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ON OCEAN WAVEGUIDE ACOUSTICS

The field of ocean acoustics is an active area of theoretical and experimental research, with a continually expanding body of literature in research journals and textbooks. Boyles' book is a welcome addition to the literature and provides a useful text for both students and practitioners in the field.

Although electromagnetic waves are strongly absorbed by water, acoustic waves can, under the proper conditions, propagate over hundreds, even thousands, of miles through the ocean. As a result, sound waves and sonar assume the major role in the ocean that electromagnetic waves and radar play in the atmosphere. Sound is used for navigation, communication, and underwater detection and as a tool for studying the oceanography of the water column and its boundaries. Active and passive sonar systems are the most important methods used by the Navy in detecting and tracking submarines in antisubmarine warfare.

For the physicist specializing in wave propagation, the ocean provides a medium in which virtually every conceivable basic problem in wave propagation can be studied. The ocean is an inhomogeneous medium with an acoustic index of refraction that varies with depth as a result of changes in temperature and hydrostatic pressure and, to a lesser extent, in salinity. On a finer spatial scale, thermal microstructure introduces a random component to the sound velocity structure. Wave propagation through inhomogeneous and random media is, therefore, an important part of ocean acoustic research. The ocean surface and bottom are, in general, rough boundaries, thus requiring the study of acoustic scattering from rough surfaces. The ocean bottom is a multilayered structure composed of sediments and rocks, which, in general, supports both compressional and shear waves, in addition to containing velocity gradients. Therefore, the interaction of

acoustic waves with multilayered media is also an active area of research in underwater acoustics.

In recent years, the inverse problem of determining oceanographic properties from acoustic measurements has become increasingly important and has given rise to the term "acoustical oceanography," a variant of "ocean acoustics" that emphasizes the oceanographic implications of acoustic experiments. A major development in this area is time-of-flight acoustic tomography in which front and eddy intensity and variability over hundreds of kilometers are measured acoustically. In ocean-bottom acoustics, direct inverse methods are being developed that utilize some measurement of the acoustic field, such as the plane wave reflection coefficient of the bottom, as direct input to algorithms for determining the acoustic properties of the bottom. This approach is to be contrasted with conventional techniques in which forward models for computing the acoustic field are run for different bottom properties until best fits to the data are obtained.

In addition to wave physics and geophysics, electrical engineering plays a major role in underwater acoustics. State-of-the-art instrumentation often involves microprocessor-controlled devices deployed under water, sometimes for extended periods of time. The processing of these signals usually requires the use of sophisticated signal processing techniques and numerical methods in order to extract the measurement of interest. These techniques contribute to an improved understanding of the physics of acoustic wave propagation, and the fields of wave physics and signal processing combine to yield an exciting area of research.

Ocean acoustics has produced a vast research and textbook literature that reflects the diversity of problems described above. Although many of the basic problems in underwater acoustics are similar to those in electromagnetic theory, seismics, and quantum mechanics, the specific details of ocean acoustic problems are sufficiently different to warrant a distinct subject area. Perhaps the best all-around graduate level text in underwater acoustics is the one by Clay and Medwin,[1] who present a well balanced view of most of the important acoustics problems, including signal processing, and their relationship to oceanography. They also provide a set of problems for the student at the end of each chapter. On the other hand, their theoretical development is somewhat elementary and lacks the depth that one would hope for in teaching

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students who are about to embark on research work in acoustical oceanography. In a similar vein, but more sophisticated theoretically, are the books by Tolstoy and Clay[2] and Officer.[3] Unfortunately, both books are out of print. On the more practical side, Urick's book[4] emphasizes the solution of practical engineering and sonar system problems at an elementary mathematical level. At the other end of the spectrum, at a high theoretical level, are the books by Brekhovskikh and Lysanov,[5] Brekhovskikh,[6] Keller and Papadakis,[7] and DeSanto.[8] The Brekhovskikh and Lysanov work has a scope that approaches that of Clay and Medwin (though no signal processing is included) and includes additional modern theoretical topics. However, the information is presented in a condensed fashion and may present a challenge to the mathematically unprepared reader. The book by Brekhovskikh is an excellent advanced text that emphasizes the topic of acoustic interaction with layered fluid and elastic media. Keller and Papadakis and DeSanto focus on special advanced topics and are most useful for active researchers in the field.

