s influence are estimated. Inclusion of more than one chamber’s absorption data helps the flow resistivity converge towards a reliable value with a standard deviation below 17%.
Estimation of surface impedance using different types of microphone arrays

This study investigates microphone array methods to measure the angle dependent surface impedance of acoustic materials. The methods are based on the reconstruction of the sound field on the surface of the material, using a wave expansion formulation. The reconstruction of both the pressure and the particle velocity leads to an estimation of the surface impedance for a given angle of incidence. A porous type absorber sample is tested experimentally in anechoic conditions for different array geometries, sample sizes, incidence angles, and distances between the array and sample. In particular, the performances of a rigid spherical array and a double layer planar array are examined. The use of sparse array processing methods and conventional regularization approaches are studied. In addition, the influence of the size of the sample on the surface impedance estimation is investigated using both experimental data and numerical simulations with a boundary element model. Results indicate that the small distance between the planar array and the sample favors a more robust estimation.

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ISI indexed (2013): ISI indexed yes
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Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.695 SNIP 1.642 CiteScore 1.68
Decay curves in coupled, reverberant spaces

This study investigates the effect of panel and boundary diffusers in a reverberant space. Diffusers are usually mounted in a reverberation chamber to increase the diffuse sound field as recommended in Annex A of ISO 354. The ISO is not specific about the location or the material of the panels; the standard only states that the absorption coefficient of a highly absorbing material will increase and approach a maximum value. This value is usually much higher than 1 when diffusers are added. It is also known that the reproducibility of absorption coefficient measurements in reverberation chambers is unsatisfying. This study investigates the effect of panel diffusers, in particular considering that their dispositioning in a room can create coupled spaces, decreasing the effective volume of the chamber, and leading to an overestimation of the absorption coefficient. The decay curves are measured in a small chamber with panels placed in a corner creating a coupled space. Both in the empty room as well as with $A = 3 \text{ m}^2$ absorbing porous sample on the floor, the decay curves are evaluated. Additionally, the effect of boundary diffusers is considered. The decay curves for different room configurations in the occupied (with high absorption on the floor) and unoccupied state (without any absorption) are compared. The decay curve in the occupied state without any panels or boundary diffusers has a breakpoint where the slope changes its value. This can also be observed in the unoccupied state with panels placed in the corner of the room.

General information

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Organisations: Department of Electrical Engineering, Acoustic Technology, Graz University of Technology, Rensselaer Polytechnic Institute
Diffuse sound field: challenges and misconceptions

Diffuse sound field is a popular, yet widely misused concept. Although its definition is relatively well established, acousticians use this term for different meanings. The diffuse sound field is defined by a uniform sound pressure distribution (spatial diffusion or homogeneity) and uniform incident intensity distribution (directional diffusion or isotropy). In practice, reverberation chambers are assumed to be acoustically diffuse, and important acoustic quantities measured in there, i.e., sound absorption, scattering, transmission, and power, etc. However, the measured quantities vary tremendously in different chambers because the chambers are non-diffuse in variously different ways. Therefore, good objective measures that can quantify the degree of diffusion and potentially indicate how to fix such problems in reverberation chambers are needed. Acousticians often blend the concept of mixing and diffuse sound field. Acousticians often refer diffuse reflections from surfaces to diffuseness in rooms, and vice versa. Subjective aspects of diffuseness have not been much investigated. Finally, ways to realize a diffuse sound field in a finite space are discussed.

Effect of modulation depth, frequency, and intermittence on wind turbine noise annoyance

Amplitude modulation (AM) may be an important factor for the perceived annoyance of wind turbine noise (WTN). Two AM types, typically referred to as “normal AM” (NAM) and “other AM” (OAM), characterize WTN AM, OAM corresponding to having intermittent periods with larger AM depth in lower frequency regions than NAM. The extent to which AM depth, frequency, and type affect WTN annoyance remains uncertain. Moreover, the temporal variations of WTN AM have often not been considered. Here, realistic stimuli accounting for such temporal variations were synthesized such that AM depth, frequency, and type, while determined from real on-site recordings, could be varied systematically. Listening tests with both original and synthesized stimuli showed that a reduction in mean AM depth across the spectrum led to a significant decrease in annoyance. When the spectrotemporal characteristics of the original far-field stimuli and the temporal AM variations were taken into account, the effect of AM frequency remained limited and the presence of intermittent OAM periods did not affect annoyance. These findings suggest that, at a given overall level, the AM depth of NAM periods is the most crucial AM parameter for WTN annoyance.
Experimental and numerical comparison of absorption optimization in small rooms

A vast majority of modern music is recorded and produced in small control room environments of volumes of around 50 m³. Several problems occur when controlling the room acoustics of such small spaces. First, the room modes will produce strong peaks and dips particularly at lower frequencies, and even in the sweet spot position the listening experience can be easily deteriorated. Second, when designing or refurbishing small rooms it is hard to adequately predict the reverberation time by using Sabine’s formula due to highly non-diffuse conditions and using a statistical approach below the Schroeder frequency. This project investigates experimentally changes in the room acoustic parameters by altering the positioning and orientation of porous materials in a small room, which are compared with finite element method (FEM) simulations. FEM is able to take into account the exact room geometry, boundary conditions, and phase information providing accuracy at low frequencies. Good agreements are found between measurements and simulations, confirming that FEM can be used as a design tool for optimizing absorption and acoustic parameters in small rooms.
Impedance estimation of a finite absorber based on spherical array measurements

A method to characterize the surface impedance of materials is presented. The estimation is based on pressure measurements with a spherical microphone array. These measurements are used to reconstruct the sound pressure and particle velocity on the sample’s surface, from which the material’s impedance is inferred. The accuracy of the reconstruction is improved by using compressive sensing, where the wave field is represented with only a few components, ideally an incident and a reflected wave. However, at low frequencies, diffraction from the edges contributes considerably to the sound field. This leads to a deterioration of the impedance estimation, which is clearly visible in initial experimental results. The proposed methodology makes it possible to characterize the edge effect, and subsequently compensate for it in the processing, emulating measurements on an infinite sample.

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In situ measurements of the oblique incidence sound absorption coefficient for finite sized absorbers

Absorption coefficients are mostly measured in reverberation rooms or with impedance tubes. Since these methods are only suitable for measuring the random incidence and the normal incidence absorption coefficient, there exists an increasing need for absorption coefficient measurement of finite absorbers at oblique incidence in situ. Due to the edge diffraction effect, oblique incidence methods considering an infinite sample fail to measure the absorption coefficient at large incidence angles of finite samples. This paper aims for the development of a measurement method that accounts for the finiteness of the absorber. A sound field model, which accounts for scattering from the finite absorber edges, assuming plane wave incidence is derived. A significant influence of the finiteness on the radiation impedance and the corresponding absorption coefficient is found. A finite surface method, which combines microphone array measurements over a finite sample with the sound field model in an inverse manner, is proposed. Besides, a temporal subtraction method, a microphone array method, impedance tube measurements, and an equivalent fluid model are used for validation. The finite surface method gives promising agreement with theory, especially at near grazing incidence. Thus, the finite surface method is proposed for further measurements at large incidence angles.

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Kurtosis as a diffuseness measure

This study presents a kurtosis analysis of room impulse responses as a potential room diffuseness measure. In the early part of an impulse response, sound pressure samples do not constitute a Gaussian distribution due to the direct sound and strong reflections. Such deterministic reflections are extreme events, which prevent the pressure samples from being normally distributed, leading to a high kurtosis. As the reflections are sparser and stronger, the sound field becomes less diffuse and the kurtosis systematically increases, indicating that it can be used as a diffuseness measure. The kurtosis converges to zero, as the reflection overlap becomes heavier, which is an important condition for a perfect diffuse field. Two rooms are analyzed. A small rectangular room shows that a non-uniform surface absorption distribution tends to increase the kurtosis significantly. A full-scale reverberation chamber is also tested with many different diffuser settings. Results show that the kurtosis from a broadband impulse response has a good correlation with the equivalent absorption coefficient according to ISO 354.
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On-site and laboratory soundscape evaluations of three recreational urban spaces

Soundscape quality was evaluated using four subjective psychological rating factors in three recreational urban spaces in which water and a variation of other natural and anthropogenic sound sources were present. The noise level was measured at each site during occupant peak flows and recordings for listening experiments were made simultaneously. Listeners answered questionnaires either on site or following playback of the recordings in the laboratory, with or without access to each site’s visual context. They rated their perception of loudness, acceptance, stressfulness, and comfort, along with their preference toward eight sound sources. The comfort ratings were negatively correlated with loudness and stressfulness and positively correlated with acceptance. The sound level was found to be a good predictor of these subjective parameters in the laboratory, but not on site. Moreover, the availability of the visual context in the listening experiment had no effect on the ratings. The presence of trees and water was also found to increase on-site comfort. Generally, the participants were more positive towards natural sound sources on-site. Overall, the results suggest that on-site context plays an important role for evaluating acoustic comfort in urban recreational areas.

Predicting the Sabine absorption coefficients of fibrous absorbers for various air backing conditions with a frequency-dependent diffuseness correction

Fibrous absorbers can be installed with various air backing conditions to fulfill a given low frequency acoustic requirement. Since absorber manufacturers cannot provide the absorption coefficients for all possible mounting conditions, acousticians have difficulties knowing the absorption characteristics of their own configurations. This study aims to predict the absorption coefficient for various mounting conditions from a single measurement of an arbitrary mounting condition by extracting the air flow resistivity of the test specimen and the frequency-dependent effect of the chamber on the measured absorption coefficients. With two homogeneous fibrous absorbers, the predicted absorption coefficients agree well with the measurements.
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Scattering from objects and surfaces in room acoustical simulations
In room acoustical simulations, scattering objects are often modeled as impenetrable boxes with high scattering coefficients assigned to the surfaces. In some cases, a cluster of objects is modeled as a virtual impenetrable box, such that no sound propagation can take place between the objects. Thus, the scattering only takes place on the boundary surfaces of the box and the acoustic volume of the room is reduced. Another challenge with representing scattering objects by reflecting surfaces is that it increases the number of surfaces, which greatly increases the calculation complexity for methods such as the image source method. In this paper a modeling method where the scattering from objects takes place in certain parts of the room volume is proposed. In this method, sound can still travel through scattering objects, but be partly scattered. This volume scattering method has at present been implemented in the simulation tool PARISM (Phased Acoustical Radiosity and Image Source Method). Scattering from objects and surfaces is likely to be strongly frequency dependent and the frequency dependence can depend on their sizes, shapes and structure. The importance of the frequency dependence is investigated and discussed through simulations.

