

SCHAUM'S  
*ouTlines*

# DIGITAL SIGNAL PROCESSING

MONSON H. HAYES

The perfect aid for better grades!

Covers all course fundamentals—supplements  
any class text

Teaches effective problem solving

Over 300 problems  
solved step-by-step

Ideal for independent  
study!

MORE THAN  
30 MILLION  
SCHAUM'S  
OUTLINES  
SOLD

Use with these courses: ☒ Signals and Systems ☒ Digital Signal Processing

☒ Digital Filters and Signal Processing ☒ Discrete-Time and Continuous-Time Linear Systems



# Contents

## SIGNALS AND SYSTEMS

1.1	Introduction	1
1.2	Discrete-Time Signals	1
1.2.1	Complex Sequences	2
1.2.2	Some Fundamental Sequences	2
1.2.3	Signal Duration	3
1.2.4	Periodic and Aperiodic Sequences	3
1.2.5	Symmetric Sequences	4
1.2.6	Signal Manipulations	4
1.2.7	Signal Decomposition	6
1.3	Discrete-Time Systems	7
1.3.1	Systems Properties	7
1.4	Convolution	11
1.4.1	Convolution Properties	11
1.4.2	Performing Convolutions	12
1.5	Difference Equations	15
	Solved Problems	18

## FOURIER ANALYSIS

2.1	Introduction	55
2.2	Frequency Response	55
2.3	Filters	58
2.4	Interconnection of Systems	59
2.5	The Discrete-Time Fourier Transform	61
2.6	DTFT Properties	62
2.7	Applications	64
2.7.1	LSI Systems and LCCDEs	64
2.7.2	Performing Convolutions	65
2.7.3	Solving Difference Equations	66
2.7.4	Inverse Systems	66
	Solved Problems	67

## SAMPLING

3.1	Introduction	101
3.2	Analog-to-Digital Conversion	101
3.2.1	Periodic Sampling	101
3.2.2	Quantization and Encoding	104
3.3	Digital-to-Analog Conversion	106
3.4	Discrete-Time Processing of Analog Signals	108
3.5	Sample Rate Conversion	110
3.5.1	Sample Rate Reduction by an Integer Factor	110
3.5.2	Sample Rate Increase by an Integer Factor	111
3.5.3	Sample Rate Conversion by a Rational Factor	113
	Solved Problems	114

<b>Chapter 4</b>	<b>THE Z-TRANSFORM</b>	<b>142</b>
4.1	Introduction	142
4.2	Definition of the $z$ -Transform	142
4.3	Properties	146
4.4	The Inverse $z$ -Transform	149
4.4.1	Partial Fraction Expansion	149
4.4.2	Power Series	150
4.4.3	Contour Integration	151
4.5	The One-Sided $z$ -Transform	151
	Solved Problems	152
<b>Chapter 5</b>	<b>TRANSFORM ANALYSIS OF SYSTEMS</b>	<b>183</b>
5.1	Introduction	183
5.2	System Function	183
5.2.1	Stability and Causality	184
5.2.2	Inverse Systems	186
5.2.3	Unit Sample Response for Rational System Functions	187
5.2.4	Frequency Response for Rational System Functions	188
5.3	Systems with Linear Phase	189
5.4	Allpass Filters	193
5.5	Minimum Phase Systems	194
5.6	Feedback Systems	195
	Solved Problems	196
<b>Chapter 6</b>	<b>THE DFT</b>	<b>223</b>
6.1	Introduction	223
6.2	Discrete Fourier Series	223
6.3	Discrete Fourier Transform	226
6.4	DFT Properties	227
6.7	Sampling the DTFT	231
6.6	Linear Convolution Using the DFT	232
	Solved Problems	235
<b>Chapter 7</b>	<b>THE FAST FOURIER TRANSFORM</b>	<b>262</b>
7.1	Introduction	262
7.2	Radix-2 FFT Algorithms	262
7.2.1	Decimation-in-Time FFT	262
7.2.2	Decimation-in-Frequency FFT	266
7.3	FFT Algorithms for Composite $N$	267
7.4	Prime Factor FFT	271
	Solved Problems	273
<b>Chapter 8</b>	<b>IMPLEMENTATION OF DISCRETE-TIME SYSTEMS</b>	<b>287</b>
8.1	Introduction	287
8.2	Digital Networks	287
8.3	Structures for FIR Systems	289
8.3.1	Direct Form	289
8.3.2	Cascade Form	289
8.3.3	Linear Phase Filters	289
8.3.4	Frequency Sampling	291



8.4	Structures for IIR Systems .....	291
8.4.1	Direct Form .....	292
8.4.2	Cascade Form .....	294
8.4.3	Parallel Structure .....	295
8.4.4	Transposed Structures .....	296
8.4.5	Allpass Filters .....	296
8.5	Lattice Filters .....	298
8.5.1	FIR Lattice Filters .....	298
8.5.2	All-Pole Lattice Filters .....	300
8.5.3	IIR Lattice Filters .....	301
8.6	Finite Word-Length Effects .....	302
8.6.1	Binary Representation of Numbers .....	302
8.6.2	Quantization of Filter Coefficients .....	304
8.6.3	Round-Off Noise .....	306
8.6.4	Pairing and Ordering .....	309
8.6.5	Overflow .....	309
	Solved Problems .....	310

<b>Chapter 9</b>	<b>FILTER DESIGN .....</b>	<b>358</b>
9.1	Introduction .....	358
9.2	Filter Specifications .....	358
9.3	FIR Filter Design .....	359
9.3.1	Linear Phase FIR Design Using Windows .....	359
9.3.2	Frequency Sampling Filter Design .....	363
9.3.3	Equiripple Linear Phase Filters .....	363
9.4	IIR Filter Design .....	366
9.4.1	Analog Low-Pass Filter Prototypes .....	367
9.4.2	Design of IIR Filters from Analog Filters .....	373
9.4.3	Frequency Transformations .....	376
9.5	Filter Design Based on a Least Squares Approach .....	376
9.5.1	Padé Approximation .....	377
9.5.2	Prony's Method .....	378
9.5.3	FIR Least-Squares Inverse .....	379
	Solved Problems .....	380

<b>INDEX .....</b>	<b>429</b>
--------------------	------------