

Contents

1. Introduction	1
1.1 The Role of A/D Conversion	2
1.2 Key Technological Challenges	3
1.3 Motivation for Photonic A/D Approaches	3
1.4 Organization of this Book	4
2. Performance Characteristics of Analog-to-Digital Converters	7
2.1 A/D Converter Characteristics	8
2.2 Sampling and Conversion Rate Characteristics	9
2.2.1 Sampling Rate	9
2.2.2 Conversion Rate	10
2.3 Performance Measures	11
2.3.1 Resolution	11
2.3.2 Dynamic Range, SQNR, and SNR Performance Measures	14
2.3.3 Spur-Free Dynamic Range	17
2.4 Performance Degradations	18
2.4.1 Two-Tone Intermodulation Distortion	18
2.4.2 Differential Nonlinearity	19
2.4.3 Integral Nonlinearity	20
2.4.4 Comparator Hysteresis	20
2.4.5 Thermal Noise	22
2.4.6 Aperture Jitter	23
2.4.7 Comparator Ambiguity	24
2.4.8 Observations	26
Summary	28
3. Approaches to Analog-to-Digital Conversion	29
3.1 A/D Converter Coding Schemes	29
3.1.1 Thermometer Coding Scheme	29
3.1.2 Gray Code Coding Scheme	31
3.1.3 Circular Coding Scheme	31
3.2 Nyquist-Rate Converter Architectures	32

3.2.1	Fully Parallel or Flash A/D Conversion	32
3.2.2	Subranging A/D Conversion	33
3.2.3	Folding Architectures	35
3.2.4	Other Parallel Architectures	36
3.2.5	Neural Network Approach to A/D Conversion.....	39
3.2.6	Full-Search A/D Conversion	43
3.2.7	Successive Approximation A/D Conversion	43
3.3	Oversampled A/D Conversion	44
3.3.1	The Modulator.....	46
3.3.2	Operation	49
3.3.3	The Digital Postprocessor	60
3.3.4	Oversampled A/D Performance	69
3.4	Parallel Oversampling A/D Conversion	79
	Summary	80
4.	Photonic Devices	
	for Analog-to-Digital Conversion.....	83
4.1	Mach-Zehnder Interferometers	83
4.2	Optical Waveguide Switches	89
4.2.1	Directional Coupler Waveguide Switches	90
4.2.2	Reversed $\Delta\beta$ Directional Coupler.....	92
4.2.3	Digital Optical Waveguide Switches.....	93
4.3	Acousto-Optic Devices	94
4.4	Multiple Quantum Well Devices	101
4.4.1	Optical Bistability	105
4.4.2	Optical Subtraction	106
4.4.3	Switching Speed and Energy Requirements	108
4.5	Smart Pixel Technology	110
4.5.1	Monolithic Integration	110
4.5.2	Direct Epitaxy	114
4.5.3	Hybrid Integration	115
	Summary	122
5.	Nyquist-Rate Photonic Analog-to-Digital Conversion	123
5.1	Electro-Optic A/D Conversion	
	Based on a Mach-Zehnder Interferometer.....	123
5.2	Optical Folding-Flash A/D Converter	127
5.3	Matrix-Multiplication and Beam Deflection	129
5.4	Other Approaches to Photonic A/D Conversion	131
	Summary	131
6.	Oversampled Photonic Analog-to-Digital Conversion.....	133
6.1	Oversampling Photonic A/D Conversion.....	133
6.2	Optical Oversampled Modulators	134
6.2.1	The Interferometric Modulator	135