Subjective evaluation of restaurant acoustics in a virtual sound environment
Many restaurants have smooth rigid surfaces made of wood, steel, glass, and concrete. This often results in a lack of sound absorption. Such restaurants are notorious for high sound noise levels during service that most owners actually desire for representing vibrant eating environments, although surveys report that noise complaints are on par with poor service. This study investigated the relation between objective acoustic parameters and subjective evaluation of acoustic comfort at five restaurants in terms of three parameters: noise annoyance, speech intelligibility, and privacy. At each location, customers filled out questionnaire surveys, acoustic parameters were measured, and recordings of restaurant acoustic scenes were obtained with a 64-channel spherical array. The acoustic scenes were reproduced in a virtual sound environment (VSE) with 64 loudspeakers placed in an anechoic room, where listeners performed subjective evaluation of noise annoyance and privacy and a speech intelligibility test for each restaurant noise background. It was found that subjective evaluations of acoustic comfort correlate with occupancy rates and measured noise levels, that survey and listening test results agreed well and that, in the VSE, speech reception thresholds were similar for the five reproduced restaurant backgrounds.
The effect of human activity noise on the acoustic quality in open plan office

A disadvantage of open plan offices is the noise annoyance. Noise problems in open plan offices have been dealt with in several studies, and standards have been set up. Still, what has not been taken into account is the effect of human activity noise on acoustic conditions. In this study, measurements of the general office noise levels and the room acoustic conditions according to ISO 3382-3 have been carried out in five open plan offices. Probability density functions of the sound pressure level have been obtained, and the human activity noise has been identified. Results showed a decrease in STI-values including the human activity noise compared to STI-values including only technical background noise as the standard recommends. Furthermore, at 500 Hz a regression analysis showed that the density of people in an room, absorption area, reverberation time as well as the ISO 3382-3 parameter D2,S have an impact on the variation in the activity noise. At 1 kHz, the technical background noise influences human activity noise positively. In both octave bands, the human activity noise level varies significantly with the office type, from a call center to a lawyer’s office.

The Effect of Objective Room Acoustic Parameters on Auditory Steady-State Responses

Verification that Hearing Aids (HA) have been fitted correctly in pre-lingual infants and hard-to-test adults is an important emerging application in technical audiology. These test subjects are unable to undergo reliable behavioral testing, so an objective method is required. Auditory steady-state responses (ASSR), recorded in a sound field is a promising technology to verify the hearing aid fitting. The test involves the presentation of the auditory stimuli via a loudspeaker, unlike the usual procedure of delivering via insert earphones. Room reverberation clearly may significantly affect the features of the stimulus important for eliciting a strong electrophysiological response, and thus complicate its detection. This study investigates the effect of different room acoustic conditions on recorded ASSRs via an auralisation approach using insert earphones. Fifteen normal-hearing listeners were tested using narrow-band (NB) CE-Chirps centered at the octave-bands of 0.5, 1.0, 2.0 and 4.0 kHz. These stimuli were convolved with impulse responses of three rooms simulated using a Green’s function approach to recreate different sound-field conditions. Comparisons with the unmodified stimuli recordings (reference condition) quantified that room acoustics significantly affects the amplitudes of the ASSRs.
Uncertainty of input data for room acoustic simulations
Although many room acoustic simulation models have been well established, simulation results will never be accurate with inaccurate and uncertain input data. This study addresses inappropriateness and uncertainty of input data for room acoustic simulations. Firstly, the random incidence absorption and scattering coefficients are insufficient when simulating highly non-diffuse rooms. More detailed information, such as the phase and angle dependence, can greatly improve the simulation results of pressure-based geometrical and wave-based models at frequencies well below the Schroeder frequency. Phase-included input data are proven to produce perceptually noticeable changes in the objective parameters, such as the sound pressure level, and loudness-based reverberation time. Surfaces should not be assumed to be locally reacting, particularly for multi-layered absorbers having air cavities. Secondly, the current measurement techniques produce uncertain input data. For example, Sabine absorption coefficients according to ISO 354 measured in reverberation chambers have a poor reproducibility. The same happens for sound scattering and transmission, which depend greatly on the test chamber. This study summarizes potential advanced absorption measurement techniques that can improve the quality of input data for room acoustic simulations. Lastly, plenty of uncertain input data are copied from unreliable sources. Software developers and users should be careful when spreading such uncertain input data. More careful citations and references to detailed information about the measurement condition may prevent from spreading uncertain room acoustic input data.

Acoustic behavior of porous ceiling absorbers based on local and extended reaction (L)
The acoustic behavior of ceiling absorbers can be predicted under different surface reaction assumptions: Local and extended reaction. This study aims to experimentally validate acoustic transfer functions near a ceiling absorber in an anechoic chamber based on the two surface reaction models. First, a ceiling absorber with two mounting conditions is modeled by equivalent fluid models, such as Delany-Bazley’s, Miki’s, and Komatsu’s model, in various ways: (1) Local vs extended reaction and (2) plane-wave vs spherical-wave incidence. For a single absorber under an echoic condition, the acoustic transfer functions for four source-receiver pairs are simulated using a pressure-based image source model, and then compared with measurements. For a rigid backing condition, both the local and extended reaction models agree well with the measurement. For an absorber backed by an air cavity, the extended reaction model agrees better at larger incidence angles at lower frequencies than the local reaction model.
Annoyance of wind-turbine noise as a function of amplitude-modulation parameters

Amplitude modulation (AM) has been suggested as an important factor for the perceived annoyance of wind-turbine noise (WTN). Two AM types, typically referred to as "normal AM" and "other AM," depending on the AM extent and frequency region, have been proposed to characterize WTN AM. The extent to which AM depth, frequency, and type affect WTN annoyance is a matter of debate. In most subjective studies, the temporal variations of WTN AM have not been considered. Here, a sinusoidally modulated WTN model accounting for temporal AM variations was used to generate realistic artificial stimuli in which the AM depth, frequency, and type, while determined from real on-site recordings, could be varied systematically. Subjective listening tests with such stimuli showed that a reduction in AM depth, quantified by the modulation depth spectrum, led to a significant decrease in annoyance. When the spectrotemporal characteristics of the original far-field stimuli were included in the model and the temporal AM variations were taken into account by varying the modulation index over time, neither AM frequency nor AM type were found to significantly affect annoyance. These findings suggest that the effect of AM parameters on WTN annoyance may depend on the intermittent nature of WTN AM.

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Authors: Ioannidou, C. (Intern), Santurette, S. (Intern), Jeong, C. (Intern)
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Characterization of diffusivity based on spherical array processing

The purpose of this study is to assess the diffuse field conditions in a reverberant space using a sound field reconstruction method based on spherical microphone array measurements. Spherical microphone arrays are particularly well suited for applications in non-anechoic enclosures, where the sound waves impinge on the array from multiple directions, as they have convenient properties such as omnidirectionality and compensable scattering from the rigid sphere. The proposed methodology makes use of a spherical equivalent source method (S-ESM) to reconstruct the sound field over a three-dimensional domain and consequently examine some of its fundamental properties: spatial distribution of sound pressure levels, particle velocity and sound intensity. The study allows for visualization of the intensity field inside a reverberant space, and successfully illustrates the behavior of the sound field in such an environment. This initial investigation shows the validity of the suggested processing and reveals interesting perspectives for future work. Ultimately, the aim is to define a proper and reliable measure of the diffuse sound field conditions in a reverberation chamber, with the prospect of improving the accuracy of sound absorption, sound power, and transmission loss measurements.
Comparing a phased combination of acoustical radiosity and the image source method with other simulation tools

A phased combination of acoustical radiosity and the image source method (PARISM) has been developed in order to be able to model both specular and diffuse reflections with angle-dependent and complex-valued acoustical descriptions of the surfaces. It is of great interest to model both specular and diffuse reflections when simulating the acoustics of small rooms with non-diffuse sound fields, since scattering from walls add to the diffuseness in the room. This room type is often seen in class rooms and offices, as they are often small rectangular rooms with most of the absorption placed on the ceiling. Here, PARISM is used for comparisons with other simulation tools and measurements. An empty, rectangular room with a suspended absorbing ceiling is used for the comparisons. It was found that including the phase information in simulations increases the spatial standard deviation, even if only the propagation phase is considered. It was furthermore found that it is difficult to match simulations with measurements, when the input data are unknown and therefore estimated.

Development and validation of a combined phased acoustical radiosity and image source model for predicting sound fields in rooms

A model, combining acoustical radiosity and the image source method, including phase shifts on reflection, has been developed. The model is denoted Phased Acoustical Radiosity and Image Source Method (PARISM), and it has been developed in order to be able to model both specular and diffuse reflections with complex-valued and angle-dependent boundary conditions. This paper mainly describes the combination of the two models and the implementation of the angle-dependent boundary conditions. It furthermore describes how a pressure impulse response is obtained from the energy-based acoustical radiosity by regarding the model as being stochastic. Three methods of implementation are proposed and investigated, and finally, recommendations are made for their use. Validation of the image source method is done by comparison with finite element simulations of a rectangular room with a porous absorber ceiling. Results from the full model are compared with results from other simulation tools and with measurements. The comparisons of the full model are done for real-valued and angle-independent surface properties. The proposed model agrees well with both the measured results and the alternative theories, and furthermore shows a more realistic spatial variation than energy-based methods due to the fact that interference is considered.
Different radiation impedance models for finite porous materials

The Sabine absorption coefficients of finite absorbers are measured in a reverberation chamber according to the international standard ISO 354. They vary with the specimen size essentially due to diffraction at the specimen edges, which can be seen as the radiation impedance differing from the infinite case. Thus, in order to predict the Sabine absorption coefficients of finite porous samples, one can incorporate models of the radiation impedance. In this study, different radiation impedance models are compared with two experimental examples. Thomasson’s model is compared to Rhazi's method when coupled to the transfer matrix method (TMM). These methods are found to yield comparable results when predicting the Sabine absorption coefficients of finite porous materials. Discrepancies with measurement results can essentially be explained by the unbalance between grazing and non-grazing sound field in the reverberation chamber. A better agreement is found when incorporating the modal decomposition method to the models.

