CONTENTS

Preface			vii		
List of Symbols			xvii		
List of Abbreviations			XX		
CHAPTER 1: Discrete Fourier Transform			1.1-1.132		
1.1	1.1 Review of Signals and Systems 1.1				
		Signals 1.1			
		Continuous Time Signal 1.2			
		Discrete Time Signal 1.2			
	1.1.4	Generation of Discrete Time Signals 1.3			
	1.1.5	Digital Signal 1.4			
	1.1.6	Mathematical Representation of Discrete Time Signals 1.6			
	1.1.7	Standard Discrete Time Signals 1.7			
	1.1.8	Systems 1.10			
	1.1.9	Continuous Time System 1.10			
	1.1.10	Discrete Time System 1.11			
	1.1.11	Differerence Equation Governing Discrete Time System (Mathematical Representation of Discrete Time System) 1.12			
	1.1.12	Block Diagram and Signal Flow Graph Representation of Discrete Time S	System 1.14		
	1.1.13	Convolution 1.16			
	1.1.14	Circular Convolution 1.19			
	1.1.15	Sectioned Convolution 1.26			
1.2	Concept	t of Frequency in Signals 1.42			
	1.2.1	Concept of Frequency in Continuous Time Signals 1.42			
	1.2.2	Concept of Frequency in Discrete Time Signals 1.44			
1.3 Summary of Analysis and Synthesis Equation for FT and DTFT 1.441.3.1 Devolopment of Fourier Transform from Fourier Series 1.44					
	1.3.2	Devolopment of Discrete Time Fourier Transform from Discrete Time Fourier	er Series 1.46		
1.4 Frequency Domain Sampling 1.47					

- 1.5 Discrete Fourier Transform (DFT) 1.49
 - 1.5.1 Deriving DFT from DTFT 1.49
 - 1.5.2 Definition of Discrete Fourier Transform (DFT) 1.50
 - 1.5.3 Frequency Spectrum Using DFT 1.50
 - 1.5.4 Inverse DFT 1.51
 - 1.5.5 Relation between DFT and Z-Transform 1.52
 - 1.5.6 Linear Convolution Using DFT 1.52
- 1.6 Properties of DFT 1.58
 - 1.6.1 Periodicity 1.58
 - 1.6.2 Symmetry 1.58
 - 1.6.3 Circular Convolution 1.62
 - 1.6.4 Linearity 1.63
 - 1.6.5 Circular Time Shift 1.63
 - 1.6.6 Time Reversal 1.64
 - 1.6.7 Conjugation 1.64
 - 1.6.8 Circular Frequency Shift 1.64
 - 1.6.9 Multiplication 1.65
 - 1.6.10 Circular Correlation 1.65
 - 1.6.11 Parseval's Relation 1.66
- 1.7 Linear Filtering Using DFT 1.68
 - 1.7.1 Filtering Long Data Sequences 1.69
 - 1.7.2 Overlap Add Method 1.69
 - 1.7.3 Overlap Save Method 1.70
- 1.8 Fast Computation of DFT (or Fast Fourier Transform (FFT)) 1.77
- 1.9 Radix-2 Decimation in Time (DIT) Fast Fourier Transform (FFT) 1.80
 - 1.9.1 8-Point DFT Using Radix-2 DIT FFT 1.82
 - 1.9.2 Flow Graph for 8-Point DFT Using Radix-2 DIT FFT 1.86
- 1.10 Radix-2 Decimation in Frequency (DIF) Fast Fourier Transform (FFT) 1.88
 - 1.10.1 8-Point DFT Using Radix-2 DIF FFT 1.91
 - 1.10.2 Flow Graph for 8-Point DFT Using Radix-2 DIF FFT 1.93
 - 1.10.3 Comparison of DIT and DIF Radix-2 FFT 1.96
- 1.11 Computation of Inverse DFT Using FFT 1.96
- 1.12 Linear Filtering Using FFT 1.102
- 1.13 Summary of Important Concepts 1.111
- 1.14 Short-Answer Questions 1.112
- 1.15 MATLAB Programs 1.118
- 1.16 Exercises 1.126

