

# Contents

|  |             |
|--|-------------|
| <i>Preface</i>                                     | <i>xiii</i> |
| <b>1. Introduction to Signals</b>                  |             |
| 1.1 Introduction to Signals                        | 1           |
| 1.2 Sampling Theorem                               | 3           |
| 1.3 Sampling of Analog Signals (Case I)            | 3           |
| 1.4 Recovery of Analog Signals (Case I)            | 6           |
| 1.5 Sampling of Analog Signals (Case II)           | 8           |
| 1.6 Recovery of Analog Signals (Case II)           | 9           |
| 1.7 Analytical Treatment                           | 11          |
| 1.8 Analytical Examples                            | 13          |
| 1.9 Anti-Aliasing Filter                           | 19          |
| <i>Summary</i>                                     | 20          |
| <i>Multiple Choice Questions</i>                   | 21          |
| <i>Review Questions</i>                            | 22          |
| <i>Problems</i>                                    | 22          |
| <b>2. Signals and Operations on Signals</b>        |             |
| 2.1 Signals  | 24          |
| 2.2 Graph Terminology and Domains                  | 27          |
| 2.3 Applications of Signals and Systems            | 33          |
| 2.3.1 Basic communication system                   | 33          |
| 2.3.2 Basic control system                         | 35          |
| 2.4 Classification of Signals                      | 36          |
| 2.4.1 Analog signals                               | 36          |
| 2.4.2 Discrete time signals (DT signals)           | 41          |
| 2.4.3 Digital signals                              | 45          |
| 2.5 Elementary Signals used for Testing of Systems | 47          |
| 2.5.1 Reasons for using test or standard inputs    | 47          |

|           |  |     |
|-----------|--|-----|
| 2.5.2     | Standard analog signals  | 48  |
| 2.5.3     | Standard DT signals  | 59  |
| 2.6       | Classification of Signals Based on Signal Properties             | 72  |
| 2.6.1     | Even and odd signals   | 72  |
| 2.6.2     | Periodic and aperiodic signals                                   | 81  |
| 2.6.3     | Causal and non-causal signals                                    | 96  |
| 2.6.4     | Deterministic and random signals                                 | 99  |
| 2.6.5     | Energy and power signals   | 100 |
| 2.7       | Operations on Signals  | 118 |
| 2.7.1     | Time shifting  | 118 |
| 2.7.2     | Time reversal  | 120 |
| 2.7.3     | Time and amplitude scaling                                       | 124 |
| 2.7.4     | Addition, subtraction and multiplication                         | 135 |
|           | <i>Summary</i>   | 147 |
|           | <i>Multiple Choice Questions</i>                                 | 149 |
|           | <i>Review Questions</i>  | 153 |
|           | <i>Problems</i>  | 154 |
| <b>3.</b> | <b>CT and DT Systems</b>   |     |
| 3.1       | Properties of CT and DT Systems – Linearity and Shift Invariance | 181 |
| 3.1.1     | Linearity property   | 182 |
| 3.1.2     | Time invariance / shift invariance property                      | 194 |
| 3.2       | Properties of CT and DT Systems – Causality and Memory           | 201 |
| 3.2.1     | Causality property   | 201 |
| 3.2.2     | Memory   | 206 |
| 3.3       | Properties of CT and DT Systems – Invertibility and Stability    | 209 |
| 3.3.1     | Invertibility  | 209 |
| 3.3.2     | Stability  | 215 |
| 3.4       | System Representation as Interconnection of Operations           | 219 |
| 3.5       | Series and Parallel Interconnection of Systems                   | 224 |
| 3.5.1     | Series interconnection of systems                                | 225 |
| 3.5.2     | Parallel interconnection of systems                              | 227 |
|           | <i>Summary</i>   | 235 |
|           | <i>Multiple Choice Questions</i>                                 | 236 |
|           | <i>Review Questions</i>  | 238 |
|           | <i>Problems</i>  | 239 |

|  |     |
|--|-----|
| <b>4. Time Domain Response of CT and DT LTI Systems</b>      |     |
| 4.1 Response of CT Systems                                   | 246 |
| 4.1.1 Zero input response                                    | 247 |
| 4.2 System Representation as Impulse Response                | 249 |
| 4.2.1 Representation of signals in terms of impulses         | 250 |
| 4.2.2 Calculation of impulse response of the system          | 252 |
| 4.3 Convolution Integral for CT Systems                      | 256 |
| 4.3.1 Zero state response                                    | 269 |
| 4.4 Response of DT Systems                                   | 271 |
| 4.4.1 Zero input response                                    | 274 |
| 4.4.2 Impulse response of DT system                          | 275 |
| 4.4.3 Zero state response of DT system                       | 277 |
| 4.5 Representation of DT Signals in Terms of Delta Functions | 278 |
| 4.5.1 Convolution sum for DT systems                         | 279 |
| 4.5.2 Convolution using MATLAB                               | 291 |
| 4.6 Unit Step Response of CT and DT LTI Systems              | 295 |
| 4.7 Properties of LTI DT Systems                             | 303 |
| 4.7.1 Memory property of CT and DT LTI systems               | 303 |
| 4.7.2 Condition of causality for CT and DT LTI systems       | 305 |
| 4.7.3 Stability for CT and DT LTI systems                    | 309 |
| 4.8 Series and Parallel Interconnection of Systems           | 315 |
| <i>Summary</i>   | 319 |
| <i>Multiple Choice Questions</i>                             | 321 |
| <i>Review Questions</i>                                      | 323 |
| <i>Problems</i>  | 323 |
| <b>5. Fourier Series Representation of Periodic Signals</b>  |     |
| 5.1 Signal Representation in Terms as Sinusoids              | 332 |
| 5.1.1 Orthogonality property                                 | 332 |
| 5.1.2 Basis functions  | 337 |
| 5.2 FS Representation of Periodic CT Signals                 | 339 |
| 5.2.1 Evaluation of fourier coefficients of trigonometric FS | 340 |
| 5.2.2 Exponential FS representation of periodic CT signals   | 342 |
| 5.3 Application of Fourier Series Representation             | 347 |
| 5.4 Properties of Fourier Series for CT Signals              | 378 |
| 5.5 Recovery of CT Signal from FS                            | 390 |

