

Stefan Wabnitz
Benjamin J. Eggleton *Editors*

All-Optical Signal Processing

Data Communication and Storage
Applications

Stefan Wabnitz · Benjamin J. Eggleton
Editors

All-Optical Signal Processing

Data Communication and Storage
Applications

 Springer

Editors

Stefan Wabnitz
Dipartimento di Ingegneria
dell'Informazione
Università degli Studi di Brescia
Brescia
Italy

Benjamin J. Eggleton
CUDOS, School of Physics
University of Sydney
Sydney, NSW
Australia

ISSN 0342-4111

ISSN 1556-1534 (electronic)

Springer Series in Optical Sciences

ISBN 978-3-319-14991-2

ISBN 978-3-319-14992-9 (eBook)

DOI 10.1007/978-3-319-14992-9

Library of Congress Control Number: 2015933154

Springer Cham Heidelberg New York Dordrecht London

© Springer International Publishing Switzerland 2015

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media
(www.springer.com)

Springer Series in Optical Sciences

Volume 194

Founded by

H.K.V. Lotsch

Editor-in-Chief

William T. Rhodes, Georgia Institute of Technology, Atlanta, USA

Editorial Board

Ali Adibi, Georgia Institute of Technology, Atlanta, USA

Toshimitsu Asakura, Hokkai-Gakuen University, Sapporo, Japan

Theodor W. Hänsch, Max-Planck-Institut für Quantenoptik, Garching, Germany

Ferenc Krausz, Ludwig-Maximilians-Universität München, Garching, Germany

Bo A.J. Monemar, Linköping University, Linköping, Sweden

Herbert Venghaus, Fraunhofer Institut für Nachrichtentechnik, Berlin, Germany

Horst Weber, Technische Universität Berlin, Berlin, Germany

Harald Weinfurter, Ludwig-Maximilians-Universität München, München, Germany

Springer Series in Optical Sciences

The Springer Series in Optical Sciences, under the leadership of Editor-in-Chief William T. Rhodes, Georgia Institute of Technology, USA, provides an expanding selection of research monographs in all major areas of optics: lasers and quantum optics, ultrafast phenomena, optical spectroscopy techniques, optoelectronics, quantum information, information optics, applied laser technology, industrial applications, and other topics of contemporary interest.

With this broad coverage of topics, the series is of use to all research scientists and engineers who need up-to-date reference books.

The editors encourage prospective authors to correspond with them in advance of submitting a manuscript. Submission of manuscripts should be made to the Editor-in-Chief or one of the Editors. See also www.springer.com/series/624

Editor-in-Chief

William T. Rhodes
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0250
USA
e-mail: bill.rhodes@ece.gatech.edu

Editorial Board

Ali Adibi
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0250
USA
e-mail: adibi@ee.gatech.edu

Toshimitsu Asakura
Faculty of Engineering
Hokkai-Gakuen University
1-1, Minami-26, Nishi 11, Chuo-ku
Sapporo, Hokkaido 064-0926, Japan
e-mail: asakura@eli.hokkai-s-u.ac.jp

Theodor W. Hänsch
Max-Planck-Institut für Quantenoptik
Hans-Kopfermann-Straße 1
85748 Garching, Germany
e-mail: t.w.haensch@physik.uni-muenchen.de

Ferenc Krausz
Ludwig-Maximilians-Universität München
Lehrstuhl für Experimentelle Physik
Am Coulombwall 1
85748 Garching, Germany and
Max-Planck-Institut für Quantenoptik
Hans-Kopfermann-Straße 1
85748 Garching, Germany
e-mail: ferenc.krausz@mpq.mpg.de

Bo A.J. Monemar
Department of Physics and Measurement Technology
Materials Science Division
Linköping University
58183 Linköping, Sweden
e-mail: bom@ifm.liu.se

Herbert Venghaus
Fraunhofer Institut für Nachrichtentechnik
Heinrich-Hertz-Institut
Einsteinufer 37
10587 Berlin, Germany
e-mail: venghaus@hhi.de

Horst Weber
Optisches Institut
Technische Universität Berlin
Straße des 17. Juni 135
10623 Berlin, Germany
e-mail: weber@physik.tu-berlin.de

