Power Management Integrated Circuits

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Devices, Circuits, and Systems

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Preface

Big data generated by the Internet of Things (IoT), healthcare, and the world wide web (WWW) are changing our lifestyle and our society. Small chips are enabling this change through data sensing, gathering, processing, storing and networking through wireless and wired connections. This explosive growth of electronic devices and their deployment in new applications have sparked an urgency to address their environmentally benign and sustainable energy needs. The spread of mobile computing and the IoT devices is limited by both battery life and form factor. Research in the field of power management circuits and systems in the last 5–10 years has explored integrated power management units with a small form factor, increased power density, and efficient performance over a wide range of output power in the quest for replacing and/or more efficiently operating with conventional rechargeable batteries and carbon-based sources.

The book begins with a comparison between inductive and capacitive dc–dc converters in terms of their passive devices, amenability to integration, and efficiency at various load conditions. A hybrid inductive–capacitive converter is proposed for wide-range dynamic voltage scaling, with details on the static, dynamic performances and discussion of different loss mechanisms. Next, the design of single inductor dual output (SIDO) and single inductor multiple output (SIMO) converters are covered in detail in Chapters 2 and 3, including the presentation of different design goals such as reducing the number of power switches and their associated power losses, extending the output current range, reducing ripple, and improving dynamic performance. Various control techniques are discussed to meet the different design goals with an emphasis on adaptive pseudo-continuous conduction mode (PCCM) detailed in Chapter 3. Design aspects of switched capacitor (SC) dc–dc converters are given in Chapters 4 through 6. While advantageous in terms of their integration potential, switched capacitor converters have been limited to lower power density applications in addition to lower efficiencies as the load moves away from optimum design conditions. Techniques such as quasi-SC converters, soft-charging or resonant SC converters, and recursive SC converters are detailed to address some of the aforementioned limitations. Chapters 7 and 8 present a different perspective on power management units through the use of GaAs pHEMTs for efficient high-frequency switching converters. The details of device design, high-quality factor passives, and circuit design techniques tailored to GaAs technology are discussed in addition to reconfigurable output passive networks to maintain the high efficiency of GaAs converters over wider voltage and current ranges. Some of the circuit techniques such as resonant gate drivers are compared in both GaAs and CMOS technologies as in Chapter 8. While many of the chapters are focused around several key publications in the field, rather than republishing the original papers, the authors have expanded the material to provide more background and breadth than the original publications. As such, the book would complement a graduate level course on power electronics integrated circuits.

We hope you find this book useful in your exploration of power management integrated circuits and systems. There are many unique challenges to working with integrated circuits whether it is in standard nanometer scale silicon technologies or in III–V technologies. However, there are also many rewards to reap from having such a "power system-on-chip" (PSOC) platform. As the editors, we would like to thank the contributors to this book, including the graduate students and the contributing authors who have worked tirelessly to share their insights with you in this book.

Mona M. Hella
Patrick P. Mercier

Series Editor

Krzysztof (Kris) Iniewski is managing R&D at Redlen Technologies Inc., a start-up company in Vancouver, Columbia, Canada. Redlen's revolutionary production process for advanced semiconductor materials enables a new generation of more accurate, all-digital, radiation-based imaging solutions. Kris is also a founder of Emerging Technologies CMOS Inc. (www.etcmos.com), an organization of high-tech events covering communications, microsystems, optoelectronics, and sensors. In his career, Dr. Iniewski held numerous faculty and management positions at the University of Toronto, University of Alberta, SFU, and PMC-Sierra Inc. He has published over 100 research papers in international journals and conferences. He holds 18 international patents granted in the USA, Canada, France, Germany, and Japan. He is a frequent invited speaker and has consulted for multiple organizations internationally. He has written and edited several books for CRC Press, Cambridge University Press, IEEE Press, Wiley, McGraw-Hill, Artech House, and Springer. His personal goal is to contribute to healthy living and sustainability through innovative engineering solutions. In his leisurely time, Kris can be found hiking, sailing, skiing, or biking in beautiful British Columbia. He can be reached at kris.iniewski@gmail.com.

Editors

Mona Mostafa Hella received a BSc and an MSc with honors from Ain Shams University, Cairo, Egypt, in 1993 and 1996, respectively, and a PhD in 2001 from The Ohio State University, Columbus, Ohio, all in electrical engineering. She is currently an associate professor in the electrical, computer, and systems engineering department at Rensselaer Polytechnic Institute. Prior to that, she has held positions at several companies, including RF Micro Devices and Spirea AB. Dr. Hella was the recipient of the Egyptian Government Award of Excellence (1993), the Micrys Fellowship (1997–1998), and the Texas Instrument Fellowship (1999–2000). She was an associate editor of the *IEEE Transactions on Very Large Scale Integration (VLSI) Systems* from 2011 to 2014. She has served on the technical program committees for ISCAS, GLS-VLSI and RFIC symposium. She has been a member of the administrative committee of the microwave theory and technique society from 2007 to 2009. She has been a trust leader for the NSF-funded engineering research center on "smart lighting" since 2010 and a Fulbright scholar in 2015. Her research interests include the areas of high frequency circuit design and mixed signal design for energy harvesting and biomedical applications.

Patrick P. Mercier received a BSc in electrical and computer engineering from the University of Alberta, Edmonton, Alberta, Canada, in 2006, and an SM and a PhD in electrical engineering and computer science from the Massachusetts Institute of Technology (MIT), Cambridge, Massachusett, in 2008 and 2012, respectively.

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Prof. Mercier received a Natural Sciences and Engineering Council of Canada (NSERC) Julie Payette fellowship in 2006, NSERC Postgraduate Scholarships in 2007 and 2009, an Intel PhD fellowship in 2009, the 2009 ISSCC Jack Kilby Award for Outstanding Student Paper at ISSCC in 2010, a Graduate Teaching Award in Electrical and Computer Engineering at UCSD in 2013, the Hellman Fellowship Award in 2014, the Beckman Young Investigator Award in 2015, and the DARPA Young Faculty Award in 2015. He currently serves as an associate editor of the *IEEE Transactions on Biomedical Circuits and Systems* and the IEEE *Transactions on Very Large Scale Integration* and is a coeditor of *Ultra-Low-Power Short-Range Radios* (Springer, 2015).

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