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Approaches to Self-Powered Biochemical Sensors for In-Vivo Applications

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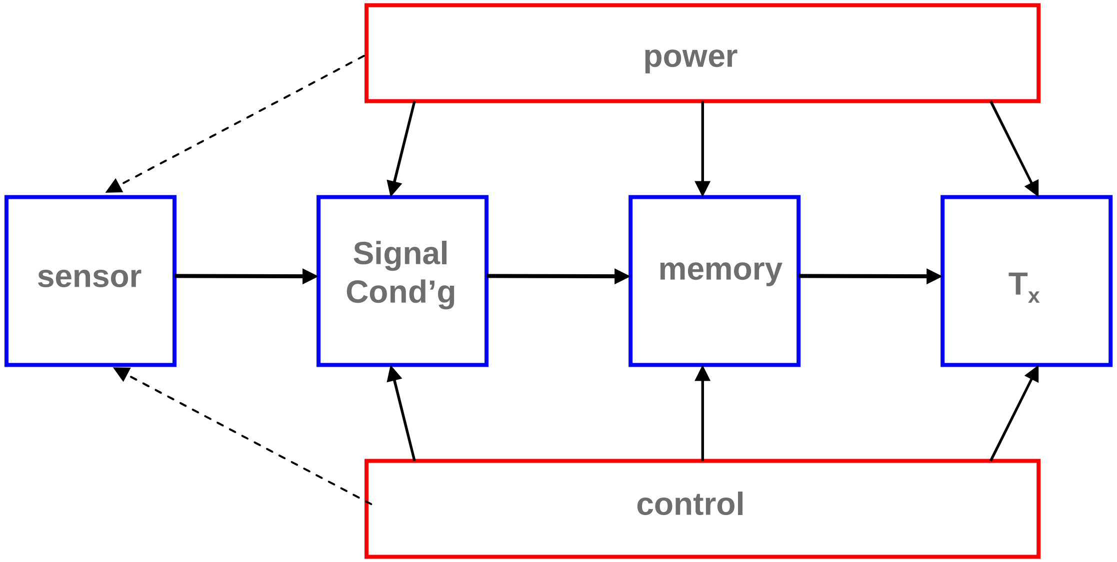
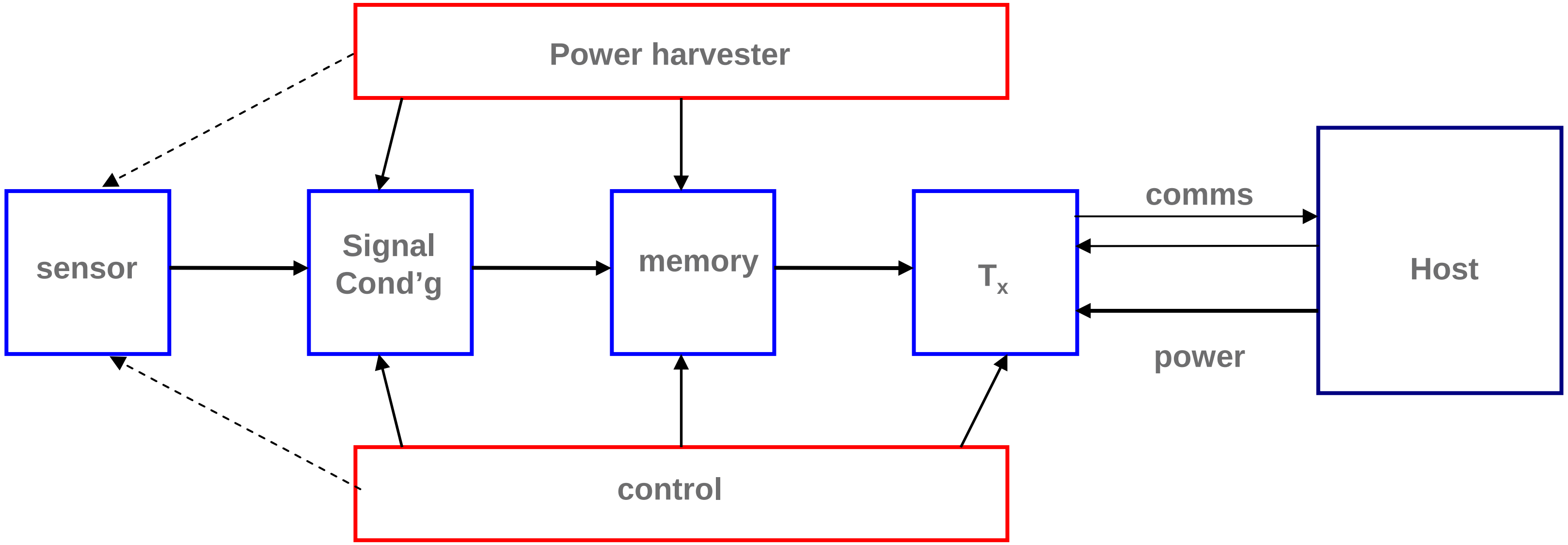
Concept

- Small, no-maintenance sensor module suitable for implantation
- Avoid battery recharging through use of energy harvesting
- Identify power needs, match to harvesting potential



