CAMBRIDGE

Cambridge University Press
978-1-107-05660-2 — Medical and Biological Microwave Sensors and Systems
Edited by Isar Mostafanezhad , Olga Boric-Lubecke , Jenshan Lin
Frontmatter
More Information

## Medical and Biological Microwave Sensors and Systems

In this comprehensive work, experts in the field detail recent advances in medical and biological microwave sensors and systems, with chapters on topics such as implantable sensors, wearable microwave tags, and ultra-wideband (UWB) technology. Each chapter explores the theory behind the technology, as well as its design and implementation. This is supported by practical examples and details of experimental results, along with discussion of system design, design tradeoffs, and possible constraints and manufacturing issues. Applications described include intracranial pressure monitoring, vital signs monitoring, and noninvasive molecular and cellular investigations. Presenting new research and advances in the field and focusing on the state of the art in medical and biological microwave sensors, this work is an invaluable resource for enthusiastic researchers and practicing engineers in the fields of electrical engineering, biomedical engineering, and medical physics.

**Isar Mostafanezhad** is the founder and CEO of Nalu Scientific in Honolulu, Hawaii. He has several years of experience in developing and commercializing products in wireless, microwave and medical fields. He is also an Associate Editor for the *IEEE Microwaves and Wireless Components Letters*.

**Olga Boric-Lubecke** is a Professor of electrical engineering at the University of Hawaii at Manoa. She cofounded and served as Chief Technical Advisor for Kai Medical and has previously worked at Bell Laboratories, researching RF integrated-circuit technology and the biomedical applications of wireless systems.

**Jenshan Lin** is a Professor at the University of Florida as well as a Fellow of the Institute of Electrical and Electronics Engineers (IEEE). Previously he has worked at Bell Laboratories and has published extensively on the subject of wireless sensors and biomedical applications of microwave technologies. He served as Editor-in-Chief of *IEEE Transactions on Microwave Theory and Techniques* in 2004–2016.

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-107-05660-2 — Medical and Biological Microwave Sensors and Systems
Edited by Isar Mostafanezhad , Olga Boric-Lubecke , Jenshan Lin
Frontmatter
More Information

## The Cambridge RF and Microwave Engineering Series

**Series Editor**
Steve C. Cripps
Distinguished Research Professor, *Cardiff University*

**Editorial Advisory Board**
James F. Buckwalter
*University of California, Santa Barbara*
Jenshan Lin
*University of Florida*
John Wood
*Maxim Integrated Products*

**Series List**

Peter Aaen, Jaime Plá and John Wood, *Modeling and Characterization of RF and Microwave Power FETs*
Dominique Schreurs, Máirtín O'Droma, Anthony A. Goacher and Michael Gadringer (eds.), *RF Amplifier Behavioral Modeling*
Fan Yang and Yahya Rahmat-Samii, *Electromagnetic Band Gap Structures in Antenna Engineering*
Enrico Rubiola, *Phase Noise and Frequency Stability in Oscillators*
Earl McCune, *Practical Digital Wireless Signals*
Stepan Lucyszyn. *Advanced RF MEMS*
Patrick Roblin, *Nonlinear RF Circuits and the Large-Signal Network Analyzer*
Matthias Rudolph, Christian Fager and David E. Root (eds.), *Nonlinear Transistor Model Parameter Extraction Techniques*
John L. B. Walker (ed.), *Handbook of RF and Microwave Solid-State Power Amplifiers*
Anh-Vu H. Pham, Morgan J. Chen and Kunia Aihara, *LCP for Microwave Packages and Modules*
Sorin Voinigescu, *High-Frequency Integrated Circuits*
Richard Collier, *Transmission Lines*
Valeria Teppati, Andrea Ferrero and Mohamed Sayed (eds.), *Modern RF and Microwave Measurement Techniques*
Nuno Borges Carvalho and Dominique Schreurs, *Microwave and Wireless Measurement Techniques*
David E. Root, Jason Horn, Jan Verspecht and Mihai Marcu, *X-Parameters*
Earl McCune, *Dynamic Power Supply Transmitters*
Hossein Hashemi and Sanjay Raman (eds.), *Silicon mm-Wave Power Amplifiers and Transmitters*
T. Mitch Wallis and Pavel Kabos, *Measurement Techniques for Radio Frequency Nanoelectronics*
Giovanni Ghione and Marco Pirola, *Microwave Electronics*
Isar Mostafanezhad, Olga Boric-Lubecke and Jenshan Lin (eds.), *Medical and Biological Microwave Sensors*

