

| | | |
|-----|--|----|
| 6.1 | Probability Distribution | 65 |
| 6.2 | The Normal Distribution | 66 |
| 6.3 | Convolutions and Convolutional Filters | 67 |
| 6.4 | Convolution and Applications to Image Processing | 68 |
| 6.5 | Recursion in Convolution Filters | 70 |
| 6.6 | Complex Demodulation | 71 |

CHAPTERS

CONTENTS

| | |
|----------|------|
| Glossary | xiii |
|----------|------|

Chapter 1

PRELIMINARY CONCEPTS

| | | |
|------|---|----|
| 1.1 | Introduction | 1 |
| 1.2 | Review of Complex Arithmetic | 1 |
| 1.3 | The Fourier Transform | 4 |
| 1.4 | The Boxcar Function and Its Fourier Transform | 13 |
| 1.5 | Linear Systems | 15 |
| 1.6 | Convolution and Causality | 19 |
| 1.7 | The Effects of Finite Sample Length | 21 |
| 1.8 | Sampled Data and the Nyquist Frequency | 24 |
| 1.9 | Discrete Fourier Transform of Length N | 29 |
| 1.10 | The z Transform | 37 |

Chapter 2

PROBABILITY AND STATISTICAL CONCEPTS

| | | |
|-----|----------------------------------|----|
| 2.1 | Introduction | 40 |
| 2.2 | Sample Values and Estimates | 43 |
| 2.3 | Normal Distribution | 45 |
| 2.4 | Correlation and Regression | 49 |
| 2.5 | Power Spectral Density Function | 52 |
| 2.6 | How to Compute Mean and Variance | 55 |
| 2.7 | Probability Histograms | 57 |

x **Contents**

| | | |
|-------------|--|-----------|
| 2.8 | Peak Probability Density Functions | 63 |
| 2.9 | Multidimensional Density Functions | 66 |
| 2.10 | Examples and Applications of Probability Density Functions | 67 |

Chapter 3
COLLECTING AND PREPROCESSING DATA

| | | |
|------------|---------------------------------------|-----------|
| 3.1 | Introduction | 76 |
| 3.2 | Data Acquisition | 77 |
| 3.3 | Digital Representation of Information | 80 |
| 3.4 | Analog to Digital Conversion | 85 |
| 3.5 | Other Errors | 89 |
| 3.6 | Conversion to Physical Units | 93 |
| 3.7 | Wild Point Editing | 95 |
| 3.8 | Trend Removal | 98 |

Chapter 4
DESIGN OF DIGITAL FILTERS

| | | |
|-------------|----------------------------------|------------|
| 4.1 | Basic Concepts | 106 |
| 4.2 | First-Order Filters | 108 |
| 4.3 | Second-Order Filters | 113 |
| 4.4 | Higher-Order Filters | 126 |
| 4.5 | Basic Ideal Filters | 133 |
| 4.6 | Sine Butterworth Lowpass Filter | 137 |
| 4.7 | Sine Butterworth Highpass Filter | 145 |
| 4.8 | Bandpass Filters | 146 |
| 4.9 | Band Reject Filters | 152 |
| 4.10 | Tangent Filters | 156 |
| 4.11 | Other Recursive Filters | 164 |
| 4.12 | Nonrecursive (FIR) Filters | 165 |
| 4.13 | Filter Approximation Techniques | 171 |

Chapter 5
PRACTICAL ASPECTS OF DIGITAL FILTERING

| | | |
|------------|----------------------|------------|
| 5.1 | Introduction | 179 |
| 5.2 | Noise and Distortion | 180 |
| 5.3 | Deterioration | 185 |

| | | |
|-----|-------------------------------------|-----|
| 5.4 | Filter Implementation | 197 |
| 5.5 | Decimation | 202 |
| 5.6 | Upwards Decimation | 209 |
| 5.7 | Reduction to a Common Sampling Rate | 211 |
| 5.8 | Complex Demodulation | 212 |

Chapter 6 FOURIER TRANSFORMS

| | | |
|-----|----------------------------------|-----|
| 6.1 | Background and Theory | 219 |
| 6.2 | Fast Fourier Transform Algorithm | 239 |
| 6.3 | Examples | 260 |

Chapter 7 COVARIANCE AND CONVOLUTION FUNCTIONS

| | | |
|-----|---|-----|
| 7.1 | Background and Theory | 277 |
| 7.2 | Differences Between Covariance and Convolution | 284 |
| 7.3 | Long Record Lengths and Basic Covariance Computations | 285 |
| 7.4 | Covariance and Convolution via FFT's | 288 |
| 7.5 | Wraparound and Aliasing Effects | 295 |
| 7.6 | How to Compute Covariance and Convolution Functions | 303 |
| 7.7 | Impulse Response Length and Bandwidth for Convolution Filtering | 304 |
| 7.8 | Normalization and Mean Removal in Covariance Computations | 306 |
| 7.9 | Examples of the Use of Covariance and Convolution | 308 |

Chapter 8 POWER AND CROSS SPECTRAL DENSITIES

| | | |
|-----|---|-----|
| 8.1 | General Considerations in Computing Spectra | 316 |
| 8.2 | Concept of Density | 319 |
| 8.3 | Effective Resolution Bandwidth | 320 |
| 8.4 | Resolution Limits | 322 |
| 8.5 | Statistical Stability | 324 |
| 8.6 | Leakage | 330 |
| 8.7 | How to Compute Spectral Functions | 334 |
| 8.8 | Tapering Functions—Data Windows | 336 |
| 8.9 | Examples of the Use of PSD Functions | 360 |

Chapter 9 TRANSFER FUNCTIONS AND COHERENCE FUNCTION

| | | |
|------|--|-----|
| 9.1 | Properties of Transfer Functions | 363 |
| 9.2 | Spectral Relationships for Single Input System | 368 |
| 9.3 | Spectral Relationships for Multiple Input Linear Systems | 371 |
| 9.4 | Ordinary, Multiple, and Partial Coherence Functions | 374 |
| 9.5 | Confidence Limits for Coherence | 376 |
| 9.6 | Confidence Limit Computations for Transfer Functions | 379 |
| 9.7 | How to Compute Transfer Functions | 382 |
| 9.8 | The Sweep Operator | 386 |
| 9.9 | Transfer Function from Sine Waves | 388 |
| 9.10 | Transfer Function from Random Inputs | 393 |
| 9.11 | Coherence Function for $B_e = 1/P$ | 394 |
| 9.12 | Examples of Transfer Function Computations | 396 |

Appendix A COMPUTER SUBROUTINES FOR TIME SERIES ANALYSIS

| | | |
|-----|---------------------------------------|-----|
| A.1 | Introduction | 413 |
| A.2 | Random Number Generator | 414 |
| A.3 | Plotting on the Printer | 416 |
| A.4 | Fast Fourier Transform | 417 |
| A.5 | Generation of Lowpass Filter Weights | 421 |
| A.6 | Transfer Function of a Digital Filter | 423 |
| A.7 | Test Case and Results | 425 |

Appendix B BLACKMAN-TUKEY COMPUTATIONAL PROCEDURE FOR PSD'S

| | | |
|----------------|-----------------------------|---------|
| B.1 | Introduction | 432 |
| B.2 | Computational Formulas | 434 |
| B.3 | Procedure for Cross Spectra | 437 |
| B.4 | Comments | 439 |
| References | | 441 |
| Index | | 445 |