

## Sound Propagation: An Impedance Based Approach

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The author, Yang-Hann Kim, has taught at KAIST (Korea Advanced Institute of Science and Technology) since 1989 and obtained a Ph.D. degree in Acoustics and Vibration from the Massachusetts Institute of Technology. The text covers acoustical fundamentals along with detailed analyses of some more complicated acoustical topics, and is recommended for upper-division undergraduate or masters-level graduate students. Detailed information presented at the end of each chapter is meant to serve as a resource for more advanced students and professionals.

The author proposes a “three-dimensional understanding” approach to define, explore, and comprehend acoustical fundamentals. These “three dimensions” are not spatial, but represent a conceptual coordinate system that seeks to provide a simpler and more effective route to learning. The dimensions are as follows: basic acoustic principles, relative acoustic quantities, and relative acoustical scales. The path to comprehension in the text is broken down into five key components that constitute the five chapters. While impedance is not necessarily explored in significantly greater detail than found in other acoustical fundamental texts, it is emphasized throughout and ties key concepts together very well.

Each of the five chapters is divided into two sections: an overall presentation of the material and an appendix section that provides additional theory, analytical expressions, practical applications, and mathematical derivations. Each chapter includes 12 to 14 exercise problems, however without their solutions. Charts, figures, and photos are heavily used in the text and help comprehension of the material.

Chapter 1 establishes the principles of vibration and one dimensional (1-D) wave propagation. Topics covered include the one-dimensional wave equation, propagation in strings, boundary conditions, reflection and transmission, and forced response. The concept of impedance is explained, along with examples of its influence on wave propagation. Examples of its influence include transmission and reflection of waves between two dissimilar strings and the coupling of wave motion into a string from a forced input. The appendix of the chapter discusses 1-D and 2-D damped harmonic oscillators and driving point impedance of bars, beams, membranes, and plates.

Chapter 2 moves from mechanical wave propagation to waves in fluids. The chapter begins with development of the 3-D wave equation with an emphasis on relative acoustical quantities, such as particle velocity and acoustic-level changes in pressure and density. Other acoustical parameters are also introduced, such as energy, intensity, and power. A four-page summary of human physiological mechanisms for hearing is aptly tethered with a discussion of frequency scales and bandwidths, weighting curves, loudness, and spectral decomposition. Impedance characteristics for plane and spherical waves are presented for far-field and near-field conditions. The chapter’s appendix presents additional mathematical details for the 3-D wave equation derivation and characteristics of multi-pole sources.

Chapter 3 applies impedance concepts from the previous two chapters to discuss wave behavior at a region of impedance change. Concepts of reflection, transmission, and incidence conditions are applied to a “flat surface of discontinuity.” The author does an excellent job of presenting applications of various complexities, including mass law for limp walls, partitions with damping properties, and plates. The appendix includes additional mathematical details for local reaction and layered transmission and reflection.

Chapter 4 looks at radiation, scattering, and diffraction of acoustic waves. Radiation impedances are defined for a sphere, baffled piston, and vibrating plate. Emphasis is made on how impedance mismatches influence whether or not an incident wave will diffract, scatter, refract, or reflect. Diffraction principles are applied to predicting the transmission loss of a barrier using the Fresnel number. Upward and downward refraction in cases of outdoor sound propagation are also mentioned. The appendix provides information on directivity, beam patterns, application of the Kirchhoff-Helmholtz Integral Equation, and 27 pages devoted to theoretical approaches to solving barrier diffraction problems.

Chapter 5 describes acoustical characteristics in acoustically-small and acoustically-large closed spaces. For acoustically-large spaces, Sabine’s Theory is used and influences of room surface impedance on the acoustic environment are explained. Transitions between the direct, reverberant, and diffuse field are defined along with room modal response and modal density. For acoustically small spaces, the concepts of acoustical compliance and inertance are illustrated by a classic Helmholtz resonator. The Helmholtz resonator components are also described in terms of individual impedances: radiation impedance, neck impedance (inertance), and cavity impedance (compliance). Duct acoustics and horns are also discussed. The Chapter 5

appendix describes surface impedance measurement methods, additional approaches for calculating reverberation time (Eyring, Millington, and Fitzroy), and 12 pages are devoted to the analysis of Helmholtz resonator array panels.

In summary, the text covers all of the topics one would expect to find in a fundamentals text, along with a few pleasant surprises. Frequent tie-ins to impedance

and solid relations between acoustical parameters aid in comprehension of the material.

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