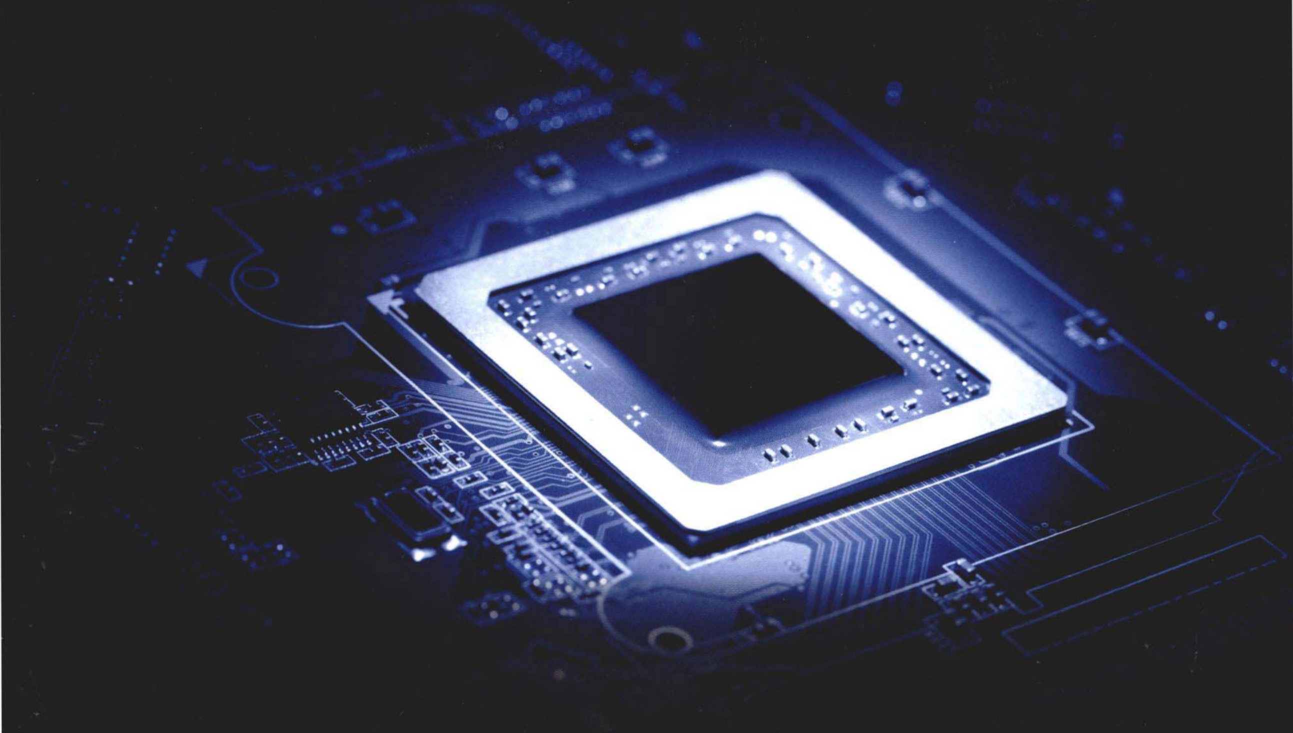
Power Management Techniques for Integrated Circuit Design



Ke-Horng Chen

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POWER MANAGEMENT TECHNIQUES FOR INTEGRATED CIRCUIT DESIGN

To my respected parents, Li-Yun Wu and He-Nan Chen, and my wife, Hsin-Hua Pai

About the Author

Ke-Horng Chen received his B.S., M.S., and Ph.D. degrees in electrical engineering from the National Taiwan University, Taipei, Taiwan in 1994, 1996, and 2003, respectively.

From 1996 to 1998, he was a part-time IC Designer at Philips, Taipei, Taiwan. From 1998 to 2000, he was an Application Engineer at Avanti Ltd., Taiwan. From 2000 to 2003, he was a Project Manager at ACARD Ltd., where he was engaged in designing power management ICs. He is currently Director of the Institute of Electrical Control Engineering and a Professor with the Department of Electrical and Computer Engineering, National Chiao Tung University, Hsinchu, Taiwan, where he has organized a Mixed-Signal and Power Management IC Laboratory. He is the author or coauthor of more than 200 papers published in journals and conferences, and also holds several patents. His current research interests include power management ICs, mixed-signal circuit designs, and display algorithm and driver designs of liquid crystal display (LCD) TVs.

