PROJECT DESCRIPTION

Title: *Energy Scavenging From Low Frequency Vibrations*

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Project Goals:

Self-powered remote microsystems and sensor networks are needed in many emerging applications such as environmental monitoring. The required power for these systems can be generated mainly in two ways: 1) by using electrochemical batteries and micro fuel cells and 2) by energy scavenging from environmental sources such as ambient heat, light, and vibration. Although electrochemical batteries and microfuel cells can provide more power, they are not desirable for some applications due to their limited lifetime, and size. A battery large enough to last the lifetime of the sensor would dominate the overall system size, and hence is not very attractive. As the sensor network increases in number and the device size decreases, the replacement of depleted batteries and fuel cells is not practical. Energy scavenging has become popular recently, because of the need for clean power generation process and long lifetime. By scavenging energy, power can be generated from various environmental sources such as ambient heat, light, acoustic noise, vibration, and ambient RF signals. The goal of this project is to develop an efficient energy scavenger for converting ambient low-frequency vibrations into electrical power. Low-frequency vibrations present a couple of significant challenges to energy scavenging: 1) as the frequency drops so does the expected power density, and 2) most of the vibrations in the applications enumerated above typically vary in frequency. Figure 1 shows the conceptual view of a vibration micro power generator.

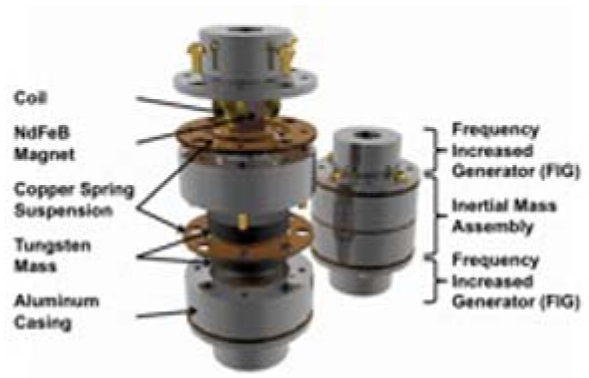

Figure 1: A vibration powered micro generator structure.

Approach and Methodology:

The goal of this project is to design an efficient energy scavenger for converting ambient low-frequency vibrations into electrical power. The importance of the low-end of the frequency spectrum cannot be overstated. Humans, animals, the environment, and bustling urban settings all give off waste kinetic energy, but these are slowly moving systems, providing peaks in the <50Hz frequency range. Further, these environments do not give off steady and periodic vibrations. Instead, their frequency response constantly changes, meaning that generators operating in this region require a high bandwidth. The contributions of this project will be in several areas. 1) The state-of-the-art in scavenging low-frequency, high-displacement vibrations will be improved. A generator architecture will be developed so that scavenging can be performed in these ambient environments. 2) As a means to develop a standalone power generator, effective strategies for power management electronics will be developed and implemented. 3) Low-frequency vibrations, by their nature, have high displacement amplitudes, which is a great impediment to miniaturization. This project will develop "dense" architectures suitable for miniaturization into the micro scale. In vibration scavengers, appropriate mechanical frequency up-converters can be used to up-convert the frequency of mechanical vibrations to higher frequencies where a better efficiency and more power can be extracted. A new design for this frequency conversion was developed and is currently being implemented in Figure 1 [5,6].

Figure 2: Photographs of the fabricated Parametri Frequency Increased Generator (PFIG).

Role in Supporting the Strategic Plan and Testbeds:

Power generation from the environment is a critical requirement for self-powered sensor modules. This project relates directly to the sensors to eventually be used in the environmental monitoring microsystems.

Results and Accomplishments:

Two generations of the Parametric Frequency Increased Generator (PFIG) generator have been developed. The PFIG is an inertial micropower scavenger prototype that converts a broad range of low-frequency (<40Hz), and large-deflection (>100μm) ambient vibrations into electrical output energy. The first generation prototype occupied a volume of 3.7cm^3 and had a peak power of 562μW and an average power of 66.79μW at an input acceleration of 1g applied at 10Hz, and it has a bandwidth of 21Hz. The first-generation prototype has the best harvester effectives (4.2%) reported in the literature to date for generators working in the frequency spectrum from 0-10Hz. A second-generation device is being developed and is shown in Figure 2. This device has a volume of 2.1cm^3. It generates a peak power of 288μW and an average power of 5.8μW from an input acceleration of 9.8m/s2 at 10Hz. The Gen2 PFIG device has a power density of 2.74μW/cm^3 beating out all other reported scavengers to date operating from similar conditions. It is currently being modified to increase the efficiency of the device.

Relevance to Other Work:

Power generation from vibration has been investigated by many groups around the world. This project is unique in that it is mainly focused on very low frequencies where most of the ambient vibration exists. The available ambient kinetic energy for many applications ideal for vibration scavenging devices lies in the low end of the frequency spectrum (<100Hz). These include wearable and implantable devices, environmental monitoring, agricultural applications, and many others.

Plans for the Coming Year:

Complete all milestones for the project

Expected Milestones and Dates:

- Finish design, fabrication, and test of second-generation device *(Completed)*
- Design and fabricate third-generation (11/01/2009)
- Test complete micropower generator (12/01/2009)

Expected Contributions, Deliverables, and Company Benefits:

- Develop an efficient energy scavenger for converting ambient, low-frequency vibrations into electrical power
- Develop a vibration-based electromagnetic micropower generator
- Develop low-power interface electronics for power transfer

References and Recent Publications:

1. H. Kulah and K. Najafi, “An Electromagnetic Micro Power Generator for Low-Frequency Environmental Vibrations,” *Proceedings of the 17th IEEE International Conference on Microelectromechanical Systems (MEMS ’04*, pp. 237–240, Maastricht, Netherlands, January 2004.
2. H. Kulah and K. Najafi, “An Electromagnetic Micro Power Generator for Low-Frequency Environmental Vibrations,” Paper #05MV-35, *2005 SAE World Congress,* Cobo Center, Detroit, Michigan, April 2005.
3. T. V. Galchev, W. C. Welch III, and K. Najafi, “Low-Temperature MEMS Process Using Plasma-Activated Silicon-On-Silicon (SOS) Bonding,” *IEEE MEMS,* Kobe, Japan, pp. 309–312, January 2007.
4. T. V. Galchev, W. C. Welch III, and K. Najafi, “Silicon-On-Silicon (SOS): A New CMOS Compatible Low-Temperature MEMS Process Using Plasma-Activated Fusion Bonding,” *Solid State Sensor, Actuator and Microsystems Workshop (Hilton Head),* Hilton Head, SC, pp. 100–102, June 2006.
5. T.V. Galchev, H. Kim, and K. Najafi, “Non-Resonant Bi-Stable Frequency-Increased Power Generator for Low-Frequency Ambient Vibration,” *15th International Conference on Solid-State Sensors, Actuators, and Microsystems (IEEE TRANSDUCERS),* Denver, Colorado, June 2009.
6. T. Galchev, H. Kim, and K. Najafi, ”A Parametric Frequency Increased Power Generator for Scavenging Low-Frequency Ambient Vibrations,” *Eurosensors XXIII,* Lausanne, CH, September 2009.