Micro Power Generators

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ECS 203

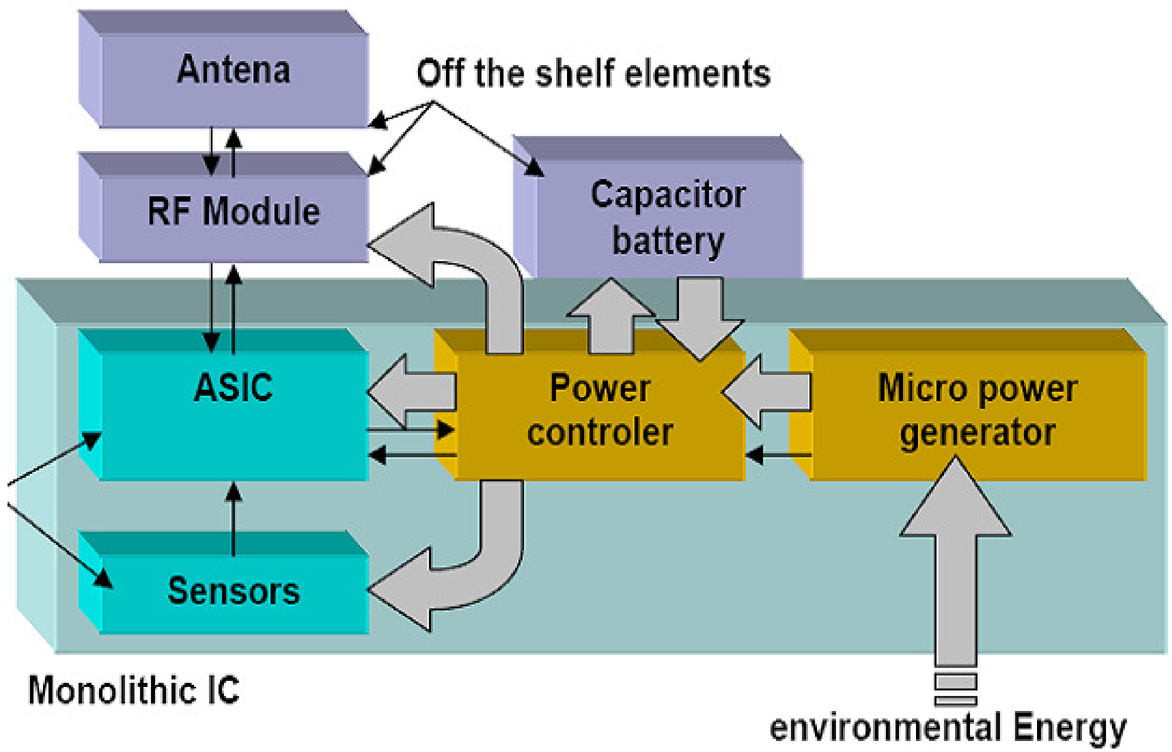
Overview

- 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



μ Power Generator Types

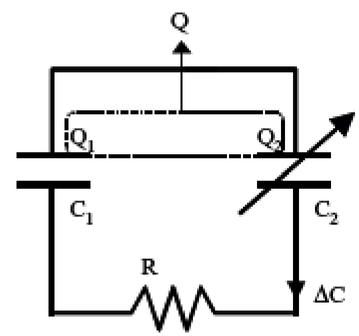
- Solar – using light as the energy source
  - Photodiodes
  - Charge couple devices (CCD)
- Kinetic – using motion as the energy source
  - Rotational motion
  - Vibrational motion
- Thermoelectric based - using heat as the energy source
  - Black-body Radiation
  - Catalytic Combustion