Into this spectrum of textbooks, Boyles has introduced a book with narrower scope than Clay and Medwin but with substantially greater theoretical sophistication. The mathematical level is comparable to that of the advanced texts described above, but Boyles' exposition typically contains considerably more background and detail. This detailed approach is useful not only in understanding his book but also as background for reading some of the other advanced texts. Herein lies the major strength of Boyles' treatment: he has written a self-contained book in which he derives the wave equation from first principles, presents the required mathematical methods, and uses these methods to solve the wave equation for waveguides of increasing complexity. Boyles states in the preface that this was in fact his intent in writing the book, which originated as a set of lecture notes for a course he taught at The Johns Hopkins University Applied Physics Laboratory.

In Chapter 1, Boyles begins with the basic equations of fluid mechanics and thermodynamics and uses them to derive the acoustic wave equation, the energy conservation equations, and the boundary conditions associated with the wave equation.

In Chapter 2, the author presents the mathematical techniques necessary to solve the boundary value problem associated with acoustic propagation through the oceanic waveguide. This includes a detailed discussion of separation of variables, Sturm-Liouville theory, the theory of eigenfunctions, Green's functions, the method of steepest descents, and Bessel and Airy functions. Boyles then uses these methods in Chapters 3 and 4 to obtain exact solutions to the wave equation for a sequence of waveguide models of increasing complexity. All of these models assume a flat, impenetrable (pressure-release) ocean surface and variation of sound velocity with depth only. He begins with the problems of one and two homogeneous layers with an impenetrable (rigid) bottom. He then solves the Pekeris wave-

guide problem that consists of a homogeneous layer overlying a homogeneous half-space. Next, he considers the normal mode solution for a model consisting of N inhomogeneous layers (terminated by a rigid boundary) where the sound velocity, attenuation, and density can be discontinuous from layer to layer.

In Chapter 5, Boyles discusses approximate solutions to the wave equation that include ray theory, ray theory with asymptotic corrections for smooth caustics, and the Wentzel, Kramers, Brillouin (WKB) approximation. He shows that ray theory can be obtained through a combination of the WKB method and the method of steepest descents. He also discusses cusp caustics and the physical basis for the formation of smooth caustics. In Chapter 6, Boyles applies ray theory and normal mode theory to velocity profiles associated with three realistic ocean environments. In two of these cases, the North Pacific and North Atlantic summer profiles, the propagation characteristics are dominated by the formation of convergence zones, while in the third, the North Atlantic winter profile, the dominant feature is surface duct propagation.

Finally, in Chapter 7, Boyles presents his original work on propagation in a waveguide where the sound speed varies both horizontally and vertically and the ocean surface is modeled as a randomly rough interface. This is recent work, some of which has appeared in journals, while some appears here for the first time in published form. Because separation of variables cannot be used in this case, he uses the method of coupled, local normal modes. The resulting sets of coupled, second-order differential equations do not lend themselves to the use of known numerical integration algorithms. But Boyles[9,10] and Dozier[11] have shown that if the equations are reformulated, they can be solved using known numerical techniques.

Boyles presents a detailed, comprehensive treatment of the topics covered, although certain major areas are conspicuously absent. These include propagation in random media, inverse problems, signal processing, and the parabolic equation method, another frequently used technique for computing acoustic fields in range-dependent environments. Although the ocean bottom is included in some of his models, he does not discuss the bottom interaction problem per se. His discussion of the physical parameters that determine the sound speed in the ocean seems out of sequence, not appearing until Chapter 6, whereas he has used a number of sound velocity profile examples prior to that. This reflects the general tone of the book, which is primarily mathematical. More physical motivation for the mathematical models considered, perhaps in an early chapter of a primarily descriptive nature, would have been desirable. Some of the figures in Chapter 6, which apparently were generated on a computer, are of lower quality than what one would hope for in a textbook. Finally, there are no problems posed for the student, thus leaving the burden of generating problems to the instructor.

Despite these criticisms, Boyles' book is of high quality and has filled a gap in the ocean acoustic text-

book literature. In the preface, he indicates his desire to produce a self-contained graduate level text that could also be used by scientists beginning to work in this field. Boyles has succeeded admirably in achieving these goals.

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