Contents xi

CHAPTER 2: Infinite Impulse Response Filters	2.1-2.184

- 2.1 Introduction 2.1
- 2.2 Characteristics of practical frequency selective filters 2.2
 - 2.2.1 Specifications of Digital IIR Lowpass Filter 2.6
- 2.3 Charcteristics of commonly used analog Butterworth filters 2.9
 - 2.3.1 Analog Butterworth Filter 2.9
 - 2.3.2 Poles of Butterworth Lowpass Filter 2.10
 - 2.3.3 Transfer Function of Analog Butterworth Lowpass Filter 2.17
 - 2.3.4 Frequency Response of Analog Lowpass Butterworth Filter 2.18
 - 2.3.5 Order of the Lowpass Butterworth Filter 2.18
 - 2.3.6 Cutoff Frequency of Lowpass Butterworth Filter 2.19
- 2.4 Charcteristics of commonly used analog Chebyshev filters 2.20
 - 2.4.1 Analog Chebyshev Filter 2.20
 - 2.4.2 Transfer function of Analog Chebyshev Lowpass Filter 2.21
 - 2.4.3 Order of Analog Lowpass Chebyshev Filter 2.22
 - 2.4.4 Cutoff Frequency of Analog Lowpass Chebyshev Filter 2.23
 - 2.4.5 Frequency Response of Analog Chebyshev Lowpass Filter 2.23
- 2.5 Design of IIR Filters from Analog filters (LPF, HPF, BPF, BRF) 2.24
 - 2.5.1 Design Procedure for Lowpass Digital Butterworth IIR Filter 2.24
 - 2.5.2 Design Procedure for Lowpass Digital Chebyshev IIR Filter 2.26
 - 2.5.3 Analog Frequency Transformation 2.28
 - 2.5.4 Digital Frequency Transformation 2.29
- 2.6 Approximation of Derivatives 2.29
- 2.7 Impulse Invariant Transformation 2.34
 - 2.7.1 Relation between Analog and Digital Filter Poles in Impulse Invariant Transformation 2.35
 - 2.7.2 Relation between Analog and Digital Frequency in Impulse Invariant Transformation 2.36
 - 2.7.3 Useful Impulse Invariant Transformation 2.37
- 2.8 Bilinear Transformation 2.43
 - 2.8.1 Relation between Analog and Digital Filter Poles in Bilinear Transformation 2.44
 - 2.8.2 Relation between Analog and Digital Frequency in Bilinear Transformation 2.45
- 2.9 Structure for Realization of IIR Filter 2.51
 - 2.9.1 Direct Form-I Structure of IIR System 2.52
 - 2.9.2 Direct Form-II Structure of IIR System 2.53
 - 2.9.3 Cascade Form Realization of IIR Sytsem 2.56
 - 2.9.4 Parallel Form Realization of IIR Sytsem 2.56

- 2.10 Examples of IIR Filter Design 2.84
- 2.11 Summary of Important Concepts 2.140
- 2.12 Short-Answer Questions 2.142
- 2.13 MATLAB Programs 2.153
- 2.14 Exercises 2.173

CHAPTER 3: Finite Impulse Response Filters

3.1-3.130

- 3.1 Design of FIR Filters 3.1
 - 3.1.1 LTI System as Frequency Selective Filters 3.2
 - 3.1.2 Ideal Frequency Response of Linear Phase FIR Filters 3.4
- 3.2 Symmetric and Anti-symmetric FIR Filters 3.6
 - 3.2.1 Linear Phase and Symmetric Impulse Response 3.6
 - 3.2.2 Linear Phase and Antisymmetric Impulse Response 3.8
- 3.3 Frequency Response of Linear Phase FIR Filters 3.8
- 3.4 Design Techniques for Linear Phase FIR Filters 3.20
- 3.5 Design of Linear Phase FIR Filters Using Fourier Series Method 3.22
- 3.6 Windows 3.40
 - 3.6.1 Rectangular Window 3.41
 - 3.6.2 Bartlett or Triangular Window 3.43
 - 3.6.3 Raised Cosine Window 3.44
 - 3.6.4 Hanning Window 3.46
 - 3.6.5 Hamming Window 3.47
 - 3.6.6 Blackman Window 3.49
 - 3.6.7 Kaiser Window 3.50
 - 3.6.8 Summary of Various Features of Windows 3.54
- 3.7 FIR Filter Design Using Windows 3.54
- 3.8 Design of FIR Filters by Frequency Sampling Method 3.79
- 3.9 FIR Filter Structures 3.92
 - 3.9.1 Direct Form Realization of FIR Systems 3.92
 - 3.9.2 Cascade Form Realization of FIR Systems 3.93
 - 3.9.3 Linear Phase Structure 3.93
- 3.10 Summary of Important Concepts 3.101
- 3.11 Short-Answer Questions 3.102
- 3.12 MATLAB Programs 3.111
- 3.13 Exercises 3.122