MEMS-Based Vibration-to-Electric Power Generator

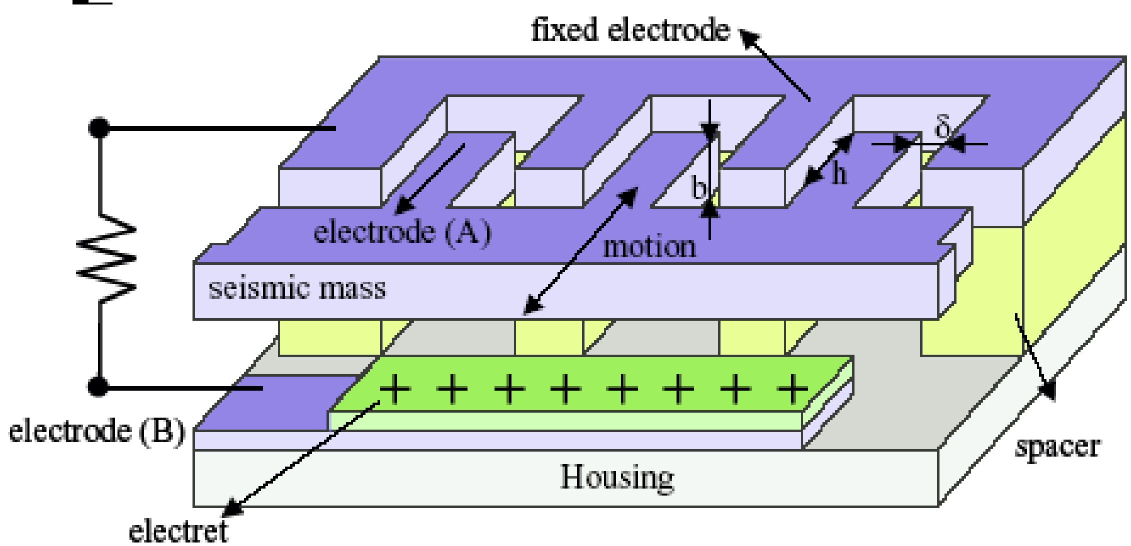
- MEMS structures convert vibrational movement into electrical energy
- A pair of varying capacitors in the presence of a static charge will generate charge transfer
- By changing the capacitance C2 to C2+ΔC, but keeping the charge Q constant, the charge Q1 increases by the same amount ΔQ as the charge Q2 decreases
- The charge transport gives rise to a current, which supplies energy to an external circuit (resistor)

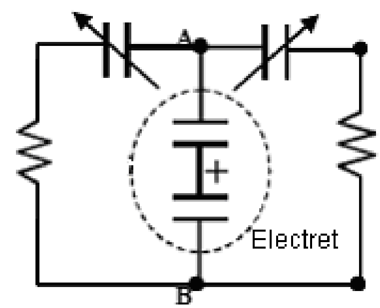
$$Q_1 = \frac{C_1}{C_1 + C_2} Q \qquad Q_2 = \frac{C_2}{C_1 + C_2} Q$$

$$\Delta Q = \frac{C_1 \Delta C}{(C_1 + C_2 + \Delta C)(C_1 + C_2)}$$



MEMS-Based Vibration to Electric Generator





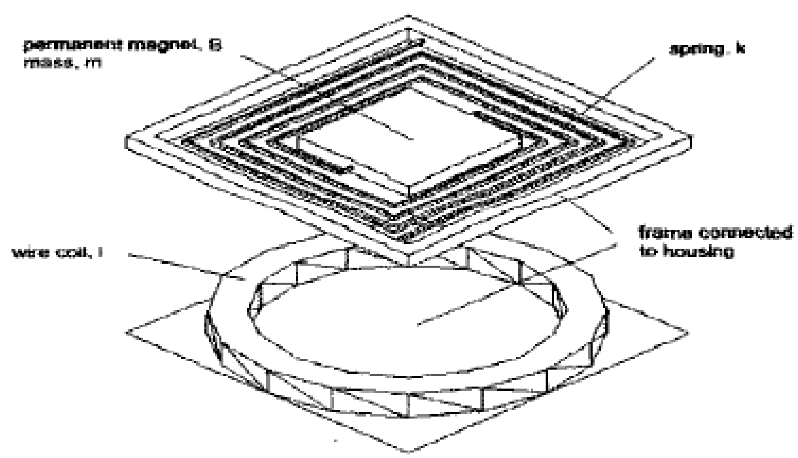
- Composed of a combed in-plane variable capacitor and a seismic mass with a moveable electrode
- As the device vibrates, the seismic mass moves in the horizontal plane, varying the capacitances relative to the fixed electrode

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 useable 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

