Modern Acoustics and Signal Processing

Ning Xiang
Gerhard M. Sessler *Editors*

Acoustics, Information, and Communication

Memorial Volume in Honor of Manfred R. Schroeder

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Acoustical Society of America

The mission of the **Acoustical Society of America** (www.acousticalsociety.org) is to increase and diffuse the knowledge of acoustics and promote its practical applications. The ASA is recognized as the world's premier international scientific society in acoustics, and counts among its more than 7,000 members, professionals in the fields of bioacoustics, engineering, architecture, speech, music, oceanography, signal processing, sound and vibration, and noise control.

Since its first meeting in 1929, The Acoustical Society of America has enjoyed a healthy growth in membership and in stature. The present membership of approximately 7,500 includes leaders in acoustics in the United States of America and other countries. The Society has attracted members from various fields related to sound including engineering, physics, oceanography, life sciences, noise and noise control, architectural acoustics; psychological and physiological acoustics; applied acoustics; music and musical instruments; speech communication; ultrasonics, radiation, and scattering; mechanical vibrations and shock; underwater sound; aeroacoustics; macrosonics; acoustical signal processing; bioacoustics; and many more topics.

To assure adequate attention to these separate fields and to new ones that may develop, the Society establishes technical committees and technical groups charged with keeping abreast of developments and needs of the membership in their specialized fields. This diversity and the opportunity it provides for interchange of knowledge and points of view has become one of the strengths of the Society.

The Society's publishing program has historically included the *Journal of the Acoustical Society of America*, the magazine *Acoustics Today*, a newsletter, and various books authored by its members across the many topical areas of acoustics. In addition, ASA members are involved in the development of acoustical standards concerned with terminology, measurement procedures, and criteria for determining the effects of noise and vibration.

Series Preface for Modern Acoustics and Signal Processing

In the popular mind, the term "acoustics" refers to the properties of a room or other environment—the acoustics of a room are good or the acoustics are bad. But as understood in the professional acoustical societies of the world, such as the highly influential Acoustical Society of America, the concept of acoustics is much broader. Of course, it is concerned with the acoustical properties of concert halls, classrooms, offices, and factories—a topic generally known as architectural acoustics, but it is also concerned with vibrations and waves too high or too low to be audible. Acousticians employ ultrasound in probing the properties of materials, or in medicine for imaging, diagnosis, therapy, and surgery. Acoustics includes infrasound—the wind-driven motions of skyscrapers, the vibrations of the earth, and the macroscopic dynamics of the sun.

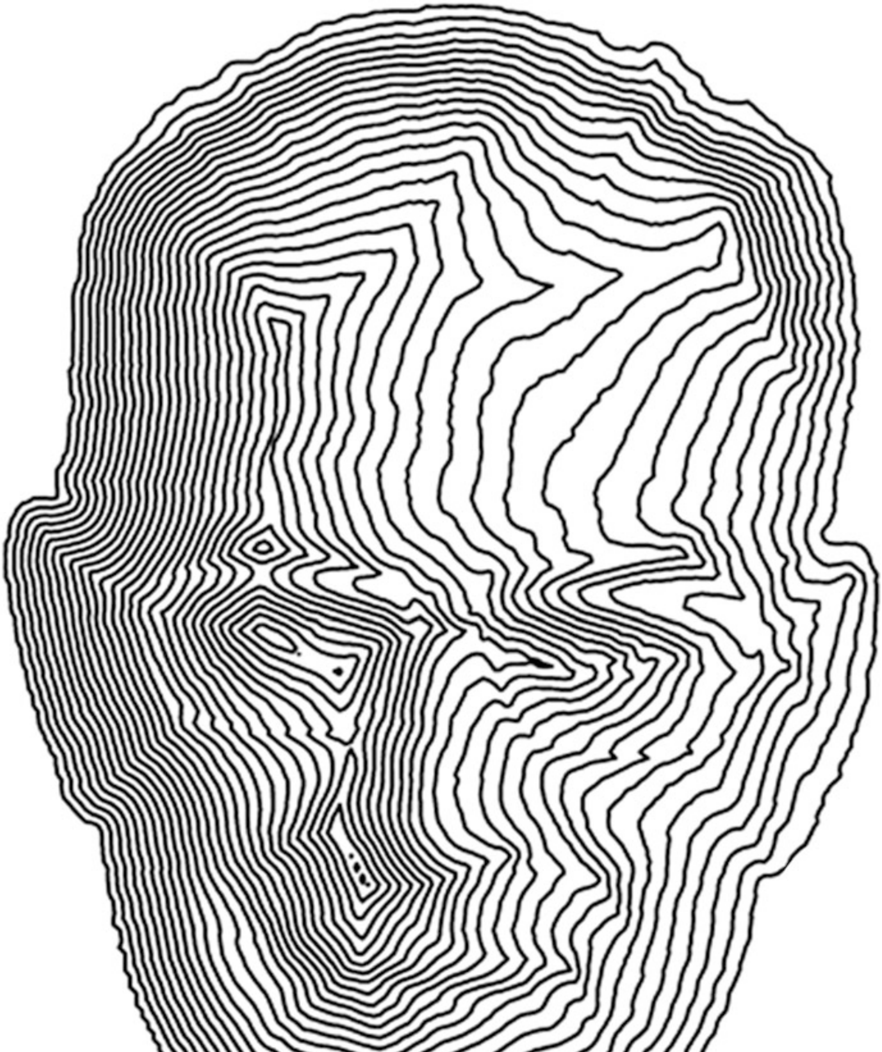
Acoustics studies the interaction of waves with structures, from the detection of submarines in the sea to the buffeting of spacecraft. The scope of acoustics ranges from the electronic recording of rock and roll and the control of noise in our environments to the inhomogeneous distribution of matter in the cosmos.

