

Preface

Energy harvesting is the conversion of ambient energy present in the environment into electrical energy. It is identical in principle to large-scale renewable energy generation, for example, solar or wind power, but very different in scale. While large-scale power generation is concerned with megawatts of power, energy harvesting typically refers to micro- to milli-watts, i.e. much smaller power generation systems. The development of energy harvesting has been driven by the proliferation of autonomous wireless electronic systems. A classic example of such systems are wireless sensor nodes which combine together to form wireless sensor networks. Each sensor node typically comprises a sensor, processing electronics, wireless communications, and power supply. Since the system is by definition wireless and cannot be plugged into a mains supply, power has to be provided locally. Typically such a local power supply is provided a battery which on the face of it is convenient and low cost. However, batteries contain a finite supply of energy and require periodic replacement or recharging. This may be fine in individual deployments but across a wireless network containing a multitude of nodes batteries are clearly not attractive. Furthermore, the need to replace batteries means the wireless system has to be accessible which may not be possible or may compromise performance. Finally, there are environmental concerns about disposing of batteries. Energy harvesting was developed, therefore, as a method for replacing or augmenting batteries. By converting ambient energy in the environment, the energy harvester can provide the required electrical power for the lifetime of the wireless system which is also free to be embedded or placed wherever it is best suited to perform its function. Energy harvesting typically exploit kinetic, thermal, solar sources, or electromagnetic radiation sources. Kinetic energy harvesting converts movement, often in the form of vibrations, into electrical energy. Thermal gradients can be exploited by using thermoelectric generators while solar energy is harvested using photovoltaics. Electromagnetic radiation can capture the energy from radio waves but unless this energy is specifically broadcast, power levels are typically very low. The challenges for energy harvesting are to maximise the available electrical power from the ambient energy found in the application environment. Vibration energy harvesters, for example, need to be tuned to match characteristic frequencies found in the environment which often means bespoke generator designs are required for different applications. It would be much better if such generators

were adaptable and able to cope with a range of frequencies. The energy conversion process does not stop with the generator; typically power conditioning electronics are also required to provide the electrical power in form acceptable to the system electronics. The design of the conditioning electronics often has an impact on the performance of the generator and therefore energy harvesting systems should be designed in a holistic manner considering all the essential blocks as a whole. This book addresses these challenges and describes the approaches that can be taken to overcome them. The first chapter provides a comprehensive introduction to operating principles of kinetic micro-generators and associated electronics with emphasis on adaptive kinetic energy harvesting. Kinetic energy harvesters, also known as vibration power generators, are typically, although not exclusively, inertial spring-mass systems where electrical power is extracted by employing one or a combination of different transduction mechanisms. As most vibration power generators are resonant systems, they generate maximum power when the resonant frequency of the generator matches the ambient vibration frequency. Adaptive generators try to minimise the difference between these two frequencies in order to maximise the amount of generated power. The chapter outlines extensively recent developments in adaptive kinetic energy harvesting and presents achievable improvements in the operating frequency range of such generators. The second chapter is devoted to design automation aspects of energy harvester systems. It presents an automated energy harvester design flow which is based on a single HDL software platform that can be used to model, simulate, configure and optimise a complete mixed physical-domain energy harvester system which includes the micro-generator, voltage booster, storage element and load. State-of-the art accurate hardware description language (HDL) modelling techniques for kinetic energy harvesters and their experimental validation are presented and discussed. Measurements have validated both the accuracy of HDL-based modelling and the efficiency of the automated design flow which can improve the amount of harvested energy in a typical system by 75%. The third chapter focuses on the power analysis and power harvesting in wireless sensor networks. Specifically, it gives an overview of power analysis simulation techniques and presents related tools and methodologies. The chapter also describes extension libraries for power analysis and models of energy harvester-based wireless sensors in SystemC and SystemC AMS complete with examples and simulation results. The final chapter presents a major industrial application of energy harvesting: the tyre pressure monitoring system (TPMS) recently developed at Infineon Technologies. Existing TPMS designs, which are based on batteries, suffer from difficulties in the energy budget management. The main challenge is to ensure a reliable RF data link from the sensor in the tyre to the receiver in the car due to the low energy available. Problems are aggravated when the car is used in extreme weather conditions, especially in winter, as batteries frequently fail in low temperatures. The chapter presents the advantages of Infineons revolutionary design which is based on an electrostatic vibration harvester. The design is highly miniaturised, with a volume less than 1 cm^3 including the power supply and is embedded in the tyre. Results obtained from this case study provide a significant step towards intelligent tyres, which would be able to measure and report additional technical parameters

for further enhancement of road safety. We hope that the reader of this book will gain a valuable insight into the state-of-the-art design techniques for autonomous wireless sensors powered by kinetic energy harvesters. The potential for electronic systems using various forms of “free energy”, such as kinetic, thermal, solar, RF and others, will continue to inspire researchers and engineers. In near future we will no doubt see new energy harvester designs, use of new materials, as well as innovative power management circuits and new solutions to energy storage. Energy harvester applications will benefit from further evolution in decreasing energy consumption due to novel circuit designs and the scaling down of nano-devices. New wireless communication techniques will also contribute to the reduction of energy consumption.

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Energy Harvesting Systems
Principles, Modeling and Applications
Każmierski, T.J.; Beeby, S. (Eds.)
2011, XI, 163 p., Hardcover
ISBN: 978-1-4419-7565-2