Analysis of Optimized Micro-Generator Architectures for Self-Powered Ubiquitous Computers

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ABSTRACT

It is advantageous for many types of ubiquitous computing artifacts to be capable of extracting energy from their environment, making them self-powered and self-sustaining. This paper presents a comparison of the two recently proposed micro-power generator architectures; the velocity damped resonant generator and the coulomb damped resonant generator. Also presented and analyzed is a new device, the parametric generator.

The analysis has shown that the parametric generator is likely to be useful when the input vibration amplitude is an order of magnitude greater than the dimensions of the micro-generator. It has also shown that for resonant generators, the efficiency of the technology used to realize the energy conversion is likely to be of greater importance in determining the output power than the architecture of generator used. Equations have been developed to enable the designer of a micro-generator to choose an optimal architecture.

Keywords

Vibration-to-electrical energy conversion, Self Powered Systems, Micro-power generators, Inertial-generators, Microelectromechanical devices.

INTRODUCTION

In order to successfully realize fully ubiquitous computing, it is necessary that each computing node is capable of running without user intervention. For computing nodes that are required to be physically small and mobile, a major obstacle to achieving this goal is the requirement of a continuous power source. Although there is continuing research into micro-batteries, this type of power source will only ever contain finite energy. Current thin-film micro-batteries can only achieve a capacity (per unit area of silicon) of 65μAh/cm^2 at around 4V [3]. A more attractive solution is for the node to scavenge energy from its environment, forming a self-powered system. This energy could be in the form of solar energy [2], thermal gradients or some form of movement [1], [4]. This paper presents a comparison of the main types of micro-generator architectures based on motion. These motion devices convert ambient mechanical vibration into electrical energy for use by ultra-low-power electronics, such as a computing artifact.

INERTIAL GENERATORS

In order to convert an input mechanical motion into electrical energy, some form of transducer is required. For the purposes of modeling the mechanics of the generator, the transducer can be realized as a damper with a suitable characteristic. The energy dissipated in the damper is the energy extracted from the mechanical system and converted into electrical energy. A typical inertial generator is shown in figure 1.

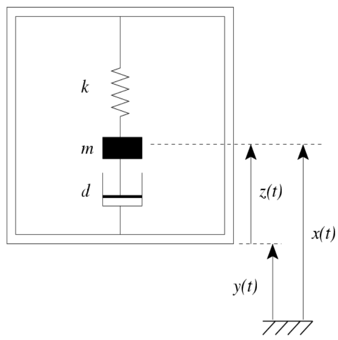

Figure 1: A Generic Resonant Inertial Generator

Types of Damping

In mechanical systems, damping is often modeled as one of the following types:

- Velocity damping
- Coulomb damping
- Hysteretic damping

A typical example of velocity damping is air resistance. An example of coulomb damping is dry friction of a body sliding along a surface, and hysteretic damping is normally used to model energy dissipated by the structural deformation of materials.

Any micro generator is likely to have little effect on the moving body that is providing the power. Thus, for the given constraints on generator mass and volume, it is important to choose the type of damping which allows most mechanical power to be coupled into the generator, dissipated in the damper and thus converted into electrical energy. It should be noted that current materials may or may not allow the chosen damping scheme to be sensibly mapped onto a particular technology.

Implementing the Damper

The following phenomena can be used to convert kinetic energy into electrical energy: Electrostatic field; electromagnetic field; piezoelectric effect.

An electrostatic generator can be realized with a moving plate capacitor. A parallel plate capacitor operated with a constant charge and a comb capacitor operated in constant voltage are both realizations of coulomb dampers. A velocity damper can be realized with a moving magnet whose flux is linked with a stationary coil. Piezo devices are best modeled as hysteretic dampers.

The Parametric Generator

In order to maximize the work done against an electric field, and thus maximize the electrical energy generated, the force-distance product should be maximized. The point of maximum force occurs when the acceleration of the input motion is at its maximum. Consequently, with the parametric generator, the moving plate of the capacitor snaps from minimum separation to maximum separation when the input acceleration is greatest. The relative plate motion (Z(t)) is shown in figure 2.