Acoustics extends to the production and reception of speech and to the songs of humans and animals. It is in music, from the generation of sounds by musical instruments to the emotional response of listeners. Along this path, acoustics encounters the complex processing in the auditory nervous system, its anatomy, genetics, and physiology—perception and behavior of living things.

Acoustics is a practical science, and modern acoustics is so tightly coupled to digital signal processing that the two fields have become inseparable. Signal processing is not only an indispensable tool for synthesis and analysis but it also informs many of our most fundamental models about how acoustical communication systems work.

Given the importance of acoustics to modern science, industry, and human welfare Springer presents this series of scientific literature, entitled Modern Acoustics and Signal Processing. This series of monographs and reference books is intended to cover all areas of today's acoustics as an interdisciplinary field. We expect that scientists, engineers, and graduate students will find the books in this series useful in their research, teaching, and studies.

July 2012 William M. Hartmann



Manfred R. Schroeder's Portrait – Solution of Eikonal equation, programed by Wolfgang Moeller (see also Chapter 20, Fig. 20.11, see also at the beginning of Part II, Fig. 28 in photo collection on page 293) (Wolfgang Moeller is one of Schroeder's former students)

Preface

Manfred Schroeder was born in Ahlen, Westphalia, Germany. In Manfred's youth, his father, a mining engineer, and his mother encouraged an early interest in the beauty and utility of mathematics. His mathematical talent was already evident in his secondary schooling. Like many science-oriented youths of the time, he was attracted to radio technology: He built short-wave receivers and transmitters. He never considered himself a legitimate "radio amateur" ("ham") because of the difficulty of obtaining a government license, and the (not unusual) additional obstacle of Morse code. But, in all other respects, he was a "ham."

Also, like many other youths of his time, Manfred's continued education was interrupted by the hostilities of World War II. At age 16, he was drafted into the German air force, serving first in Poland and later in Holland. Because of his talent for electronics, he was trained in the early uses of radar for detecting range and direction. He thereby became part of an intensive technology race, an experience that no doubt contributed to his later remarkable zeal in acoustics research.

After the conclusion of hostilities, he returned home, rejoicing that his family was intact and unharmed in this turbulent time. Manfred continued his education and entered the University of Göttingen to study physics and mathematics. In due course, as his university studies advanced, he fell under the tutelage of Professor Erwin Meyer, director of the Drittes Physikalisches Institut (Third Physics Institute) and an internationally recognized authority in acoustics. Working towards his doctoral degree, Manfred conducted fundamental research on the distribution of microwave and acoustic normal modes in enclosures, relations that characterize the frequency response and spatial spread of electromagnetic and sound energy in structures such as waveguides, rooms, and auditoria. He received his Dr. rer. nat. degree as a student of Professor Meyer in 1954. Later that year he joined Bell Laboratories in Murray Hill, New Jersey. Manfred went on to be appointed Head of the Acoustics Research Department in 1958 and Director of the Acoustics and Speech Research Laboratory in 1963. Soon thereafter, he assumed responsibility for all areas of acoustics, speech, and mechanics research at Bell Labs. In 1969, while still maintaining some of his responsibilities at Bell, he was appointed Professor of Physics and Director of the Drittes Physikalisches Institut at the

University of Göttingen. After his retirements from Bell Labs and the University in 1987 and 1991, respectively, Manfred continued his activities as a scientist and teacher.