Effects of different diffuser types on the diffusivity in reverberation chambers

Knowledge of sound absorption properties of typical building materials is essential for all tasks related to room acoustic design. The Sabine absorption coefficient is measured in a reverberation chamber according to the international standard ISO 354. It is known that inter-laboratory reproducibility of these results is poor, which leads to uncertainties in prediction and nonconformity with building contracts. It is assumed that differences in the diffuse field conditions between laboratories are the main cause of the poor reproducibility. Achieving a diffuse sound field is the most important requirement for the reverberation chamber. Diffusing elements are therefore typically installed in reverberation chambers. In this study, the effects of hanging panel diffusers and hanging spherical volume diffusers on the diffusivity of the sound field in a reverberation chamber are investigated. The sound field diffusivity is characterized based on the equivalent sound absorption area of a highly sound absorptive sample and the diffuse field factor, which is the ratio of the measured spatial standard variation of the reverberation time to the theoretical spatial standard variation under diffuse field conditions. The results indicate that the diffuse field factor, as a potential diffuse field indicator, is suitable for rough estimation of the diffuse sound field conditions but does not constitute a reliable measure of the diffusivity in a reverberation chamber.
Reproducibility of The Random Incidence Absorption Coefficient Converted From the Sabine Absorption Coefficient. Absorption coefficients measured in reverberation chambers, Sabine absorption coefficients, suffer from two major problems. Firstly, they sometimes exceed unity. Secondly, the reproducibility of the Sabine absorption coefficients is quite poor, meaning that the Sabine absorption coefficients vary largely depending on the test room. Several conversion methods for porous absorbers from the Sabine absorption coefficient to the random incidence absorption coefficient were suggested by considering the finite size of a test specimen and non-uniformly incident energy onto the specimen, which turned out to be successful in terms of the trueness. However, the reproducibility of the converted random incidence absorption coefficients has not been investigated. The present study mainly focuses on the reproducibility of the random incidence absorption coefficients that are converted from the Sabine absorption coefficients measured in 13 different chambers in a recent round-robin test, revealing that the reproducibility of the converted random incidence absorption coefficient is improved significantly compared to that of the Sabine absorption coefficient. Between the two optimization methods used, the flow resistivity optimization outperforms the surface impedance optimization in terms of the reproducibility.
Ratings:
BFI (2017): BFI-level 2
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Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
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Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.597 SNIP 1.6 CiteScore 1.05
ISI indexed (2013): ISI indexed yes
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Scopus rating (2012): SJR 0.602 SNIP 0.963 CiteScore 0.81
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Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.515 SNIP 0.918 CiteScore 0.65
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
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Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
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BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.651 SNIP 0.978
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Scopus rating (2007): SJR 0.53 SNIP 0.937
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.311 SNIP 0.862
Scopus rating (2005): SJR 0.257 SNIP 0.855
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.242 SNIP 0.639
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.365 SNIP 0.882
Web of Science (2003): Indexed yes
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Scopus rating (2001): SJR 0.23 SNIP 0.349
Web of Science (2001): Indexed yes
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Publication: Research - peer-review › Journal article – Annual report year: 2014

Sabine Absorption Coefficient Predictions Using Different Radiation Impedances of a Finite Absorber
Early in 2002 the Municipality of Rovereto, North Italy, planned the theatre restoration works, which were ended in success by reopening of the theatre on October 18th 2014 with the 9th Beethoven Symphony. The most important interventions regarded the raising of the stage tower by 5 m, the revision of the stalls floor, the refurbishing of structures and box finishing and the implementation of a new air ventilation system. During the works acoustics were monitored step by step by dedicated acoustical measures and predictions to ensure that the many changes introduced in the stage-house and in the hall did not compromise the good reputation that acoustics had among local theatre goers and musicians. In a 2006 work the authors showed the current state of the works, but at that time more was to come. In this work the problems encountered will be reviewed with special emphasis to the prediction, verification and final tuning of the impact of the stage-house on the main hall. In fact, the "as built" fly tower differed from the original design and thus an additional acoustics assessment was necessary to comply with the initial requirements. Other issues related to the acoustical properties of surfaces in the boxes seemed decisive together with the refurbishment of the original seats. Data and predictions supporting the work will be presented and the performance of this opera theatre as a concert hall will be briefly discussed too.

General information
State: Published
Organisations: Department of Electrical Engineering, Acoustic Technology, Università degli studi di Ferrara, Technical University of Denmark
Authors: Pompoli, R. (Ekstern), Prodi, N. (Ekstern), Ortega, I. (Ekstern), Jeong, C. (Intern)
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Conference: 22nd International Congress on Sound and Vibration, Florence, Italy, 12/07/2015 - 12/07/2015
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Publication date: 2015

Acoustic comfort in eating establishments
The subjective concept of acoustic comfort in eating establishments has been investigated in this study. The goal was to develop a predictive model for the acoustic comfort, by means of simple objective parameters, while also examining which other subjective acoustic parameters could help explain the feeling of acoustic comfort. Through several layers of analysis, acoustic comfort was found to be rather complex, and could not be explained entirely by common subjective parameters such as annoyance, intelligibility or privacy. A predictive model for the mean acoustic comfort for an eating establishment was obtained through linear regression, though a small sample size gave rise to discussions about the sturdiness of the model.

General information
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Organisations: Department of Electrical Engineering, Acoustic Technology, Lloyd’s Register Consulting
Authors: Svensson, D. (Ekstern), Jeong, C. (Intern), Brunskog, J. (Intern)
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BFI conference series: Forum Acusticum (5010988)
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Source: PublicationPreSubmission
An objective measure for the sensitivity of room impulse response and its link to a diffuse sound field

This study is relevant to acoustic measurements in reverberation rooms such as measurements of sound transmission, sound absorption, and sound power levels of noise sources. The study presents a quantitative measure for the diffuseness in a room, which is first introduced theoretically and subsequently examined experimentally. The sensitivity of a room due to changes in the initial conditions is quantified by measuring a pair of impulse responses in a room differing only in the sound source position. Such changes are linked to mixing and the diffuse sound field. The measure is based on the maximum of the absolute value of the cross-correlation between the time windowed sections of the two impulse responses. By integrating this quantity normalized by the energy of the impulse response of the room, a single number rating is obtained. Results based on three sets of experiments indicate that the diffusers and absorbers in the room influence the proposed sensitivity measures systematically.

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Organisations: Department of Electrical Engineering, Acoustic Technology
Authors: Prislan, R. (Ekstern), Brunskog, J. (Intern), Jacobsen, F. (Intern), Jeong, C. (Intern)
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Web of Science (2012): Indexed yes
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Scopus rating (2011): SJR 0.695 SNIP 1.642 CiteScore 1.68
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 0.754 SNIP 1.528
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 0.783 SNIP 1.717
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Description and validation of a combination of acoustical radiosity and the image source method

A model that combines image source modelling and acoustical radiosity with complex boundary conditions, thus including phase shifts on reflection, has been developed. The model is denoted Phased Acoustical Radiosity and Image Source Model (PARISM). It has been developed in order to be able to model both specular and diffuse reflections with complex-valued acoustical descriptions of the surfaces. This paper mainly describes the combination of the two models and the implementation of the angle dependent surface descriptions both in the image source model and in acoustical radiosity. It furthermore describes how a pressure impulse response is obtained from the energy based radiosity model. Validation of the image source model with real-valued boundary conditions is done by comparison with the analytical Green’s function in an enclosure. The full model is compared with measurements done in a rectangular room with a highly absorbing ceiling.

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State: Published
Organisations: Department of Electrical Engineering, Acoustic Technology, Saint-Gobain Ecophon
Authors: Marbjerg, G. H. (Intern), Jeong, C. (Intern), Brunskog, J. (Intern), Nilsson, E. (Ekstern)
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Main Research Area: Technical/natural sciences
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

Eigenbeamforming array systems for sound source localization

Microphone array technology has been widely used for the localization of sound sources. In particular, beamforming is a well-established signal processing method that maps the position of acoustic sources by steering the array transducers toward different directions electronically. The present PhD study aims at enhancing the performance of uniform circular arrays, and to a lesser extent, spherical arrays, for two- and three-dimensional localization problems, respectively. These array geometries allow to perform eigenbeamforming, beamforming based on the decomposition of the sound field in a series of orthogonal functions. In this work, eigenbeamforming is particularly developed to improve the performance of circular arrays at low frequencies. Compared to conventional delay- and-sum beamforming, the proposed technique, named circular harmonics beamforming, provides a better resolution at the expense of being more vulnerable to noise. A simple way to further improve the array performance is to flush-mount the transducers on a rigid scatterer. For a circular
array, an ideal solution is a rigid cylindrical scatterer of infinite length. Due to its impracticality, the use of a rigid spherical scatterer is recommended instead. A better visualization in the entire frequency range can be achieved with deconvolution methods, as they allow the recovery of the sound source distribution from a given beamformed map. Three efficient methods based on spectral procedures, originally conceived for planar-sparse arrays, are adapted to circular arrays. They rely on the fact that uniform circular arrays present an azimuthal response that is rather independent on the focusing direction. Finally, a method based on the combination of beamforming and acoustic holography is introduced for both circular and spherical arrays. This new approach, also expressible in terms of eigenbeamforming, extends the frequency range of operation of conventional delay-and-sum beamforming toward the low frequencies.

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Enhancing the beamforming map of spherical arrays at low frequencies using acoustic holography
Recent studies have shown that the localization of acoustic sources based on circular arrays can be improved at low frequencies by combining beamforming with acoustic holography. This paper extends this technique to the three dimensional case by making use of spherical arrays. The pressure captured by a rigid spherical array under free-field conditions is used to compute the expected pressure on a virtual and larger sphere by means of acoustic holography. Beamforming is then applied with the pressure predicted at the virtual array. Since the virtual array has a larger radius compared to the one of the physical array, the low frequencies (the ones with larger wavelength) are better captured by the virtual array, and therefore, the performance of the resulting beamforming system is expected to improve at these frequencies. The proposed method is examined with simulations based on delay-and-sum beamforming. In addition, the principle is validated with experiments.

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Influence of impedance phase angle on sound pressures and reverberation times in a rectangular room
In most room acoustic predictions, phase shift on reflection has been overlooked. This study aims to quantify the effects of the surface impedance phase angle of the boundary surfaces on room acoustic conditions. As a preliminary attempt, a medium-sized rectangular room is simulated by a phased beam tracing model, after verifying it numerically against
boundary element simulations. First, the absorption characteristic of the boundary surfaces varies uniformly from 0.2 to 0.8, but with various impedance phase angles. Second, typical non-uniform cases having hard walls and floor, but with an absorptive ceiling are investigated. The zero phase angle, which has commonly been assumed in practice, is regarded as reference and differences in the sound pressure level and early decay time from the reference are quantified. As expected, larger differences in the room acoustic parameters are found for larger impedance phase angles. Additionally, binaural impulse responses are compared in a listening test for the uniform absorption cases, revealing that non-zero impedance phase angle cases can be perceptually different from the reference condition in terms of reverberance perception. For the non-uniform settings, the change in the impedance phase angle of the ceiling does not affect the acoustic conditions significantly.