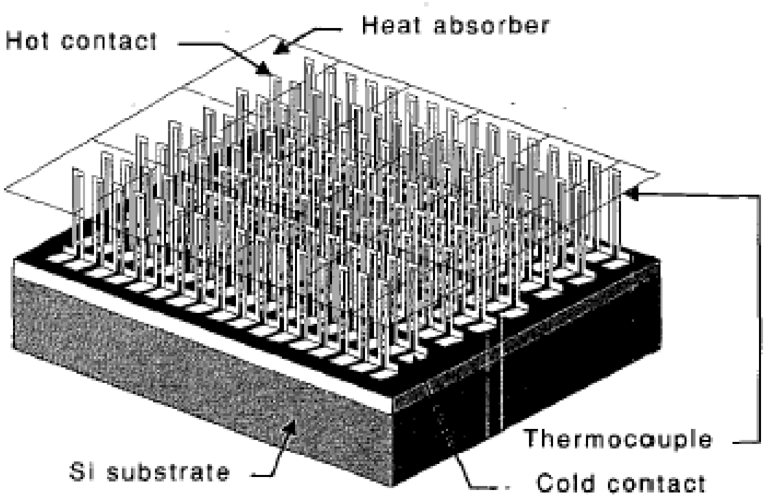
- A permanent magnet suspended by a spring produces current flow through an underlying wire coil through inductive effects
- As the housing is vibrated, the magnet will move up and down, passing a magnetic flux through the center of the coil, generating current flow

