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Qihu Li

# **Digital Sonar Design in Underwater Acoustics**

## **Principles and Applications**

With 418 figures



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*To my wife Xiaoping,  
my children Hai and Ye,  
my grandson Mike*

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## Preface

Sound wave is the only physical medium which can propagate over a long distance in the ocean. Other physical media, such as electromagnetic, optical or laser beams will quickly dissipate in the ocean because sea water is a good electrical conductor.

Sound navigation and ranging (Sonar) is a technique which is based on sound propagation to navigate, to communicate with or to detect other vessels. It is used extensively in ocean development and military applications.

Digital sonar is a sonar system that uses digital signal processing theory and techniques and that realizes system integration in a digital manner. Compared with the analogue processing of signal, digital processing has many advantages, as digital data are easy to store, transmit, and process.

With the rapid development of the semiconductor industry, digital chips have become more and more powerful and can now complete very complicated algorithms which were impossible to perform in the past. As a result, the performance of digital sonar has improved greatly.

The design of a modern digital sonar depends not only on the theory of underwater acoustic signal processing but also on our knowledge of the ocean environment, including ambient noise, the acoustic channel, the characteristics of the sea surface and sea floor, etc.

This book aims to describe the basic design principles of digital sonar and its applications. We have tried to focus our description on the basic theory and design techniques of modern digital sonar by stripping away all unimportant details.

Most theoretical results are illustrated with a practical example so that the reader should understand the application background of the basic theory.

I would like to emphasize that the best way of learning the theory of digital sonar design is to design a modern digital sonar for a particular application area. Experiments in lake or sea water are essential. I believe that experiments at sea provide some of the most important lessons for aspiring sonar designers.

The theoretical and experimental results described in this book include a wide

variety of contributions from my colleagues and graduate students at the Institute of Acoustics, Chinese Academy of Sciences. I would like to express my sincerely thanks to Dr. C.H. Zhang, J.B. Liu, B.X. Xie, B.L. Tu, X.P. Chen, T. Xu, C.Y. Sun, S.Q. Li, L. Yin, H.N. Huang, J.S. Tang, J.Y. Liu, J.D. Luan, G.Q. Sun, X.T. Yang, M. Li, H.B. Yu, G. Liu, L. Wang, X.H. Chen, C.H. Wei and L.P. Dong.

Any comments or criticisms about this book are most welcome.

Qihu Li  
June, 2011

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## Abbreviations

### A

A-RCI: Acoustic rapid COTS insertion  
ABF: Adaptive beamforming  
ADCAP: Advanced capability  
ADS: Advanced Deployable System  
ADSL: Asynchronous digital subscriber line  
AEGIS: Air early guard integration system  
AERONET: Aerosol Robotic Network  
AGC: Automatic gain control  
AIP: Air Independent Propulsion  
AMFP: Adaptive matched field processing  
ALE: Adaptive line enhancer  
ANC: Adaptive noise canceling  
ASDIC: Anti-submarine division-ics  
ASK: Amplitude Shift Keying  
ATM: Asynchronous transfer mode  
ATOC: Acoustic thermometry of ocean climate  
AUTEC: Atlantic undersea test and evaluation center

### B

BATS: Bermuda Atlantic Time Series

### C

C2: Command and control  
C3: Command, control and communication  
C4ISR: Command, control, communication and computer,  
information, surveillance and recognition  
CBF: Conventional beamforming  
CDMA: Code division multiple access  
CGS: Centimeter Gram Second  
CORDIC: Coordinate rotation digital computer  
COTS: Commercial off the shelf

CSDM: Cross spectral density matrix

## **D**

DARPA: Defense advanced research project agency

DCT: Discrete Cosine Transform

DDS: Diver detection sonar

DEOS: Dynamics of Earth and Ocean System

DELTIC: Delay Line Time Compressor

DEMON: Demodulation on noise

DFT: Discrete Fourier transforms

DICANNE: Digital Interference Canceling Adaptive Network Nulling Equipment

DICASS: Directional command-activated sonobuoy system

DIFAR: Directional frequency analysis and ranging

DIMUS: Digital multi-beam system

DOA: Direction of arrival

DoD: Department of defense

DOFIX: Doppler fixing

DRAM: Dynamic random access memory

DWDM: Dense Wave Division Multiplexing

DS: Direct sequence

DSP: Digital signal processing, Digital Signal processor

DWDM: Dense wave division multiplexing

## **E**

E3: Effective, Engagement, Envelope

ENIAC: Electronic Numerical Integrator and Calculator

ESONET: European sea floor observatory network

ESPRIT: Estimation of signal parameters via rotational invariant techniques

EVM: Evaluation module

## **F**

FDDI: Fiber distributed data interface

FDS: Fixed Distributed System

FFT: Fast Fourier Transform

FH: Frequency hopper

FIR: Finite Impulse Response

FM: Frequency modulation

FOM: Figure of Merit

FRONT: Front resolving observatory network with telemetry

FSK: Frequency shift keying

FSS: Fixed Surveillance System

## **G**

GOOS: Global ocean observatory system

GPS: Global positioning system

GSC: Grey scale conversion  
 GSS: Generic sonar simulator

## **H**

H2O: Hawaii-2 observatory  
 HCI: Human computer interface  
 HMS: Hull mounted sonar