**General information**
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Organisations: Department of Electrical Engineering, Acoustic Technology, Hearing Systems, University of Sydney, Korea Advanced Institute of Science & Technology
Authors: Jeong, C. (Intern), Lee, D. (Ekstern), Santurette, S. (Intern), Ih, J. (Ekstern)
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Scopus rating (2012): SJR 0.763 SNIP 1.622 CiteScore 1.75
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Scopus rating (2011): SJR 0.695 SNIP 1.642 CiteScore 1.68
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Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 0.754 SNIP 1.528
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 0.783 SNIP 1.717
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.848 SNIP 1.633
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.865 SNIP 1.647
Modelling classroom conditions with different boundary conditions

A model that combines image source modelling and acoustical radiosity with complex boundary condition, thus including phase shifts on reflection has been developed. The model is called PARISM (Phased Acoustical Radiosity and Image Source Model). It has been developed in order to be able to model both specular and diffuse reflections with complex-valued acoustical descriptions of the surfaces. In this paper the PARISM model is used to simulate a rectangular room with most of the absorption located in the ceiling. This room configuration is typical for classroom conditions. The simulations are done using different boundary conditions in order to investigate the influence of phase shifts in reflections, the angle dependence of the reflection coefficient and the scattering coefficient. The focus of the simulations is to investigate the influence of the boundary condition on room acoustic measures which are important for evaluation of the acoustics in classrooms.

Sabine absorption coefficients to random incidence absorption coefficients

Absorption coefficients measured by the chamber method are referred to as Sabine absorption coefficients, which sometimes exceed unity due to the finite size of a specimen and non-uniform intensity in the test chamber. In this study, several methods that convert Sabine absorption coefficients into random incidence absorption coefficients for porous absorbers are investigated. Two optimization-based conversion methods are suggested: the surface impedance estimation for locally reacting absorbers and the flow resistivity estimation for extendedly reacting absorbers. The suggested conversion methods are validated with measured data.
The effect of interaural-time-difference fluctuations on apparent source width

For the perception of spaciousness, the temporal fluctuations of the interaural time differences (ITDs) and interaural level differences (ILDs) provide important binaural cues. One major characteristic of spatial perception is apparent source width (ASW), which describes the perceived width of a sound image. The temporal fluctuations of the binaural cues cause the signals at a listeners’ ears to be decorrelated. Therefore, ASW has traditionally been measured by using the interaural cross-correlation (IACC). In particular, ITD fluctuations (below 2kHz) have been suggested to be the dominant cue for the perception of ASW. However, the contribution of the ITD statistics on the percept of ASW has not yet been clarified. In the present study, the impact of ITD fluctuations in different frequency bands on the perceived ASW was investigated. In a psychoacoustic evaluation, a source signal was convolved with individual binaural room impulse responses (BRIRs) and presented to the listener via headphones. The obtained signals were passed through a gammatone filterbank with an analysis and synthesis stage which enabled the modification of the ITD fluctuation statistics in individual frequency bands. The ITD fluctuations of broadband noise stimuli were compressed while the effect of this compression on the ILD statistics was kept minimal. The IACC was kept the same for stimuli with compression below 2kHz and for the uncompressed noise which should lead to the same ASW percept in the two conditions. However, the psychoacoustic data showed a reduced ASW for the modified signals, particularly in conditions with an applied compression around 1 kHz. In contrast, above 2kHz, the compression had no effect on ASW, whereas the IACC increased. The results suggest that the broadband IACC can be a misleading objective measure of ASW and that ITD fluctuations around 1kHz are crucial for ASW perception.

General information
State: Published
Organisations: Department of Electrical Engineering, Hearing Systems, Acoustic Technology, Technical University of Denmark, Samsung Advanced Institute of Technology
Authors: Käsbach, J. (Intern), May, T. (Intern), Oskarsdottir, G. (Ekstern), Jeong, C. (Intern), Chang, J. (Ekstern)
Number of pages: 5
Publication date: 2014

The use of a reference absorber for absorption measurements in a reverberation chamber

The statistical incidence absorption coefficient is measured in a reverberation room according to ISO 354. This absorption coefficient is referred to as Sabine absorption coefficient, which assumes the chamber to be completely diffuse. It is known that the reproducibility of these results is poor and the differences in the results between laboratories are much larger than can be accepted from a jurisdictional point of view. Actions should therefore be taken to reduce the spread. The intention of this paper is to set requirements on the diffusivity of the sound field and to apply a reference absorber, which will be used for qualification of the room and correction of the results. The present research establishes the requirements for a proper design of such an absorber and its reference absorption data. The diffuse field factor was used to quantify the diffuse sound field in several reverberation rooms. Furthermore, calculations and measurements were conducted to optimise the reference absorber. A small round robin test was performed with this reference absorber in five European laboratories. The results of this research will be used in the proposal for the new ISO 354.

General information
State: Published
Organisations: Department of Electrical Engineering, Acoustic Technology, Peutz Bv
An objective measure for the sensitivity of the room impulse response

This study is relevant for a number of important acoustic measurements in reverberation rooms such as measurement of sound transmission and measurement of sound power levels of noise sources. From a pair of impulse responses measured in a room differing only in the position of the sound source, it might be possible to quantify the sensitivity of the room due to changes in initial conditions. Such changes are linked to mixing. The proposed measure is the maximum of the absolute value of the cross-correlation between the time windowed sections of the two impulse responses. By integrating this quantity normalized by the energy of the impulse response of the room, a single number rating is obtained. The proposed measure is examined experimentally and the results are discussed. The results indicate that the number of absorbers and diffusers in the room influences the proposed measures systematically.

Combination of acoustical radiosity and the image source method.

A combined model for room acoustic predictions is developed, aiming to treat both diffuse and specular reflections in a unified way. Two established methods are incorporated: acoustical radiosity, accounting for the diffuse part, and the image source method, accounting for the specular part. The model is based on conservation of acoustical energy. Losses are taken into account by the energy absorption coefficient, and the diffuse reflections are controlled via the scattering
coefficient, which defines the portion of energy that has been diffusely reflected. The way the model is formulated allows for a dynamic control of the image source production, so that no fixed maximum reflection order is required. The model is optimized for energy impulse response predictions in arbitrary polyhedral rooms. The predictions are validated by comparison with published measured data for a real music studio hall. The proposed model turns out to be promising for acoustic predictions providing a high level of detail and accuracy.

**General information**

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Authors: Koutsouris, G. I. (Intern), Brunskog, J. (Intern), Jeong, C. (Intern), Jacobsen, F. (Intern)
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Scopus rating (2014): SJR 0.788 SNIP 1.423 CiteScore 1.8
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.705 SNIP 1.966 CiteScore 2
ISI indexed (2013): ISI indexed yes
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ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
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BFI (2009): BFI-level 2
Scopus rating (2009): SJR 0.783 SNIP 1.717
Web of Science (2009): Indexed yes
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Scopus rating (2007): SJR 0.865 SNIP 1.647
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.752 SNIP 1.559
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.954 SNIP 1.749
Converting Sabine absorption coefficients to random incidence absorption coefficients.

Absorption coefficients measured by the chamber method are referred to as Sabine absorption coefficients, which sometimes exceed unity due to the finite size of a sample and non-uniform intensity in the reverberation chambers under test. In this study, conversion methods from Sabine absorption coefficients to random incidence absorption coefficients are proposed. The overestimations of the Sabine absorption coefficient are investigated theoretically based on Miki's model for porous absorbers backed by a rigid wall or an air cavity, resulting in conversion factors. Additionally, three optimizations are suggested: An optimization method for the surface impedances for locally reacting absorbers, the flow resistivity for extendedly reacting absorbers, and the flow resistance for fabrics. With four porous type absorbers, the conversion methods are validated. For absorbers backed by a rigid wall, the surface impedance optimization produces the best results, while the flow resistivity optimization also yields reasonable results. The flow resistivity and flow resistance optimization for extendedly reacting absorbers are also found to be successful. However, the theoretical conversion factors based on Miki's model do not guarantee reliable estimations, particularly at frequencies below 250 Hz and beyond 2500 Hz.

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Authors: Jeong, C. (Intern)
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  Web of Science (2015): Indexed yes
  BFI (2014): BFI-level 2
  Scopus rating (2014): SJR 0.788 SNIP 1.423 CiteScore 1.8
  Web of Science (2014): Indexed yes
Development of a pressure based room acoustic model using impedance descriptions of surfaces

If a simulation tool is to be used for the optimization of absorbent ceilings, it is important that the simulation tool includes a good description of the surface. This study therefore aims at developing a model which can describe surfaces by their impedance values and not just by their statistical absorption coefficient, thus retaining the phase and the angle dependence. The approach of the proposed model will be to calculate the pressure impulse response using a combination of the image source method and acoustic radiosity. The image source method will account for the specular reflections and acoustic radiosity will account for the diffuse reflections. This paper presents the motivation for the new model in the form of results in literature, which show the importance of retaining the angle dependence and phase information in reflections along with simple examples of angle dependent reflection from a porous absorber.
Improved low frequency room responses by considering finiteness of room boundary surfaces

For room acoustic simulations, the acoustic characteristics of room boundary surfaces are typically calculated under the assumption that the surfaces are sufficiently large. In this study, a reflection coefficient for finite surfaces is suggested and its performance is assessed through case studies involving simulation of rectangular rooms using a phased beam tracing method. The suggested reflection coefficient employs the radiation impedance of a finite surface by combining the radiation impedance of an infinitely large surface and that of the finite surface backed by an infinite rigid baffle. For 28 surface impedance values that are assigned to all the boundary surfaces, the suggested reflection coefficient is found to improve low frequency responses compared to the infinite panel theory; larger improvements are found for a more disproportionate room, more absorptive surfaces, and surfaces having larger negative phase angles of the surface impedance. A larger improvement is also found for a nonuniform absorption case than for a uniform absorption setting having a similar equivalent absorption coefficient.
Reflection and absorption coefficients for use in room acoustic simulations

Two ideas to improve the boundary conditions for room acoustic simulations are presented. First, all rooms have finite boundary surfaces, thereby a reflection coefficient for finite surfaces should be physically more suitable than that for infinitely large surfaces. Second, absorption coefficients measured by the chamber method, so-called the Sabine absorption coefficients, have certain problems to be used in geometrical acoustics simulations; one serious problem is that they often exceed unity for porous absorbers due to the finite sample size and non-uniform intensity in the test reverberation chamber. Therefore the Sabine absorption coefficients should be converted into the random incidence absorption coefficients, which never exceed unity, thus are more proper for room acoustic simulations.

