## Contents

**Preface**

1. **Introduction to Signals**
   1.1 Introduction to Signals  
   1.2 Sampling Theorem  
   1.3 Sampling of Analog Signals (Case I)  
   1.4 Recovery of Analog Signals (Case I)  
   1.5 Sampling of Analog Signals (Case II)  
   1.6 Recovery of Analog Signals (Case II)  
   1.7 Analytical Treatment  
   1.8 Analytical Examples  
   1.9 Anti-Aliasing Filter

**Summary**

20

**Multiple Choice Questions**

21

**Review Questions**

22

**Problems**

22

2. **Signals and Operations on Signals**

   2.1 Signals  
   2.2 Graph Terminology and Domains  
   2.3 Applications of Signals and Systems  
     2.3.1 Basic communication system  
     2.3.2 Basic control system  
   2.4 Classification of Signals  
     2.4.1 Analog signals  
     2.4.2 Discrete time signals (DT signals)  
     2.4.3 Digital signals  
   2.5 Elementary Signals used for Testing of Systems  
     2.5.1 Reasons for using test or standard inputs
## Contents

2.5.2 Standard analog signals  
2.5.3 Standard DT signals  
2.6 Classification of Signals Based on Signal Properties  
2.6.1 Even and odd signals  
2.6.2 Periodic and aperiodic signals  
2.6.3 Causal and non-causal signals  
2.6.4 Deterministic and random signals  
2.6.5 Energy and power signals  
2.7 Operations on Signals  
2.7.1 Time shifting  
2.7.2 Time reversal  
2.7.3 Time and amplitude scaling  
2.7.4 Addition, subtraction and multiplication  

### Summary

147

### Multiple Choice Questions

149

### Review Questions

153

### Problems

154

### 3. CT and DT Systems

3.1 Properties of CT and DT Systems – Linearity and Shift Invariance  
3.1.1 Linearity property  
3.1.2 Time invariance / shift invariance property  
3.2 Properties of CT and DT Systems – Causality and Memory  
3.2.1 Causality property  
3.2.2 Memory  
3.3 Properties of CT and DT Systems – Invertibility and Stability  
3.3.1 Invertibility  
3.3.2 Stability  
3.4 System Representation as Interconnection of Operations  
3.5 Series and Parallel Interconnection of Systems  
3.5.1 Series interconnection of systems  
3.5.2 Parallel interconnection of systems  

### Summary

235

### Multiple Choice Questions

236

### Review Questions

238

### Problems

239
4. Time Domain Response of CT and DT LTI Systems
   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

Summary 319

Multiple Choice Questions 321
Review Questions 323
Problems 323

5. Fourier Series Representation of Periodic Signals 332
   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
Summary 603

Multiple Choice Questions 604

Review Questions 609

Problems 610

8. Z Transform
   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

Summary 685

Multiple Choice Questions 687

Review Questions 688

Problems 689

9. Random Signals and Processes
   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
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.7</td>
<td>Estimation of ESD and PSD</td>
<td>747</td>
</tr>
<tr>
<td>9.7.1</td>
<td>Computation of energy density spectrum of deterministic signal</td>
<td>747</td>
</tr>
<tr>
<td>9.7.2</td>
<td>Estimation of power density spectrum of random signal</td>
<td>756</td>
</tr>
</tbody>
</table>

**Summary**
759

**Multiple Choice Questions**
760

**Review Questions**
762

**Problems**
763

**Index**
767