## **I**

IBF: Inverse beamforming  
 IDFT: Inverse discrete Fourier transform  
 IDS: Intrude detection sonar  
 IFS: Iterated Function System  
 IIR: Infinite Impulse Response  
 IP: Internet protocol  
 ISDN: Integrated service digital network  
 IT-21: Information technology for the 21th century Initiative  
 IUSS: Integrated Undersea Surveillance System

## **J**

JAMSTEC: Japan marine science & technology center  
 JPEG: Joint Photographic Experts Group  
 JV 2010: Joint vision 2010

## **L**

LAN: Local area network  
 LOFAR: Low frequency analysis record  
 LOFIX: LOFAR Fixing

## **M**

MAP: Maximum à posterior probability  
 MARS: Monterey accelerated research system  
 MBP: Model based processing  
 MDW: Mass destruction weapon  
 MFLOPS: Million Floating-Point Operations Per Second  
 MFP: Matched field processing  
 MIPS: Mega Instruction Per Second  
 MIUW: Mobile in-shore undersea warfare  
 MOPS: Mega Operation Per Second  
 MPEG: Moving Pictures Experts Group  
 MQPSK: Modified quadric-phase shift keying  
 MSE: Minimum mean square error  
 MTBCF: Mean Time Between Critical Failure  
 MTBF: Mean Time Between Failures  
 MTTF: Mean Time to Failure

MTTR: Mean Time to Repair  
MUSIC: Multiple signal classification

## **N**

NEPTUNE: North east Pacific time series undersea network experiments  
NATO: North Atlantic Treaty Organization  
NCOIC: Network Center Operation Industry Consortium  
NCSL: Naval Coastal System Laboratory  
NCW: Network Centric Warfare  
NOPP: National oceanographic partnership program  
NUWC: Navy underwater warfare center  
NURC: NATO Undersea Research Center

## **O**

ODN: Own Doppler null  
OFDM: Orthogonal frequency division multiplexing  
ONR: Office of naval research  
ORBIS: Object-oriental rule based interactive system  
OTA: Order truncate average

## **P**

PCI: Personal Computer Interface  
PDM: Pulse duration modulation  
PFA: Passive Fixed Array  
PLL: Phase lock loop  
PRS: Passive ranging sonar  
PSK: Phase Shift Keying  
PVDF: Polyvinylidene fluoride

## **Q**

QoS: Quality of service  
QPSK: Quadrature phase shift keying

## **R**

ROC: Receiver operating curve

## **S**

SABSOON: South Atlantic Bight Synoptic offshore observatory  
SAS: Synthetic Aperture Sonar  
SDS: Swimmer detection sonar  
FRONT: Front-Resolving Observational Network with Telemetry  
SHARC: Super Harvard architecture  
SNR: Signal-to-noise ratio  
SOFAR: Sound frequency and ranging channel  
Sonar: Sound navigation and ranging

SONET: Synchronous optical network  
SOSS: Soviet Ocean Surveillance System  
SOSUS: Sound Surveillance Sonar  
SPAWAR: Space and naval warfare systems center  
SRAM: Static random access memory  
SSBN: Nuclear ballistic missile submarine  
SSN: Nuclear attack submarine  
SSP: Sound speed profile  
STDV: System technology demonstration vehicle  
STFT: Short Time Fourier Transform  
SURTASS: Surveillance Towed Array Sensor System  
SVP: Sound velocity profile  
SWATH: Small water area twin hull

## **T**

TAGOS: Tactical Auxiliary General Ocean Surveillance  
TALON: Tactical acoustic littoral ocean network  
TCP/IP: Transmission control protocol/Internet protocol  
TDMA: Time division multiple access  
TMA: Target moving analysis  
TOGA: Tropical ocean and the global atmosphere  
TRM: Time reversal mirror  
TVG: Time Varying Gain

## **U**

UDT: Underwater defense technology  
UUV: Unmanned undersea vehicle  
UUVI: Unmanned undersea vehicle initiative

## **V**

VDS: Variable depth sonar  
VENUS: Victoria experimental network under the sea  
VIM: Vibration isolate module  
Virtual Collaboration  
VME: Versa Module Europe  
VTC: Video teleconference

## **W**

WAA: Wide Aperture Array  
WHOI: Woods hole oceanographic institute  
WOCE: World ocean circulation experiment  
WTD: Wehrternisshe Dienststelle