**Forthcoming**

Richard Carter, *Microwave and RF Vacuum Electronic Power Sources*
José Carlos Pedro, David Root, Jianjun Xu and Luis Cotimos Nunes, *Nonlinear Circuit Simulation and Modeling*
Michael Schröter and Martin Claus, *Carbon Nanotube Electronics for Analog Radio-Frequency Applications*

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-107-05660-2 — Medical and Biological Microwave Sensors and Systems
Edited by Isar Mostafanezhad , Olga Boric-Lubecke , Jenshan Lin
Frontmatter
More Information

# Medical and Biological Microwave Sensors and Systems

ISAR MOSTAFANEZHAD
University of Hawaii, Nalu Scientific, LLC, Manoa

OLGA BORIC-LUBECKE
University of Hawaii at Manoa

JENSHAN LIN
University of Florida

CAMBRIDGE
UNIVERSITY PRESS

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-107-05660-2 — Medical and Biological Microwave Sensors and Systems
Edited by Isar Mostafanezhad , Olga Boric-Lubecke , Jenshan Lin
Frontmatter
More Information

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India

79 Anson Road, #06–04/06, Singapore 079906

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107056602
10.1017/9781107297302
© Cambridge University Press 2018

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2018

Printed in the United Kingdom by TJ International Ltd. Padstow Cornwall

*A catalogue record for this publication is available from the British Library.*

*Library of Congress Cataloging-in-Publication Data*
Names: Mostafanezhad, Isar, editor. | Boric-Lubecke, Olga, 1966– editor. | Lin, Jenshan, 1984– editor.
Title: Medical and biological microwave sensors and systems / [edited by] Isar Mostafanezhad, Olga Boric-Lubecke, Jenshan Lin.
Other titles: Cambridge RF and microwave engineering series.
Description: Cambridge, United Kingdom ; New York : Cambridge University Press, 2017. | Series: The Cambridge RF and microwave engineering series | Includes bibliographical references and index.
Identifiers: LCCN 2016047634 | ISBN 9781107056602 (Hardback : alk. paper)
Subjects: | MESH: Biosensing Techniques | Microwaves–therapeutic use | Wireless Technology | Biomedical Technology
Classification: LCC QP82.2.R33 | NLM QT 36.4 | DDC 612/.014481–dc23
LC record available
at https://lccn.loc.gov/2016047634

ISBN 978-1-107-05660-2 Hardback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party Internet websites referred to in this publication and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

CAMBRIDGE

Cambridge University Press
978-1-107-05660-2 — Medical and Biological Microwave Sensors and Systems
Edited by Isar Mostafanezhad , Olga Boric-Lubecke , Jenshan Lin
Frontmatter
More Information

# Contents

*List of Contributors* *page* viii

**1 Implantable Wireless Medical Devices for Gastroesophageal Applications** 1
Smitha Rao and J.-C. Chiao

1.1 Introduction 1
1.2 Wireless Communication in Medical Implant Applications 2
1.3 Implementation Methods 3
1.4 Endoluminal Capsule Applications 4
1.5 An Endoluminal Application Example: Reflux Monitoring 6
1.6 Batteryless Wireless Impedance and pH Sensor Capsule 16
1.7 Conclusion 30

**2 Embedded Wireless Device for Intracranial Pressure Monitoring** 40
Usmah Kawoos, Mohammad-Reza Tofighi, Francis Kralick, Xu Meng, and Arye Rosen

2.1 Introduction 40
2.2 Existing Technologies for the Measurement and Monitoring of ICP 43
2.3 Desired Features of the Implant 44
2.4 Operating Principle 45
2.5 Antennas 48
2.6 Packaging Concept of Implant 58
2.7 Methods for Evaluation of Implant Performance *In Vitro* 61
2.8 *In Vitro* Bench-Test Results 68
2.9 *In Vivo* Evaluation of the Implant 73
2.10 Sources of Error in ICP Measurements 83
2.11 Discussion 84
Acknowledgments 85

**3 Wireless Intracranial Pressure Systems for the Assessment of Traumatic Brain Injury** 89
Xu Meng, Kevin D. Browne, D. Kacy Cullen, Mohammad-Reza Tofighi, Usmah Kawoos, and Arye Rosen

