Micro Power Generators

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Overview

- Why Micro Power Generators are becoming important
- Types of Micro Power Generators
- Power Generators Reviewed
  - Ambient Vibrational energy
  - Radiant heat energy
  - Combustion-based heat energy
- Proposed Dual-Source Hybrid Generator
- Analysis of Hybrid Generator
- IR Transmitter Application
- Conclusion
Introduction

- Microelectronics devices are becoming increasingly popular due to advances in technology.
- More complex circuits demand small & efficient powering schemes.
- Batteries are heavy, their lifetime is limited and recharging may be difficult.
- Portable devices can be recharged, but sensor nodes cannot.
- MEMS technology allows the realization of complex structures that can harness environmental energy.
- Reusable self-powered devices are ideal and many schemes have been proposed.
Power generator system integration

Diagram showing the integration of power generator system components:
- Antenna
- RF Module
- Capacitor battery
- ASIC
- Power controller
- Micro power generator
- Sensors

Flow of information from environmental Energy to Monolithic IC, then to the other components and back.
Power Generator Types

- Solar – using light as the energy source
  - Photodiodes
  - Charge couple devices (CCD)

- Kinetic – using motion as the energy source
  - Rotational motion
  - Vibrational motion

- Thermoelectric based - using heat as the energy source
  - Black-body Radiation
  - Catalytic Combustion
MEMS-Based Vibration-to-Electric Power Generator

- MEMS structures convert vibrational movement into electrical energy
- A pair of varying capacitors in the presence of a static charge will generate charge transfer
- By changing the capacitance $C_2$ to $C_2 + \Delta C$, but keeping the charge $Q$ constant, the charge $Q_1$ increases by the same amount $\Delta Q$ as the charge $Q_2$ decreases
- The charge transport gives rise to a current, which supplies energy to an external circuit (resistor)

$$Q_1 = \frac{C_1}{C_1 + C_2} Q \quad Q_2 = \frac{C_2}{C_1 + C_2} Q$$

$$\Delta Q = \frac{C_1 \Delta C}{(C_1 + C_2 + \Delta C)(C_1 + C_2)}$$
MEMS-Based Vibration to Electric Generator

- Composed of a combed in-plane variable capacitor and a seismic mass with a moveable electrode

- As the device vibrates, the seismic mass moves in the horizontal plane, varying the capacitances relative to the fixed electrode
Discussion: MEMS-Based Vibration to Electric Generator

- Advantages
  - Theoretically infinite power supply
  - Easily fabricated using MEMS technology

- Disadvantages
  - The dimensions and characteristics of the components need to be optimized in order to produce any usable power
  - The fabrication process used here is difficult to optimize since it is difficult to realize a low resonance frequency
Laser-Micromachined Vibration Induced Power Generator

- A permanent magnet suspended by a spring produces current flow through an underlying wire coil through inductive effects.
- As the housing is vibrated, the magnet will move up and down, passing a magnetic flux through the center of the coil, generating current flow.
Discussion: Laser-Micromachined Vibration Induced Power Generator

- a DC output voltage of 2.3V at 40uA for 100uW power was realized
  - enough power to operate a small infrared transmitter circuit

Advantages
- Precise control of the mechanical resonance due to precise fabrication of spring geometry
- Batch fabrication, allowing low-cost mass production

Disadvantages
- Laser micromachined from copper, not on silicon
  - Not part of a MEMS fabrication process
- Not integrated with control circuits on a single substrate
  - Additional wiring to circuits
  - Increased parasitics
Thermoelectric Micro Power Generator

- Converts ambient heat energy into electrical power using a thermopile composed of thermocouples.
- A thermocouple has a hot contact and cold contact. When the hot contact is heated, an electric current between its two terminals is generated by the Seebeck effect.
- Heat absorber is used to concentrate heat at hot junctions. Silicon substrate serve as the cold junction.
Thermocouple dimensions and materials

- Thermocouple composed of two materials: Au/Cr and n-type polysilicon
- Gain determined by Seebeck coefficient of material $\alpha$ (V/K)
- Voltage output given by

$$V_{out} = \left( \alpha_{Au} - \alpha_{n-poly-Si} \right) (T_1 - T_0)$$
Discussion: Thermoelectric Micro Power Generator

- Advantages
  - Simple, has no moving parts
  - Vertical thermocouples allow greater isolation between its contacts

- Disadvantages
  - Thermocouple under a 307K black body source generates around 110uV at a 2mm distance and around 50 uV at a 7mm distance from its source
  - Not enough power for a circuit unless used in great numbers
A Combustion-based MEMS Thermoelectric Power Generator

- Converts heat generated by catalytic combustion into electrical energy
- Composed of a silicon substrate with an etched channel and a catalyst and a thermopile
- The air-mixture diffuses onto the membrane where they react with the catalyst, generating heat. The heated thermopile generates electricity.

*Figure 1: (a) Micrograph of Device (b) Diagram of Device*
Discussion: A Combustion-based MEMS Thermoelectric Power Generator

- **Advantages**
  - Combustion of air and fuel produces much higher power density than batteries
  - Thermoelectric generators are simple, have no moving parts and are ideal for miniaturization

- **Disadvantages**
  - Low efficiency – more suitable for portable applications where fuel recharging is possible
  - Waste heat and gases removal needed
Hybrid: Combustion and Radiant-based Power Generator

- Hybrid device uses combustion-generated heat as well as black body radiant heat to generate electricity
- Dual power sourcing
- Allows the integration of control circuitry
- Various configuration options
- Can be used as a temperature sensor as well as a power generator
Hybrid: Fabrication Process

(a) Si substrate

(b) Si substrate

(c) Si substrate

(d) Si substrate

(e) Si substrate

(f) Si substrate

(g) Si substrate

(h) KOH Etched Channel

(i) Catalyst

(j) Shadowmask

(k) Heat Absorber
Low power IR transmitter

- Simple IR transmitter operation can periodically send a pulsed beacon to a base station.
- Supply power to the circuitry using the hybrid generator as the supply.
- Charge an appropriately sized capacitor to power the IC.

### Specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Operating frequency</td>
<td>38.4kHz</td>
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<tr>
<td>Encoder IC Power requirement</td>
<td>3 to 5VDC</td>
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<tr>
<td>Operating Current</td>
<td>&lt;1μA @ 3V or 5V DC</td>
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<tr>
<td>Key-Press (hold)</td>
<td>1.7mA @ 5VDC, 2.83mA @ 3VDC</td>
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<tr>
<td>Signal Range</td>
<td>up to 100’</td>
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Summary and Conclusions

- Discussed various power generation techniques taking advantage of MEMS and microfabrication.
- Introduced a MEMS hybrid device using combustion and radiant heat energy.
- Discussed the power requirements of an IR transmitter application.
- MEMS allows the power generator to share the same substrate as its circuits, less parasitics.
- In sensor networks power generation must be self-sustaining.
- Combustion-based micropower generation is ideal for portable applications rather than sensor networks.