

# Preface

Wireless communication is becoming increasingly ubiquitous today, with many consumer, industrial, medical, and military devices leveraging newly found untethered freedoms to enable exciting new applications and opportunities. To date, the cellular and computer industries have been the primary driver of advances in wireless functionality, exemplified by the popularity and continuing advances in 4G carrier aggregation and next-generation WiFi products. While these (and other) standards support the high throughput and range necessary for cellular and computing applications, there are emerging classes of applications including sensor networks, Internet of Things (IoT), and body-area networks that have very different requirements. Specifically, devices used in these applications are not necessarily looking for the fastest throughput, but instead focus on achieving *sufficient* throughput under ultra-low-power budgets. To reduce power, these devices typically operate over shorter ranges, pushing the power requirements of long-haul communications to more energy-rich gateways. It is expected that these ultra-low-power, short-range radios will begin to comprise a large fraction of total volume of radios as these emerging application spaces mature.

To support these application spaces, there are currently a number of standards specifically responsive to the needs of low-power short-range communications. Examples include Bluetooth, Bluetooth Low Energy, and IEEE 802.15.6 (Wireless Body Area Networks), with a few other standards that support low-power though not necessarily short-range (e.g., Zigbee and 802.11ah). However, in many cases strictly adhering to standards can limit design creativity, potentially resulting in solutions with higher-than-desired power. Thus, the majority of this book does not focus on developing radios for specific standards, but instead focuses on circuit and system techniques that achieve ultra-low-power while not sacrificing too much on other important metrics. Many of the discussed techniques can then be applied to standards-based radios, though some techniques are naturally better suited for custom, proprietary solutions.

In either case, the purpose of this book is not to act as a textbook or a design manual for specific radios, but should instead be used by engineers who have a background in RF to better understand the challenges, requirements, circuits, and system-level techniques that can be used to design ultra-low-power short-range radios.

## Organization of the Book

This book is organized into 12 chapters. To set the tone, the first chapter begins with an overview of general trends in low-power radio design, including a benchmarking section that covers state-of-the-art performance in this space. Then, chapter “Channel Modeling for Wireless Body Area Networks” discusses channel modeling, with a specific emphasis on the body channel, in order to help the reader better understand the requirements placed on ultra-low-power short range radios. Following these discussions, the book dives into the details of specific use-cases and implementations of ultra-low-power short-range radios, starting with narrowband radios, then moving to alternative forms of wireless communication, and concluding with very short-range communications and energy management.

On the topic of narrowband radios, chapter “Circuit Techniques for Ultra-Low Power Radios” discusses design techniques that, through crystal-based injection-locking approaches, enable the achievement of ultra-low-power operation without the use of phase-locked loops (PLLs). As an alternative approach, chapter “Architectures for Ultra-Low-Power Multi-Channel Resonator-Based Wireless Transceivers” introduces a similar concept, but in this case using higher frequency high- $Q$  resonators as PLL and front-end filter replacements. Chapter “Ultra-Low Power Wake-Up Radios” then considers low-power wake-up radios for applications that have asynchronous, event-driven communication needs. Chapter “Commercially Viable Ultra-Low Power Wireless” reviews trends and techniques that are appropriate for commercial, standards-driven radios, and chapter “Synchronization Clocks for Ultra-Low Power Wireless Networks” discusses ultra-low-power timing circuits necessary for synchronization amongst radios in both standards-based and custom radio networks.

In applications that require ultra-high throughput or secure, non-radiating communication, techniques other than narrowband communication may offer superior performance. To this end, chapter “Pulsed Ultra-Wideband Transceivers” discussed ultra-wideband (UWB) circuits and systems for use in ultra-low-power short-range applications. For on-body communication applications, chapter “Human Body Communication Transceiver for Energy Efficient BAN” reviews the history and recent trends regarding human-body communications (HBC) and its application to wearable, biomedical monitoring devices.

Chapters “Centimeter-Range Inductive Radios” and “Near-Field Wireless Power Transfer” then introduce near-field communication (NFC) and power delivery concepts for applications where communication over a few centimeters is desired.

Specifically, chapter “Centimeter-Range Inductive Radios” focuses on increasing the throughput of NFC links, while chapter “Near-Field Wireless Power Transfer” reviews resonant coupling theory and derives formulae describing optimal conditions for efficient or maximal delivery of wireless power. Finally, chapter “Energy Harvesting Opportunities for Low-Power Radios” concludes the book with a discussion on energy harvesting and energy management circuits and devices that are appropriate to extend operational lifetime of many ultra-low-power short-range wireless devices.

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San Diego, CA, USA  
Cambridge, MA, USA

Patrick P. Mercier  
Anantha P. Chandrakasan

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Mercier, P.P.; Chandrakasan, A.P. (Eds.)

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