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Optoelectronic Circuits in Nanometer CMOS Technology

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Preface

Highly integrated communication systems are required to fulfil the growing demand for higher data rates in telecommunication networks. The optical fiber links are the best candidates to deal with large volumes of data since they provide superior performance compared to conventional electrical links in terms of bandwidth, channel loss, electromagnetic interference, reflection, and crosstalk. Optical receivers and transmitters are known to be the most important building blocks in optical communication systems. But since the scaling of CMOS structure sizes, clock frequencies of digital logic grew tremendously and the chip area necessary for logic functions decreased dramatically. Digital signal processing, equalization, error correction and the physical layers causing a lot of overhead became much more important. Therefore there is a general trend to integrate optical receivers and transmitters with a lot of digital circuitry together reducing their price in large volume production considerably. Low-cost and high performance optical receivers are required for high data rate telecommunication networks.

For plastic optical fiber receivers, fully integrated optical receivers with integrated silicon photodiodes provide advantages over hybrid implementations, including low-cost, reduced parasitic capacitance and no bond-wire inductance. Nanometer CMOS technologies have been rapidly advanced, enabling the implementation of integrated optical receivers for data rates of several Giga-bits per second. In particular, low-cost silicon CMOS optoelectronic integrated circuits become very attractive because they can be extensively applied to short-distance optical communications, such as local area network, chip-to-chip and board-to-board interconnects.

The different chapters in this book give a brief overview of the optoelectronics applications for long-haul optical communication systems, short distance optical communication like fiber to the home, in-home network and optical interconnects. CMOS optoelectronics for short distance optical communications and optical interconnect will be also discussed.

Optical sensor technology is another growing field of application for nanometer optoelectronic CMOS circuits. One very important field is image sensors, where the

pixel count of camera chips grew up to more than 10 megapixels thanks to the shrinking of CMOS structure sizes. New applications are time-of-flight based distance sensors also needing small-sized transistors for processing the distance information. Optically based medical investigation methods like positron emission tomography (PET) and magnetic resonance imaging (MRI) require a high spatial resolution, i.e. many pixels, and complex signal processing fostering nanometer CMOS circuits.

In the beginning of this book, Chap. 1 introduces the motivation for using optoelectronic integrated circuits in different applications like long and short distance optical communications, optical interconnects, image sensors, and medical applications.

Chapter 2 provides the description for optical communications fundamentals including optical communication building blocks, optical transmitter, and optical receiver. Also optical, data formats, binary data formats, multilevel signaling, DC balance code, eye diagram, bit error rate (BER), sensitivity, noise models, bandwidth and rise/fall times, intersymbol interference (ISI), jitter, nonlinearity, power penalty, dynamic range will be discussed.

Chapter 3 includes the mathematical models and physical prosperities for photodiodes, optical absorption, photocurrent generation, carrier diffusion, carrier drift, photodiode capacitance, photodiode bandwidth, quantum efficiency, internal quantum efficiency, optical quantum efficiency, photodiode responsivity, photodiode dark and noise currents, as well as photodiode small-signal and noise equivalent circuit models.

Chapter 4 introduces discrete photodiodes for visible light and infrared light. Also the photodetectors connected via bond wires or via flip-chip technique are provided.

Chapter 5 provides different types of integrated photodiodes in nanometer CMOS technologies like classical PN junctions, double-junction photodiodes, PW/DNW/P-substrate double photodiode P+/NW/P-sub avalanche double photodiode, P+/NW/P-substrate photodiode with guard, finger photodiodes, PIN photodiode, spatially modulated light detector, triple junction photodetector, and avalanche photodiodes. The end of this chapter dedicates itself to a comparison of the performance of the different photodiodes.

Chapter 6 discusses transimpedance amplifiers (TIAs) and their gain, bandwidth, and noise. The effect of manufacturing technology and different TIAs topologies are provided including simplest preamplifier, open loop TIAs, common gate input stage, regulated-cascode TIA, inverter based common-drain feedback TIA, and shunt-shunt feedback TIA. Frequency response, noise analysis of shunt feedback TIA, noise of ideal TIA, TIA with common-source input stage, multistage inverter based CMOS TIA, noise canceling TIA, inverter based cascode TIA, and differential TIA are covered. Advanced techniques for gain control gain, compression, bandwidth enhancement techniques for TIAs, super-gm technique, inductive peaking, active inductive peaking, and negative capacitance will be discussed.

