Room Acoustics — Sixth Edition
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I became acquainted with this book during my undergraduate studies, when in 1980, the late Richard Waterhouse suggested it as a supplemental text for an independent reading class in room acoustics I took with him. I welcomed the book's more mathematical grounding than other texts assigned for the class. That second edition became a resource for other classes and found frequent use when I entered industry. Since that time, the book has been updated about every 7 years to reflect current thinking and new topics. The present edition adds reflections from spherical waves, sound field calculations using finite element analysis, and acoustic auralization and virtualization to an already broad coverage of room acoustics.

The book is built on first principles and topics are presented in a concise manner devoid of extensive equation derivations. Concepts introduced earlier in the book are expanded upon, or referred to when a new topic is introduced, creating a unified presentation. The first six chapters are more theoretical and the last four chapters contain practical guidance with references back to the theory. Each of the 10 chapters concludes with an extensive reference list; however, many references are in the German language.

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Chapter 1 introduces the reader to basic acoustic concepts to include the wave equation, plane and spherical waves, concepts of energy density and intensity, basic signal system analysis, sound pressure and sound power, hearing basics, and elementary sound sources. There is sufficient coverage of the fundamentals for a quick acoustics introduction and many of the topics are expanded upon in later chapters.

Reflection and scattering of sound from surfaces is the subject of Chapter 2. The author discusses sound reflections separately for plane, spherical and random incidence wave fronts. Other topics include surface reflection, absorption and impedance aspects of boundaries, reflections from finite sized objects, and number theory diffusing surfaces. A concise definition of a locally reacting surface is welcomed as are examples of sound absorption mechanisms and surface impedance concepts.

Chapter 3 provides the first instance of earlier material presented in greater depth. Here, the wave equation is expanded beyond the simple concepts introduced in Chapter 1 to include finite element methods of solution. Other topics cover normal modes in rectangular rooms, eigenfrequency density, non-rigid walls, steady state sound fields, decaying modes and the first introduction of reverberation. A topic I have not found in other texts is an introduction to elementary room transfer functions for frequencies above the Schroeder frequency.

Geometrical room acoustics principles are covered in Chapter 4. The basics of specular reflections evolve into the basics of image sources including those that are visible and contribute to the room impulse response. The number of reflections received within a time interval is introduced, and this, along with the energy density, is used to derive the reverberation time for an exponentially decaying sound field. Sound reflections from concave surfaces are addressed where this geometry can result in sound focusing or diffusion based on the positions of sound source and receiver. The chapter concludes with two theoretical treatments: the radiosity integral and the diffusion equation. The former is introduced by way of diffuse surface scattering according to Lambert's law and progressing to the concept of irradiance. Different ideas for the diffusion equation based on energy flux models proposed by several researchers are described with a conclusion that sound particles undergo a Brownian motion due to irregular room geometry.

Chapter 5 summarizes concepts of reverberation and steady-state energy density in more detail than in earlier chapters. The chapter starts with a description of diffuse sound fields and sound decay to include factors that influence sound field diffusiveness. The traditional mean free path length is described, as is the author's contribution of the relative variance of the mean free path length distribution. Unequal path lengths are treated in terms of probability distribution of surface sound reflections to calculate the resultant sound energy. From the energy and relative variance, a modified Sabine reverberation time equation is derived with an absorption exponent accounting for the relative variance of the path length distributions. This equation, as pointed out by the author, is only applicable to simple room geometries. A sound source driving an enclosed volume is covered next and considers the reverberant and direct sound energy density components and the critical distance where these values are equal. Lastly, the chapter applies the radiosity integral concept to consider the more realistic condition of non-ideal diffuse field room conditions where the surface boundary reflects sound according to Lambert's cosine law. Examples of non-uniform boundary absorption are presented in terms of the difference between Sabine and Eyring reverberation times for different room shapes and volumes.

Sound absorption mechanisms are reviewed in Chapter 6. Absorption by air is described first followed by membranes and perforated sheets. Resonance phenomena are explained separately for panel absorbers and Helmholtz resonators. Sound propagation through porous materials uses the Rayleigh model to describe this process followed by practical examples of porous absorbers based on impedance considerations. The chapter concludes with the effects of audience and seat absorption and requirements for designing anechoic rooms.

Chapter 7 addresses subjective aspects of room acoustics and how these principles can be applied to design better sounding rooms. The first major topic described is the perception of sound reflections and echoes, both in terms of audibility threshold and timbral effects. Some of the more common early energy ratios for quantifying subjective room acoustics are outlined followed by evaluations of reverberation and spaciousness. The chapter concludes with an overview of methods developed by researchers to subjectively assess concert hall sound quality.

Chapter 8 covers in-situ and laboratory room acoustic measurements. An introduction to instrumentation is followed by descriptions of measuring and evaluating the room impulse response using maximum length sequences and swept sine wave signals. Energy ratios and reverberation measurement techniques then follow. Spatial sound fields are covered with an emphasis on the measurement techniques and evaluation developed by Japanese researchers in the late 1980s and early 1990s. Laboratory acoustic measurements for determining sound absorption via impedance tube and reverberation chamber techniques are presented. The chapter concludes with a brief description of measurement methods to evaluate material surface scattering coefficients based on the research of D'Antionio, Vorländer, and Mommertz.

Room acoustic design concepts for large assembly spaces are reviewed in Chapter 9 outlined as a practical tutorial. Topics include noise level prediction (more applicable for large non-assembly spaces such as offices and workshops), seating layout for maximizing direct sound on the audience, room shaping to avoid sound focusing and to promote useful early sound reflections and reverberation time including simplified calculations, damping constants, and coupled rooms. A brief synopsis of precedent concert halls and large multi-purpose halls illustrates various acoustic and architectural features that contribute to their success. Current room acoustic design techniques, such as computer modeling and virtual reality auralization, are explained in the context of the earlier widespread use of physical scale models.

The book concludes with Chapter 10 addressing electroacoustic systems both for sound reinforcement and acoustic enhancement functions. This is a useful topic in a room acoustics book because most large assembly spaces have electroacoustic systems and the acoustician should have a basic understanding of their design principles. The chapter starts with a basic review of loudspeakers to include cone, horn and line array types followed by acoustic power output requirements for the room. Loudspeaker position is then covered with primary emphasis on central cluster and delayed loudspeaker configurations. The mechanism of electroacoustic feedback is covered in some depth in terms of the system gain structure that causes feedback to occur. Control methods such as frequency flattening and frequency shifting are described to limit feedback potential. Acoustic enhancement systems are covered with emphasis on external reverberators, including wave front synthesis, and controlled feedback, such as "assisted resonance" systems.

When reading through the book, I found approximately 15 editing errors, most of which include typos, inconsistent use of equation symbols and a few incorrect references to equation or figure numbers. Clear graphics complement the text, with much material repeated from earlier editions. A welcome feature is a symbols list at the beginning of the book.

Overall, this edition provides valuable new material to keep this classic text up-to-date. If your work or studies involves room acoustics, this book should be your first port of call.

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