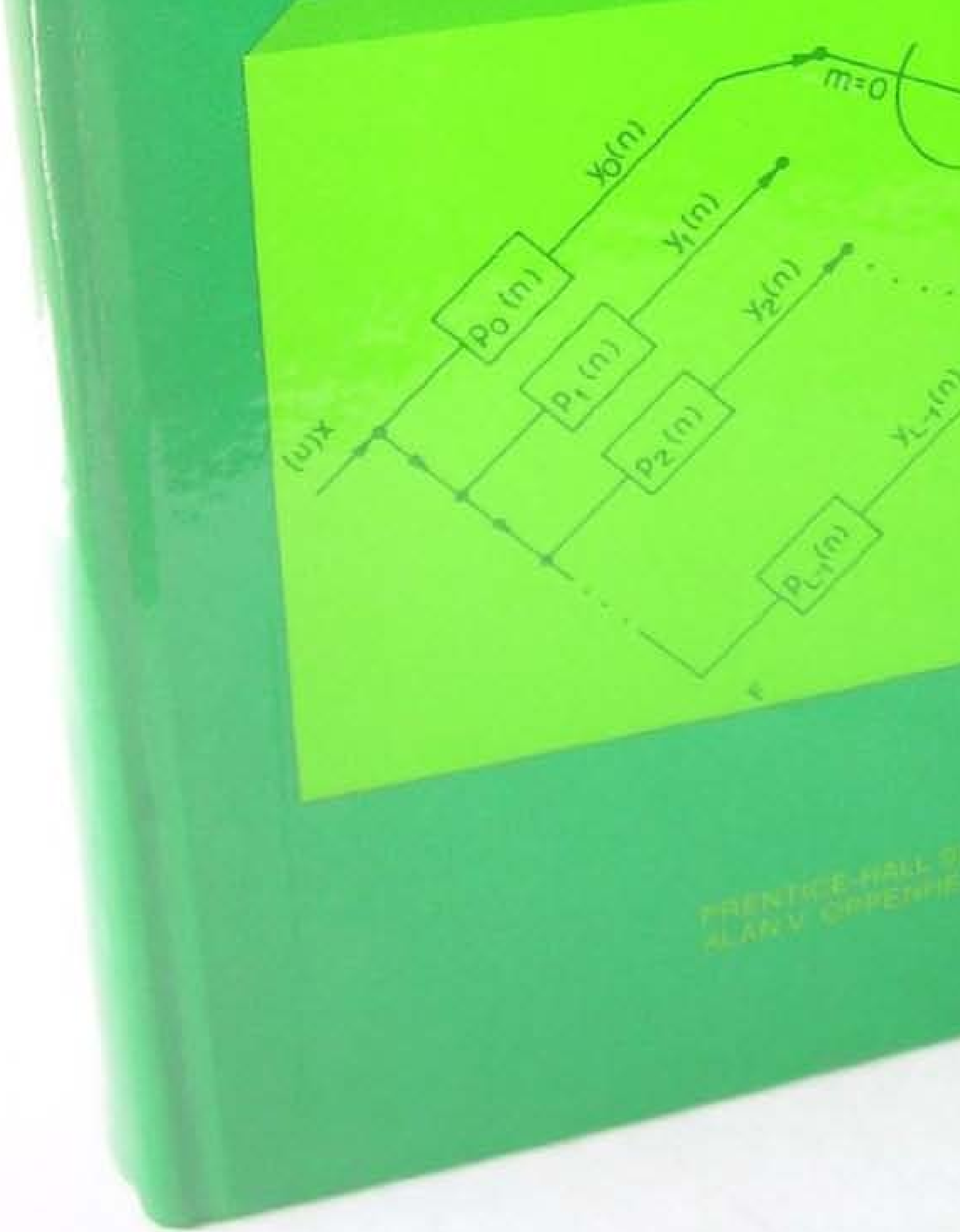
m=0
y0(n)
y1(n)
y2(n)
P0(n)
P1(n)
P2(n)
PRENTICE-HALL
ALAN V