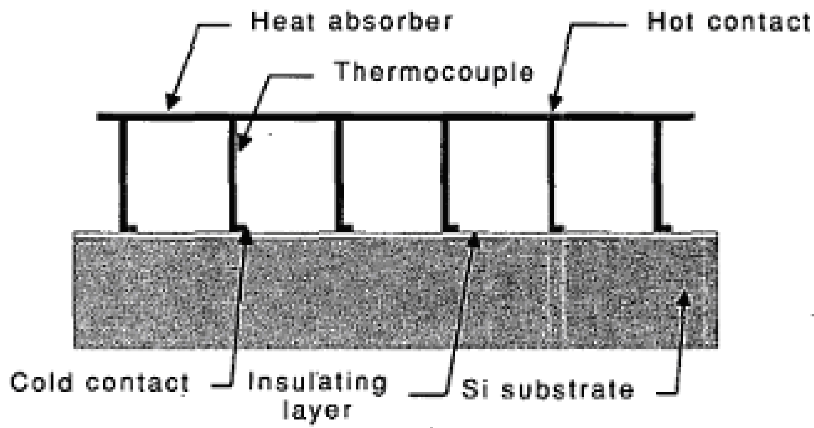


Discussion: Laser-Micromachined Vibration Induced Power Generator

- 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

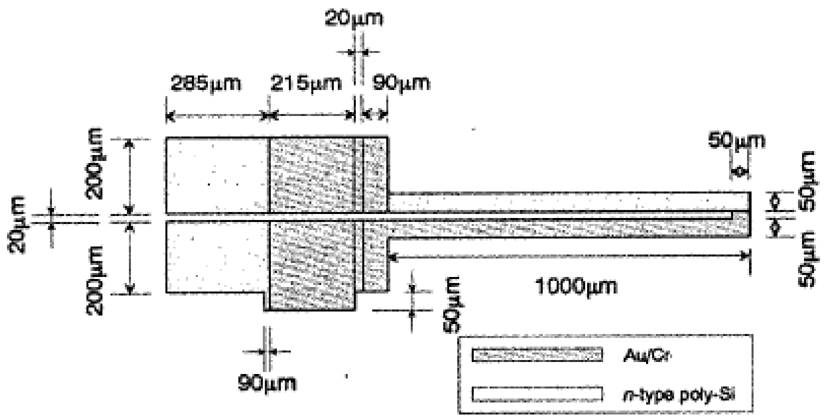
Thermoelectric Micro Power Generator

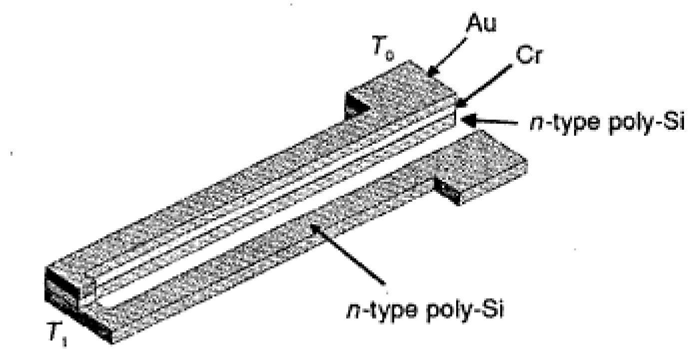




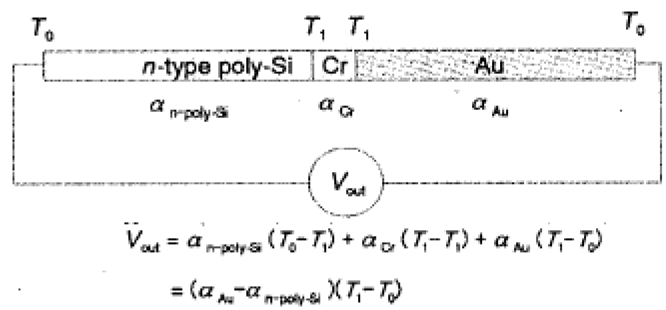
- Converts ambient heat energy into electrical power using a thermopile composed of thermocouples
- A thermocouple has a hot contact and cold contact. When the hot contact is heated, an electric current between its two terminals is generated by the Seebeck effect
- Heat absorber is used to concentrate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