|           |  |     |
|-----------|--|-----|
| 5.5.1     | Gibbs phenomenon   | 391 |
| 5.6       | FS Representation of DT Periodic Signals                           | 394 |
|           | <i>Summary</i>   | 398 |
|           | <i>Multiple Choice Questions</i>                                   | 400 |
|           | <i>Review Questions</i>  | 402 |
|           | <i>Problems</i>  | 403 |
| <b>6.</b> | <b>Fourier Transform Representation of Aperiodic Signals</b>       |     |
| 6.1       | Fourier Transform Representation of Aperiodic CT Signals           | 410 |
| 6.1.1     | Evaluation of magnitude and phase response using hand calculations | 412 |
| 6.2       | Fourier Transform of Some Standard CT Signals                      | 423 |
| 6.2.1     | Use of dirac delta function  | 435 |
| 6.2.2     | Applications of dirac delta function                               | 436 |
| 6.3       | Fourier Transforms of Periodic CT Signals                          | 441 |
| 6.4       | Inverse Fourier Transform  | 444 |
| 6.5       | FT of Aperiodic DT Signals (DTFT)                                  | 449 |
| 6.5.1     | FT of standard aperiodic DT signals                                | 456 |
| 6.6       | Properties of FT and DTFT  | 470 |
| 6.7       | FT and DTFT of Signals using FT/DTFT Properties                    | 483 |
| 6.8       | Analysis of LTI System using FT and DTFT                           | 495 |
|           | <i>Summary</i>   | 499 |
|           | <i>Multiple Choice Questions</i>                                   | 501 |
|           | <i>Review Questions</i>  | 506 |
|           | <i>Problems</i>  | 506 |
| <b>7.</b> | <b>Laplace Transform</b>   |     |
| 7.1       | Definition of Laplace Transform                                    | 513 |
| 7.2       | Laplace Transform of Some Standard Functions                       | 519 |
| 7.3       | Properties of LT   | 527 |
| 7.4       | Solved Examples on LT  | 539 |
| 7.4.1     | LT of standard aperiodic signals                                   | 551 |
| 7.4.2     | LT of standard periodic signals                                    | 558 |
| 7.4.3     | LT of signals using properties of LT                               | 564 |
| 7.4.4     | Properties of ROC  | 571 |
| 7.5       | Inverse LT   | 572 |
| 7.5.1     | Transform analysis of LTI systems                                  | 586 |
| 7.5.2     | Total response of the system using LT                              | 592 |
| 7.5.3     | Stability considerations in $S$ domain                             | 598 |

|   |     |
|---|-----|
| <i>Summary</i>  | 603 |
| <i>Multiple Choice Questions</i>                                  | 604 |
| <i>Review Questions</i>   | 609 |
| <i>Problems</i>   | 610 |
| <b>8. Z Transform</b>   |     |
| 8.1 Physical Significance of a Transform                          | 619 |
| 8.2 Relation between LT and ZT                                    | 619 |
| 8.3 Relation between Fourier Transform (FT) and Z Transform       | 621 |
| 8.4 Solved Problems on Z Transform                                | 622 |
| 8.5 Properties of ROC   | 630 |
| 8.6 Properties of Z Transform                                     | 642 |
| 8.7 Relation between Pole Locations and Time Domain Behavior      | 655 |
| 8.8 Inverse Z Transform   | 660 |
| 8.8.1 Power series method/long division method                    | 660 |
| 8.8.2 Partial fraction expansion method                           | 664 |
| 8.8.3 Residue method  | 674 |
| 8.9 Solution of Difference Equation using Z Transform             | 678 |
| 8.9.1 Applications of ZT and IZT                                  | 685 |
| <i>Summary</i>  | 685 |
| <i>Multiple Choice Questions</i>                                  | 687 |
| <i>Review Questions</i>   | 688 |
| <i>Problems</i>   | 689 |
| <b>9. Random Signals and Processes</b>                            |     |
| 9.1 Probability   | 693 |
| 9.1.1 Conditional probability                                     | 696 |
| 9.1.2 Bayes theorem   | 701 |
| 9.2 Random Variable   | 706 |
| 9.2.1 Cumulative distribution function (CDF)                      | 707 |
| 9.2.2 Probability density function (pdf)                          | 710 |
| 9.3 Statistical Properties of Random Variables                    | 716 |
| 9.4 Standard Distribution Functions                               | 722 |
| 9.4.1 Probability distribution functions for continuous variables | 722 |
| 9.4.2 Probability distribution functions for discrete variables   | 731 |
| 9.4.3 Functions for finding moments                               | 738 |
| 9.5 Central Limit Theorem and Chi Square Test, K-S Test           | 740 |
| 9.6 Random Processes  | 744 |

|       |  |     |
|-------|--|-----|
| 9.7   | Estimation of ESD and PSD                                      | 747 |
| 9.7.1 | Computation of energy density spectrum of deterministic signal | 747 |
| 9.7.2 | Estimation of power density spectrum of random signal          | 756 |
|       | <i>Summary</i>   | 759 |
|       | <i>Multiple Choice Questions</i>                               | 760 |
|       | <i>Review Questions</i>  | 762 |
|       | <i>Problems</i>  | 763 |
|       | <i>Index</i>   | 767 |