Manfred's scientific contributions are so numerous that it would require much more space than we have in this Preface to provide a complete introduction. One field about which Manfred was always enthusiastic and to which he made many fundamental and far-reaching contributions is room acoustics. As mentioned above, this area fascinated him as early as his thesis work in the early 1950s in Göttingen, where he developed his brilliant statistical theory of frequency responses of enclosures. Manfred built vacuum-tube-based devices for electromagnetic waves to validate his hypothesis. His "radio amateur" experience and early use of radar along with the dynamic research environment at Erwin Meyer's Institute prepared Manfred to be an excellent experimentalist. In a series of publications Manfred described the relations between the eigenmodes and the frequency response of a room. He explained the random character of the response above a certain frequency (today known as the Schroeder frequency). Other ingenious contributions followed, such as the use of frequency shifting to suppress feedback in public address systems and the integrated-tone-burst method for measuring sound energy decay functions of enclosures (today known as Schroeder curves via Schroeder's integration or backwards integration). His seminal paper in 1965 on backwards integration has led to numerous research activities in room acoustics (see Chap. 3 by Xiang). Manfred introduced binary maximum-length sequences in architectural acoustics in 1979—the so-called fast M-sequence transform for room impulse response measurements (see Chap. 6 by Xiang, Xie & Cox). Another outstanding achievement is Manfred's invention of pseudo-random surface structures based on number-theoretical schemes (Schroeder diffusers, see Chap. 6 by Xiang et al. and Chap. 9 by D'Antonio). Such devices are used to scatter sound waves in all directions, and hence improve the acoustics of concert halls by providing lateral sound reflections.

Of much public interest was Manfred's involvement in the activities to improve the acoustics of Philharmonic Hall in New York City. Soon after the opening of the Hall in 1962, grave deficiencies in its acoustics were detected, and Manfred together with a few acoustic consultants was invited to analyze and remedy the situation. He was asked to make an objective evaluation of the acoustics of the Hall and decided to use a novel measuring method based on digital signal generation and processing. It was in this period that Manfred first began to develop his backwards integration method. Preparation, performance, and evaluation of these experiments turned into a scientifically challenging project for Manfred and his coworkers. Later on, while at Göttingen, Manfred and his students evaluated 20 of the major concert halls of the world by subjective auditory comparison, thereby gaining significant information about subjective parameters of room acoustics, such as lateral reflections. In addition to these new digital measuring techniques, between 1968 and 1969 Manfred pioneered a ray-tracing method of computer simulation of large halls. This was shortly followed by active research followed in room-acoustics simulations, leading to many refined methods (see Chap. 2 by Krokstad et al.). These methods have gained great practical importance for the planning of new auditoria.

Manfred Schroeder was the first to recognize the importance of digital signal processing, not only in room acoustics but in many other areas as well, and also the first to actually employ these methods. Examples are the generation of artificial reverberation (Schroeder's all-pass filter) and artificial stereophony as well as digital signal processing applications in ultrasonics, speech, and electroacoustics. Manfred is also one of the pioneers of computer graphics: For his application of concepts from mathematics and physics to the creation of artistic works he was awarded the First Prize at the 1969 International Computer Art Competition.

Another area where Manfred made fundamental contributions is speech and hearing acoustics. Among his outstanding achievements in this field are the invention of the voice-excited vocoder in 1960 and the introduction of linear predictive coding (LPC) in 1967 during the exciting days of the digital revolution at Bell Labs. LPC remains an important technique for analysis and synthesis of speech and music signals. Also in 1967 Manfred used acoustic flectrometry to determine the human vocal tract. He also worked on early development of the concept of surround sound. His mathematical model of the inner ear has inspired much of the following subsequent work in auditory research.

Manfred's interest in mathematics and especially in number theory motivated him in 1984 to write his very successful treatise "Number Theory in Science and Communication," now in its fifth edition. This book differs from other texts on the topic by its intuitive approach and by emphasizing the applications of number theory to such diverse fields as cryptography, physics, computing, and self-similarity. Many amazing relationships are uncovered in this text which is not only stimulating to read but also a lot of fun to muse about. Similarly, Manfred's 1992 book "Fractals, Chaos, Power Laws: Minutes from an Infinite Paradise" illustrates the far-reaching influence of the concept of self-similarity on science, music, and the visual arts. Both books are marvellous examples of how to present difficult subjects transparently and in an amusing style. Manfred's third book, "Computer Speech," first published in 1999, spans an arch from speech recognition and synthesis to monaural and binaural hearing and modern signal analysis. This text summarizes Manfred's long involvement with speech and hearing research at Bell Labs. Apart from these monographs, Manfred Schroeder published more than 350 papers, many of them seminal communications, and holds 45 US patents.

