

PROJECT DESCRIPTION

Title: MEMS-Based Energy Harvesting for Low-Frequency Vibrations

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Project Goals:

Power generation for remote-controlled microsystems has faced limitations due to its energy source. Batteries are not the best option for applications where chemical reactions are involved, or access to the device is severely limited. Thus, energy scavenging from environmental sources can be an alternative. Energy harvesting has become important recently, because of the almost infinite lifetime and the non-dependency on fuels for clean-energy generation. By scavenging energy from sources such as light and vibration, power can be generated. Power generation through light sources can yield a high output, although it is not always a practical choice. In some cases, energy generation from vibration becomes feasible because of the abundant oscillations of the surrounding environment. This vibration frequency is typically below 10Hz. For example, human movements peak at around 1Hz. Thus, harvesting these low-frequency vibrations can generate energy for environmental, wearable, or implantable systems. The focus of this project is on generating energy efficiently from low-frequency vibration. In particular, MEMS-scale energy generators will be explored. A demonstration model will be built and optimized to illustrate how energy can be generated using low-frequency vibrations. Energy scavenging from body motion poses a challenge to traditional resonant frequency generators due to the large displacements and broad frequency spectrum inherently associated with human movement. The non-resonant rotational generator design presented here is found to be well suited for these types of motions.

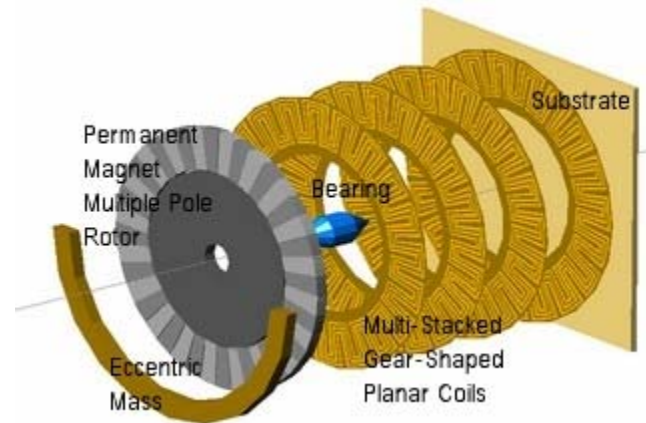


Figure 1: 3-D schematic of the oscillating rotational microgenerator with details of the planar coil and the multipole permanent magnet ring.

Approach and Methodology:

For a vibrating system, the available power is proportional to the square of the acceleration and inversely proportional to the oscillation frequency, meaning that higher accelerations and lower frequencies carry more power. Ambient vibration is typically associated with environments where the acceleration change and the oscillation amplitude tend to be quite high at low frequency, like those corresponding to human body movements. Thus, the use of ambient vibration as an energy source is attractive, because of its abundance. In nature, most of this vibration is found in the low-frequency range (1-10Hz). Vibration harvesting techniques based on electromagnetic, piezoelectric, and electrostatic transduction have been reported widely. Even though power has been generated, the operation of those devices is reported to be at frequencies of over several hundred Hz, as shown by devices operating at the kHz range. The goal of this project is to conduct research that will allow harvesting of energy from low-frequency vibration sources. The challenge centers on the need to harness the power of large oscillation amplitudes (over 1mm) at low frequencies on the MEMS-scale. Overcoming this obstacle could mean that environmental, wearable, or implantable biomedical applications will not be limited by battery lifetime. The first step for the project is the construction of a mathematical model to be used to simulate and optimize a proposed design. Later, a mesoscale prototype will be fabricated to validate the chosen design. The final step will be the design and realization of a practical MEMS prototype for energy scavenging. The basic design of the microgenerator consists of an eccentric weight connected to a multipole permanent magnet (PM) ring rotor, a radial planar coil bonded to the stator, and a rotating pivot arrangement. The gear-shaped radial planar coil is manufactured using a single-via pad to interconnect coil layers. A change on the magnetic flux density induces a voltage in the radial coil when the multipole PM ring rotates over it.

Role in Supporting the Strategic Plan and Testbeds:

Understanding the trade-offs of energy harvesting at low frequencies is important to both the Environmental Monitoring and to the Implantable Neural Prosthesis Testbeds. Power generation from environmental sources is a critical requirement for self-powered microsystems.

Results and Accomplishments:

A preliminary mesoscale prototype composed of discrete NdFeB permanent magnets inserted in a 25mm slotted PMMA disc with an eccentric mass on top was built to test the design concept. A prototype using jewel bearings (μ VPG-nr-1.3, with a two layer coil, 2cc volume) was found to produce up to $54.7\mu\text{W}$ placed on the ankle while walking, for a power density of $27.5\mu\text{W}/\text{cc}$. Further optimization is expected to increase the power output. A new gear-shaped planar coil (made of copper-coated polyimide film) was developed for reducing electrical wiring, and using a single-via pad for interconnecting stacked layers. A general model describing the maximum available power was also developed.

Relevance to Other Work:

Power-generation research on energy scavenging from vibration sources has been investigated widely. Some research has been conducted on low-frequency vibrations (1–10Hz); however, little research has been related to rotational generators at this frequency level. Thus, research in this area will help in the development of autonomous microsystems.

Plans for the Coming Year:

Working prototypes for energy harvesting at low frequencies are being fabricated at the mesoscale. MEMS prototypes are being studied.

Expected Milestones and Dates:

- Modeling of mesoscale prototype (Completed)
- Fabrication and testing of mesoscale prototype (10/31/2009)
- Design of MEMS prototype (04/30/2009)

Expected Contributions, Deliverables, and Company Benefits:

- Develop a low-frequency vibration prototype design
- Demonstrate the feasibility of energy scavenging at low vibration
- Demonstrate the feasibility of energy scavenging from body motion

References and Recent Publications:

1. E. Romero, R. O. Warrington, and M. R. Neuman, "Energy Scavenging Sources for Biomedical Sensors," *Physiol. Meas.* 30 (2009) R35-R62.
2. E. Romero, T. Galchev, E. Aktakka, N. Ghafouri, H. Kim, M. Neuman, K. Najafi, and R. Warrington, "Micro Energy Scavengers," *Electronic Proc. COMS 2008*, Puerto Vallarta, September 2008, "Best Paper Award".
3. E. Romero, M. R. Neuman, and R. O. Warrington, "Passive Energy Harvesting From Human Activities," *Proc. ES 2009*, pp. 1–8, San Francisco, CA, July 2009.
4. E. Romero, R. O. Warrington, and M. R. Neuman, "Body Motion for Powering Biomedical Devices," *Proc. EMBC 2009*, pp. 2752–2755, September 2009.