ARCHITECTURAL ACOUSTICS

Blending Sound Sources, Sound Fields, and Listeners

Yoichi Ando

Modern Acoustics and Signal Processing

ARCHITECTURAL ACOUSTICS

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I gratefully dedicate this volume to my mother.

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Series Preface

Soun is noght but air y-broke
—Geoffrey Chaucer
end of the 14th century

Traditionally, acoustics has formed one of the fundamental branches of physics. In the twentieth century, the field has broadened considerably and has become increasingly interdisciplinary. At the present time, specialists in modern acoustics can be encountered not only in physics departments, but also in electrical and mechanical engineering departments, as well as in mathematics, oceanography, and even psychology departments. They work in areas spanning from musical instruments to architecture to problems related to speech perception. Today, six hundred years after Chaucer made his brilliant remark, we recognize that sound and acoustics is a discipline extremely broad in scope, literally covering waves and vibrations in all media at all frequencies and at all intensities.

This series of scientific literature, entitled Modern Acoustics and Signal Processing (MASP), covers all areas of today's acoustics as an interdisciplinary field. It offers scientific monographs, graduate-level textbooks, and reference materials in such areas as architectural acoustics, structural sound and vibration, musical acoustics, noise, bioacoustics, physiological and psychological acoustics, speech, ocean acoustics, underwater sound, and acoustical signal processing.

Acoustics is primarily a matter of communication. Whether it be speech or music, listening spaces or hearing, signaling in sonar or in ultrasonography, we seek to maximize our ability to convey information and, at the same time, to minimize the effects of noise. Signaling has itself given birth to the field of signal processing, the analysis of all received acoustic information or, indeed, all information in any electronic form. With the extreme importance of acoustics for both modern science and industry in mind, AIP Press, now an imprint of Springer-Verlag, initiated this series as a new and promising publishing venture. We hope that this venture will be beneficial to the entire international acoustical community, as represented by the Acoustical Society of America, a founding member of the American Institute of Physics, and other related societies and professional interest groups.

It is our hope that scientists and graduate students will find the books in this series useful in their research, teaching, and studies. As James Russell Lowell once wrote, "In creating, the only hard thing's to begin." This is such a beginning.

Robert T. Beyer
Series Editor-in-Chief

Preface

Concert hall acoustics can be thought of as the place where science and art meet. Imagine how many scientists have contributed to its development. The oldest known writing on the subject, which concerns theater acoustics in ancient Greece and Rome, dates from about 25 B.C. It describes advanced designs for better acoustics, which involved digging holes between chairs and placing bronze vessels upside down in the holes according to mathematics-based music theory. New York Philharmonic Hall, which opened in 1962, was designed on the basis of temporal factors representative of reverberation time. The hall was not well received by the public, however, and was closed in 1978 for extensive renovation. The most important objective is to blend acoustics and music in such a way that each individual's feelings harmonize with the hall's acoustics. Concert hall acoustics has been my major area of study for approximately 30 years; the first 20 years were devoted to the physical and psychological approaches. The goal was to calculate the overall subjective preferences of audience members in each seat. The findings are summarized as follows (Ando, Y., *Concert Hall Acoustics*, Springer-Verlag, Heidelberg, 1985):

(1) A hall should be designed for only a certain type of music, because the sound quality depends on the effective duration of the autocorrelation function of music signals and the temporal acoustic factors of sound fields. Musicians seem to compose their music with acoustics in mind: pipe organ music was written for large spaces, such as Notre Dame Cathedral, and Mozart's string quartets were intended to be heard in court salons.
(2) The newly introduced spatial factor (IACC) is the most effective on subjective preference and subjective diffuseness among acoustic factors of sound fields.
(3) The theory allows calculating the global preference of each seat at the design stage with four physical orthogonal factors of sound fields: the relative sound pressure level (LL), the initial time delay (Δt_1) between the direct sound and the first reflection, the subsequent reverberation time T_{sub}, and the magnitude of the interaural cross-correlation IACC.

For the past 10 years, my focus has been on auditory–brain function and the individual. This research shows that the left cerebral hemisphere is associated with

the temporal factors, Δt_1 and T_{sub}, and that the right cerebral hemisphere is activated by the more spatial factors, IACC and LL. The information corresponding to subjective preference of sound fields is found in brain waves. Surprisingly, individual differences in subjective preference appear in brain waves and are recognized mainly in temporal factors and LL, not in IACC. Individual differences in LL may be related to the hearing level. For different values of Δt_1 and T_{sub}, significant individual preferences arise. It is most likely the result of difference in individual temporal activities of the brain. This evidence ensures that the basic theory of subjective preference may be applied to each individual preference as well. The other fundamental subjective attributes for sound fields can also be described by the theory, based on the auditory–brain model with correlation mechanisms and the cerebral-hemispheres specialization.

To blend sound sources and sound fields in a concert hall, the sound fields must first be designed to maximize the average preference at each seat. Musicians must select music programs appropriate for the hall and performing positions on the stage that both maximize the ease of the performers and the preference of the listeners. A seat-selection system for satisfying individual preference was introduced at the Kirishima International Concert Hall in 1994, and the first international symposium of experts in the art and science of sound, Music and Concert Hall Acoustics (MCHA), was held in May 1995. As described in this book, 106 participants took part in a test procedure for seat selection.

I hope that the theory of incorporating temporal and spatial values for both levels of global subjective preferences and individual preference of sound fields can be generalized to blend nature, the built environment, and people.

Yoichi Ando

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The studies described in this book were performed at the Graduate School of Science and Technology, Kobe University, and partially at the Drittes Physikalisches Institut, University of Göttingen, Germany. I express my appreciation to both institutions and their staffs. Special thanks are due to Professor Manfred R. Schroeder for his continuous invitation to work at his institute since 1971. In the summer of 1995, I started preparing the manuscript for this book in Göttingen at Professor Schroeder's suggestion, as well as at the invitation of Professor Werner Lauterborn, director of the institute.

I am very grateful to Professor Robert T. Beyer, Brown University, for his continuing warm encouragement since my first book, *Concert Hall Acoustics*, was published in 1985 and for the substantial improvement of the English usage in that book. Also, I am deeply grateful to Professor Emeritus Isamu Suda, Kobe University, for his talk in 1979, which provided me with a source of inspiration for research into the work described in Sections 5.2 and 5.3.

Most of the illustrations have previously been published by me and/or my colleagues. I express my appreciation to the authors and publishers who have granted permissions, and I thank Dr. Zvi Ruder and Dr. Charles Doering, then editors at AIP Press, for their encouragement in publishing this book. Finally, the generous support of the Alexander von Humboldt Foundation, Bonn, since 1975, enabled me to concentrate on the research necessary to complete this monograph.

Yoichi Ando

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