General information

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Electronic versions: jeong_ask13.pdf
Room acoustic transition time based on reflection overlap
A transition time is defined based on the temporal overlap of reflected pulses in room impulse responses. Assuming specular reflections only, the temporal distance between adjacent reflections, which is proportional to the volume of a room, is compared with the characteristic width of a pulse at time t, which is mainly controlled by the absorption characteristics of the boundary surfaces of the room. Scattering, diffuse reflections, and diffraction, which facilitate the overlapping process, have not been taken into account. Measured impulse responses show that the transition occurs earlier in a room with nonuniform absorption and furniture than in a room that satisfies the underlying assumptions.

The equivalent incidence angle for porous absorbers backed by a hard surface
An equivalent incidence angle is defined as the incidence angle at which the oblique incidence absorption coefficient best approximates the random incidence absorption coefficient. Once the equivalent angle is known, the random incidence absorption coefficient can be estimated by a single experiment using a free-field absorption measurement technique with a source at the equivalent angle. This study investigates the equivalent angle for locally and extendedly reacting porous media mainly by a numerical approach: Numerical minimizations of a cost function that is the difference between the oblique incidence absorption coefficient at a specific incidence angle and the random incidence absorption coefficient. The equivalent angle is found to be around 55 under local reaction conditions, and 45 for extendedly reacting porous absorbers. As practical guidelines for measuring absorption coefficients by free-field techniques, a broad incidence angle range can be suggested: 20° to 65° for extended reaction and 40° to 65° for locally reacting porous absorbers, if an average difference of 0.05 is allowed.
Towards an enhanced performance of uniform circular arrays at low frequencies

Beamforming using uniform circular arrays of microphones can be used, e.g., for localization of environmental noise sources and for conferencing. The performance depends strongly on the characteristics of the array, for instance the number of transducers, the radius and whether the microphones are mounted on a scatterer such as a rigid cylinder or a sphere. The beamforming output improves with increasing frequency, up to a certain frequency where spatial aliasing occurs. At low frequencies the performance is limited by the radius of the array; in other words, given a certain number of microphones, an array with a larger radius will perform better than a smaller array. The aim of this study is to improve the performance of the array at low frequencies without modifying its physical characteristics. This is done by predicting the sound pressure at a virtual and larger concentric array. The propagation of the acoustic information captured by the microphones to the virtual array is based on acoustic holography. The predicted pressure is then used as input of the beamforming procedure. The combination of holography and beamforming for enhancing the beamforming output at low frequencies is examined with computer simulations and experimental results.

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Audience noise in concert halls during musical performances

Noise generated by the audience during musical performances is audible and sometimes disturbing. In this study, an attempt to estimate such audience noise was carried out. From the recordings of performances in five performance spaces (four concert halls and one opera house), probability density functions of the sound pressure levels were obtained in octave bands, which were fitted with three Gaussian distribution curves. The Gaussian distribution curve with the lowest mean value corresponds to a mixture of the technical background noise and audience generated noise, which is named the mixed background noise. Finally, the audience noise distribution is extracted by energy subtraction of the technical background noise levels measured in an empty condition from the mixed background noise levels. As a single index, L-90 of the audience noise distribution is named the audience noise level. Empirical prediction models were made using the four orchestra concert halls, revealing that the audience noise level is significantly correlated with the technical background noise level. It is therefore concluded that a relaxation of the current background noise recommendations for concert halls is not recommended. (C) 2012 Acoustical Society of America.

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Authors: Jeong, C. (Intern), Marie, P. (Ekstern), Brunskog, J. (Intern)
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Absorption and impedance boundary conditions for phased geometrical-acoustics methods

Defining accurate acoustical boundary conditions is of crucial importance for room acoustic simulations. In predicting sound fields using phased geometrical acoustics methods, both absorption coefficients and surface impedances of the boundary surfaces can be used, but no guideline has been developed on which boundary condition produces accurate results. In this study, various boundary conditions in terms of normal, random, and field incidence absorption coefficients and normal incidence surface impedance are used in a phased beam tracing model, and the simulated results are validated with boundary element solutions. Two rectangular rooms with uniform and non-uniform absorption distributions are tested. Effects of the neglect of reflection phase shift are also investigated. It is concluded that the impedance, random incidence, and field incidence absorption boundary conditions produce reasonable results with some exceptions at low frequencies for acoustically soft materials.

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ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 0.754 SNIP 1.528
Web of Science (2010): Indexed yes
Absorption boundary conditions for geometrical acoustics

Defining accurate acoustical boundary conditions is of crucial importance for room acoustic simulations. In predicting sound fields using phased geometrical acoustics methods, the absorption coefficients or surface impedances of the boundary surfaces can be used, but no guideline has been developed on which boundary condition produces the best results. In this study, various boundary conditions in terms of normal and random incidence absorption coefficients, and normal incidence surface impedances are used in a phased beam tracing model, and simulated results are validated with boundary element solutions. Two rectangular rooms with uniform and non-uniform absorption distributions are tested. It is concluded that the impedance and random incidence absorption boundary conditions produce reasonable results with some exceptions at low frequencies for acoustically soft materials.

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Electronic versions: prod21341220987267.CHJ_IN12_Papers_.pdf
A combination of the acoustic radiosity and the image source method

A combined model for room acoustic predictions is developed, aiming to treat both diffuse and specular reflections in a unified way. Two established methods are incorporated: acoustical radiosity, accounting for the diffuse part, and the image source method, accounting for the specular part. The model is based on conservation of acoustical energy. Losses are taken into account by the energy absorption coefficient, and the diffuse reflections are controlled via the scattering coefficient, which defines the portion of energy that has been diffusely reflected. The way the model is formulated allows for a dynamic control of the image source production, so that no fixed maximum order is required.

Audible reflection density for different late reflection criteria in rooms

For reasonably accurate but practical auralizations, some simplifications and approximations are needed. The main issue in the present investigation is to determine the reflection density of a room impulse response, in theory, increases so fast as a quadratic function of the elapsed time, even assuming only specular reflections. Therefore in this study, the upper threshold for audible reflection density is investigated for four different transition times of 25, 50, 75, and 100 ms through a headphone listening test. Binaural impulse responses and speech signals simulated in three rooms with different characteristics (an empty office, a lecture room, and an auditorium) are used as stimuli. Subjects are asked to increase/decrease the reflection density of a stimulus until they cannot distinguish it from the stimulus that follows the theoretical reflection density for the different transition times in the three rooms. When using binaural impulse responses, the upper limit of the audible reflection density turns out to be limited to 2800 reflections per second. For speech signals, the maximum audible reflection density is shown to be as low as 300 reflections per second, regardless of the room and transition time.

Audience noise in concert halls during musical performances

Noise generated by the audience during musical performances is audible and sometimes disturbing. In this study, an attempt to estimate such audience noise was carried out. From the recordings of performances in five performance
spaces (four concert halls and one opera house), probability density functions of the sound pressure levels were obtained in octave bands, which were fitted with three Gaussian distribution curves. The Gaussian distribution curve with the lowest mean value corresponds to a mixture of the technical background noise and audience generated noise, which is named the mixed background noise. Finally, the audience noise distribution is extracted by energy subtraction of the technical background noise levels measured in an empty condition from the mixed background noise levels. As a single index, L90 of the audience noise distribution is named the audience noise level. Empirical prediction models were made using the four orchestra concert halls, revealing that the audience noise level is significantly correlated with the technical background noise level. It is therefore concluded that a relaxation of the current background noise recommendations for concert halls is not recommended.

Effects of source and receiver locations in predicting room transfer functions by a phased beam tracing method
The accuracy of a phased beam tracing method in predicting transfer functions is investigated with a special focus on the positions of the source and receiver. Simulated transfer functions for various source-receiver pairs using the phased beam tracing method were compared with analytical Green's functions and boundary element solutions up to the Schroeder frequency in simple rectangular rooms with different aspect ratios and absorptions. Only specular reflections were assumed and diffraction was neglected. Three types of error definitions were used: average error level over a narrow band spectrum, average error level over a 1/3 octave band spectrum, and dissimilarity measure. The narrow band error and dissimilarity increased with the source-to-receiver distance but converged to a certain value as the reverberant field became dominant. The 1/3 octave band error was found to be less dependent on the source-receiver distance. The errors are increased as the aspect ratio becomes more disproportionate. By changing the wall absorption from 0.2 to 0.8 for a rectangular room, the average narrow and 1/3 octave band error are deviated by around 1.5 dB. A realistic nonuniform distribution of the absorption increases the error, which might be ascribed to wave phenomena evoked by the impedance-discontinuous boundary.
Thresholds for the slope ratio in determining transition time and quantifying diffuser performance in situ

This study is concerned with an objective measure called the slope ratio that can detect acoustic defects due to unexpected pressure increases such as strong reflections and coincidental constructive interference. The slope ratio is the ratio of the instantaneous slope to the mean slope in a decay curve. The slope ratio was suggested for determining the room acoustic transition time experimentally, but its threshold criteria have not been thoroughly investigated. The thresholds for the slope ratio, particularly for applications such as determining the room acoustic transition time and quantifying in situ diffuseness, are examined for various room impulse responses. For the tested rooms, a slope ratio threshold of 11 gives the most consistent and systematic results.

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Scopus rating (2011): SJR 0.695 SNIP 1.642 CiteScore 1.68
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
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Scopus rating (2010): SJR 0.754 SNIP 1.528
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BFI (2009): BFI-level 2
Scopus rating (2009): SJR 0.783 SNIP 1.717
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.848 SNIP 1.633
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.865 SNIP 1.647
Web of Science (2007): Indexed yes
Are binaural recordings needed for subjective and objective annoyance assessment of traffic noise?

Humans are annoyed when they are exposed to environmental noise. Traditional measures such as sound pressure levels may not correlate well with how humans perceive annoyance, therefore it is important to investigate psychoacoustic metrics that may correlate better with the perceived annoyance of environmental noise than the A-weighted equivalent sound pressure level. This study examined whether the use of binaural recordings of sound events improves the correlation between the objective metrics and the perceived annoyance, particularly for road traffic noise. Metrics based on measurement with a single microphone and on binaural sound field recordings have been examined and compared. In order to acquire data for the subjective perception of annoyance, a series of listening tests has been carried out. It is concluded that binaural loudness metrics from binaural recordings are better correlated with the subjective annoyance assessment.

