Preface

Passive wireless microsystems harvest their operational power from radio-frequency waves or other energy sources such as vibration and solar. The absence of bulky batteries not only minimizes the physical dimension and implementation cost of these microsystems, it also removes the need for maintenance. As a result, passive wireless microsystems can be embedded in products or implanted in living bodies permanently to provide the unique identification of the products and living bodies in which they reside, to carry out precision measurement of the parameters of the products or living bodies, or to perform micron-scale control actions that otherwise cannot be performed.

Attributive to their small, wireless accessibility and programmability, and maintenance-free operation, passive wireless microsystems have found a broad range of emerging applications in biomedical implants such as cochlear implants and retinal prosthetic implants, swallowable capsule endoscopy, multi-site pressure sensors for wireless arterial flow characterization, embedded micro-strain sensors for product performance and safety monitoring, wireless temperature sensors for human body and environmental monitoring, and radio-frequency identification tags for logistic automation, to name a few. Passive wireless microsystems are also a viable choice for low-cost high-security product authentication to replace existing product authentication methods such as holograms, water-marks, invisible barcodes, security threads, chemical, and DNA markers that are often too costly to be used for general goods.

This book provides a comprehensive treatment of CMOS circuits for passive wireless microsystems. It focuses on the design of the key blocks of passive wireless microsystems. These blocks include radio-frequency power harvesters, demodulators, low-power precision voltage references, system clock generation and calibration, and ultra-low power analog-to-digital converters. The materials presented in the book are compiled from recently published work in this fast-evolving field. The book is organized as the follows :

Chapter 1 provides an overview of passive wireless microsystems and highlights the key considerations and design challenges of these microsystems.

Chapter 2 begins with a brief examination of the parameters that characterize the performance of radio-frequency power harvesters. Our focus is then turned to power-matching and gain-boosting using LC networks and step-up transformers to increase the voltage at the input of voltage multipliers so as to boost their power efficiency. An emphasis is given to the power efficiency of the power-matching and gain-boosting network itself as the overall power efficiency of a power harvester is determined by the power efficiency of its power-matching and gain-boosting network, that of its voltage multiplier, and the efficiency of its antenna. The design of voltage multipliers for passive wireless microsystems is then investigated in detail.

Chapter 3 examines the pros and cons of commonly used data encoding schemes for wireless communications and explores their suitability for passive wireless microsystems. Non-return-to-zero encoding popular in high-speed data communications over wire channels is studied first. It is followed by an investigation of return-to-zero encoding. Manchester encoding and its characteristics are examined. Miller encoding and Miller-modulated sub-carrier encoding are also studied. An emphasis is given to the distinct characteristics of Miller-modulated sub-carrier encoding and its usefulness in encoding data to be backscattered to base stations. FM0 encoding and pulse interval encoding that are widely used in radio-frequency identification systems are then explored. The chapter is concluded with a comparison of the performance of the encoding schemes studied in the chapter.

Chapter 4 deals with modulation and demodulation. The chapter starts with a close look at the three basic modulation schemes, namely amplitude-shift-keying (ASK), frequency-shift-keying (FSK), and phase-shift-keying (PSK). The pros and cons of these modulation schemes are studied and compared in detail. ASK modulators and demodulators for passive wireless microsystems are investigated. A significant portion of this section is devoted to CMOS circuits for ASK demodulators. FSK modulators and demodulators are then examined in detail. An in-depth study of the advantages and design constraints of FSK demodulators for biomedical implants is provided. The advantages of PSK modulation over FSK modulation in biomedical implants and the design challenges encountered are investigated. Both coherent and non-coherent demodulation of BPSK-modulated signals are presented. The performance of recently published ASK, FSK, and PSK demodulators for passive wireless microsystems is compared.

Chapter 5 is concerned with temperature-independent precision voltage references for passive wireless microsystems. The chapter starts with a brief examination of the figure-of-merits that characterize the performance of voltage references. It is followed by a detailed investigation of the temperaturedependent characteristics of semiconductors. First-order voltage references are studied in a great detail. An in-depth investigation of high-order voltage references follows. The performance of first-order voltage reference and that of high-order voltage references are compared. Ultra low-power voltage references where devices operate in weak inversion are also studied.

Chapter 6 deals with the generation and calibration of the system clock of passive wireless microsystems. The generation of the system clock of passive wireless microsystems directly from the carrier of the received RF signal is investigated first. It is followed by a close look at the generation of the system clock from the envelope of the received RF signal. Direct generation of the system clock from the received RF signal using injection-locked frequency division to take the advantage of its low power consumption and high frequency accuracy is investigated. The system clock of passive wireless microsystems can also be generated using a local oscillator directly. Since the frequency of the local oscillator is subject to the effect of process, voltage, and temperature (PVT) variations, calibrating the frequency of the local oscillator prior to any data communications becomes indispensable. Calibration of the frequency of the system clock using injection-locking with the carrier as the injection signal is investigated first. Frequency calibration of the local oscillator using digital trimming techniques is followed. Our focus is then turned to the presentation of frequency calibration using either phase-locked loops or frequency-locked loops. The chapter further explores the calibration of the frequency of the local oscillator using injection-locking with the envelope as the injection-locking signal. Integrating feedback is employed to increase the lock range of frequency calibration using injection-locking with the envelope as the injection-locking signal.

Chapter 7 focuses on the architecture and design of low-power analog-to-digital converters (ADCs). The fundamentals of ADCs are studied first. It is followed by a close examination of the figure-of-merits used to quantify the performance of ADCs. Integrating ADCs are investigated. Both single-slope and dual-slope integrating ADCs, and their advantages and disadvantages are examined and compared. The design of oscillation-based ADCs for temperature measurement is explored. A close attention is paid to both relaxation oscillator and ring oscillator based temperature ADCs. Time-to-digital converter based ADCs for temperature measurement is also investigated. As compared with oscillator-based temperature ADCs, these ADCs have the advantage of low power consumption. The chapter then moves on to investigate frequency-to-digital based ADCs for temperature measurement. Charge redistribution successive approximation ADCs are investigated in a great detail. Our focus is given to the design of charge-scaling digital-to-analog converters (DACs) used in charge redistribution successive approximation ADCs. Three configurations of charging-scaling capacitor arrays, namely single-stage binary-weighted capacitor arrays, two-stage binary-weighted capacitor arrays, and C-2C capacitor arrays are studied in detail and their pros and cons are examined.

Since the objective of the book is to provide readers with the state-of-the-art of CMOS circuits for passive wireless microsystems, the details of the operation of semiconductor devices and basic microelectronic circuits are omitted due to a space constraint. Readers are assumed to have the basic knowledge of electrical networks, semiconductor devices, microelectronic circuits, signals and systems, and digital communications. A rich collection of recently published work on passive wireless microsystems is provided at the end of the book for readers to seek further information on the subjects.

Although an immense amount of effort was made in preparation of the manuscript, flaws and errors will still exist due to erring human nature and the limited knowledge of the author on the subjects. Suggestions and corrections from readers will be gratefully appreciated by the author.

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