6.2.2	The Noninterferometric Modulator	138
6.3	The Digital Postprocessor	140
6.3.1	Electronic Postprocessing	140
6.3.2	Optoelectronic Postprocessing	141
6.3.3	Observations	141
6.4	Performance Analysis	142
6.4.1	Linear Arithmetic Errors	142
6.4.2	Quantization Noise Spectra	143
6.4.3	Cascade Error Tolerances	151
6.5	Experimental Proof-of-Concept Photonic Modulator Demonstration	157
6.5.1	Noninterferometric Optical Subtraction	158
6.5.2	Experimental Photonic First-Order Oversampled Modulator	162
	Summary	166
7.	Low Resolution, Two-Dimensional Analog-to-Digital Conversion: Digital Image Halftoning	169
7.1	Introduction	169
7.2	Approaches to Halftoning	170
7.3	The Error Diffusion Algorithm	171
7.4	Neural Network Formalism	175
7.4.1	The Hopfield-Type Neural Network	175
7.4.2	Observations	180
7.5	The Error Diffusion Neural Network	181
7.5.1	The Error Diffusion Filter	186
7.5.2	Observations	189
7.6	Quantitative Performance Metrics	191
7.6.1	Power Spectrum Estimation	193
7.6.2	Radially Averaged Power Spectra and Anisotropy	195
7.7	Performance Analysis	198
7.7.1	Floyd–Steinberg Performance Analysis	198
7.7.2	Symmetric Jarvis Performance Analysis	202
7.7.3	Error Diffusion Neural Network Performance Analysis	202
7.8	Extensions to Color	211
	Summary	212
8.	A Photonic-Based Error Diffusion Neural Network	215
8.1	First-Generation CMOS-SEED Error Diffusion Neural Array	216
8.2	Second-Generation CMOS-SEED Error Diffusion Neural Array	219
8.2.1	Detailed Circuit Description	225
8.2.2	Modeling and Simulation	227
8.2.3	Experimental Performance	231

XII Contents

8.2.4	Observations	235
8.3	OPTOCHIP: A 2-D Neural Array Employing Epitaxy-on-Electronics	238
8.3.1	The OPTOCHIP Project	238
8.3.2	Description of Device Architecture	239
8.3.3	Observations	248
8.4	Extensions: A Photonic Error Diffusion Filter	249
8.4.1	Design of the Diffractive Optical Filter	250
8.4.2	Fabrication Error Analysis	255
8.4.3	Experimental Characterization	256
8.4.4	Impact of Fabrication Errors on Halftoning Performance	260
	Summary	262
9.	Photonic A/D Conversion Based on a Fully Connected Distributed Mesh Feedback Architecture	267
9.1	Temporal and Spatial Error Diffusion	267
9.1.1	Spectral Noise Shaping Duality	268
9.1.2	Postprocessing Duality	271
9.1.3	Limit Cycle Oscillation Duality	272
9.1.4	Observations	272
9.2	Spatially Distributed Oversampled A/D Conversion	272
9.3	A 2-D Fully Connected Distributed Mesh Feedback Architecture	276
9.3.1	Mismatch Effects in the Fully Connected Distributed Mesh Feedback Architecture	278
9.4	A/D Conversion Using Spatial Oversampling and Error Diffusion	280
9.4.1	Temporal-to-Spatial Conversion	281
9.4.2	The Two-Dimensional Error Diffusion Neural Network	281
9.4.3	The Postprocessor	282
9.4.4	Spectral Noise Shaping	283
9.4.5	Observations	283
9.5	Three-Dimensional Extensions	284
9.5.1	Space–Time Processing Architectures	285
	Summary	286
10.	Trends in Photonic Analog-to-Digital Conversion	289
10.1	Time-Interleaving A/D Converter Architectures	289
10.1.1	Understanding Time-Interleaved Architectures	289
10.1.2	Mismatch Effects in Time-Interleaved Architectures	292
10.1.3	Block Filter Description of Time-Interleaving	300
10.2	Photonic Channelized A/D Architectures	306
10.2.1	Optical Time-Division Demultiplexing Architectures	306

Contents XIII

10.2.2 Wavelength Channelization Architectures	308
10.3 Time-Stretching Using Dispersive Optical Elements	311
10.4 Ultra-Fast Laser Sources with Low Jitter	313
10.5 Novel Optical Sampling Techniques	313
10.6 Broadband Optical Modulators and Switches	314
Summary	315
References	317
Index	327