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Organisations: Acoustic Technology, Department of Electrical Engineering, Hearing Systems, Technical University of Denmark, Brüel & Kjær A/S
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http://www.mixnoise2011.com/
Source: orbit
Source-ID: 282986
Publication: Research - peer-review › Article in proceedings – Annual report year: 2011

Equal autophonic level curves under different room acoustics conditions
The indirect auditory feedback from one's own voice arises from sound reflections at the room boundaries or from sound reinforcement systems. The relative variations of indirect auditory feedback are quantified through room acoustic parameters such as the room gain and the voice support, rather than the reverberation time. Fourteen subjects matched the loudness level of their own voice (the autophonic level) to that of a constant and external reference sound, under different synthesized room acoustics conditions. The matching voice levels are used to build a set of equal autophonic level curves. These curves give an indication of the amount of variation in voice level induced by the acoustic environment.
as a consequence of the sidetone compensation or Lombard effect. In the range of typical rooms for speech, the variations in overall voice level that result in a constant autophonic level are on the order of 2 dB, and more than 3 dB in the 4 kHz octave band. By comparison of these curves with previous studies, it is shown that talkers use acoustic cues other than loudness to adjust their voices when speaking in different rooms.
Guideline for Adopting the Local Reaction Assumption for Porous Absorbers in Terms of Random Incidence Absorption Coefficients

Room surfaces have been extensively modeled as locally reacting in room acoustic predictions although such modeling could yield significant errors under certain conditions. Therefore, this study aims to propose a guideline for adopting the local reaction assumption by comparing predicted random incidence acoustical characteristics of typical building elements made of porous materials assuming extended and local reaction. For each surface reaction, five well-established wave propagation models, the Delany-Bazley, Miki, Beranek, Allard-Champoux, and Biot model, are employed. Effects of the flow resistivity and the absorber thickness on the difference between the two surface reaction models are examined and discussed. For a porous absorber backed by a rigid surface, the assumption of local reaction always underestimates the random incidence absorption coefficient and the local reaction models give errors of less than 10% if the thickness exceeds 120 mm for a flow resistivity of 5000 Nm-4s. As the flow resistivity doubles, a decrease in the required thickness by 25 mm is observed to achieve the same amount of error. For an absorber backed by an air gap, the thickness ratio between the material and air cavity is important, since the thicker the cavity, the more extendedly reacting the absorber. If the absorber thickness is approximately 40% of the cavity depth, the local reaction models give errors below 10% even for a low flow resistivity case.

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Scopus rating (2015): SJR 0.617 SNIP 1.093 CiteScore 1.11
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 0.615 SNIP 1.071 CiteScore 0.89
Web of Science (2014): Indexed yes
Random incidence absorption coefficients of porous absorbers based on local and extended reaction models

Room surfaces have been extensively modeled as locally reacting in room acoustic predictions although such modeling could yield significant errors under certain conditions. Therefore, this study aims to propose a guideline for adopting the local reaction assumption by comparing predicted random incidence acoustical characteristics of typical building elements made of porous materials assuming extended and local reaction. For each surface reaction, five well-established wave propagation models, the Delany-Bazley, Miki, Beranek, Allard-Champoux, and Biot model, are employed. Effects of the flow resistivity and the absorber thickness on the difference between the two surface reaction models are examined and discussed. For a porous absorber backed by a rigid surface, the local reaction models give errors of less than 10% if the thickness exceeds 120 mm for a flow resistivity of 5000 Nm-4s. As the flow resistivity doubles, a decrease in the required thickness by 25 mm is observed to achieve the same amount of error. For an absorber backed by an air gap, the thickness ratio between the material and air cavity is important. If the absorber thickness is approximately 40% of the cavity depth, the local reaction models give errors below 10% even for a low flow resistivity case.

General information
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Room acoustic investigation of actors’ positions and orientations for various theatre configurations in a moderate-sized drama theatre

The present study is concerned with optimum positions and orientations of theatre performers when acting off-stage in a moderate-sized theatre. It is a case study in which five theatre configurations of the drama theatre, a proscenium, an arena, and three extended stage configurations, have been numerically investigated after calibrating computer models with experimental data. An analysis of a human voice pattern in a free-field concluded that a speech in a range of the azimuth angle [50, 50] with respect to the performer’s frontal direction is equally loud in a statistical sense. As a consequence of the directive human voice, an early energy ratio, Definition (D50), is higher within this azimuth angle range. By changing the orientation and/or the position of an actor, the mean D50 over the audience can be improved by more than one just noticeable difference (JND). In terms of uniformity and degree of speech intelligibility, the edge of the extended platform for the conventional and the boundary of the acting area for the arena and extended stage configurations are generally recommended.
Subjective response to foot-fall noise, including localization of the source position

Although an impact noise level is objectively evaluated the same according to current standards, a lightweight floor structure is often subjectively judged more annoying than a heavy homogeneous structure. The hypothesis of the present investigation is that the subjective judgment of impact noise is more annoying if the source position can be localized; lightweight structures have a more localized radiation than heavy structures. For the heavy structures the reverberant vibration field is dominant, therefore having a distributed radiation. A listening test is used to assess the subjective annoyance, using simulated binaural room impulse responses, with sources being a moving point source or a non-moving surface source, and rooms being a room with a reverberation time of 0.5 s or an anechoic room. The paper concludes that no strong effect of the source localization on the annoyance can be found.
Subjective Response to Foot-Fall Noise, Including Localization of the Source Position
Although an impact noise level is objectively evaluated the same according to current standards, a lightweight floor structure is often subjectively judged more annoying than a heavy homogeneous structure. The hypothesis of the present investigation is that the subjective judgment of impact noise is more annoying if the source position can be localized; lightweight structures have a more localized radiation than heavy structures. For the heavy structures the reverberant vibration field is dominant, therefore having a distributed radiation. A listening test is used to assess the subjective annoyance, using simulated binaural room impulse responses, with sources being a moving point source or a nonmoving surface source, and rooms being a room with a reverberation time of 0.5 s or an anechoic room. The paper concludes that no strong effect of the source localization on the annoyance can be found.

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Scopus rating (2015): SJR 0.617 SNIP 1.093 CiteScore 1.11
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Web of Science (2011): Indexed yes
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Scopus rating (2010): SJR 0.538 SNIP 0.876
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.544 SNIP 0.756
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.651 SNIP 0.978
Vocal effort with changing talker-to-listener distance in different acoustic environments
Talkers adjust their vocal effort to communicate at different distances, aiming to compensate for the sound propagation losses. The present paper studies the influence of four acoustically different rooms on the speech produced by 13 male talkers addressing a listener at four distances. Talkers raised their vocal intensity by between 1.3 and 2.2 dB per double distance to the listener and lowered it as a linear function of the quantity “room gain” at a rate of 3.6 dB/dB. There were also significant variations in the mean fundamental frequency, both across distance (3.8 Hz per double distance) and among environments (4.3 Hz), and in the long-term standard deviation of the fundamental frequency among rooms (4 Hz). In the most uncomfortable rooms to speak in, talkers prolonged the voiced segments of the speech they produced, either as a side-effect of increased vocal intensity or in order to compensate for a decrease in speech intelligibility.
A room acoustic transition time based on the overlap of reflected waves.

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Organisations: Acoustic Technology, Department of Electrical Engineering
Authors: Jeong, C. (Intern), Brunskog, J. (Intern), Jacobsen, F. (Intern)
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Main Research Area: Technical/natural sciences
Audience noise in performance spaces

General information
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Organisations: Department of Electrical Engineering, Acoustic Technology
Authors: Marie, P. (Ekstern), Jeong, C. (Intern), Brunskog, J. (Intern)
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Influence of the acoustic environment on the loudness of one's own voice.

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Organisations: Acoustic Technology, Department of Electrical Engineering
Authors: Pelegrin Garcia, D. (Intern), Mendizábal, O. F. (Ekstern), Brunskog, J. (Intern), Jeong, C. (Intern)
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Main Research Area: Technical/natural sciences
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2010

Non-uniform sound intensity distributions when measuring absorption coefficients in reverberation chambers using a phased beam tracing

Measured absorption coefficients in reverberation chambers often differ from theoretical random incidence absorption coefficients, because ideal assumptions for the theoretical random incidence absorption coefficient are not fulfilled during measurements in actual reverberation chambers. Therefore sound intensity distributions on absorber under measurement conditions have been simulated using a phased beam tracing, and used as correction functions for reducing discrepancies between the measured and theoretical absorption coefficients. Two reverberation rooms were investigated by assuming that a test specimen was attached to a vertical surface and the floor. The frequency-dependent sound intensity distributions on absorbers were found to be affected by the reverberation chamber geometry and dimensions, the absorption capability of the specimen, and the placement of the specimen. High frequency intensity distributions above 1 kHz were similar for all studied cases, but some variations in low frequency intensity distributions were observed. If the non-uniform intensity distribution and a finite size effect are taken into account for correcting the theoretical absorption coefficients, a good agreement is found between corrected and measured statistical absorption coefficients. The non-uniform sound intensity can account for the discrepancy at high frequencies.

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Obtaining a frequency independent reverberation time in listening rooms.

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Authors: Adelman-Larsen, N. W. (Ekstern), Jeong, C. (Intern), Liu, J. (Ekstern)
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Room acoustic transition time based on reflection overlap
A transition time is defined based on the temporal overlap of reflected pulses in room impulse responses. Assuming specular reflections only, the temporal distance between adjacent reflections, which is proportional to the volume of a room, is compared with the characteristic width of a pulse at time t, which is mainly controlled by the absorption characteristics of the boundary surfaces of the room. Scattering, diffuse reflections, and diffraction, which facilitate the overlapping process, have not been taken into account. Measured impulse responses show that the transition occurs earlier in a room with nonuniform absorption and furniture than in a room that satisfies the underlying assumptions.

