

# Contents

Preface to First Edition	xiii
Preface	xv
About the Author	xvii
<b>1 Introduction to Optical Communications</b>	<b>1</b>
1.1 Brief History	1
1.2 Generic Optical System	2
1.3 Design Challenges	5
1.4 State of the Art	6
<b>2 Basic Concepts</b>	<b>8</b>
2.1 Properties of Random Binary Data	8
2.2 Generation of Random Data	12
2.3 Data Formats	14
2.3.1 NRZ and RZ Data	14
2.3.2 8B/10B Coding	14
2.4 Effect of Bandwidth Limitation on Random Data	16
2.4.1 Effect of Low-Pass Filtering	16
2.4.2 Eye Diagrams	16
2.4.3 Effect of High-Pass Filtering	18
2.5 Effect of Noise on Random Data	21
2.6 Phase Noise and Jitter	24
2.6.1 Phase Noise	24
2.6.2 Jitter	27
2.6.3 Relationship Between Phase Noise and Jitter	28
2.6.4 Jitter Due to Additive Noise	28
2.7 Transmission Lines	30
2.7.1 Ideal Transmission Lines	30
2.7.2 Lossy Transmission Lines	33
<b>3 Optical Devices</b>	<b>36</b>
3.1 Laser Diodes	36
3.1.1 Operation of Lasers	38

3.1.2	Types of Lasers . . . . .	40
3.1.3	Properties of Lasers . . . . .	42
3.1.4	External Modulation . . . . .	45
3.2	Optical Fibers . . . . .	46
3.2.1	Fiber Loss . . . . .	47
3.2.2	Fiber Dispersion . . . . .	48
3.3	Photodiodes . . . . .	55
3.3.1	Responsivity and Efficiency . . . . .	55
3.3.2	PIN Diodes . . . . .	56
3.3.3	Avalanche Photodiodes . . . . .	57
3.4	Optical Systems . . . . .	58
<b>4</b>	<b>Transimpedance Amplifiers</b>	<b>62</b>
4.1	General Considerations . . . . .	62
4.1.1	TIA Performance Parameters . . . . .	64
4.1.2	SNR Calculations . . . . .	69
4.1.3	Noise Bandwidth . . . . .	72
4.2	Open-Loop TIAs . . . . .	73
4.2.1	Low-Frequency Behavior . . . . .	73
4.2.2	High-Frequency Behavior . . . . .	81
4.3	Feedback TIAs . . . . .	87
4.3.1	First-Order TIA . . . . .	87
4.3.2	Second-Order TIA . . . . .	89
4.4	Supply Rejection . . . . .	97
4.5	Differential TIAs . . . . .	100
4.6	High-Performance Techniques . . . . .	103
4.6.1	Gain Boosting . . . . .	103
4.6.2	Capacitive Coupling . . . . .	105
4.6.3	Feedback TIAs . . . . .	106
4.6.4	Inductive Peaking . . . . .	110
4.7	Automatic Gain Control . . . . .	114
4.8	Case Studies . . . . .	118
4.9	New Developments in TIA Design . . . . .	122
<b>5</b>	<b>Limiting Amplifiers and Output Buffers</b>	<b>130</b>
5.1	General Considerations . . . . .	130
5.1.1	Performance Parameters . . . . .	130
5.1.2	Cascaded Gain Stages . . . . .	132
5.1.3	AM/PM Conversion . . . . .	136
5.2	Broadband Techniques . . . . .	138
5.2.1	Inductive Peaking . . . . .	138
5.2.2	Capacitive Degeneration . . . . .	140
5.2.3	Cherry-Hooper Amplifier . . . . .	143
5.2.4	$f_T$ Doublers . . . . .	147

