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Energy Harvesting
for Low-Power Autonomous Devices and Systems

Jahangir Rastegar
Harbans S. Dhadwal

Tutorial Texts in Optical Engineering
Volume TT108

SPIE PRESS
Bellingham, Washington USA
Introduction to the Series

Since its inception in 1989, the Tutorial Texts (TT) series has grown to cover many diverse fields of science and engineering. The initial idea for the series was to make material presented in SPIE short courses available to those who could not attend and to provide a reference text for those who could. Thus, many of the texts in this series are generated by augmenting course notes with descriptive text that further illuminates the subject. In this way, the TT becomes an excellent stand-alone reference that finds a much wider audience than only short course attendees.

Tutorial Texts have grown in popularity and in the scope of material covered since 1989. They no longer necessarily stem from short courses; rather, they are often generated independently by experts in the field. They are popular because they provide a ready reference to those wishing to learn about emerging technologies or the latest information within their field. The topics within the series have grown from the initial areas of geometrical optics, optical detectors, and image processing to include the emerging fields of nanotechnology, biomedical optics, fiber optics, and laser technologies. Authors contributing to the TT series are instructed to provide introductory material so that those new to the field may use the book as a starting point to get a basic grasp of the material. It is hoped that some readers may develop sufficient interest to take a short course by the author or pursue further research in more advanced books to delve deeper into the subject.

The books in this series are distinguished from other technical monographs and textbooks in the way in which the material is presented. In keeping with the tutorial nature of the series, there is an emphasis on the use of graphical and illustrative material to better elucidate basic and advanced concepts. There is also heavy use of tabular reference data and numerous examples to further explain the concepts presented. The publishing time for the books is kept to a minimum so that the books will be as timely and up-to-date as possible. Furthermore, these introductory books are competitively priced compared to more traditional books on the same subject.

When a proposal for a text is received, each proposal is evaluated to determine the relevance of the proposed topic. This initial reviewing process has been very helpful to authors in identifying, early in the writing process, the need for additional material or other changes in approach that would serve to strengthen the text. Once a manuscript is completed, it is peer reviewed to ensure that chapters communicate accurately the essential ingredients of the science and technologies under discussion.

It is my goal to maintain the style and quality of books in the series and to further expand the topic areas to include new emerging fields as they become of interest to our reading audience.

James A. Harrington
Rutgers University
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Preface

Energy harvesting is an energy-to-energy conversion technology involving processes that generate electrical energy from other sources of energy such as mechanical, thermal, chemical, solar, and radio frequency. Use of mechanical and solar energy represents the most developed technologies and offers solutions over a broad range of energy levels. Solar cells are used to power wrist watches, calculators, and road signs, whereas mechanical-energy-harvesting solutions based on piezoelectric transducers are being used to harvest energy from sources such as vibration or shock loading. Radio-frequency-based harvesters, for example, are finding use in converting ambient electromagnetic energy to power sensor nodes. Conversion of thermal gradients to electrical energy is another promising technology.

This book is restricted to the generation of small amounts of electrical energy on a local scale and for conversion of mechanical potential and kinetic energy to electrical energy. Persons interested in learning more about the fundamental concepts of energy harvesting will find the treatment of relevant topics readable with little prerequisite requirement of engineering topics. This book will be of particular interest to application engineers from diverse disciplines and industries. It provides a fundamental view of the scope of the energy-harvesting technology as well as the trade-offs and limitations for practical systems.

The book will be of interest to those who want to know the potentials as well as shortcomings of energy-harvesting technologies. It is particularly useful for energy-harvesting system design because it provides a systematic approach to: selection of the proper transduction mechanisms, methods of interfacing with a host system, and electrical energy collection and conditioning options.

The book is divided into five chapters. Chapter 1 briefly describes the various energy-conversion processes currently being used in the generation of electrical energy from sources such as solar, radio frequency, thermoelectric, and energy from human activity.

Chapter 2 describes the three primary types of transducers typically used for converting mechanical energy to electrical energy, that is, piezoelectric, electromagnetic, and electrostatic. Magnetostrictive-based transducers are also briefly introduced.
Chapter 3 presents an in-depth analysis of the interfacing mechanisms used for coupling the host system to the energy harvester for effective transfer of mechanical kinetic and/or potential energy to the transducer.

Chapter 4 addresses collection and conditioning circuits needed to extract the generated electrical energy for delivery to a load. The theme of chapters 2, 3, and 4 shows the connection between the three components of an energy-harvesting system, namely, the host interfacing mechanism, the transducer, and the collection and conditioning circuit.

In addition to the design of efficient energy harvesters, this book also discusses how certain types of energy harvesters can be configured to provide self-powered sensing capabilities. Additional circuitry not requiring any external power may also provide further enhancement by including logic functionality. Case studies with particular emphasis on shock-loading-based energy harvesting and sensory applications are presented in Chapter 5.

An extensive list of references is provided to direct the reader to appropriate literature for more in-depth material not covered in the book.

We thank James Harrington, SPIE Tutorial Text Series Editor, for encouraging us to write the book and Tim Lamkins, SPIE Press Manager, for his editorial suggestions and support. We very much appreciate the effort, patience, and guidance provided by Nicole Harris, our editor at SPIE.

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