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Authors: Jeong, C. (Intern), Brunskog, J. (Intern), Jacobsen, F. (Intern)
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Absorption coefficients of standing audiences in halls

General information
A Correction of Random Incidence Absorption Coefficients for the Angular Distribution of Acoustic Energy under Measurement Conditions

Most acoustic measurements are based on an assumption of ideal conditions. One such ideal condition is a diffuse and reverberant field. In practice, a perfectly diffuse sound field cannot be achieved in a reverberation chamber. Uneven incident energy density under measurement conditions can cause discrepancies between the measured value and the theoretical random incidence absorption coefficient. Therefore the angular distribution of the incident acoustic energy onto an absorber sample should be taken into account. The angular distribution of the incident energy density was simulated using the beam tracing method for various room shapes and source positions. The averaged angular distribution is found to be similar to a Gaussian distribution. As a result, an angle-weighted absorption coefficient was proposed by considering the angular energy distribution to improve the agreement between the theoretical absorption coefficient and the reverberation room measurement. The angle-weighted absorption coefficient, together with the size correction, agrees satisfactorily with the measured absorption data by the reverberation chamber method. At high frequencies and for large samples, the averaged weighting corresponds well with the measurement, whereas at low frequencies and for small panels, the relatively flat distribution agrees better.

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Main Research Area: Technical/natural sciences
A note on the proper frequency resolution for the room transfer function in the phased beam tracing method

In the simulation of acoustic response of a room, one cannot satisfactorily estimate the transfer function or the impulse response with a sparse frequency resolution. We have studied about the frequency resolution for a satisfactory estimation of room transfer function or the reverberation time using the phased beam tracing method. In order to investigate what happens with the frequency resolution, a number of frequency resolution (0.01-1 Hz), which are usually employed in the numerical analysis, was tested for a room model. It was found that the total accumulated phase in a transfer function and the late part of an impulse response of a room are influenced by the frequency resolution. Main reason for the difference is the correct detection of non-minimum phase zeros, depending on the frequency resolution. A criterion for a proper frequency resolution was suggested by considering the modal density of three-dimensional space. When a sparse dataset was initially given, we showed that cubic spline interpolation can be used to enhance the precision of detection for non-minimum phase zeros. (C) 2007 Elsevier Ltd. All rights reserved.
A room acoustic investigation of an actor's position and orientation for drama performances

This study is concerned with optimum positions and orientations of theatre performers when acting off stage. Five audience settings of a drama theatre; a proscenium, an arena and three extended stages have been numerically investigated after a calibration. An analysis of a human voice pattern in a free-field concludes that the sound pressure levels in the range of the azimuth angle [-50º, 50º] with respect to the performer's frontal direction are equally loud. This holds irrespective of frequency and the elevation angle. Although this optimum speech aperture angle (OSAA) is based on the free-field speech directivity, fairly uniform spatial distributions of D50 were found within the OSAA range for most theatre settings. Among several orientations of the actor tested, an orientation based on the OSAA results in the highest speech intelligibility. For an actor on the extended stage, the verge of the stage gives the best results. When the actor performs among the audience in an U-shaped or arena configurations, the boundary of the acting area is generally recommended rather than the central region.

A study on the sound quality evaluation model of mechanical air-cleaners

In operating the air-cleaner for a long time, people in a quiet enclosed space expect low sound at low operational levels for a routine cleaning of air. However, in the condition of high operational levels of the cleaner, a powerful yet nonannoying sound is desired, which is connected to a feeling of an immediate cleaning of pollutants. In this context, it is important to evaluate and design the air-cleaner noise to satisfy such contradictory expectations from the customers. In this study, a model for evaluating the sound quality of air-cleaners of mechanical type was developed based on objective and subjective analyses. Sound signals from various aircleaners were recorded and they were edited by increasing or decreasing the loudness at three wide specific-loudness bands: 20-400 Hz (0-3.8 barks), 400-1250 Hz (3.8-10 barks), and 1.25- 12.5 kHz bands (10-22.8 barks). Subjective tests using the edited sounds were conducted by the semantic differential method (SDM) and the method of successive intervals (MSI). SDM tests for seven adjective pairs were conducted to find the relation between subjective feeling and frequency bands. Two major feelings, performance and annoyance, were factored out from the principal component analysis. We found that the performance feeling was related to both low and high frequency bands, whereas the annoyance feeling was related to high frequency bands. MSI tests using the seven scales were conducted to derive the sound quality index to express the severity of each perceptive descriptor. Annoyance and performance indices of air-cleaners were modeled from the subjective responses of the juries and the measured sound quality metrics: loudness, sharpness, roughness, and fluctuation strength. The multiple regression method was employed to generate sound quality evaluation models. Using the developed indices, sound quality of the measured data was evaluated and compared with the subjective data. The difference between predicted and tested scores was less than 0.5 points. © 2009 by ASME.
Effects of nearfield waves and phase information on the vibration analysis of curved beams

General information
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Organisations: Acoustic Technology, Department of Electrical Engineering
Reconstruction of Sound Source Pressures in an Enclosure Using the Phased Beam Tracing Method

Source identification in an enclosure is not an easy task due to complicated wave interference and wall reflections, in particular, at mid-high frequencies. In this study, a phased beam tracing method was applied to the reconstruction of source pressures inside an enclosure at medium frequencies. First, surfaces of an extended source are divided into reasonably small segments. From each source segment, one beam is projected into the field and all emitted beams are
traced. Radiated beams from the source reach array sensors after traveling various paths including the wall reflections. Collecting all the pressure histories at the field points, source-observer relations can be constructed in a matrix-vector form for each frequency. By multiplying the measured field data with the pseudo-inverse of the calculated transfer function, one obtains the distribution of source pressure. An omni-directional sphere and a cubic source in a rectangular enclosure were taken as examples in the simulation tests. A reconstruction error was investigated by Monte Carlo simulation in terms of field point locations. When the source information was reconstructed by the present method, it was shown that the sound power of the source in an enclosure could be estimated.

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Sound intensity on an absorber in reverberation conditions

When the source is enclosed by room surfaces, it is not easy, though not totally impossible, to apply conventional modal methods for source identification. This is because there are too many complicated wave interferences and effects of wall impedance, in particular at medium frequencies. The phased beam tracing method was suggested as a fast and efficient acoustic simulation tool at the medium frequencies in an enclosure, which overcomes the defects of geometrical acoustics techniques. In this study, the phased beam tracing method, implemented in its inverse form, was applied to the identification of the acoustic sources inside a chamber. In the simulation tests, spherical and rectangular shaped sources operating in a room were taken as examples. When the source pressure distribution was reconstructed by this numerical inverse technique, the sound power spectrum radiated from the source could be estimated by eliminating the contribution from surface reflections. Reconstruction error was investigated by the Monte Carlo simulation in terms of the signal-to-noise ratio.
An Approximate Treatment of Reflection Coefficient in the Phased Beam Tracing Method for the Simulation of Enclosed Sound Fields at Medium Frequencies

The phased beam tracing method (PBTM) was suggested as a medium-frequency simulation technique for the calculation of impulse response, although main assumptions of geometric acoustics still hold. The phased method needs the reflection coefficient for characterizing the acoustic property of a surface and the complex wave number for describing the propagation characteristics. In this study, two types of approximate real reflection coefficients derived from the measured absorption coefficient were tested for a practical applicability. As a test example, pressure impulse responses and energy impulse responses computed from the PBTM were compared with those from the measurement and the ordinary beam tracing method. The PBTM employing the approximate reflection coefficients greatly increased the accuracy of the prediction compared to the ordinary beam tracing method, in particular at the medium-frequency range in octave bands above the Schroeder cutoff frequency. A comparison was made between angle-dependent and angle-independent reflection coefficients in the calculation of acoustic measures. Although the angle-dependent reflection coefficient yielded best matched results with measured data, the simple angle-independent reflection coefficient can be also used with a reasonably good precision.
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On the Errors of the Phased Beam Tracing Method for the Room Acoustic Analysis

To overcome the mid frequency limitation of geometrical acoustic techniques, the phased geometrical method was suggested by introducing the phase information into the sound propagation from the source. By virtue of phase information, the phased tracing method has a definite benefit in taking the interference phenomenon at mid frequencies into account. Still, this analysis technique has suffered from difficulties in dealing with low frequency phenomena, so called, wave nature of sound. At low frequencies, diffraction at corners, edges, and obstacles can cause errors in simulating the transfer function and the impulse response. Due to the use of real valued absorption coefficient, simulated results have shown a discrepancy with measured data. Thus, incorrect phase of the reflection characteristic of a wall should be corrected. In this work, the uniform theory of diffraction was integrated into the phased beam tracing method (PBTM) and the result was compared to the ordinary PBTM. By changing the phase of the reflection coefficient, effects of phase information were investigated. Incorporating such error compensation methods, the acoustic prediction by PBTM can be further extended to low frequency range with improved accuracy in the room acoustic field.

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Consideration of Wall Reflection and Diffraction in the Room Acoustic Prediction Using the Phased Beam Tracing Method

The geometrical acoustics methods have been used to simulate the acoustics of rooms at high frequencies whereas the wave based methods have been devoted to calculate the low frequency response. The modified method, so called phased geometrical acoustics technique, was suggested for the extension of the applicability of the geometrical methods to mid frequency. Several studies on this method have demonstrated a good possibility to analyze the sound field in an enclosure at mid frequency. In this study, further considerations on wall reflection and diffraction have been investigated. The main suggestions are the use of approximated reflection coefficient and the integration with the theory of diffraction. This study aimed to improve the precision of the present method in mid frequency range and extend the applicability to the low frequency below Schroeder cutoff frequency. Because this method is originated from the geometrical acoustics, the wave-particle duality can be discussed by comparing with result from modal method. The calculation parameters were thoroughly investigated. The number of beams and the frequency resolution were proved to be the most important parameters in the analysis and consequently the guidelines were suggested for these parameters. The approximate angle-dependent/independent reflection coefficients were tested. The angle dependent reflection coefficient can take the angle dependence of the incident wave into account as well as the size effect of the surface. Also, the merit of representing the negative real part was discussed. The PBTM result shows a good agreement with the measurement especially in the early part of impulse response and at mid frequency. The new method of binaural simulation for the PBTM was suggested. The peculiar feature of frequency domain calculation of the PBTM gives advantages in the binaural simulation. Particularly in the early part of the impulse response at mid frequency, the binaural simulation result shows an excellent correspondence with the measurement in the application of a conference room. The diffraction phenomenon was incorporated into the PBTM based on the uniform theory of diffraction for the low to mid frequency simulation. The diffraction of edge, which is the topmost problem in an enclosed space, was tested. The simulated results by combining the PBTM with UTD agreed well with the previous research. Besides, the measurement in an anechoic chamber agreed better with the combined method than the ordinary PBTM in the octave band. The simulation of an enclosure having a diffracting edge validates the improvement by comparing with the BEM result. One actual concert hall was tested to simulate the diffraction at receivers under a balcony According to the result of PBTM, the PBTM can be a mid-frequency method bridging the gap between the low frequency method and high frequency method for the acoustic simulation of an enclosure as a unified approach. Furthermore, when a proper technique such as uniform theory of diffraction is integrated into, the present method can even deal with the low to mid frequency range, which has been considered as the typical territory for the wave based methods for a long time. The capability of calculating a room transfer function enables this
method to be used in the analysis, design, diagnosis and refinement of a space. Because the applicable frequency range was extended to low-to-mid frequency, the small-to-medium sized room can be dealt with, vice versa. Therefore a small space like vehicle cabin and aircraft cabin can be dealt with by the present method as well as a large performance spaces.