Thermocouple dimensions and materials





(a) Structure



(b) Eauivalent circuit

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

$$Vout = (\alpha_{Au} - \alpha_{n-poly-Si})(T_1 - T_0)$$

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

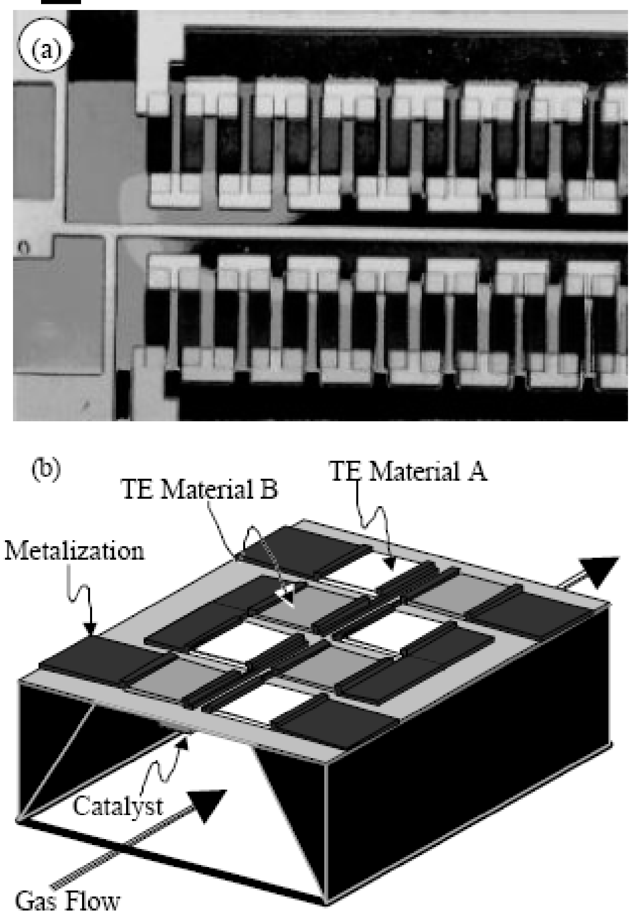


Figure 1: (a) Micrograph of Device
(b) Diagram of Device

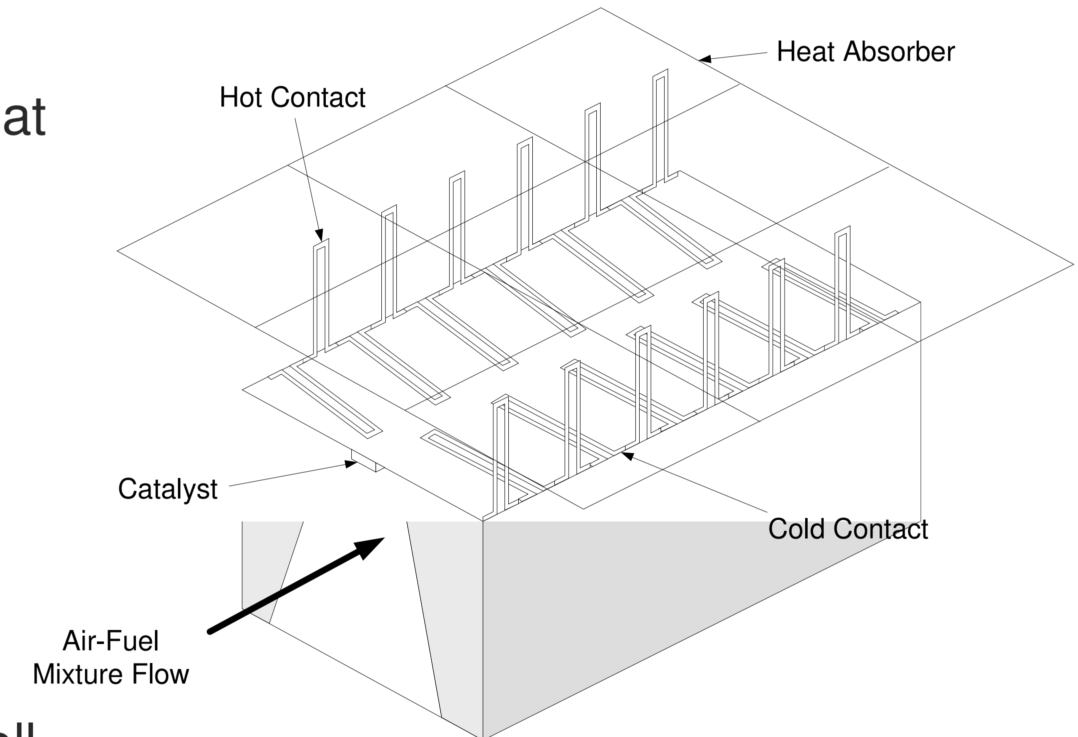
- Converts heat generated by catalytic combustion into electrical energy
- Composed of a silicon substrate with an etched channel and a catalyst and a thermopile
- The air-mixture diffuses onto the membrane where they react with the catalyst, generating heat. The heated thermopile generates electricity.