As a professor and teacher at Göttingen University, Manfred was able to attract excellent students due to his inspiring lectures on such diverse topics as physics, acoustics, mathematics, and signal processing. Most of the over 45 Ph.D. candidates whom he supervised successfully continued their careers either in academia or in industry, many of them as professors, heads of companies, or chief scientists.

Manfred received numerous accolades and professional recognitions throughout his long and varied career. He was elected a member of the U.S. National Academy of Engineering and the Göttingen Academy of Science, and Fellow of the American Academy of Arts and Sciences and of the New York Academy of Sciences. As mentioned above, in 1969 he was awarded First Prize at the International Computer Art Competition for his application of concepts from mathematics and physics to the creation of artistic works. He was a founding member of the Institute de

Recherche Acoustique Musique of (IRCAM) in Paris. Manfred has also been recognized for his scientific achievements as the recipient of Gold Medals from the Audio Engineering Society in 1972 and the Acoustical Society of America in 1991. In addition, he was presented with the Rayleigh Medal from the British Institute of Acoustics in 1987, the Lower Saxonion State price in 1992, the Helmholtz-Medal of the German Acoustical Society in 1995, and the Technology prize of the Eduard Rhein-Foundation in 2004.

This introduction to Manfred Schroeder would be incomplete without a few words about Manfred's personality. Everybody who has met Manfred knows his kindness, his humor and cheerfulness, his ease of communication. Many of these attributes were demonstrated in his farewell lecture, presented at the occasion of his official "retirement," to an overflow audience in Göttingen's largest lecture hall: For 90 min, Manfred fascinated his listeners with a brilliant, lucid, and amusing demonstration of the most beautiful experiments from the fields of acoustics, optics, and chaos physics.

In December 2006, the Acoustical Society of America, at its Joint-Meeting with the Acoustical Society of Japan in Honolulu (ASA), organized an honorific session for Manfred, chaired by Ning Xiang, Juergen Schroeter, and Akiro Omoto. The ASA also organized a memorial session for Manfred, chaired by the present authors, at its Seattle meeting in May 2011. Among the invited speakers of these two Sessions were his former colleagues and students (in alphabetic order).

Joshua Atkins, Bishnu Atal, Peter Cariani (coauthor with Yoichi Ando), Peter D'Antonio, James Flanagan, Hiroya Fujisaki, Fumitada Itakura, Birger Kollmeier, Armin Kohlrausch, Roland Kruse, Heinrich Kuttruff, Max Mathews (deceased), Volker Mellert, Jean-Dominque Polack, Gerhard Sessler, Michael Vorlaender, James West, and Ning Xiang.

The first part of this book contains 13 chapters, written by colleagues and former students of Manfred, on a variety of topics. These range from architectural acoustics (chapters by James West and Joshua Atkins, Ning Xiang, Guillaume Defrance & Jean-Dominique Polack, Asbjørn Krokstad, Peter Svenson & Svein Strøm, Jean-Dominique Polack, Peter D'Antonio), psychological acoustics (Yoichi Ando & Peter Cariani, Armin Kohlrausch & Steven van de Par), and speech (Bishnu Atal) audio, acoustics measurements to electro acoustics (Roland Kruse & Volker Mellert, Gerhard Sessler, and Ning Xiang, Bosun Xie & Trevor J. Cox) and underwater acoustics (Dieter Guicking). The style of the chapters ranges from truly scientific to absolutely colloquial. Many chapters refer not only to Manfred's original work but also to new studies that originated from Manfred's studies. In all these papers, the relationship of the problems discussed to Manfred's own fields of interest is, in general, evident.

The second part of the book consists of memoirs which Manfred wrote over the last decade of his life. We are grateful to Manfred's wife Anny Schroeder and to Manfred's children Marion, Julian, and Alexander Schroeder for granting us permission to include the memoirs in this book. These recollections shed light on many aspects not only of Manfred's life but also on that of many of his colleagues, friends, and contemporaries. They also portray political, social, and scientific events during a time span that extends from the pre-war period to the present. These memoirs, written in an inimitable and witty style, are full of information, entertaining, and fun to read. We trust that the reader will find this volume useful and stimulating.

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