

Ocean Acoustics
Ivan Tolstoy and Clarence S. Clay
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Preface to the Reprint Edition

Since 1966 the field of ocean acoustics has blossomed mightily.

A huge number of papers has been published on non-separable models and, notably, on acoustic propagation in oceans of variable depth and/or horizontally varying stratification. Among the more important new techniques used in this context are the parabolic approximation and hybrid mode-ray methods. Major progress has been achieved in understanding bottom-caused attenuation, notably through the somewhat belated

recognition of the importance of Biot's theory of propagation in porous media. (Much of the relevant literature here is cited in a recent paper by R.P. Ogushwitz)

Not only has a great deal of new work been done on scatter-we also feel that our original discussion was incomplete. Our section on scattering of sound at a rough surface followed Eckart's formulation. Briefly, we used incident plane waves and stopped short of introducing incident spherical waves. An extension of the Eckart formulation that includes spherical wave fronts is in Clay and Medwin's *Acoustical Oceanography*. The work of Twersky deserves more than the passing reference given in the original edition of *Ocean Acoustics*. The T matrix method is an equally important calculation technique needing careful presentation. The treatment of stochastically rough surfaces by Bass and Fuchs-i.e., the so-called perturbation technique-and its extensions have been developed in the last two decades. The use of equivalent smoothed boundary conditions, both in the stochastic context and for averaged or deterministic models, is also an important development. Significant here has been the prediction of a far-field dominant rough surface boundary mode. Inclusion of attenuation due to incoherent scatter suggests that, for harmonic point sources near the rough surface, this mode of propagation yields a substantially complete far-field description of scatter near grazing incidence. Elegant experimental work by Medwin and collaborators has shown excellent agreement with the predictions of the theory. Important work by (Flatté, Dashen, Munk, and others on volume scatter has greatly increased our understanding of the ocean's bulk acoustic properties. A number of useful books on ocean acoustics and allied subjects has also appeared in the last ten years. All of this is but a small fraction of the relevant literature which has appeared since the first edition of *Ocean Acoustics*.

Our extension of normal mode methods to realistic waveguides includes the beginning of a theory for the use of arrays in a waveguide. The word "beginning" is proper because we display troubles without giving solutions. An optimum solution was derived while the text was in its publication phase. The theory of the matched array filter was years ahead of experimental technology. Since then many papers on the use of mode filters to study waveguide propagation have been published.

To update our book would clearly require the writing of one or more additional volumes. This edition must, like its predecessor, be viewed as a brief introduction to what has become a very large field-a new, highly sophisticated branch of geophysics/geoacoustics which has borrowed techniques from many other fields and, occasionally, created a few of its own.

The present edition differs from the original 1966 McGraw-Hill version by the addition of a number of new appendices-reprints of some of our earlier work on propagation. Their purpose is to update and clarify some ideas discussed or adumbrated in the first edition. For example, when the latter was being written, the question of pulse shape changes under internal reflection was still being discussed in the literature-a fact which was reflected in a measure of untidiness in the discussion concluding Sec. 5.2. The issue was subsequently clarified and put into the context of caustic/turning point phase changes in a 1968 paper which is reproduced here as Appendix 4. Appendix 5, which is also new, is a reprinting of the original paper of Biot and Tolstoy on normal coordinates. Whereas Chap. 3 of *Ocean Acoustics* offers a good introduction to this method, it was felt that the original paper more clearly underlines the generality and potential (still largely unused) of the concept for acoustic and elastic wave propagation theory. In addition, it reproduces (which Chap. 3 does not) a simple, rigorous, closed-form solution for the diffraction of a spherical pulse by hard wedges or corners of arbitrary aperture ** ** *. This solution provided the basis of some interesting recent work by Medwin and others showing excellent agreement between theory and experiment. They demonstrate how such solutions can be combined to yield useful approximations for angular bodies of other shapes.