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**Errors in the Low to Mid Frequency Prediction by Using the Phased Beam Tracing Method**

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**Implementation of the Uniform Theory of Diffraction in the Phased Beam Tracing Method**

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**Introduction and Applications of Phased Beam Tracing Method: Can We Interpret Low Frequency Response by the Particle Property?**

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State: Published
Organisations: Korea Advanced Institute of Science & Technology
Authors: Jeong, C. (Intern), Ih, J. (Ekstern)
A Study on the Characteristics of Phased Beam Tracing Method for the Acoustic Simulation of an Enclosure at Mid Frequencies

High frequency acoustic analysis of an enclosure has been dealt with by geometrical acoustic techniques and low frequency response can be estimated by modal methods; however, mid frequency range has been a grey zone. The phased beam tracing method (PBTM) is one of the mid-frequency techniques, which can calculate a pressure impulse response rather than energy reflectogram, although main assumptions in geometric acoustics still hold. The phased method utilizes the reflection coefficient representing the acoustic property of a surface and the complex wave number to describe the propagation characteristics. In this study, a room was chosen as a demonstration example and the proposed method was applied to this room; the result was compared with measurements. Diffraction and scattering effects were assumed to be negligible and only the geometrical law of reflection was considered. It was found that the phased method is advantageous compared to the conventional ray/beam tracing method: accurate prediction of early part of impulse response, better agreement with measured data, lower and extendable frequency range. This means that the technique can be employed in calculating the sound quality metrics and the auralization of rooms. If the demerit of disregarding diffraction and scattering effects is improved, this method can be a mid-frequency bridge to connect the modal method and geometrical acoustic method for the acoustic simulation of an enclosure in a unified approach.
Objective Evaluation of Engine Noise Quality with the Change of Engine Oil

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Organisations: Korea Advanced Institute of Science and Technology
Authors: Jeong, C. (Intern), Cho, W. (Ekstern), Ih, J. (Ekstern), Shin, S. (Ekstern), Ryoo, J. (Ekstern)
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On the Proper Selection of Frequency Resolution of the Room Transfer Function by Using the Phased Beam Tracing Method

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Vibro-acoustic Analysis for the Reduction of HDD Noise

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Authors: Cheol-Ho, J. (Intern), Kim, S. (Ekstern), Ih, J. (Ekstern), Hong, E. (Ekstern), Kim, W. (Ekstern), Lee, H. (Ekstern)
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Investigation of the Acoustic Performance of Music Halls Using Measured Radiation Characteristics of the Korean Traditional Musical Instruments

There have been always some difficulties in target setting and conditioning of acoustic performances or the Korean traditional music hall due mainly to the lack of the information on the sound radiation characteristics of Korean musical sources. As the 2nd experiment succeeding the previous study[1], the radiation characteristics of eight typical Korean traditional musical sources were investigated if precision. The selected musical sources were Geomungo, Haegeum (string), Piri, Taepyeonqso (woodwind), Buk, Kwaengguari, Jing (drum), and male Pansori Chang (vocal Performance). The results show that the directivity pattern of each instrument is different and has their own directivity characteristics.
Measured directional and spectral characteristics of traditional Korean music sources were implemented into the computation of architectural acoustic measures. Significant differences in the acoustic measures at receiver positions were observed between the results in using the omni-directional source and the directional one. In order to investigate the acoustical characteristics of the instruments depending on the spatial variation four different shapes of halls were introduced including rectangular, fan, horse-shoe and geometrical shapes. Room acoustical parameters such as RT, SPL, C80, LF, STI were calculated at each type or hall. As the results, it was found that the rectangular hall has the most high clarity, lateral energy and STI values among low shapes of halls. It is thought that the suggested source data and design method can be used as a basic reference in the future acoustic design of performance halls for the Korean traditional music.

A Comparison between Predicted and Measured Acoustic Characteristics of Jeonmin Catholic Church

An Application Example of SEA for KOMPSAT-I Satellite Model
An Experimental Study on the Radiation Characteristics of the Korean Traditional Musical Instruments

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Publication: Research › Article in proceedings – Annual report year: 2004

Prediction of the Acoustic Performance of a Music Hall Considering the Radiation Characteristics of Korean Traditional Music Sources

There have been always some difficulties in target setting and conditioning of acoustic performances of the Korean traditional music hall due mainly to the lack of the information on the sound radiation characteristics of Korean musical sources. In this study, the radiation characteristics of four typical Korean traditional musical sources were investigated in precision and their usage was demonstrated: The selected musical sources were Gayageum (string), Daegeum (woodwind), Jango (drum), and Pansori Chang (vocal performance). Each sound source was located at the center of a semi-anechoic chamber and the directivity was determined by the measured sound pressure levels in every 10° angular position, for both vertical and horizontal directions. The directivity pattern of Gayageum varies from a uniform to a complex pattern having many side lobes with the increase of frequency. The main radiation of Daegeum is toward the upward direction. The directivity pattern of Jango is clearly a side-oriented one and the left direction intensity is sharper than its right side at low frequencies. For the Chang, the directivity pattern change from a uniform pattern to a frontally directed one as the frequency goes high. Measured directional and spectral characteristics of traditional Korean music sources were implemented into the computation of architectural acoustic measures for the Busan National Korean Traditional Music Hall which is under construction. Parameters such as RT, SPL, C80, IE, STI were calculated at two receiver positions by using a ray tracing technique. Significant differences in the acoustic measures at receiver positions were observed between the results in using the omni-directional source and the directional one. It is thought that the suggested source data and design method can be used as a basic reference in the future acoustic design of performance halls for the Korean traditional music.

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A Study on the Radiation Characteristics of Korean Traditional Musical Sources

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Effect of Modal Overlap Factor on the Ray Tracing Analysis of the Curved Beam Structure

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Evaluation of Coupling Loss Factors for the Scale Model of KOMPSAT-II

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High Frequency Vibration Analysis of Curved Beam Structures by Using the Ray Tracing Method

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**Modeling of Sound Fields Considering the Acoustical Characteristics of Korean Traditional Musical Instruments**

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**High Frequency Vibration Analysis of Connected Curved Beam Structures**

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**Vibro-acoustic Analysis of Simplified Satellite Model by Using the Statistical Energy Analysis Technique**

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High Frequency Vibration Analysis of Single Curved Beam Using the Ray Tracing Method

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Main Research Area: Technical/natural sciences
Conference: Autumn Meeting of the Korean Society for Noise and Vibration Engineering (KSNVE), Yongpyong, 01/01/2001

Projects:

Efficient low frequency room acoustic modelling
Department of Electrical Engineering
Period: 15/12/2016 → 14/12/2019
Number of participants: 4
Phd Student:
Mondet, Boris Jean-Francois (Intern)
Supervisor:
Christensen, Claus Lyng (Ekstern)
Jeong, Cheol-Ho (Intern)
Main Supervisor:
Brunskog, Jonas (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Industrial PhD
Project: PhD

Architecture acoustics: an improved design process using integrated hybrid room acoustic simulations
Department of Electrical Engineering
Period: 01/11/2016 → 31/10/2019
Number of participants: 4
Phd Student:
Pind Jörgensson, Finnur Kári (Intern)
Supervisor:
Engsig-Karup, Allan Peter (Intern)
Strømann-Andersen, Jakob Bjern (Intern)
Main Supervisor:
Jeong, Cheol-Ho (Intern)

Financing sources
Source: Internal funding (public)
**Effect of room acoustics and head movements on aided and unaided sound-field auditory steady state response (ASSR) measurements**

Department of Electrical Engineering  
Period: 01/07/2016 → 30/06/2019  
Number of participants: 5  
Phd Student:  
Zapata Rodriguez, Valentina (Intern)  
Supervisor:  
Brunskog, Jonas (Intern)  
Harte, James (Intern)  
Laugesen, Søren (Intern)  
Main Supervisor:  
Jeong, Cheol-Ho (Intern)

**Financing sources**  
Source: Internal funding (public)

Name of research programme: Industrial PhD  
Project: PhD

**Characterization of acoustic properties of surfaces based on spatio-temporal information**

Department of Electrical Engineering  
Period: 15/12/2015 → 14/12/2018  
Number of participants: 4  
Phd Student:  
Richard, Antoine Philippe André (Intern)  
Supervisor:  
Brunskog, Jonas (Intern)  
Jeong, Cheol-Ho (Intern)  
Main Supervisor:  
Fernandez Grande, Efren (Intern)

**Financing sources**  
Source: Internal funding (public)

Name of research programme: Institut stipendie (DTU)  
Project: PhD

**Quantification of diffuseness chambers for sound absorption measurements**

Department of Electrical Engineering  
Period: 01/08/2015 → 31/07/2018  
Number of participants: 3  
Phd Student:  
Nolan, Melanie (Intern)  
Supervisor:  
Jeong, Cheol-Ho (Intern)  
Main Supervisor:  
Brunskog, Jonas (Intern)

**Financing sources**  
Source: Internal funding (public)

Name of research programme: Samfinansieret - Andet  
Project: PhD

**Room acoustic simulation tool for optimization of absorbent ceiling**

Department of Electrical Engineering
Acoustic array methods for identification of noise sources in vehicles

Department of Electrical Engineering
Period: 01/10/2010 → 26/01/2015
Number of participants: 7
Phd Student: Tiana Roig, Elisabet (Intern)
Supervisor: Agerkvist, Finn T. (Intern)
Main Supervisor: Jeong, Cheol-Ho (Intern)
Examiner: Juhl, Peter Møller (Intern)
Rafaely, Boaz (Ekstern)
Song, Wookeun (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

New measurement techniques: Optical methods for characterizing sound fields

Department of Electrical Engineering
Period: 01/04/2010 → 19/03/2014
Number of participants: 6
Phd Student: Torras Rosell, Antoni (Intern)
Supervisor: Barrera Figueroa, Salvador (Intern)
Main Supervisor: Agerkvist, Finn T. (Intern)
Examiner: Jeong, Cheol-Ho (Intern)
Gazengel, Bruno (Ekstern)
Humphrey, Victor F. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD