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A Study of the Transient Charging Behavior of Several Approaches to Piezoelectric Energy Harvesting

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ABSTRACT

This paper presents several designs for harvesting energy from a piezoelectric transducer to charge a storage capacitor. These designs involve the synchronized discharge or inversion of the voltage stored in the piezoelectric beam at the peak of its displacement. Specifically, the transient dynamics of the system during the charging phase are analyzed. These dynamics are important for low-voltage applications, such as wireless sensors, where the useable voltage across the storage unit is much lower than the open-circuit voltage of the piezoceramic. Theoretical models of each harvesting circuit design are developed in order to predict the time-varying power delivered to the storage capacitor and the time required to charge it to a specified voltage. The differences in these theoretical circuits and physically realizable ones are presented. Also, an analysis of the errors introduced by modeling assumptions and non-ideal circuit components is given. These errors are cited in order to justify the deviations in experimental results from theoretical predictions.

Keywords: piezoelectric, power harvesting, charging dynamics

1. INTRODUCTION

Interest in extending the useable lifetime of wireless sensors and communications systems has generated much recent research in power harvesting systems. In particular, harvesting power from ambient vibrations using piezoelectric material is a promising means to gather energy from the environment (see [1] for a review). Recent research in the field of piezoelectric power harvesting has focused on improved modeling of the electromechanical transducer [2,3] and developing more sophisticated harvesting circuits than the typical rectifier [4,5].

In order to extend the range of applicability of power harvesting systems, the harvesting energy can be stored and used in bursts for devices requiring more power than is gathered. In such a system, an energy storage buffer is necessary to store the energy harvested temporarily when the device is idle and then release the energy when the device is turned on. Rechargeable batteries are an option for this energy storage purpose. Unfortunately, rechargeable batteries have notorious memory effects and have limited charge/discharge endurance; thus, field-deployed wireless sensors need to be serviced when the installed battery breaks down. Ultra-/super capacitors are another promising energy storage buffer. Unfortunately, the properties of ultra-capacitors are much different from those of rechargeable batteries: ultra-capacitors are characterized as reactive loads as opposed to resistive