Appendix 6 is a reprint of papers on the optimum theory for transmissions in a waveguide. It introduces the matched array filter. The derivation shows that the optimum array filter in a waveguide multidimensional analogue of the familiar matched filter in the frequency domain where each normal mode is analogous to a frequency. Full satisfaction of the optimum condition includes source range and source depth and it is obvious that one could compute a set of matched array filters for trial source positions to search for an actual source.

The authors were gratified that several institutions used the 1966 edition of *Ocean Acoustics* as a textbook and, while the present edition differs only by the addition of the above mentioned appendices (and by the removal of a number of misprints and minor errors), they hope that it will still be useful as a reasonable

introduction to the field-leaving the topics mentioned earlier in this introduction, and the references listed below, as the proper subject matter for a more advanced level course.

Ivan Tolstoy
Clarence S. Clay

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Preface to the Original Edition

This book deals primarily with the theory of sound propagation in the oceans and with comparisons of theory with experiment when such comparisons are possible.

Perhaps the chief difficulty in writing such a book is to decide what type of reader one hopes to interest. Very few, if any, of the people doing research in this field have had any special training prior to their beginning work on some specific problem in underwater acoustics. Most of the current workers have drawn from a remarkably varied range of technical and academic background. Theoretical physicists, applied mathematicians, geophysicists, oceanographers, a sprinkling of professional acousticians, electrical engineers, spectroscopists, and many other backgrounds are represented. In the future, underwater acoustics will continue to depend, for its progress, upon people of these varied qualifications, since the subject is hardly ever taught as a field in its own right. Because those who might have an interest in this book will have an unusually diversified assortment of technical background, it did not seem likely that we could write something satisfying, or even accessible, to all. We have therefore aimed at those graduates who, one would assume, have had a graduate course in theoretical mechanics and one in partial differential equations. This should include most budding and seasoned physicists, mathematicians, geophysicists, and engineering scientists (today's classical physicists).

Concerning the subject matter, we must immediately make a number of points clear, if only to forestall part of the criticism to which this book may be vulnerable. Over the last twenty-five years, underwater acoustics has grown into a somewhat untidy subject; a good deal of it is "systems oriented" in the sense that it developed, inevitably, under the pressure of practical problems. As a result, there exists a large body of data that has not been, and probably cannot be, compared with theory and that has gone into constructing empirical rules of the handbook variety, with heavy reliance on the usual smoothing paraphernalia. Although this type of empirical information does have a certain limited practical utility, it is of no interest to us here. We have limited ourselves exclusively to the use of published data that have been successfully compared with theory. We have likewise concentrated on those aspects of the theory that have some experimental confirmation or, at least, some fairly immediate and obvious uses. This has considerably reduced both the volume of data and the body of theory that have gone into this book. Thus we have set ourselves a relatively modest goal. But, even within these rather narrow limits, we make no claims at completeness. For instance, we have omitted a number of theoretical concepts and methods, such as Keller's interesting generalization of ray theory, the classic Laplace transform method (i.e. the Cagniard-Pekeris-Heaviside approach), a number of promising numerical

techniques, such as Longman's integration procedure for oscillating integrands, etc. We felt that we should write a book that would be as systematic and as direct as we could make it and that multiplying unnecessarily the number of techniques to be used on the same problem, or exploring interesting theoretical sidelines that we did not subsequently apply, would make for a turgid and indigestible end product. It may be that the result still strikes the reader as muddy; let him be assured, nevertheless, that we did our best to spare him such unnecessary material. Future writers may not be so kind.

