

The Math Behind Transducers

By: Alan Hardiman

Acoustics: Sound Fields and Transducers

by Leo L. Beranek and Tim J. Mellow

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Intended as a textbook for senior or graduate engineering students and as a basic reference for practicing acoustical engineers, *Acoustics: Sound Fields and Transducers* is an updated edition of Beranek's classic *Acoustics*, first published in 1954 when he was a professor at MIT. Recognizing the fragmentation and diversification of acoustics over the past half century and the specialization to which this has given rise, the authors have expanded the first half of the original edition, dealing with electroacoustics, to produce this thorough exposition of the current theoretical framework and mathematics underlying sound radiation and the development of electro-mechanico-acoustic transducers, such as loudspeakers, microphones, and vibration pickups. The title has therefore been revised accordingly.

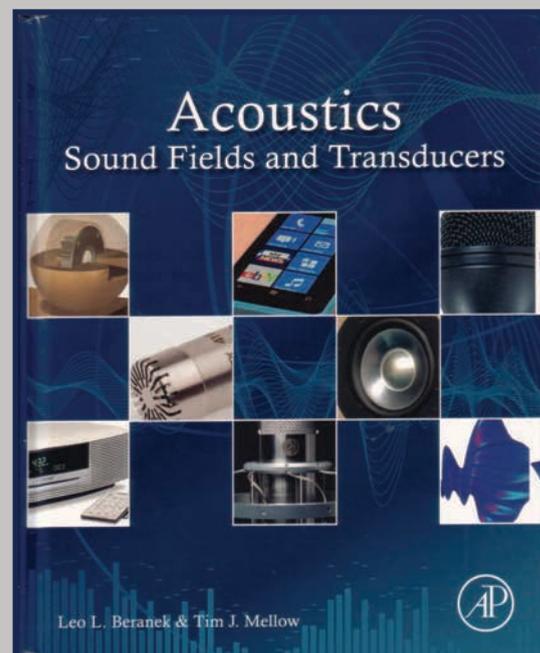
Beranek is legendary in the pro-audio community, having co-founded Bolt, Beranek and Newman (now BBN Technologies) in 1948 to provide consultation services for major auditoriums. Among many achievements, BBN developed the ARPANET, forerunner of the Internet. Electronics design engineer Tim Mellow recently co-founded Mellow Acoustics Ltd. to develop high-fidelity loudspeakers and amplifiers.

Given the book's highly theoretical orientation, I have approached this

review mindful of the diverse backgrounds of LSA's readers, and I have attempted to highlight those parts of this rather dry and clinical text most interesting to non-academics.

One of Beranek's most important achievements in describing the behavior of transducers in the original edition was his introduction of theoretical electro-mechanico-acoustic "circuits" that are analogous to electrical circuits. In doing so, he rendered a tremendous service to the sound industry, then in its relative infancy, by extending the familiar schematic representations of such concepts as resistance, capacitance, inductance, transformance, and gyration to vibrational phenomena that had previously been represented almost entirely by the differential equations of calculus.

As the authors note in the current edition, the widespread adoption of this approach to conceptualizing acoustics and mechanics by the then-leading writers on loudspeaker design, including Villchur, Thiele, Small, and Ashley, among others, "has led to the high quality of audio reproduction that we enjoy today" and lies behind the development of such diverse inventions as wave guides and miniature cell phone loudspeakers. "Schematic diagrams made it possible for engineers to visualize the performance of a circuit without



laboriously solving its equations."

Naturally, acoustic elements are discussed extensively: air, air cavities, tubes, slots, and porous screens of metal or cloth both in front of and behind actively vibrating diaphragms. While it is certainly not necessary to understand this theory before setting up a windscreen or pop filter in front of a performer's microphone, it is nonetheless reassuring to be aware of the pros and cons of the practice beyond merely intuiting that it's going to produce the anticipated effect. As in all legitimate sciences, hypothesis and theory are integrated with empirical observation and testing.