Chapter 7 discusses equalizer types including passive equalizer, active equalizer, source degeneration, continuous time linear equalizer (CTLE) with multi-shunt-shunt feedbacks, inductive load equalizer, adaptive equalization, and continuous time adaptive equalizer. Discrete time adaptive equalizer, continuous time FIR filter implementation, discrete time FIR filter implementation, nonlinear equalization, decision feedback equalizer (DFE), maximum likelihood sequence estimator (MLSE) are described.

Chapter 8 presents circuit descriptions, results for post amplifiers, cascaded gain stages, differential post amplifier, amplifier with automatic gain control, limiting amplifier, offset compensation, broad band amplifier techniques, cherry-hooper amplifiers, interleaved active feedback, and transit-frequency doubler.

Chapter 9 introduces laser and modulator drivers, LEDs, specifications, rise and fall times, modulation current, extinction ratio, turn-on delay (TOD), output voltage (compliance voltage), laser driver circuit design, pre-driver, output driver, high voltage laser driver, laser automatic power control, and modulator drivers.

The last Chap. 10 gives circuit descriptions and experimental results of optoelectronic circuits in nanometer CMOS technology, fully integrated optical receivers in 180 nm CMOS, in 65 nm CMOS, and in 40 nm CMOS, as well as infrared optical receivers with external photodiode in 90 nm CMOS and in 40 nm CMOS. Optical sensors, 2D image sensors, 3D image sensors, and medical sensors are also introduced.

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Assiut, Egypt
Vienna, Austria
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Contents

1	Why Optoelectronic Circuits in Nanometer CMOS?	1
1.1	Long-Haul Communication	2
1.2	Fiber to the Home (FTTH)	3
1.3	In-Home Network	4
1.4	Optical Interconnects	5
1.5	Optical Receivers	7
1.6	Optical Sensors	10
	References	11
2	Optical Communications Fundamentals.	13
2.1	Optical Communication Building Blocks	13
2.1.1	Optical Transmitter	13
2.1.2	Optical Receiver	14
2.1.3	Optical Fiber	15
2.2	Data Formats	18
2.2.1	Binary Data Formats	18
2.2.2	Multilevel Signaling	19
2.3	DC Balance Code	20
2.4	Eye Diagram	21
2.5	Bit Error Rate (BER)	21
2.6	Sensitivity	24
2.7	Noise Models	26
2.8	Bandwidth and Rise/Fall Times	28
2.9	Intersymbol Interference (ISI)	29
2.10	Jitter	30
2.11	Nonlinearity	31
2.12	Power Penalty	33
2.13	Dynamic Range	33
	References	34

3	Basics of Photodiodes	37
3.1	Optical Absorption and Photocurrent Generation	37
3.2	Carrier Drift and Diffusion	39
3.2.1	Carrier Diffusion	40
3.2.2	Carrier Drift	42
3.3	Photodiode Capacitance	45
3.4	Photodiode Speed.	46
3.5	Quantum Efficiency	47
3.5.1	Internal Quantum Efficiency.	48
3.5.2	Optical Quantum Efficiency.	48
3.6	Photodiode Responsivity	52
3.7	Photodiode Dark and Noise Currents	54
3.8	Photodiode Small-Signal and Noise Equivalent Circuit Model	55
	References	57
4	Discrete Photodiodes	59
4.1	Discrete Photodiodes for Visible Light	59
4.2	Discrete Photodiodes for Infrared Light.	61
4.3	External Photodetector Connected with Bond Wires	63
4.4	External Photodetector Connected Using Flip-Chip Technique	63
	References	65
5	Integrated Photodiodes in Nanometer CMOS Technologies	67
5.1	Effects of Technology Selection and Scaling on Photodiode Performance	67
5.2	Classical PN Junctions	69
5.3	Double-Junction Photodiodes.	79
5.3.1	PW/DNW/P-Substrate Double Photodiode	79
5.3.2	P+/NW/P-Sub Avalanche Double Photodiode	83
5.3.3	P+/NW/P-Substrate Photodiode with Guard	89
5.4	Finger Photodiodes.	91
5.5	PIN Photodiode	93
5.6	Spatially Modulated Light Detector	96
5.7	Triple Junction Photodetector.	98
5.8	Avalanche Photodiodes	99
5.9	Comparison of Photodiodes.	101
	References	103
6	Transimpedance Amplifiers	105
6.1	Transimpedance Gain, Bandwidth, and Noise	105
6.2	Effect of Technology Scaling.	106
6.3	Simplest Preamplifier	107

