

Fundamentals of Signals and Systems

A Building Block Approach

**Philip D. Cha and
John I. Molinder**

CAMBRIDGE

Contents

<i>List of figures</i>	<i>page</i> x
<i>List of tables</i>	xxi
<i>Preface</i>	xxiii
<i>Acknowledgments</i>	xxvii
1 Introduction to signals and systems	1
1.1 Signals and systems	1
1.2 Examples of signals	4
1.3 Mathematical foundations	7
1.4 Phasors	9
1.5 Time-varying frequency and instantaneous frequency	12
1.6 Transformations	14
1.7 Discrete-time signals	18
1.8 Sampling	22
1.9 Downsampling and upsampling	23
1.10 Problems	24
2 Constructing signals from building blocks	29
2.1 Basic building blocks	29
2.2 The orthogonality principle	33
2.3 Orthogonal basis functions	35
2.4 Fourier series	42
2.5 Alternative forms of the Fourier series	43
2.6 Approximating signals numerically	47
2.7 The spectrum of a signal	49
2.8 The discrete Fourier transform	56
2.9 Variations on the DFT and IDFT	59

2.10	Relationship between $X[k]$ and c_k	60
2.11	Examples	62
2.12	Proof of the continuous-time orthogonality principle	69
2.13	A note on vector spaces	72
2.14	Problems	78
3	Sampling and data acquisition	85
3.1	Sampling theorem	87
3.2	Discrete-time spectra	88
3.3	Aliasing, folding and reconstruction	89
3.4	Continuous- and discrete-time spectra	96
3.5	Aliasing and folding (time domain perspective)	97
3.6	Windowing	104
3.7	Aliasing and folding (frequency domain perspective)	106
3.8	Handling data with the FFT	110
3.9	Problems	112
4	Lumped element modeling of mechanical systems	118
4.1	Introduction	118
4.2	Building blocks for lumped mechanical systems	121
4.3	Inputs to mechanical systems	131
4.4	Governing equations	132
4.5	Parallel combination	141
4.6	Series combination	144
4.7	Combination of masses	146
4.8	Examples of parallel and series combinations	146
4.9	Division of force in parallel combination	147
4.10	Division of displacement in series combination	148
4.11	Problems	150
5	Lumped element modeling of electrical systems	158
5.1	Building blocks for lumped electrical systems	158
5.2	Summary	165
5.3	Inputs to electrical systems	166
5.4	Governing equations	167
5.5	Parallel combination	172
5.6	Series combination	175
5.7	Division of current in parallel combination	177

Contents

5.8	Division of voltage in series combination	177
5.9	Problems	178
6	Solution to differential equations	183
6.1	First-order ordinary differential equations	184
6.2	Second-order ordinary differential equations	185
6.3	Transient response	189
6.4	Transient specifications	196
6.5	State space formulation	199
6.6	Problems	211
7	Input–output relationship using frequency response	217
7.1	Frequency response of linear, time-invariant systems	219
7.2	Frequency response to a periodic input and any arbitrary input	221
7.3	Bode plots	222
7.4	Impedance	238
7.5	Combination and division rules using impedance	241
7.6	Problems	249
8	Digital signal processing	266
8.1	More frequency response	268
8.2	Notation clarification	270
8.3	Utilities	271
8.4	DSP example and discrete-time FRF	272
8.5	Frequency response of discrete-time systems	281
8.6	Relating continuous-time and discrete-time frequency response	291
8.7	Finite impulse response filters	299
8.8	The mixer	305
8.9	Problems	307
9	Applications	310
9.1	Communication systems	310
9.2	Modulation	310
9.3	AM radio	311
9.4	Vibration measuring instruments	317
9.5	Undamped vibration absorbers	323
9.6	JPEG compression	325
9.7	Problems	335

10	Summary	341
10.1	Continuous-time signals	343
10.2	Discrete-time signals	345
10.3	Lumped element modeling of mechanical and electrical systems	347
10.4	Transient response	350
10.5	Frequency response	351
10.6	Impedance	353
10.7	Digital signal processing	354
10.8	Transition to more advanced texts (or, what's next?)	356
	Laboratory exercises	363
	Laboratory exercise 1 Introduction to MATLAB	365
L1.1	Objective	365
L1.2	Guided introduction to MATLAB	365
L1.3	Vector and matrix manipulation	366
L1.4	Variables	370
L1.5	Plotting	371
L1.6	M-files	373
L1.7	Housekeeping	377
L1.8	Summary of MATLAB commands	378
L1.9	Exercises	379
	Laboratory exercise 2 Synthesize music	382
L2.1	Objective	382
L2.2	Playing sinusoids	382
L2.3	Generating musical notes	383
L2.4	<i>Für Elise</i> project	385
L2.5	Extra credit	386
L2.6	Exercises	387
	Laboratory exercise 3 DFT and IDFT	388
L3.1	Objective	388
L3.2	The discrete Fourier transform	388
L3.3	The inverse discrete Fourier transform	391
L3.4	The fast Fourier transform	392
L3.5	Exercises	393
	Laboratory exercise 4 FFT and IFFT	394
L4.1	Objective	394
L4.2	Frequency response of a parallel <i>RLC</i> circuit	395

Contents

L4.3	Time response of a parallel <i>RLC</i> circuit to a sweep input	396
L4.4	Exercises	399
	Laboratory exercise 5 Frequency response	400
L5.1	Objective	400
L5.2	Automobile suspension	400
L5.3	Frequency response	400
L5.4	Time response to sinusoidal input	401
L5.5	Numerical solution with the Fourier transform	402
L5.6	Time response to step input	403
L5.7	Optimizing the suspension	404
L5.8	Exercises	404
	Laboratory exercise 6 DTMF	405
L6.1	Objective	405
L6.2	DTMF dialing	405
L6.3	fdomain and tdomain	406
L6.4	Band-pass filters	407
L6.5	DTMF decoding	407
L6.6	Forensic engineering	408
L6.7	Exercises	408
	Laboratory exercise 7 AM radio	409
L7.1	Objective	409
L7.2	Amplitude modulation	409
L7.3	Demodulation	410
L7.4	Pirate radio	411
L7.5	Exercises	412
	<i>Appendix A Complex arithmetic</i>	413
	<i>Appendix B Constructing discrete-time signals from building blocks – least squares</i>	416
	<i>Appendix C Discrete-time upsampling, sampling and downsampling</i>	419
	<i>Index</i>	425