PRENTICE-HALL SIGNAL PROCESSING SERIES

Alan V. Oppenheim, Editor

ANDREWS and HUNT *Digital Image Restoration*
BRIGHAM *The Fast Fourier Transform*
CASTLEMAN *Digital Image Processing*
CROCHIERE and RABINER *Multirate Digital Signal Processing*
DUDGEON and MERSEREAU *Multi-Dimensional Signal Processing*
HAMMING *Digital Filters, 2nd edition*
LEA (editor) *Trends in Speech Recognition*
LIM (editor) *Speech Enhancement*
McCLELLAN and RADER *Number Theory in Digital Signal Processing*
OPPENHEIM (editor) *Applications of Digital Signal Processing*
OPPENHEIM and SCHAFER *Digital Signal Processing*
OPPENHEIM, WILLSKY with YOUNG *Signals and Systems*
RABINER and GOLD *Theory and Applications of Digital Signal Processing*
RABINER and SCHAFER *Digital Processing of Speech Signals*
ROBINSON and TREITEL *Geophysical Signal Analysis*
TRIBOLET *Seismac Applications of Homomorphic Signal Processing*

MULTIRATE DIGITAL SIGNAL PROCESSING

RONALD E. CROCHIERE

LAWRENCE R. RABINER

Acoustics Research Department
Bell Laboratories
Murray Hill, New Jersey

Prentice-Hall, Inc., Englewood Cliffs, New Jersey 07632

Library of Congress Cataloging in Publication Data

Crochiere, Ronald E.
Multirate digital signal processing.

(Prentice-Hall signal processing series)
Includes index.
1. Signal processing—Digital techniques.
I. Rabiner, Lawrence R. II. Title.
III. Series.
TK5102.5.C76 1983 621.38'043 82-23113
ISBN 0-13-605162-6

Text processing: *Donna Manganelli*
Editorial/production and supervision by *Barbara Cassel* and *Mary Carnis*
Cover design: *Mario Piazza*
Manufacturing buyer: *Anthony Caruso*

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN 0-13-605162-6

Prentice-Hall International, Inc., *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Prentice-Hall of Southeast Asia Pte. Ltd., *Singapore*
Whitehall Books Limited, *Wellington, New Zealand*

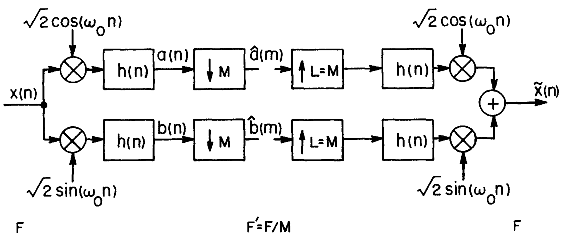

Figure 2.25 Block diagram of a quadrature modulator and sampling of bandpass signals using integer decimation and interpolation.

$$1 > \frac{L}{M} \geqslant \frac{\omega_\Delta}{2\pi} \tag{2.110}$$

As seen in Fig. 2.26, the outputs of the cosine and sine modulators are first increased in sampling rate by a factor L. They are then lowpass filtered by the filters $h(k)$, which must approximate the ideal characteristic (referenced to the sampling rate $F' = LF$)

$$\tilde{H}(e^{j\omega'}) = \begin{cases} 1, & 0 \leqslant |\omega'| \leqslant \dfrac{\omega_\Delta}{2L} \\ 0, & \text{otherwise} \end{cases} \tag{2.111}$$

and then decimated by M. The resulting quadrature signals are at the sampling rate $F'' = (L/M)F$. In the quadrature demodulator the reverse process takes place, as seen in Fig. 2.26.

2.4.4 Single-Sideband Modulation

The quadrature modulation approach coupled with methods of interpolation and decimation as discussed in the preceding section permits the sampling of bandpass signals, with arbitrary band edges, at their minimum required sampling rate. One consequence of this method, however, is that the resulting sampled signal $\hat{a}(m) + j\hat{b}(m)$ is a complex signal, and in some applications this may not be desired. By a slight modification of the quadrature approach, however, it can be shown that a real signal output can be obtained which corresponds to a "single-sideband" modulated format at the minimal sampling rate [2.5, 2.6].

Figure 2.27 illustrates this approach. The complex signal $a(n) + jb(n)$ is modulated by $e^{-j(\omega_\Delta/2)n}$ and its conjugate is modulated by $e^{j(\omega_\Delta/2)n}$ to produce the respective sideband signals X_γ^- and X_γ^+, as shown in Fig. 2.27(b). Summing these

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase®
Smarter legal research.