Power Optimization of Vibration Energy Harvesters Utilizing Passive and Active Circuits

ADAM M. WICKENHEISER[1,]* AND EPHRAHIM GARCIA[2]

[1]*Department of Mechanical & Aerospace Engineering, George Washington University, Washington, DC, USA*

[2]*Sibley School of Mechanical & Aerospace Engineering, Cornell University, Ithaca, NY, USA*

ABSTRACT: This article presents the maximum power operating conditions for piezoelectric energy harvesters when connected to several different circuit topologies. Four circuits are studied herein for comparison: a simple resistive load, the standard rectifier circuit, and parallel and series synchronized switch harvesting on inductor. A single-mode model of a vibration-based energy harvester under base excitation is developed to capture the important dynamics near its fundamental resonance while providing a simple basis for performing design optimization. Relevant dimensionless parameters are given to provide a scale-free context for discussing the optimal operating points. For a prescribed vibration energy harvester, the base excitation frequency and load impedance for maximum power generation are provided by the results of this study. Furthermore, the effects of mechanical damping, electromechanical coupling, circuit quality factor, and rectifier forward voltage are presented. These effects are discussed in order to cite the salient parameters in the design of these energy harvesting systems.

Key Words: energy harvesting, piezoelectric, power optimization.

INTRODUCTION

As the demand for wireless devices increases, so does the need for a practical means of providing sufficient energy to meet their design requirements. Onboard batteries provide a straightforward energy source for wireless devices; however, their relatively low energy densities make them impractical for certain applications (Warneke et al., 2001; Reissman et al., 2007). Furthermore, batteries may be infeasible due to the cost of replacement – both in currency and manpower. This cost may be especially prohibitive as the number of devices increases. A means of reducing or eliminating these maintenance expenses may prove critical to the expansion of wireless technologies into new environments and applications.

Energy harvesting – the ability to harness, store, and distribute energy from the local surroundings of an electronic device – has generated significant research over the past decade. This ability has the potential to reduce the frequency of battery replacement or altogether eliminate the need by continuously replenishing the consumed electrical energy by tapping into nearby sources in the environment. The relatively nascent field of vibration-based energy harvesting has received particular attention due to the ubiquity of untapped vibrational energy available in or around most manmade systems (Roundy et al., 2003). This great potential has spurred research into several methods of electromechanical transduction, including electromagnetic induction (e.g., Glynne-Jones et al., 2004), electrostatic varactance (e.g., Mitcheson et al., 2004), and the piezoelectric effect, the latter being the focus of this study.

In the existing literature, the piezoelectric transducer is predominantly modeled as a lumped, single-degree-of-freedom (DOF) system undergoing periodic forcing. Significant effort has been devoted to modeling piezoelectric power harvesters based on their geometry and material properties in order to predict their performance and to optimize the harvested power for a given application. The models generally fall under two categories: lumped parameter (single DOF) models (Roundy and Wright, 2004; duToit et al., 2005) and distributed parameter (multi-DOF) models (Sodano et al., 2004; duToit et al., 2005; Erturk and Inman, 2008). These studies, however, generally only consider simple resistive loads under steady state, alternating current conditions; they do not represent practical systems in which the harvested energy may be accumulated for later use.

Unfortunately, the vibrational energy scavenged from the environment is usually stochastic, time-varying, and insufficient to power wireless devices continuously at

*Author to whom correspondence should be addressed.
E-mail: amwick@gwu.edu

1045-389X/10/13 1343–19 $10.00/0 DOI: 10.1177/1045389X10376678