3.1 Introduction 89
3.2 Traumatic Brain Injury 90



© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-107-05660-2 — Medical and Biological Microwave Sensors and Systems
Edited by Isar Mostafanezhad , Olga Boric-Lubecke , Jenshan Lin
Frontmatter
More Information



3.3 Methods 92
3.4 Dynamic Evaluation of AICP Implants for Assessment of Rotational Head Injury 94
3.5 Design and *In Vitro* Evaluation of DICP Implants 97
3.6 Dynamic Evaluation of DICP Implants for Assessment of Rotational Head Injury 104
3.7 Conclusion and Future Work 118

**4 Microwave Biosensors for Noninvasive Molecular and Cellular Investigations** 124
Katia Grenier and David Dubuc

4.1 Introduction 124
4.2 Interests in Miniature Microwave-Based Biosensors for Noninvasive Molecular and Cellular Investigations 125
4.3 Microwave Analysis of Biomolecules in Aqueous Solution 131
4.4 Cellular Investigations 137
4.5 Conclusions 148
Acknowledgments 149

**5 Wearable Radar Tag Systems for Physiological Sensing/Monitoring** 154
Aditya Singh, Olga Boric-Lubecke, and Victor Lubecke

5.1 Introduction 154
5.2 Frequency-Doubling Tags 155
5.3 Experimental Verification 160
5.4 Experimental Verification II 161
5.5 Two-Frequency Radar 163
5.6 Adaptive Noise Cancellation 164
Summary 168

**6 Physiological Radar Sensor Chip Development** 172
Changzhi Li and Changzhan Gu

6.1 Theory and Recent Advancements 172
6.2 System Integration 176
6.3 Chip Integration 187
6.4 Application Case Studies 197

**7 Noise- and Interference-Reduction Methods for Microwave Doppler Radar Vital Signs Monitors** 202
Isar Mostafanezhad, Olga Boric-Lubecke, Danilo Mandic, and Ehsan Yavari

7.1 Introduction 202
7.2 Cancellation of Unwanted Antenna Motion Using Motion Sensors 203
7.3 Empirical Mode Decomposition 208
7.4 Removing a Subject's Fidgeting Using EMD 212

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-107-05660-2 — Medical and Biological Microwave Sensors and Systems
Edited by Isar Mostafanezhad , Olga Boric-Lubecke , Jenshan Lin
Frontmatter
More Information



7.5 Cancellation of Unwanted Antenna Motion Using EMD 219
7.6 Conclusions 225

**8 Biomedical Applications of UWB Technology** 228
Aly Fathy and Yazhou Wang

8.1 Introduction 228
8.2 Overview of UWB Technology for Indoor Positioning Systems 228
8.3 Vital Signs Detection and Human Gait Analysis 239
8.4 Early Breast Cancer Detection 250

*Index* 265

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-107-05660-2 — Medical and Biological Microwave Sensors and Systems
Edited by Isar Mostafanezhad , Olga Boric-Lubecke , Jenshan Lin
Frontmatter
More Information

# Contributors

**Olga Boric-Lubecke**
University of Hawaii at Manoa

**Kevin D. Browne**
University of Pennsylvania

**J. C. Chiao**
University of Texas at Arlington

**D. Kacy Cullen**
University of Pennsylvania

**David Dubuc**
LAAS-CNRS, France

**Aly Fathy**
University of Tennessee

**Katia Grenier**
LAAS-CNRS, France

**Changzhan Gu**
Texas Tech University

**Usmah Kawoos**
Naval Medical Research Center

**Francis Kralick**
Naval Medical Research Center

**Changzhi Li**
Texas Tech University



© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-107-05660-2 — Medical and Biological Microwave Sensors and Systems
Edited by Isar Mostafanezhad , Olga Boric-Lubecke , Jenshan Lin
Frontmatter
More Information



**Victor Lubecke**
University of Hawaii at Manoa

**Danilo Mandic**
Imperial College London

**Xu Meng**
Drexel University

**Isar Mostafanezhad**
University of Hawaii at Manoa

**Smitha Rao**
University of Texas at Arlington

**Arye Rosen**
Drexel University

**Aditya Singh**
Queens Medical Center, Honolulu, Hawaii

**Mohammad-Reza Tofighi**
Pennsylvania State University

**Yazhou Wang**
Qorvo, Inc.

**Ehsan Yavari**
University of Hawaii

© in this web service Cambridge University Press www.cambridge.org