Principles of Sonar Performance Modeling

Michael A. Ainslie

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To Anna

Preface

The science of sonar performance modeling is traditionally separated into a ‘‘wet end’’ comprising the disciplines of acoustics and oceanography and a ‘‘dry end’’ of signal processing and detection theory. This book is my attempt to bring both aspects together to serve as a modern reference for today’s sonar performance modeler, whether for research, design, or analysis, as Urick’s *Principles of Underwater Sound* did for sonar engineers of his day. The similarity in the title is no accident.

During the process I made some valuable discoveries that I now share with the reader. The radar literature provides a deep mine of resources, with applicable results from the theories of wave propagation, signal processing, and (an especially rich vein, largely unexploited in the sonar literature) statistical detection. From oceanography we learn that each of the world’s oceans has its own unique physical, chemical, and biological signature, with sometimes profound consequences for sonar.

Marine mammals have evolved a sonar of their own, the remarkable properties of which we are only beginning to unravel, as reported in the increasingly sophisticated bioacoustics literature. Governments and industry around the world have begun to take seriously the environmental consequences of man’s use, whether deliberate or incidental, of sound in the sea. I have done my best to provide a representative snapshot of this rapidly developing field.

Some readers will treat this book as a repository of facts, figures, and formulas, while others will seek in it explanations and clarity. It has been my intention to satisfy the needs of both types of reader by including mathematical derivations and worked examples, supplemented with measurements or estimates of relevant input parameters. Of all readers I request the patience to overlook the flaws that undoubtedly remain, despite my best attempts to weed them out.

Michael A. Ainslie
TNO, The Hague, The Netherlands, March 2010

Foreword

Underwater acoustics is largely a branch of physics, perhaps merging with geophysics and oceanography, but as soon as one attempts to assess a sonar's performance under realistic conditions, a host of other engineering factors come into play. Is the desired target signal louder than all the other natural noise from wind, waves, ship engines, strumming cables? Is it louder than sound scattered from other distant objects? How do the standard signal-processing techniques such as beamforming, spectral analysis, and statistical analysis influence the probability of achieving a target detection and the probability of a false alarm?

The author, Dr. Mike Ainslie, is a physicist with a considerable academic publication record and many years' hands-on experience in sonar assessment for the U.K.'s MOD and for TNO in The Netherlands. Through a firm foundation in physics, always taking great care over the physical units, *Principles of Sonar Performance Modeling* introduces rigor and clarity into the traditional sonar equation while still answering the fundamental engineering questions. As well as dealing with the more pure disciplines of sound generation, propagation, and reverberation, it tackles sound sources, targets, signal processing, and detection theory for man-made and biological sonar.

Underlying all this is a desire "to see the wood for the trees". For instance, it is often the case with propagation that, despite all the complexities of refraction, reflection, diffraction, scattering, and so on, some simple mechanism dominates, and sometimes one can express the entire transmission loss, ambient noise level, or reverberation level by a simple formula. This insight, or even revelation, is an important bonus and check if one is to have faith in numerical assessment of complicated search scenarios. It can also become a useful shortcut when a particular scenario is to be investigated under many different acoustic, or processing, conditions. Examples of such insights will be found throughout.

The cornerstone is the derivation of the sonar equations—too often presented as indisputable fact—from simple physical principles. The derivation is presented initially in terms of ratios of simple physical quantities, and converted to decibels only at the end. Such an approach provides both clarity and a systematic rationale for determining how to evaluate each sonar equation term, and occasionally throws up unexpected new corrections.

The book will provide a useful reference for acousticians, engineers, physicists, mathematicians, sonar designers, and naval sonar operators whether working in research labs, the defense industry, or universities.

Chris Harrison
NATO Undersea Research Centre (NURC), Italy, March 2010

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Through his written publications, David Weston is an eternal inspiration—I have lost count of the number of times his name is cited. I also benefited from discussions with Chris Harrison, Chris Morfey, Christ de Jong, Dale Ellis, Frans-Peter Lam, Mario Zampolli, Peter Dahl, and Tim Leighton.

Data or artwork were made available to me by Pascal de Theije (Figure 7.6), Peter Dahl (Figure 8.3), Alvin Robins (Figure 8.5), Vincent van Leijen (Figure 8.13), Peter van Holstein (Figure 8.14), Henry Dol (Figures 9.24 and 9.25), Mathieu Colin (all figures in Chapter 9 making use of either BELLHOP or SCOOTER), Robbert van Vossen (Figures 9.28 and 9.29), Wim Verboom (miscellaneous seal and porpoise audiograms), Garth Mix (thumbnail images of marine mammals), and Paul Wensveen (Figure 11.20).

The computer model INSIGHT (version 1.4.2) was used, with permission of CORDA Ltd., to illustrate many of the sonar performance calculations. Also used were the acoustic propagation models SCOOTER and BELLHOP from the Ocean Acoustics Library (*http://oalib.hlsresearch.com*). Other valuable Internet resources include FishBase (*www.fishbase.org*), the Ocean Biogeographic Information System (*www.iobis.org*), Mathworld (*http://mathworld.wolfram.com*) and Wikipedia (*www.wikipedia.org*).

Phillipe Blondel and Clive Horwood were always available when needed for advice. Neil Shuttlewood is responsible for a professional end-product.

Last but not least, none of this would have been possible without the unquestioning love and support from my wife Pilar and patience of my daughter Anna, whose teenage years are forever tinted with shades of sonar performance.

Michael A. Ainslie
TNO, The Hague, The Netherlands, March 2010

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