Harald Weinfurter
Sektion Physik
Ludwig-Maximilians-Universität München
Schellingstraße 4/III
80799 München, Germany
e-mail: harald.weinfurter@physik.uni-muenchen.de

More information about this series at <http://www.springer.com/series/624>

Preface

Although it holds the promise for substantial processing speed improvements, in today's communication infrastructure optics remains largely confined to the signal transport layer, as it lags behind electronics as far as signal processing is concerned. This situation is bound to change in the near future as the tremendous growth of data traffic requires the development of new, energy efficient, and fully transparent all-optical networks for telecom and datacom applications. This book provides a comprehensive review of the state of the art of all-optical devices based on nonlinear optical materials for applications to optical signal processing. Contributors to this book present breakthrough solutions for enabling a pervasive use of optics in data communication and signal storage applications. The book content ranges from the development of innovative materials and devices, such as graphene and photonic crystal structures, to the use of nonlinear optical signal processing for secure quantum information processing, for increasing the transmission channel capacity, and for enhancing the performance of broadband radio frequency signal processing. The book is expected to benefit all researchers in the fields of optical communications, photonic devices for optical signal processing, nonlinear guided wave optics, quantum information processing, and microwave photonics, including senior undergraduate and postgraduate students and industry researchers.

Chapter 1 summarizes the recent progress in materials and structures for all-optical signal processing that employ either second- or third-order optical nonlinearities. The dominant choice for quadratic materials is provided by periodically poled lithium niobate waveguides. For cubic nonlinearities, the range of materials ranges from glasses to both active and passive semiconductor devices: a brief summary of the advantages and disadvantages of each class of materials and device structure is provided. In Chap. 2, recent advances in new nonsilicon CMOS-compatible platforms for nonlinear integrated optics are revised, focusing on Hydex glass and silicon nitride. The promising new platform of amorphous silicon is also briefly discussed. These material systems have opened up new functionalities such as on-chip optical frequency comb generation, ultrafast optical pulse generation, and measurement. Chapter 3 overviews the principles of optical switching devices, based on either optical or electrical control signals, which permit to avoid the

necessity of electro-optic conversion. Discussed devices include nonlinear mode couplers and interferometers based on optical fibers, and integrated waveguides based on photonic crystal structures or surface wave interactions in novel materials such as graphene. Chapter 4 reviews the recent progress on using nonlinear optical fibers for optical pulse shaping in the temporal and spectral domains. Significant examples that are most relevant for applications include the synthesis of specialized temporal waveforms, the generation of ultrashort pulses, and optical supercontinuum.

Given the exponential growth rate of the total volume of data transported across the communication network, energy consumption, alongside increased information capacity, has become a critical driver in deploying new technologies. In addition to transponders at the end terminals of an optical network, certain signal processing functions, such as regeneration, format conversion, wavelength conversion, and arbitrary waveform generation, are often proposed. The following chapters of the book discuss how many of these intermediate functions may be performed all-optically, with the primary advantage of increased bandwidth and consequent resource sharing. In Chap. 5 the need, the general principles, and the approaches used for the all-optical regeneration of mainly phase encoded signals of differing levels of coding complexity are discussed. The key underpinning technology and the current state of the art of optical regeneration, including a historic perspective, are presented.

Chapter 6 presents the theory and experiments of photonic signal processing, logic operations, and computing. These functionalities take advantage of nonlinear processes with ultrafast response time to perform high speed operations either on analog or digital optical signals directly in the optical domain. Practical all-optical frequency generation and conversion requires highly efficient parametric interactions across a wide spectral band. Chapter 7 presents a new class of traveling wave parametric mixers for efficient, cavity-free frequency generation. Driven by continuous-wave seeds, these devices combine inherently more stable lasers with distributed noise inhibition in dispersion-managed parametric processes. The operating principles, the design methodology, and the performance limits of parametric mixers are discussed, together with applications to signal multicasting and ultrafast channel processing.

Optical pulse shaping techniques are an active area of research for increasing the spectral efficiency of optical modulation formats in dense wavelength division multiplexed (DWDM) transmissions, by avoiding interchannel and intersymbol interference. In Chap. 8 the main pulse shapes of interest are introduced, the different available techniques for their generation are presented, along with the associated signal multiplexing schemes, namely orthogonal frequency division multiplexing (OFDM) and Nyquist pulse modulation. The relative performances of electronic and optical signal processors for implementing Fourier transforms and Nyquist pulse generation are discussed.

As previously mentioned, energy saving will be a main driver for the transition from electronic to optical signal processing solutions. Chapter 9 describes advanced functionalities for optical signal processing with reduced energy consumption using

optical time lenses. This approach permits broadband optical processing, which is also capable of handling many bits in a single operation. In this way, the processing energy is shared by the many bits, and the energy per bit is reduced. The basic functionality is serial-to-parallel conversion in a single time lens. Combining time lenses into telescopic arrangements allows for more advanced signal processing solutions, such as conversion of OFDM signals into DWDM-like signals, which can be separated passively, i.e., without additional energy consumption. The previously discussed signal processing functions may also be performed by using the very optoelectronic devices used in the transponders themselves, either including decision circuitry and/or forward error correction or as linear media converters. In Chap. 10, the performance and energy consumption of digital coherent transponders, linear coherent repeaters, and modulator-based pulse shaping/frequency conversion is analyzed, thus setting an important benchmark for the proposed all-optical implementations.

The exponential growth in demand for information transmission capacity requires a rethinking of the maximum or Shannon capacity of the fiber-optic communication channel, in the presence of fiber nonlinearity. Chapter 11 addresses the problem of estimating the Shannon capacity for nonlinear communication channels, and discusses the potential of different optical signal coding, transmission, and processing techniques to improve the information capacity and increase the system reach of fiber-optic links.

Information and communication technologies based on quantum optics principles may lead to greatly improved functionalities such as enhanced sensing, exponentially faster computing, and the secure transfer of information. Chapter 12 overviews techniques for the nonlinear optics-based encoding and fully secure transfer of information in a quantum communication optical network. Chapter 13 discusses how classical optical signal processing techniques can be extended to nonclassical entangled photon states, thus permitting unprecedented control of the time frequency correlations shared by these light quanta. Moreover, in Chap. 13 it is shown that quantum properties produce interesting effects that are not observable with classical fields. Examples include Fourier transform pulse shaping, which relies on programmable spectral filtering and electro-optic modulation, where the temporal phase or amplitude of the entangled photon state is manipulated by means of an electrical signal.

Chapter 14 discusses how nonlinear optical effects in photonic chip scale devices may be exploited for enhancing the performance of radio frequency (RF) signal processing in microwave photonics applications. Specific examples presented in Chap. 14 include frequency agile and high suppression microwave bandstop filters, general purpose programmable analog signal processors, and high performance active microwave filters. Finally, Chap. 15 presents recent advances in optical signal processing techniques for wireless RF signals. Specifically, Chap. 15 discusses photonic architectures for wideband analog signal processing, including RF beamforming, co-channel interference cancelation, and physical layer security.

Besides broadband operation, photonics offers reduced size, weight, and power, in addition to low transmission loss, rapid reconfigurability, and immunity to electromagnetic interference.

We would like to thank Dr. Claus E. Ascheron, Springer Executive Editor for Physics, for inviting us, during the 2013 Conference on lasers and electro-optics in Munich, Germany, to bring a volume on all-optical signal processing to a wider audience. We also acknowledge helpful comments and suggestions by Dr. Herbert Venghaus of the Fraunhofer Institute for Telecommunications, and Editor of the Springer Series in Optical Sciences. Last but not the least, we are most grateful to all colleagues who contributed to this book for their brilliant work and continued effort in bringing this project to reality.

Brescia, Italy
Sydney, Australia

Stefan Wabnitz
Benjamin J. Eggleton

Contributors

Antonella Bogoni CNIT, National Laboratory of Photonic Networks, Pisa, Italy

Sonia Boscolo School of Engineering and Applied Science, Aston Institute of Photonic Technologies, Aston University, Birmingham, UK

Camille-Sophie Brès Institute of Electrical Engineering, Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland

John Chang Princeton University, Princeton, NJ, USA

Matthew P. Chang Princeton University, Princeton, NJ, USA

Duk-Yong Choi Centre for Ultrahigh-bandwidth Devices of Optical Systems, Laser Physics Centre, RSPE, The Australian National University, Canberra, ACT, Australia

Alex S. Clark School of Physics, Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS), Institute of Photonics and Optical Science (IPOS), University of Sydney, Camperdown, NSW, Australia

Anders Clausen DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

Matthew J. Collins School of Physics, Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS), Institute of Photonics and Optical Science (IPOS), University of Sydney, Camperdown, NSW, Australia

Costantino De Angelis Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Brescia, Brescia, Italy

Benjamin J. Eggleton School of Physics, Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS), Institute of Photonics and Optical Science (IPOS), University of Sydney, Camperdown, NSW, Australia

Andrew Ellis School of Engineering and Applied Science, Aston Institute of Photonic Technologies, Aston University, Birmingham, UK

Simon Fabbri School of Engineering and Applied Science, Aston Institute of Photonic Technologies, Aston University, Birmingham, UK

Julien Fatome Laboratoire Interdisciplinaire CARNOT de Bourgogne, UMR 6303 CNRS-Université de Bourgogne, Dijon, France

Christophe Finot Laboratoire Interdisciplinaire CARNOT de Bourgogne, UMR 6303 CNRS-Université de Bourgogne, Dijon, France

Xin Gai Centre for Ultrahigh-bandwidth Devices of Optical Systems, Laser Physics Centre, RSPE, The Australian National University, Canberra, ACT, Australia

Michael Galili DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

Pengyu Guan DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

Lukas G. Helt MQ Photonics Research Centre and CUDOS, Department of Physics and Astronomy, Macquarie University, North Ryde, NSW, Australia

Hao Hu DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

Joseph Kakande Bell Laboratories, Alcatel-Lucent, Holmdel, NJ, USA

Bill P.-P. Kuo Department of Computer and Electrical Engineering, University of California San Diego, La Jolla, CA, USA

Juerg Leuthold Institute of Electromagnetic Fields, ETH-Zurich, Zurich, Switzerland

Mads Lilliehölm DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

Andrea Locatelli Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Brescia, Brescia, Italy

Joseph M. Lukens Purdue University, West Lafayette, IN, USA

Barry Luther-Davies Centre for Ultrahigh-bandwidth Devices of Optical Systems, Laser Physics Centre, RSPE, The Australian National University, Canberra, ACT, Australia

Steve Madden Centre for Ultrahigh-bandwidth Devices of Optical Systems, Laser Physics Centre, RSPE, The Australian National University, Canberra, ACT, Australia

David Marpaung School of Physics, Centre for Ultrahigh Bandwidth Devices for Optical Systems (CUDOS), Institute of Photonics and Optical Science (IPOS), University of Sydney, Camperdown, NSW, Australia

Mary McCarthy School of Engineering and Applied Science, Aston Institute of Photonic Technologies, Aston University, Birmingham, UK

Guy Millot Laboratoire Interdisciplinaire CARNOT de Bourgogne, UMR 6303 CNRS-Université de Bourgogne, Dijon, France

Daniele Modotto Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Brescia, Brescia, Italy

Roberto Morandotti INRS-EMT, Varennes, QC, Canada

David J. Moss School of Electrical and Computer Engineering, RMIT University, Melbourne, VIC, Australia

Hans Christian Hansen Mulvad DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

Mitchell A. Nahmias Princeton University, Princeton, NJ, USA

Leif Katsuo Oxenløwe DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

Evarist Palushani DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

Ravi Pant School of Physics, Centre for Ultrahigh Bandwidth Devices for Optical Systems (CUDOS), Institute of Photonics and Optical Science (IPOS), University of Sydney, Camperdown, NSW, Australia

Francesca Parmigiani Optoelectronics Research Centre, University of Southampton, Southampton, Hampshire, UK

Periklis Petropoulos Optoelectronics Research Centre, University of Southampton, Southampton, Hampshire, UK

Paul R. Prucnal Princeton University, Princeton, NJ, USA

Stojan Radic Department of Computer and Electrical Engineering, University of California San Diego, La Jolla, CA, USA

David Richardson Optoelectronics Research Centre, University of Southampton, Southampton, Hampshire, UK

Bhavin J. Shastri Princeton University, Princeton, NJ, USA

Radan Slavík Optoelectronics Research Centre, University of Southampton, Southampton, Hampshire, UK

Mariia Sorokina School of Engineering and Applied Science, Aston Institute of Photonic Technologies, Aston University, Birmingham, UK

Kartik Srinivasan Center for Nanoscale Science and Technology, National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA

Michael J. Steel MQ Photonics Research Centre and CUDOS, Department of Physics and Astronomy, Macquarie University, North Ryde, NSW, Australia

Alexander N. Tait Princeton University, Princeton, NJ, USA

Sergei K. Turitsyn School of Engineering and Applied Science, Aston Institute of Photonic Technologies, Aston University, Birmingham, UK

Stefan Wabnitz Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Brescia, Brescia, Italy

Andrew M. Weiner Purdue University, West Lafayette, IN, USA

Alan Willner Department of Electrical and Computer Engineering, University of Southern California, Los Angeles, CA, USA

Ben Wu Princeton University, Princeton, NJ, USA

Chunle Xiong School of Physics, Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS), Institute of Photonics and Optical Science (IPOS), University of Sydney, Camperdown, NSW, Australia

Contents

1	Materials and Structures for Nonlinear Photonics	1
	Xin Gai, Duk-Yong Choi, Steve Madden and Barry Luther-Davies	
1.1	Introduction	1
1.2	All-Optical Processing Using $\chi^{(2)}$ Nonlinearities	4
1.3	All-Optical Processing Using $\chi^{(3)}$ Nonlinearities	8
1.3.1	Properties of $\chi^{(3)}$ Materials and Devices	10
1.4	All-Optical Processing in Semiconductor Optical Amplifiers	18
1.4.1	Types and Origins of Nonlinear Effects in Semiconductor Optical Amplifiers	18
1.4.2	Impairments in SOA Devices	19
1.4.3	Current State of the Art and Future Prospects for SOA Nonlinear Processing	23
	References	26
2	CMOS Compatible Platforms for Integrated Nonlinear Optics	35
	David J. Moss and Roberto Morandotti	
2.1	Introduction	35
2.2	Platforms	38
2.3	Low Power Nonlinear Optics in Ring Resonators	46
2.4	Microresonator-Based Frequency Combs	48
2.5	Advanced Frequency Comb Generation	53
2.6	Supercontinuum Generation	55
2.7	Comb Coherence and Dynamic Properties	56
2.8	Ultrashort Pulsed Modelocked Lasers	60
2.9	Ultrafast Phase Sensitive Pulse Measurement	60
2.10	Conclusions	65
	References	66

3	Optical Guided Wave Switching	71
	Costantino De Angelis, Daniele Modotto, Andrea Locatelli and Stefan Wabnitz	
3.1	Introduction: Optical Switching Using Guided-Waves	71
3.2	All-Optical Pulse Switching in Optical Fibers	72
3.2.1	Nonlinear Mode Coupling	72
3.2.2	Nonlinear Fiber Couplers	74
3.2.3	Nonlinear Mach-Zehnder Interferometers	77
3.2.4	Nonlinear Loop Mirrors	78
3.2.5	Nonlinear Passive Loop Resonators	81
3.2.6	Optical Soliton Switching	82
3.3	Optical Switching in Integrated Optical Waveguide Structures	83
3.3.1	All-Optical Switching in Photonic Crystal Couplers	83
3.3.2	Graphene-Assisted Control of Coupling Between Surface Plasmon Polaritons	90
3.3.3	Graphene-Assisted Control of Coupling Between Optical Waveguides	93
3.4	Conclusions	99
	References	100
4	Temporal and Spectral Nonlinear Pulse Shaping Methods in Optical Fibers.	105
	Sonia Boscolo, Julien Fatome, Sergei K. Turitsyn, Guy Millot and Christophe Finot	
4.1	Introduction	105
4.2	Pulse Propagation in Optical Fibers	106
4.3	Pulse Shaping in Normally Dispersive Fibers: From the Generation of Specialized Temporal Waveforms to Spectral Sculpturing	108
4.3.1	Generation of Specialized Temporal Waveforms	108
4.3.2	Spectral Sculpturing	112
4.4	Pulse Shaping in the Anomalous Dispersion Regime: From Ultrashort Temporal Structures to Ultra-Broad Spectra	115
4.4.1	Generation of High-Repetition-Rate Ultrashort Pulses	115
4.4.2	Generation of Frequency-Tunable Pulses	117
4.4.3	Supercontinuum Generation and Optical Rogue Waves	119
4.5	Conclusions and Perspectives	122
	References	123

5	Optical Regeneration	129
	Francesca Parmigiani, Radan Slavík, Joseph Kakande, Periklis Petropoulos and David Richardson	
5.1	Introduction to Optical Regeneration	129
5.2	Optical Regenerators for Simple Amplitude Encoded Signals	130
5.3	Regeneration of Phase-Only Encoded Signals	134
5.3.1	Modulation Format Specific PSA Regenerators	138
5.3.2	Modulation Format Transparent PSA	144
5.4	Regeneration of Amplitude and Phase Encoded Signals	145
5.4.1	Modulation Format Specific PSA Regenerators	146
5.4.2	Modulation Format Transparent PSA Schemes	150
5.5	Conclusions	150
	References.	151
6	Photonic Signal Processing for Logic and Computation	157
	Antonella Bogoni and Alan Willner	
6.1	Introduction	157
6.2	Photonic Logic and Computation Functions for Multi-Format Data Communication and Storage	158
6.3	Overview of Nonlinear Processes	158
6.3.1	Wave Mixing	159
6.3.2	Phase Modulation	163
6.4	Enabling Technologies	164
6.4.1	Optical Fiber	164
6.4.2	Semiconductor Devices	164
6.4.3	Photonic Crystals	165
6.4.4	Periodically Poled Lithium Niobate Waveguides	165
6.4.5	Silicon Devices.	165
6.5	State of the Art for Logic	166
6.5.1	Overview of Logic Functions and Achieved Results	166
6.5.2	OOK 640 Gbit/s Logic Operations	166
6.5.3	PSK 160 Gbit/s Logic Functions.	168
6.5.4	Hexadecimal 16PSK Addition	170
6.6	State of the Art for Computation.	171
6.6.1	Overview of Tapped Delay Lines	171
6.6.2	Fundamental Tools to Enable Photonic TDL	171
6.6.3	Optical 1D Correlation Results Using Nonlinearities and On-Chip MZIs	173
6.6.4	Optical WDM Correlator and 2D Correlation	176
6.6.5	Discrete Fourier Transforms Using Nonlinearities and On-Chip MZIs	178
	References.	181

7	Wide-Band and Noise-Inhibited Signal Manipulation in Dispersion-Engineered Parametric Mixers	185
	Bill P.-P. Kuo and Stojan Radic	
7.1	Introduction	185
7.2	Fundamentals of Parametric Mixers.	187
7.2.1	One-Pump Parametric Mixing.	187
7.2.2	Two-Pump Parametric Mixing	189
7.2.3	Signal Processing Functions of Parametric Mixers.	190
7.2.4	Effect of Chromatic Dispersion.	191
7.3	Dispersion-Stable Waveguide Engineering for Wide-Band Parametric Mixer Synthesis	192
7.3.1	Wide-Band Parametric Mixing—The Atomic-Scale Challenge.	193
7.3.2	Post-Fabrication Dispersion Fluctuations Rectification.	193
7.3.3	Waveguide Design Methods for Achieving Intrinsic Dispersion Stability	197
7.4	Inhomogeneous Dispersion Engineering for Noise-Inhibited Parametric Mixing	201
7.4.1	Self-seeded Two-Pump Parametric Mixing—Homogeneous Limit	201
7.4.2	Inhomogeneous Dispersion Engineering.	202
7.4.3	Applications.	205
7.5	Conclusions	210
	References.	211
8	All-Optical Pulse Shaping for Highest Spectral Efficiency	217
	Juerg Leuthold and Camille-Sophie Brès	
8.1	Introduction	217
8.2	Fundamentals.	218
8.3	Orthogonal Frequency Division Multiplexing (OFDM)	223
8.3.1	OFDM Tx and Rx Implementations	223
8.3.2	Optical Fourier Transform Processors and Optical OFDM	227
8.3.3	OFDM Tx and Rx—Experimental Implementations.	234
8.4	Nyquist Pulse Shaping.	237
8.4.1	Electronic Nyquist Processing.	241
8.4.2	Digital Signal Processing Based Generation	243
8.4.3	Optical Processors.	244
8.4.4	Implementations	252
	References.	257