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Mohamed Atef · Horst Zimmermann

Optoelectronic Circuits in Nanometer CMOS Technology

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Mohamed Atef
Faculty of Engineering
Assiut University
Assiut
Egypt

Horst Zimmermann
Institute of Electrodynamics, Microwave and Circuit Engineering
TU Wien
Vienna
Austria

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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 opto-electronic 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 — Mohamed Atef
Vienna, Austria — Horst Zimmermann
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About the Authors

Mohamed Atef received the B.Sc. and M.Sc. degrees in electrical engineering, electronics and communications from Assiut University, Egypt, in 2000 and 2005 respectively. From 2006 to 2007 he was a researcher in Czech Technical University in Prague, Department of Microelectronics, improving the optical properties of quantum dots. He received his Ph.D. in 2010 from Vienna University of Technology, Institute of Electrodynamics, Microwave and Circuit Engineering, and then worked at this institute as a post-doctoral researcher to the end of 2012. Since September 2015, M. Atef is a visiting Professor to BiCASL Lab, Shanghai Jiao Tong University, China. He is currently an Associate Professor in Assiut University, Egypt. His research interests are in the area of integrated circuits, optoelectronic integrated circuit, and communications over plastic optical fiber. He is an author of the Springer book 'Optical Communication over Plastic Optical Fibers: Integrated Optical Receiver Technology'. Furthermore, he is author and co-author of more than 45 scientific publications. Since 2012 he is senior member IEEE.

Horst Zimmermann received the Dr.-Ing. degree in the Fraunhofer Institute for Integrated Circuits (IIS-B), Erlangen, Germany in 1991. Then, Dr. Zimmermann was an Alexander-von-Humboldt Research-Fellow at Duke University, Durham, N.C., where he worked on diffusion in Si, GaAs, and InP. In 1993, he joined the Chair for Semiconductor Electronics at Kiel University, where he lectured optoelectronics and worked on optoelectronic integration. Since 2000 he is full professor for Electronic Circuit Engineering at Vienna University of Technology, Austria. His main interests are in design and characterization of analog deep-sub-micron, nanometer CMOS and optoelectronic integrated (Bi)CMOS circuits as well as electronic-photonic integration. He is author of the two Springer books ‘Integrated Silicon Optoelectronics’ and ‘Silicon Optoelectronic Integrated Circuits’ as well as co-author of ‘Highly Sensitive Optical Receivers’, ‘Optical Communication over Plastic Optical Fibers: Integrated Optical Receiver Technology’, ‘Analog Filters in Nanometer CMOS’ and Comparators in Nanometer CMOS Technology. Furthermore, he is author and co-author of more than 450 scientific publications. Since 2002 he is senior member IEEE.