Contents

Preface ix
About the Authors xi

1 Introduction to Signal Processing 1
  1.1 Descriptions of Physical Data (Signals) 6
  1.2 Classification of Data 7

Part I Deterministic Signals 17

2 Classification of Deterministic Data 19
  2.1 Periodic Signals 19
  2.2 Almost Periodic Signals 21
  2.3 Transient Signals 24
  2.4 Brief Summary and Concluding Remarks 24
  2.5 MATLAB Examples 26

3 Fourier Series 31
  3.1 Periodic Signals and Fourier Series 31
  3.2 The Delta Function 38
  3.3 Fourier Series and the Delta Function 41
  3.4 The Complex Form of the Fourier Series 42
  3.5 Spectra 43
  3.6 Some Computational Considerations 46
  3.7 Brief Summary 52
  3.8 MATLAB Examples 52

4 Fourier Integrals (Fourier Transform) and Continuous-Time Linear Systems 57
  4.1 The Fourier Integral 57
  4.2 Energy Spectra 61
  4.3 Some Examples of Fourier Transforms 62
  4.4 Properties of Fourier Transforms 67
CONTENTS

4.5 The Importance of Phase 71
4.6 Echoes 72
4.7 Continuous-Time Linear Time-Invariant Systems and Convolution 73
4.8 Group Delay (Dispersion) 82
4.9 Minimum and Non-Minimum Phase Systems 85
4.10 The Hilbert Transform 90
4.11 The Effect of Data Truncation (Windowing) 94
4.12 Brief Summary 102
4.13 MATLAB Examples 103

5 Time Sampling and Aliasing 119
5.1 The Fourier Transform of an Ideal Sampled Signal 119
5.2 Aliasing and Anti-Aliasing Filters 126
5.3 Analogue-to-Digital Conversion and Dynamic Range 131
5.4 Some Other Considerations in Signal Acquisition 134
5.5 Shannon’s Sampling Theorem (Signal Reconstruction) 137
5.6 Brief Summary 139
5.7 MATLAB Examples 140

6 The Discrete Fourier Transform 145
6.1 Sequences and Linear Filters 145
6.2 Frequency Domain Representation of Discrete Systems and Signals 150
6.3 The Discrete Fourier Transform 153
6.4 Properties of the DFT 160
6.5 Convolution of Periodic Sequences 162
6.6 The Fast Fourier Transform 164
6.7 Brief Summary 166
6.8 MATLAB Examples 170

Part II Introduction to Random Processes 191

7 Random Processes 193
7.1 Basic Probability Theory 193
7.2 Random Variables and Probability Distributions 198
7.3 Expectations of Functions of a Random Variable 202
7.4 Brief Summary 211
7.5 MATLAB Examples 212

8 Stochastic Processes; Correlation Functions and Spectra 219
8.1 Probability Distribution Associated with a Stochastic Process 220
8.2 Moments of a Stochastic Process 222
8.3 Stationarity 224
8.4 The Second Moments of a Stochastic Process; Covariance (Correlation) Functions 225
8.5 Ergodicity and Time Averages 229
8.6 Examples 232
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>vii</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.7 Spectra</td>
<td>242</td>
</tr>
<tr>
<td>8.8 Brief Summary</td>
<td>251</td>
</tr>
<tr>
<td>8.9 MATLAB Examples</td>
<td>253</td>
</tr>
<tr>
<td>9 Linear System Response to Random Inputs: System Identification</td>
<td>277</td>
</tr>
<tr>
<td>9.1 Single-Input Single-Output Systems</td>
<td>277</td>
</tr>
<tr>
<td>9.2 The Ordinary Coherence Function</td>
<td>284</td>
</tr>
<tr>
<td>9.3 System Identification</td>
<td>287</td>
</tr>
<tr>
<td>9.4 Brief Summary</td>
<td>297</td>
</tr>
<tr>
<td>9.5 MATLAB Examples</td>
<td>298</td>
</tr>
<tr>
<td>10 Estimation Methods and Statistical Considerations</td>
<td>317</td>
</tr>
<tr>
<td>10.1 Estimator Errors and Accuracy</td>
<td>317</td>
</tr>
<tr>
<td>10.2 Mean Value and Mean Square Value</td>
<td>320</td>
</tr>
<tr>
<td>10.3 Correlation and Covariance Functions</td>
<td>323</td>
</tr>
<tr>
<td>10.4 Power Spectral Density Function</td>
<td>327</td>
</tr>
<tr>
<td>10.5 Cross-spectral Density Function</td>
<td>347</td>
</tr>
<tr>
<td>10.6 Coherence Function</td>
<td>349</td>
</tr>
<tr>
<td>10.7 Frequency Response Function</td>
<td>350</td>
</tr>
<tr>
<td>10.8 Brief Summary</td>
<td>352</td>
</tr>
<tr>
<td>10.9 MATLAB Examples</td>
<td>354</td>
</tr>
<tr>
<td>11 Multiple-Input/Response Systems</td>
<td>363</td>
</tr>
<tr>
<td>11.1 Description of Multiple-Input, Multiple-Output (MIMO) Systems</td>
<td>363</td>
</tr>
<tr>
<td>11.2 Residual Random Variables, Partial and Multiple Coherence Functions</td>
<td>364</td>
</tr>
<tr>
<td>11.3 Principal Component Analysis</td>
<td>370</td>
</tr>
<tr>
<td>Appendix A Proof of $\int_{-\infty}^{\infty} 2M \sin \frac{2\pi aM}{2\pi} da = 1$</td>
<td>375</td>
</tr>
<tr>
<td>Appendix B Proof of $</td>
<td>S_{xy}(f)</td>
</tr>
<tr>
<td>Appendix C Wave Number Spectra and an Application</td>
<td>381</td>
</tr>
<tr>
<td>Appendix D Some Comments on the Ordinary Coherence Function $\gamma_{xy}^2(f)$</td>
<td>385</td>
</tr>
<tr>
<td>Appendix E Least Squares Optimization: Complex-Valued Problem</td>
<td>387</td>
</tr>
<tr>
<td>Appendix F Proof of $H_W(f) \rightarrow H_1(f)$ as $\kappa(f) \rightarrow \infty$</td>
<td>389</td>
</tr>
<tr>
<td>Appendix G Justification of the Joint Gaussianity of $X(f)$</td>
<td>391</td>
</tr>
<tr>
<td>Appendix H Some Comments on Digital Filtering</td>
<td>393</td>
</tr>
<tr>
<td>References</td>
<td>395</td>
</tr>
<tr>
<td>Index</td>
<td>399</td>
</tr>
</tbody>
</table>