Preface

Autonomous sensors do not use cables either for transmitting data or for powering electronics. They can be found in wireless sensor networks (WSNs) or in remote acquisition systems. Primary batteries provide a simple design for the powering of autonomous sensors. However, batteries must be replaced when depleted, which can lead to unacceptable maintenance costs whenever the number of autonomous sensors is very large or their accessibility is difficult or impractical. An alternative is to extract energy from the ambient, which is usually known as *energy harvesting*. However, the reduced dimensions of most autonomous sensors lead to a low available power from the energy transducer. Thus, efficient methods and circuits to manage and gather the energy are a must.

This book tackles the powering of autonomous sensors, providing an integral approach by considering both primary batteries and energy harvesting. Two rather different forms of energy harvesting are further dealt with: optical (solar) and radiofrequency (RF). Optical energy presents high energy density, especially outdoors, whereas RF remote powering can be the most feasible option for autonomous sensors embedded into the soil or within structures. Throughout the different chapters, devices such as primary and secondary batteries, supercapacitors, and the energy transducers are extensively reviewed. Then, circuits and methods found in the literature to efficiently extract and gather the energy are presented. Finally, new proposals based in our own research are analyzed and tested. Each chapter is written to be rather independent, incorporating the related literature references into each one.

Chapter 1 first presents autonomous sensors and the feasible energy sources. Both primary batteries and energy harvesters are considered and basic concepts to take into account are detailed. The chapter also provides a general overview of the main problems that appear when designing the power supply of autonomous sensors and refers to some of the most important previous works on this topic.

Chapter 2 analyzes the power consumption of an autonomous sensor and adds some remarks on voltage regulators. In particular, a review is presented, from the point of view of power consumption, on some of the typical devices found in autonomous sensors such as microcontrollers and transceivers. A short introduction to sensors and their signal conditioners is also presented. Finally, a general model based on a pulsed current sink is proposed and experimentally validated.

Chapter 3 reviews the ambient energy sources amenable to powering autonomous sensors: radiant, mechanical, thermal, magnetic, and biochemical. The associated energy transducers are also described and some of the most relevant literature is referenced.

Chapter 4 presents the electrical characteristics and models of primary and secondary batteries, and supercapacitors. Low capacity batteries (up to 3 Ah), both primary and secondary, were experimentally characterized and the parameters of a simplified Randles model are fitted. Several types of supercapacitors were also characterized, obtaining the equivalent series resistances. One of them was further tested to obtain its leakage resistance. Temperature tests, both for batteries and supercapacitors were also carried out. On the other hand, the use of hybrid storage units is proposed in order to reduce the power waste and voltage drop caused by high-resistance batteries. Design criteria for choosing a suitable value of the accompanying supercapacitor are presented. Runtime extensions between 16% and 33% are reported.

Chapter 5 considers optical energy for powering autonomous sensors. A generic model for optical energy transducers, namely solar cells or photovoltaic (PV) panels, is employed to compute the *I–V* and *P–V* curves as well as their dependency on optical power and on temperature. Based on this model, the efficiency of direct-coupled solutions was also computed, ranging from 70% to 90%. With respect to maximum power point trackers (MPPTs), a new open-circuit voltage (OCV) method has been proposed and tested, providing a tracking efficiency greater than 99.5%, higher than that reported for current implementations of OCV methods. Additionally, we devised and tested a novel MPPT method that provides a tracking efficiency greater than 99.6% and an overall efficiency greater than 92% for a PV panel power greater than 100 mW.

Chapter 6 is dedicated to remote RF powering of autonomous sensors and in particular to RF energy harvesters. The RF energy transducer (antenna), matching networks, and ensuing rectifiers are presented. Based on circuits proposed in the literature, extensive simulations for several incoming power levels at the antenna (from −10 dBm to 10 dBm) were performed. We determine that circuit efficiency slightly depends on the number of stages used for the voltage rectifier multiplier, but varies widely with the received power (ranging, when using a shunt-inductor matching network, from 10% at −10 dBm to 80% at 10 dBm). Additionally, as the power level increases, so does the output voltage corresponding to maximum efficiency. For low power levels, *L*C matching networks provided higher efficiencies than shunt-inductor networks, at the cost of greater sensitivity to output voltage variations and to the value of the inductor. Experimental tests were performed with a folded dipole antenna (about 300 Ω), shunt inductor matching, a three-stage rectifier, and a storage unit composed of two series connected NiMH batteries.

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