5.3	Output Buffers . . . . .	149
5.3.1	Differential Signaling . . . . .	149
5.3.2	Double Termination . . . . .	153
5.3.3	Predriver Design . . . . .	156
5.4	Distributed Amplification . . . . .	159
5.4.1	Monolithic Transmission Lines . . . . .	159
5.4.2	Distributed Amplifiers . . . . .	163
5.4.3	Distributed Amplifiers with Lumped Devices . . . . .	170
5.5	Other Broadband Techniques . . . . .	171
5.5.1	T-Coil Peaking . . . . .	171
5.5.2	Negative Capacitance . . . . .	174
5.5.3	Active Feedback . . . . .	178
5.5.4	Triple-Resonance Peaking . . . . .	180
<b>6</b>	<b>Oscillator Fundamentals</b>	<b>185</b>
6.1	General Considerations . . . . .	185
6.2	Ring Oscillators . . . . .	187
6.3	LC Oscillators . . . . .	198
6.3.1	Crossed-Coupled Oscillator . . . . .	201
6.3.2	Colpitts Oscillator . . . . .	204
6.3.3	One-Port Oscillators . . . . .	207
6.4	Voltage-Controlled Oscillators . . . . .	211
6.4.1	Tuning in Ring Oscillators . . . . .	214
6.4.2	Tuning in LC Oscillators . . . . .	222
6.5	Mathematical Model of VCOs . . . . .	227
<b>7</b>	<b>LC Oscillators</b>	<b>233</b>
7.1	Monolithic Inductors . . . . .	233
7.1.1	Loss Mechanisms . . . . .	235
7.1.2	Inductor Modeling . . . . .	239
7.1.3	Inductor Design Guidelines . . . . .	242
7.2	Monolithic Varactors . . . . .	246
7.3	Basic LC Oscillators . . . . .	248
7.3.1	Differential Control . . . . .	251
7.3.2	Design Procedure . . . . .	253
7.4	Quadrature Oscillators . . . . .	255
7.4.1	In-Phase Coupling . . . . .	257
7.4.2	Antiphase Coupling . . . . .	259
7.5	Distributed Oscillators . . . . .	261
<b>8</b>	<b>Phase-Locked Loops</b>	<b>264</b>
8.1	Simple PLL . . . . .	264
8.1.1	Phase Detector . . . . .	264
8.1.2	Basic PLL Topology . . . . .	265
8.1.3	Dynamics of Simple PLL . . . . .	274

8.2	Charge-Pump PLLs . . . . .	280
8.2.1	Problem of Lock Acquisition . . . . .	281
8.2.2	Phase/Frequency Detector and Charge Pump . . . . .	282
8.2.3	Basic Charge-Pump PLL . . . . .	286
8.3	Nonideal Effects in PLLs . . . . .	293
8.3.1	PFD/CP Nonidealities . . . . .	293
8.3.2	Jitter in PLLs . . . . .	297
8.4	Delay-Locked Loops . . . . .	300
8.5	Applications . . . . .	302
8.5.1	Frequency Multiplication and Synthesis . . . . .	303
8.5.2	Skew Reduction . . . . .	305
8.5.3	Jitter Reduction . . . . .	306
<b>9</b>	<b>Clock and Data Recovery</b>	<b>308</b>
9.1	General Considerations . . . . .	308
9.2	Phase Detectors for Random Data . . . . .	320
9.2.1	Hogge Phase Detector . . . . .	320
9.2.2	Alexander Phase Detector . . . . .	324
9.2.3	Half-Rate Phase Detectors . . . . .	329
9.3	Frequency Detectors for Random Data . . . . .	333
9.4	CDR Architectures . . . . .	338
9.4.1	Full-Rate Referenceless Architecture . . . . .	338
9.4.2	Dual-VCO Architecture . . . . .	339
9.4.3	Dual-Loop Architecture with External Reference . . . . .	341
9.4.4	Quarter-Rate Phase Detectors . . . . .	342
9.5	Jitter in CDR Circuits . . . . .	344
9.5.1	Jitter Transfer . . . . .	345
9.5.2	Jitter Generation . . . . .	349
9.5.3	Jitter Tolerance . . . . .	351
<b>10</b>	<b>Multiplexers and Laser Drivers</b>	<b>356</b>
10.1	Multiplexers . . . . .	356
10.1.1	2-to-1 MUX . . . . .	356
10.1.2	MUX Architectures . . . . .	361
10.2	Frequency Dividers . . . . .	364
10.2.1	Flipflop Dividers . . . . .	364
10.2.2	Miller Divider . . . . .	372
10.3	Laser and Modulator Drivers . . . . .	374
10.3.1	Performance Parameters . . . . .	374
10.4	Design Principles . . . . .	378
10.4.1	Power Control . . . . .	384
10.5	New Developments in Laser Driver Design . . . . .	385
<b>11</b>	<b>Burst-Mode Circuits</b>	<b>393</b>
11.1	Passive Optical Networks . . . . .	393

11.2	Burst-Mode TIAs . . . . .	395
11.2.1	TIA with Top and Bottom Hold . . . . .	396
11.2.2	Burst-Mode TIA Variants . . . . .	400
11.2.3	Offset Correction in Limiting Amplifiers . . . . .	402
11.3	Burst-Mode CDR Circuits . . . . .	404
11.3.1	Effect of Finite Delays . . . . .	405
11.3.2	Effect of Frequency Mismatch and Offset . . . . .	406
11.3.3	Jitter Characteristics . . . . .	410
11.4	Alternative BM CDR Architectures . . . . .	413
	<b>Index</b>	<b>417</b>