6.4	Open Loop TIAs	108
6.4.1	Common Gate Input Stage	109
6.4.2	Regulated-Cascode TIA	117
6.4.3	Inverter Based Common-Drain Feedback TIA	122
6.5	Shunt-Shunt Feedback TIA	127
6.5.1	Frequency Response	129
6.5.2	Noise Analysis of Shunt Feedback TIA.	131
6.5.3	Noise of Ideal TIA	132
6.5.4	TIA with Common-Source Input Stage	133
6.5.5	Multistage Inverter Based CMOS TIA	134
6.5.6	Noise Canceling TIA	140
6.5.7	Inverter Based Cascode TIA	145
6.6	Differential TIA	148
6.7	TIA with Gain Control	149
6.8	TIA with Gain Compression	150
6.9	Bandwidth Enhancement Techniques for TIAs.	153
6.9.1	Super-Gm	153
6.9.2	Inductive Peaking.	155
6.9.3	Active Inductive Peaking.	157
6.9.4	Negative Capacitance	158
	References	159
7	Equalizers	163
7.1	Passive Equalizer	164
7.2	Active Equalizer	165
7.3	Source Degeneration.	165
7.4	Continuous Time Linear Equalizer (CTLE) with Multi-Shunt-Shunt Feedbacks.	166
7.5	Inductive Load Equalizer.	167
7.6	Adaptive Equalization.	169
7.6.1	Continuous Time Adaptive Equalizer	169
7.6.2	Discrete Time Adaptive Equalizer	171
7.7	Continuous Time FIR Filter Implementation	172
7.8	Discrete Time FIR Filter Implementation.	175
7.9	Nonlinear Equalization	176
7.9.1	Decision Feedback Equalizer (DFE)	177
7.9.2	Maximum Likelihood Sequence Estimator (MLSE)	179
	References	181
8	Post Amplifiers	183
8.1	Noise	183
8.2	Cascaded Gain Stages.	184

- 8.3 Bandwidth. 185
- 8.4 Differential Post Amplifier. 186
- 8.5 Amplifier with Automatic Gain Control 187
- 8.6 Limiting Amplifier 190
- 8.7 Offset Compensation. 191
- 8.8 Broad Band Amplifier Techniques 193
 - 8.8.1 Cherry-Hooper Amplifiers 194
 - 8.8.2 Interleaved Active Feedback 195
 - 8.8.3 f_i Doubler 196
- References 197
- 9 Laser and Modulator Drivers 199**
 - 9.1 LEDs, Laser Diodes, and VCSELs. 199
 - 9.1.1 Small-Signal Model 201
 - 9.2 Laser and Modulator Driver. 202
 - 9.3 Laser Driver Specifications 203
 - 9.3.1 Rise and Fall Times 203
 - 9.3.2 Modulation Current 203
 - 9.3.3 Extinction Ratio 204
 - 9.3.4 Turn-on Delay (ToD) 205
 - 9.3.5 Output Voltage (Compliance Voltage). 206
 - 9.4 Laser Driver Circuit Design. 206
 - 9.4.1 Predriver 206
 - 9.4.2 Output Driver 206
 - 9.4.3 High Voltage Laser Driver 208
 - 9.5 Laser Automatic Power Control 213
 - 9.6 Modulator Drivers 214
 - 9.6.1 External Modulator. 214
 - 9.6.2 Modulator Driver Circuitry 215
 - References 216
- 10 Optoelectronic Circuits in Nanometer CMOS Technology 217**
 - 10.1 Fully Integrated Optical Receivers 217
 - 10.1.1 180 nm CMOS Fully Integrated Optical Receiver. 218
 - 10.1.2 65 nm CMOS Fully Integrated Optical Receiver 220
 - 10.1.3 40 nm CMOS Fully Integrated Optical Receiver 221
 - 10.2 Infrared Optical Receivers with External Photodiode. 225
 - 10.2.1 Infrared Optical Receiver in 90 nm CMOS
with External Photodiode 225
 - 10.2.2 Infrared Optical Receivers in 40 nm CMOS
with External Photodiode 230

Contents	xiii
10.3 Optical Sensors	234
10.3.1 2D Image Sensors	234
10.3.2 3D Image Sensors	235
10.3.3 Medical Sensors	238
References	239
Index	241

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