Discussion: A Combustion-based MEMS Thermoelectric Power Generator

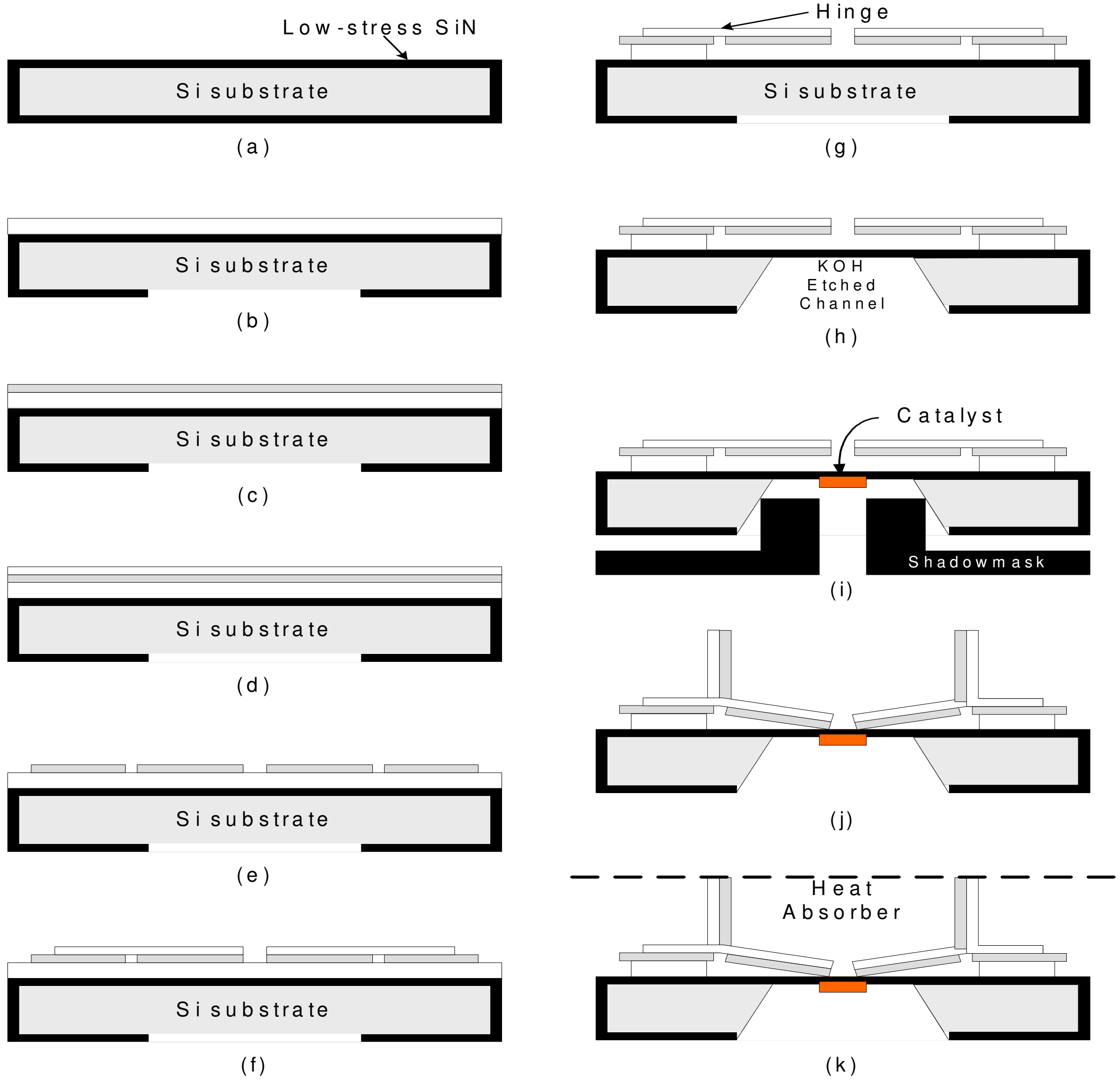
- Advantages
  - Combustion of air and fuel produces much higher power density than batteries
  - Thermoelectric generators are simple, have no moving parts and are ideal for miniaturization
- Disadvantages
  - Low efficiency – more suitable for portable applications where fuel recharging is possible
  - 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 generator 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

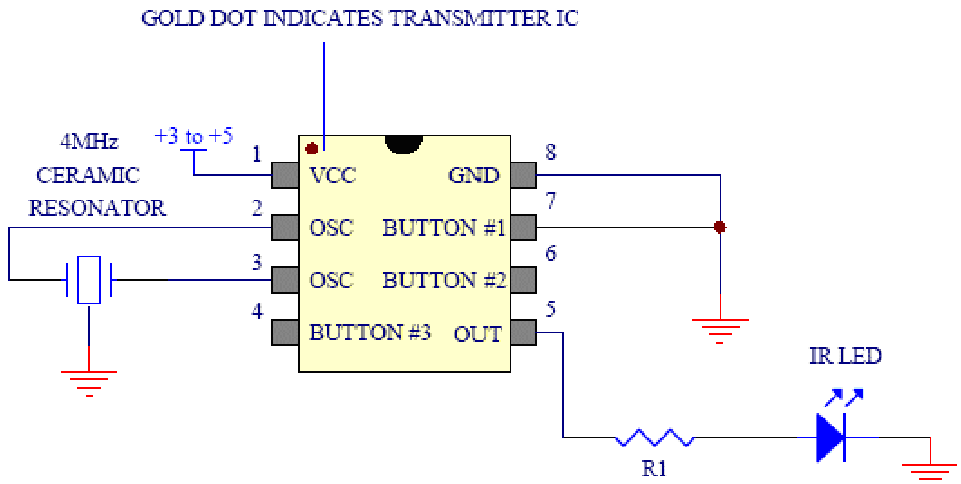


Hybrid: Fabrication Process



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	Value
Operating frequency	38.4kHz
Encoder IC Power requirement	3 to 5VDC
Operating Current	<1uA @ 3V or 5V DC
Key-Press (hold)	1.7mA @ 5VDC, 2.83mA @ 3VDC
Signal Range	up to 100’

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