Dr. Chen has served as an Associate Editor of *IEEE Transactions on Power Electronics* and *IEEE Transactions on Circuits and Systems – Part II: Express Briefs*. He is also an Associate Editor of *IEEE Transactions on Circuits and Systems – Part I*. He joined the Editorial Board of *Analog Integrated Circuits and Signal Processing* in 2013. He is on the IEEE Circuits and Systems (CAS) VLSI Systems and Applications Technical Committee, and the IEEE CAS Power and Energy Circuits and Systems Technical Committee. He belongs to the Society for Information Display (SID) and International Display Manufacturing Conference (IDMC) Technical Program Sub-committees. He is Tutorial Co-Chair of IEEE Asia Pacific Conference on Circuits and Systems (APCCAS) 2012 and Track Chair of Integrated Power Electronics, IEEE International Conference on Power Electronics and Drive Systems (PEDS) 2013. He is Technical Program Co-Chair of IEEE International Future Energy Electronics Conference (IFEEC) 2013. He has served as CAS Taipei Section Chair since 2015. He is also Technical Program Committee Member, European Solid-State Circuits Conference (ESSCIRC) 2014–present.

Preface

Over the past three decades, power management technology has become more important as portable and wearable electronics have become part of our daily lives. It is important to realize the detailed design of power management circuits, including low dropout (LDO) regulators, switching power converters (SWRs), switched-capacitor designs among others, if battery usage lifetime and power-conversion efficiency need to be extended. Although some circuits can be found in analog or power electronics books, the reader cannot get an overall understanding of power management designs. Thus, I have written this book to collect useful material related to power management designs in recent years.

Power management IC designs use low-voltage (LV) and high-voltage (HV) devices. The specialty of this book is including LV and HV power management designs. Moreover, the objective of the book is to let the reader understand the process trend and demand of today's applications from the first. The mathematical analysis in the book is simplified, because in my opinion the reader needs to have the ability to understand the function of power management circuits. After that, the reader can analyze the whole power system and derive the complicated mathematical results. Thus, I have used many easy-to-understand figures in the book to let the reader realize why and how power management should be implemented. Although the reader can understand this via derived equations in some similar books, they can have the fun of thinking about and implementing their own designs if they study the circuits in this book by inspection rather than by equations. Moreover, digital and analog design techniques are introduced because a combination of digital and analog skills can give maximum performance of power management in system-on-chip (SoC) applications.

I have taught most of the material in this book both at the National Chiao Tung University, Hsinchu, Taiwan and in Taiwan industry. The order, the format, and the content are all carefully polished when I deliver the material to readers. It is a pity that much material is not included in this book. However, I encourage the reader to apply the concepts to similar power management designs. I have included some design guidelines in this book to let the reader realize the objective of each design.

Chapter 1 provides the reader with knowledge of LV and HV device characteristics and structure in different advanced technologies for learning the material in this book.

Chapter 2 describes the general design of an LDO regulator used in many power management circuits. Compensation skills are introduced to let the reader realize how to ensure power stability in case of any disturbance from input, output, and loading. A digital LDO regulator is also included for LV applications.

Chapter 3 includes the design guidelines of voltage-mode and current-mode switching power regulators. Compensation skills are also introduced to quantify the behavior of basic pulse-width-modulation (PWM) SWRs by inspection.

Chapter 4 introduces the ripple-based control technique for some applications that demand the features of fast transient response, low power consumption, and compact size solution. In particular, fast transient response is the trend for SWR designs to improve the performance of dynamic voltage/frequency scaling techniques and/or reference tracking techniques.

Chapter 5 shows some ripple-based control techniques to improve the performance of basic designs. Even if parasitic effects become large, the techniques presented here can still have excellent performance. Readers can train themselves by using the circuits in this book, proved for silicon, to implement useful power management circuits.

Chapter 6 shows state-of-the-art single-inductor multiple-output (SIMO) converters used in SoC to minimize the power module size. The power stage design and controller design are included in this chapter. We use the design concepts introduced in Chapters 2–5. The reader can obtain advanced training in power management designs here.

Chapter 7 shows the switching-based battery charger to complete the full function of power management in SoC designs. The basic stability proved by some behavior simulators can let the reader know how to model and increase the whole battery charger system.

Chapter 8 includes some energy-harvesting techniques to let the reader realize the possibility of obtaining energy from the environment. How to convert and how to improve efficiency are shown in this chapter.

Acknowledgments

This book has benefited from the recent research results of my Master and Ph.D. students. Many experts in both this research field and industry contributed much useful material to this book. Among them are Shen-Yu Peng (National Chiao Tung University, Hsinchu, Taiwan), Meng-Wei Chien (RealTek Corporation, Hsinchu, Taiwan), and Ying-Wei Chou (MediaTek Inc., Hsinchu, Taiwan). I say "thank you" to them.

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My wife, Hsin-Hua, has made some contributions to this book. She encouraged me to complete the whole book using a range of useful circuits proved for silicon. She collected much useful material, including simulation and experimental results.

The book's production was made possible with the cooperation of staff at John Wiley. I thank James Murphy, Preethi Belkese, Maggie Zhang, Gunalan Lakshmipathy, Revathy Kaliyamoorthy, and Clarissa Lim. Without their help, there would be no book.

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