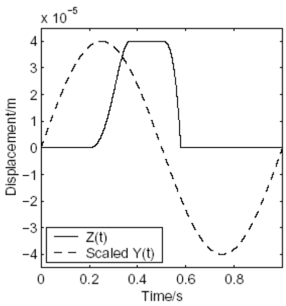

Figure 2: Optimal Parametric Motion

DISCUSSION OF RESULTS

Electro-mechanical generators have many independent variables associated with them. This means that assessing and fairly comparing the performance metrics of different generators is difficult. Analytic expressions for generator performance have been developed and verified with time domain simulation. As an example, the analytic expression for the optimal power generation by parametric generator is:

$$P = 2\beta \frac{\omega^3 m Y_0 Z_0}{\pi}$$

Where m is the proof mass, ω and Y_o are the input frequency and amplitude, β is the fraction of maximum acceleration at which generation starts and ω_c is the input frequency normalized to the resonant frequency. It has been found that when the force is optimized in order to maximize the energy dissipated in the damper, it is possible to plot the performance characteristics of all three generators on normalized axes. Figure 3 shows the optimal generator configuration for a set of normalized operating conditions. The types are, from lightest to darkest: Parametric Generator, Coulomb Damped Generator and Velocity Damped Generator. As can be seen, the parametric generator is optimal when the source of motion has an order of magnitude greater than the dimensions of the device. If a resonant device is used, there is little to differentiate the coulomb and velocity damped cases, and so a choice should be made depending on the efficiency of the implementation of each.

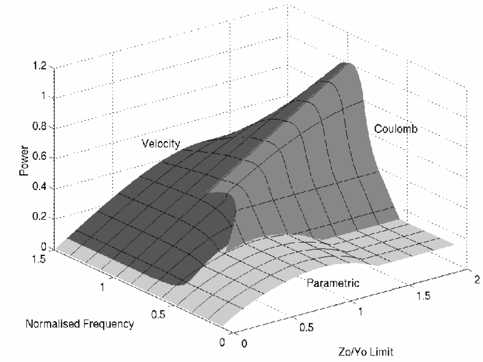

Figure 3: Optimal Generator Configuration

A parametric generator has been fabricated on a quartz wafer, to minimize parasitic capacitance, and is in the process of being tested. In order to realize a successful generator, the micro-power power-electronics and control and synchronization of the generator are important. There are trade-offs with the level of control used to ensure optimal power generation for a given input, and the power consumed by the control circuitry itself.

ACKNOWLEDGMENTS

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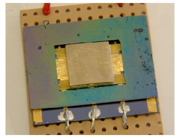
Poster layout

Analysis of Optimized Micro-Generator Architectures for Self-Powered Ubiquitous Computers

Introduction

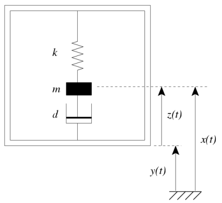
- Discussion of the Need for Self Powered Systems
- Methods of achieving self-powered artifacts
- Difficulty and importance of choosing an optimal architecture



Our Latest Fabricated Device

Results of device – Capacitance against distance

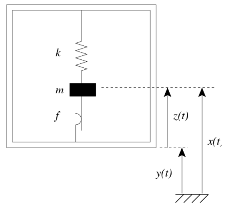
Velocity Damped Resonant Generator



Graphs of performance with likely constraints

- *Equations of motion*
- *Equations of Maximal Power under different constraints*

Coulomb Damped Resonant Generator



Graphs of performance with likely constraints

- *Equations of motion*
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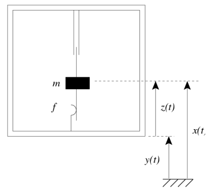
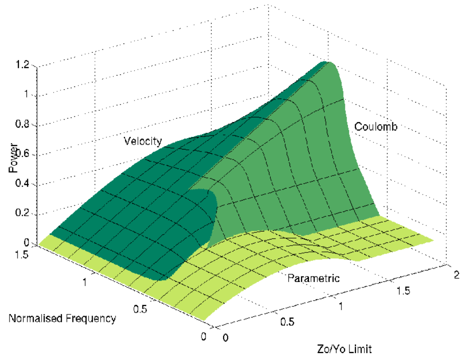
Parametric Generator



Graphs of performance with likely constraints

- *Equations of motion*
- *Equations of Maximal Power under different constraints*

Comparison of Architectures



Conclusions and likely Application Areas of Each Architecture

- Velocity
- Coulomb
- Parametric

Challenges of Micro-Power Implementation

- Charge Leakage
- Semiconductor losses
- High Voltage, Low Current

Graphs of initial simulation of power electronics

Sponsor and Project information