Contents

CHA	APTER 4:	Finite Word Length Effects	4.1-4.68	
4.1	1 Introduction 4.1			
4.2	4.2.1 4.2.2 4.2.3	ntation of Numbers in Digital Systems 4.2 Binary Codes 4.2 Radix Number System 4.3 Fixed Point Representation 4.4 Floating Point Representation 4.8		
4.3	4.3.1 4.3.2 4.3.3 4.3.4	Arithmetic in Digital Systems 4.12 One's Complement Addition 4.12 Two's Complement Addition 4.13 Floating Point Addition 4.14 Floating Point Multiplication 4.15 Comparison of Fixed Point and Floating Point Arithmetic 4.16		
4.4	_	Quantization 4.16 Quantization Steps 4.17		
4.5	4.5.1 4.5.2 4.5.3	tion by Truncation and Rounding 4.18 Truncation 4.19 Quantization Error due to Truncation 4.20 Rounding 4.22 Quantization Error due to Rounding 4.23		
4.6	Quantiza 4.6.1	ntion Noise due to Input/Output Quantization 4.24 Steady State Output Noise Variance (Power) due to Quantization Error S	Signal 4.25	
4.7	Coefficient Quantization Error 4.29			
4.8		Quantization Error 4.37 Output Noise Power (Roundoff Noise Power) due to Product Quantization	on 4.39	
4.9	Overflow Error 4.52			
4.10	0 Limit Cycle Oscillation due to Product Quantization and Summation 4.53			
4.11	1 Scaling to Prevent Overflow 4.61			
4.12	2 Summary of Important Concepts 4.72			

CHAPTER 5: Introduction to Digital Signal Processors

5.1-5.114

5.1 Digital Signal Processors 5.1

4.13 Short-Answer Questions 4.74

4.14 Exercises 4.80

5.2	DSP (Di	igital Signal Processor) Functionalities 5.3	
	5.2.1	Fast Data Access 5.3	
	5.2.2	Fast Computation 5.4	
	5.2.3	Numerical Fidelity 5.5	
	5.2.4	Fast Execution Control 5.6	
	5.2.5	Circular Buffering 5.6	
	5.2.6	Addressing Formats in DSP 5.7	
	5.2.7	Functional Modes in DSP 5.8	
5.3	DSP (Di	igital Signal Processor) Architecture 5.9	
	5.3.1	VLIW (Very Long Instruction Word) Architecture 5.10	
	5.3.2	Multiprocessor Architecture 5.11	
	5.3.3	Fixed and Floating Point Architecture Principles 5.11	
5.4	TMS320	0C5x Family of Fixed Point Digital Signal Processors 5.12	
	5.4.1	Pin Diagram of TMS320C5x Processor 5.14	
	5.4.2	Architecture of TMS320C5x Processor 5.18	
	5.4.3	Functional Units of CPU of TMS320C5x Processor 5.19	
	5.4.4	On-Chip in Memory TMS320C5x Processor 5.23	
	5.4.5	On-Chip Peripherals of TMS320C5x Processor 5.23	
	5.4.6	Addressing Modes of TMS320C5x Processor 5.25	
	5.4.7	Instruction Pipelining in TMS320C5x Processor 5.27	
	5.4.8	Instruction of TMS320C5x Processor 5.28	
	5.4.9	Programming and Application Examples in TMS320C5x Processors 5.3	39
5.5	TMS320	0C54x Family of Fixed Point Digital Signal Processor 5.48	
	5.5.1	Pin Diagram of TMS320C54x Processor 5.51	
	5.5.2	Architecture of TMS320C54x Processor 5.54	
	5.5.3	Functional Units of CPU of TMS320C54x Processor 5.55	
	5.5.4	On-Chip in Memory in TMS320C54x Processor 5.60	
	5.5.5	On-Chip Peripherals of TMS320C54x Processor 5.61	
	5.5.6	Addressing Modes of TMS320C54x Processor 5.64	
	5.5.7	Circular Buffer and Circular Addressing of TMS320C54x Processor 5.	66
	5.5.8	Instruction Pipelining in TMS320C54x Processor 5.67	
	5.5.9	Instruction Set of TMS320C54x Processor 5.67	
	5.5.10	Programming and Application Examples in TMS320C54x Processor 5.	76
5.6	TMS320	C3x Family of Floating Point Digital Signal Processors 5.80	
	5.6.1	Pin Diagram of TMS320C31 Processor 5.81	
	5.6.2	Data Format Supported by TMS320C3x Processor 5.84	
	5.6.3	Architecture of TMS320C31 Processor 5.86	
	5.6.4	Functional Units of CPU of TMS320C31 Processor 5.86	
	5.6.5	CPU Primary Register File of TMS320C31 Processor 5.87	

Contents

- 5.6.6 Memory Organization 5.90
- 5.6.7 Addressing Modes of TMS320C31 Processor 5.90
- 5.6.8 Instruction Set of TMS320C31 Processor 5.94
- 5.6.9 Programming and Application Examples in TMS320C31 Processor 5.100
- 5.7 Summary of Important Concepts 5.103
- 5.8 Short-Answer Questions 5.105
- 5.9 Exercises 5.110

APPENDICES A.1-A.14

Appendix 1 Important Mathematical Relations A. 1

Appendix 2 MATLAB Commands and Functions A. 4

Appendix 3 Summary of Properties of DFT A. 9

Appendix 4 Summary of Important Equations for FIR Filter Design A. 10

Appendix 5 Summary of Important Equations for IIR Filter Design A. 14

INDEX I.1– I.6