Preface

The ever increasing demand for computing and communications especially for wearable devices, coupled with some of the unique applications that require non-interruptible operation, dictates the need for innovation in energy harvesting and power management. Further, the advancements in circuit design, systems and communication coupled with semiconductor technology scaling have enabled ultra-low power systems in the range of microwatt to nanowatt. This development along with the necessity for near perpetual operations, especially for wearable devices, low cost and small size, brings new challenges to energy sources and power managements. In addition, the single digit improvement in battery technology has resulted in increasing the focus on energy harvesting as the main power source.

The usage of wearable devices in healthcare has led to a proliferation of research toward smaller, smarter, connected systems operating at low power consumption. These devices have attracted huge interest to monitor different vital signs over long time such as heart rate, oxygen level, breath rate, and glucose rate. In addition, having this information monitored continuously could help doctors to track the health status of their patients without being physically in the hospital. This reduces the effort, especially for elderly patients, of frequent visits to the hospitals. In healthcare, it is critical to have long time operation due to the fact that data interruption is not preferred especially when monitoring vital signs. Further, the inconvenience of recharging/replacing batteries has pushed to find better solutions to extend their lifetime. Energy harvesting is an emerging topic that can be utilized to solve the issue of a short lifetime for wearable applications. Although energy harvesting has been known for decades, it is now becoming more feasible to consider for applications in wearable devices and Internet-of-Things (IoT) since the power consumption requirements of such devices are normally low enough and can, in fact, be supported by energy harvesting sources. In addition, state-of-the-art harvesters have become small, efficient, and flexible which allow them to be integrated into a small form factor that fit the wearables. Furthermore, energy harvesters could be used directly to power devices without the existence of a battery. The battery-free operation enables new classes of applications in medical devices, environmental sensors, hard to reach places, smart buildings, and implantables.

This book provides breadth and depth coverage of energy harvesting techniques with a focus on wearable devices. It reflects the cutting-edge technology in designing a complete energy harvesting systems starting from the harvester model and analysis toward powering different systems. This includes deep details on circuit topologies and control circuits that are necessary to achieve high efficient multi-source energy harvesting system. Although the focus of this book is on energy harvesting in general, however, thermal harvesting have received a major concentration due to its global availability in wearable applications.

The book is structured as follows. The first chapter explains the latest trend in the wearable application within the era of the Internet-of-Things and the need for energy harvesting. Further, a comparison between using batteries and capacitors is carried out to power wearable devices. In addition, state-of-the-art low power devices that are reported in the literature are compared.

Chapter 2 explores common energy harvesting sources and provides details about their electrical model along with some measurements examples. In addition, different power conversion circuits are presented that are commonly used in energy harvesting applications. This includes linear dropout regulator, switch capacitor circuits, and inductor-based converters.

Chapter 3 supplies the reader with the main interface circuits and control techniques for energy harvesting in general focusing on human body thermal harvesting. This includes the design of high gain inductor-based boost converter with the associated control techniques.

In Chap. 4, zero crossing switching methods for thermal harvesting are explained and compared in regard to design, complexity, and efficiency. Also, a new technique is proposed with measurement results that enhances the efficiency as well as the dynamic of the inductor boost converter.

Polarity circuits for thermoelectric generators are demonstrated in Chap. 5 and a novel technique is proposed and supported by measurement results. This technique is simple yet effective, fully integrated on-chip, all digital with low overhead.

Finally, the design of energy combiner with power manager to form a complete energy harvesting system is explained in Chap. 6. In addition, the design of an efficient energy combiner is proposed with power manager circuit. Furthermore, a sleep mode operation for low power processor is explained which is necessary when the input energy is variable.

This book could be used as a reference for design engineers, practitioners, scientists, and marketing managers in the semiconductor industry developing integrated self-powered platform system-on-chip solutions for wearable devices and the Internet-of-Things. It is also highly recommended for graduate students in electrical and computer engineering and physics pursuing research in integrated devices and circuits, energy harvesting, power management as well as overall system integration. This book could also be useful for researchers that are in other disciplines since the material is rich with basic information that familiarizes the reader with the energy harvesting subject.

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