Discussing the design of loudspeaker enclosures, the authors note that "the very mention of directivity is guaranteed to spark a lively debate amongst audio engineers, with some favoring a wide pattern while others

prefer a narrow pattern, although virtually all agree that a constant pattern is desirable to ensure that the room reflections produced by the off-axis sound have the correct frequency balance.” As this applies generally to theatre sound, wide dispersion may be preferred for a conventional line array or center cluster that must provide wide coverage with only one or two audio signals, whereas multiple cabinets with much higher directivity—ideally no greater than about 40-60° horizontally—are required for modern source-oriented reinforcement techniques where accurate localization of individual performers is specified as part of the sound design.

The authors present a number of different cabinet designs for direct-radiator loudspeakers, typically used to reproduce high-fidelity music and in cars, with three complete examples worked out in laborious detail, noting that, “unfortunately, the calculations are sometimes tedious, but there is

no shortcut to the answer.” Following many dense pages replete with the promised tedious calculations attendant on designing infinite baffle, acoustic suspension, and bass reflex enclosures, the authors turn their attention to transmission-line enclosures, such as those used in the Bose Wave music system.

The transmission line, a long, folded tube between the rear of the loudspeaker’s diaphragm and the outside of the enclosure, certainly helps to increase low-frequency performance, but its output must somehow be attenuated “at frequencies where it cancels the sound from the front of the loudspeaker diaphragm, even if the standing waves within it are well damped using absorbent filling material. However, many products now contain a digital signal processor, which can be used to equalize the resulting lumpy frequency response.” The authors recommend the use of a tapered, rather than folded, transmis-

sion line if the object is “to design a stand-alone loudspeaker with a smooth frequency response.”

In contrast to direct-radiator loudspeakers, with efficiency of sound radiation typically less than 1%, horn loudspeakers of the sort used in theatres, concert halls, and other large facilities have much higher efficiency ratings, ranging from 10% to 50%, but this comes with the twin disadvantages of larger size and higher price. The authors describe a horn as an acoustic transformer, transforming “a small-area diaphragm into a large-area diaphragm” that results in more power being radiated at low frequencies. In addition, the directivity of a horn is controllable, the radiation angle being determined by the flare angle of the mouth.

We know from experience that low-frequency horns tend to be folded in order to fit into cabinets of reasonable size. The authors attribute the scarcity of good data on the com-



Photos: Courtesy of Sonoma State University and Monterey Bay Aquarium



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BOOK OF THE MONTH

parative performance of folded horns partly to the difficulty of measuring their response in an anechoic chamber and “partly because commercial companies guard their data.” Having attempted on several occasions to describe loudspeakers impartially in industry publications, I can attest to the paranoia exhibited by some manufacturers in this regard.

I found it interesting that the authors believe the best material for horn construction to be concrete or plaster, 1" or 2" thick. The weight

and internal damping of such a horn would keep it from resonating at low frequencies, thus preventing dips in the power output curve. To me, this seems to imply that building horns into the concrete structure of a new or renovated building might be something worthy of consideration. What we encounter much more commonly is well-braced plywood, at least 3/4" thick—what the authors dub “the next best material.”

Moving on to the behavior of

sound in enclosures, they deal with the usual matters—standing waves, room modes, and reverberation—before discussing a very important question for the theatre: How much sound pressure is required to achieve realistic volumes for speech and music in large auditoria? The authors present a table of varying SPLs for rooms of varying sizes for orchestral music, conversational speech, and declamatory speech. I expect that the speech of the theatre falls somewhere between conversational and declamatory speech, depending on the genre of the work being performed. Sadly, only three pages of the text are given to this discussion.

Most of Beranek’s material on sound in concert halls now appears in a companion volume, *Concert Halls and Opera Houses: Music, Acoustics, and Architecture* (Springer, 2004). He devotes scarcely more than a single page to the subject in the present volume and then only as an introduction to a discussion of high-fidelity reproduction in home listening rooms.

The book is handsomely produced and, aside from a single typographical error of no consequence, is well-edited, although I do not have anywhere near the requisite math background to assess the accuracy of the book’s many equations. Footnote references are collected at the end of each chapter, but I found the lack of a bibliography frustrating.

I expect that few sound designers, mixers, and technicians will take the time to wade through the book’s many extensive mathematical computations, but we can all be grateful if this book finds a place in the curriculum of the schools that train the engineers and acousticians who build the facilities in which we enjoy the fruits of our labor. 📶



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Pictured: Kelly Hansen, Foreigner lead vocalist with the HH transmitter.



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