The plan of the book is simple. In the first chapters we treat the field as a problem in linear, undamped acoustics. This enables us to formulate the main outlines of the problem in uncluttered terms. Later, we introduce more realistic models with attenuation, scattering, and fluctuations as perturbations. It is fortunately possible to cover most of the significant material in this manner. Thus, Chap. 1 gives a brief introduction to the pertinent acoustical properties of the ocean, sufficient, we hope, to explain the use of some approximations and idealizations made in the next two chapters. Chapter 2 outlines the basic properties of plane waves in the absence of attenuation and the major physical concepts of rays, reflection, waveguides, characteristic equations, dispersion, and certain approximations. Chapter 3 explains the use of normal coordinates, or modes, and establishes the basic solutions which will be needed in subsequent developments-especially in the next two chapters. In Chap. 4 we examine that application of these results to the propagation of sound in shallow water when the wavelength and water depth are of the same order. We show why and how attenuation must be introduced as a perturbation of the undamped theory and how model experiments conducted at Brown University show quantitatively the effect and importance of specific mechanisms of attenuation. In Chap. 5 we apply the results of Chaps. 2 and 3 to deep-water propagation, i.e., to problems involving wavelengths that are small in comparison with the water depth. Factors which in practice, often perturb our idealized models are considered in Chap. 6. In particular, we give an account of the effects of boundary roughness. Chapter 7 supplies the reader with the basics of information processing and linear filter theory useful in handling the uncontrollable and unpredictable fluctuations typical of so many geophysical field measurements. In Chap. 8 we review the preceding chapters and conclude, perhaps unwisely, with some guesses about the future of this field.

We have used both ray and mode concepts throughout this book. But, whenever possible, emphasis has been on the normal-mode point of view. This provides a flexible and general formulation for all pertinent problems. It has perhaps not been sufficiently appreciated by workers in this and in allied fields of geophysics (e.g., seismology) that the concept of modes is both general and rigorous, embracing in principle all isentropic linear propagation processes in bounded and unbounded media.

Ocean acoustics began largely as a branch of acoustics and has inherited some of the practices of that field. Frequently data are reported in decibels (dB), i.e. $20 \log_{10}(\text{acoustic pressure}/\text{constant})$. Unfortunately there has been little agreement concerning the choice of the constant, and both 1 dyne/cm² and 0.0002 dyne/cm² are widely used. Geophysicists usually report pressures in dyne/cm² or ^{**}bar. We have generally followed this practice, since we see no compelling reason to express geophysical measurements in unit that were chosen for physiological reasons.

For those wishing to pursue further the subject of acoustic and elastic wave propagation in natural or artificial media, a number of books have appeared in the last decade. Insofar as underwater acoustics specifically is concerned, the number of even moderately up-to-date sources in book form is small indeed. For thorough treatments of quite similar problems encountered in the study of electromagnetic wave propagation in the earth's atmosphere, there is a somewhat broader choice of references, of which we give three at the end of this preface. A more general account of mechanical radiation theory is given in Lindsay's book.

We are very grateful to Professor A.O. Williams, Jr., of Brown University, whose careful and critical comments on our manuscript we greatly appreciated.

Most of our research reported in this book was originally supported by the Office of Naval Research and has already appeared elsewhere primarily in the Journal of the Acoustical Society of America. But the writing of this book has been a private undertaking, carried out entirely at our own expense.

IVAN TOLSTOY
C.S. CLAY

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Understanding Ocean Acoustics. Sharon Nieu Kirk, Research Assistant Acoustic Monitoring Project NOAA Pacific Marine Environmental Laboratory. What is Sound? Ocean acoustics is the study of sound and its behavior in the sea. When underwater objects vibrate, they create sound-pressure waves that alternately compress and decompress the water molecules as the sound wave travels through the sea. Sound waves radiate in all directions away from the source like ripples on the surface of a pond. Ocean acoustics is a broad field focused on the study of sound, its propagation and behavior underwater. Sounds travels really well in the ocean, so sound is also used for the study of many phenomena across ocean sciences, including properties of the earth, ocean, and animals living in the ocean. As a result, scientists working on ocean acoustics span all areas of science found at Scripps: Earth Science, Biology, and Oceans and Atmosphere. The Ocean Acoustics library contains acoustic modeling software and data. It is supported by the U.S. Office of Naval Research (Ocean Acoustics Program) as a means of publishing software of general use to the international ocean acoustics community. Welcome to the Ocean Acoustics Library. The Ocean Acoustics Library has moved. The new url is <https://oalib-acoustics.org/>. If you are looking for the AcousticsToolbox only, you can find it at <http://oalib.hlsresearch.com/AcousticsToolbox>.