Smart Mater. Struct. 18 (2009) 055012 (14pp) doi:10.1088/0964-1726/18/5/055012

Modeling and experimental verification of synchronized discharging techniques for boosting power harvesting from piezoelectric transducers

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Received 14 July 2008, in final form 9 February 2009
Published 6 April 2009
Online at stacks.iop.org/SMS/18/055012

Abstract
This paper presents analytical models for studying the transient behavior of several power harvesting circuit topologies for use with piezoelectric bending transducers. Specifically, the problem of charging a large storage capacitor, which is inherently a time-varying process, is considered. Three circuit designs are studied—direct charging, synchronized switching and discharging to a storage capacitor, and synchronized switching and discharging to a storage capacitor through an inductor (SSDCI)—and they are compared to a matched resistive load case. Analytical models are developed for these cases to predict the charging rates and output power for various values of storage capacitance and quality factor. Experimental circuit designs are given and their results are compared to the theoretical predictions. It is shown that these predictions are accurate when the losses in the circuit are considered in the model. In spite of these losses, it is demonstrated that the SSDCI design can produce about 200% the output power of the idealized, matched resistive load case throughout the charging process and substantially reduce the charging time of the storage capacitor.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

The rapid advancement of CMOS low power circuitry and the upsurge in wireless sensor applications have generated much interest in developing new means for extending the lifetime of these devices. Scavenging energy from the ambient environment as a power source for wireless sensors may in fact prove critical to the proliferation of these technologies. In particular, harvesting power from ambient vibrations using piezoelectric material is a promising means to gather energy from the environment (see Sodano *et al* 2004a for a review). Significant research has been devoted to modeling piezoelectric power harvesters in order to predict their performance and to optimize the harvested power for a given application. These models generally fall under two categories: lumped parameter (single DOF) models (Roundy and Wright 2004, and duToit *et al* 2005) and distributed parameter (multi-DOF) models (Sodano *et al* 2004b, duToit *et al* 2005 and Erturk and Inman 2008). These studies, however, generally only consider simple resistive loads under steady-state conditions.

Unfortunately, the energy scavenged from the environment is usually time-varying and insufficient to power wireless sensors continuously. Thus, a power management scheme that uses a buffer stage and energy storage is usually required in practical applications. Many studies have been devoted to optimizing the interfacing circuit to maximize the power output of a piezoelectric transducer on specific resistive loads. DC–DC

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