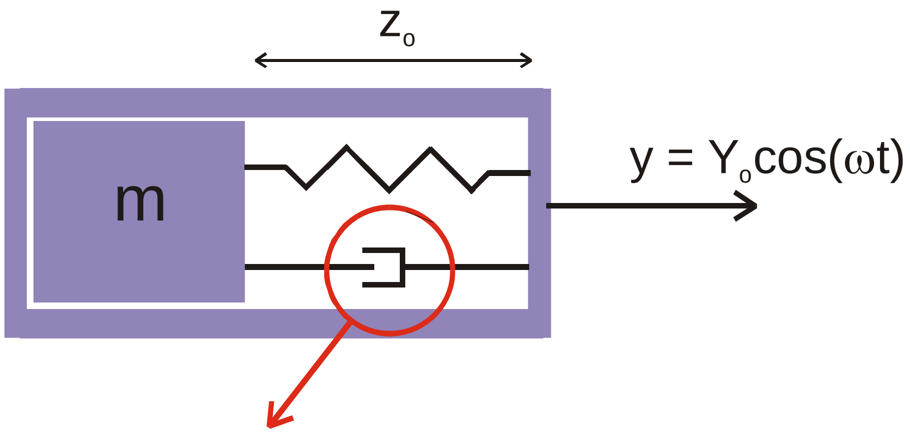
Possible Approach

- Continuous measurement and data storage, powered by harvester
- Data transmission to host using power from host
- Unpowered sensors (passive potentiometric)
- Low power A-D and memory



Inertial Energy Scavengers

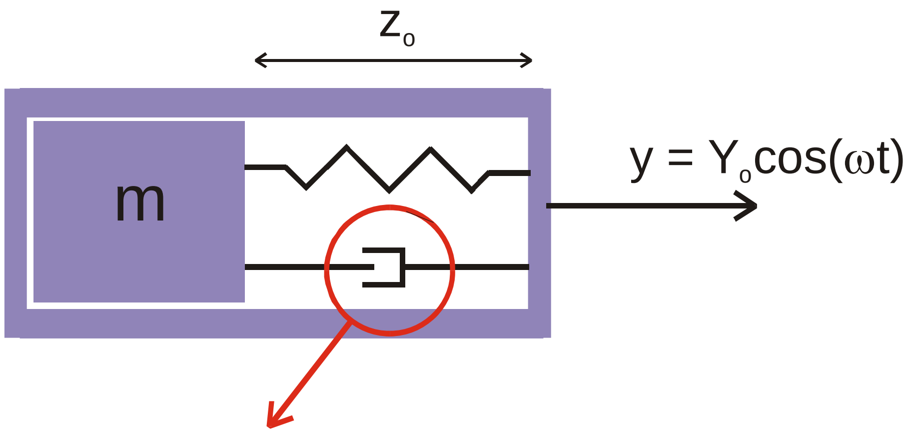
- Proof mass attached to frame by suspension
- Frame attached to moving “host”
- Motion of host causes internal motion of proof mass
- Transducer damps internal motion, generates power



damper implements energy conversion

Achievable Power

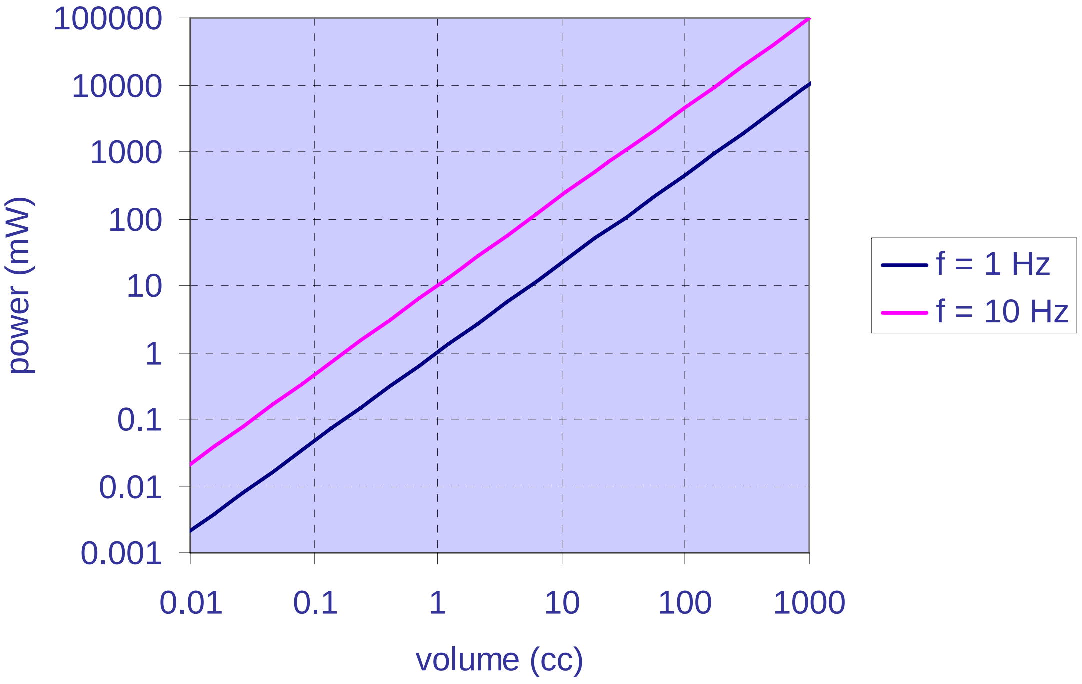
- Peak inertial force on proof mass $F = ma = m\omega^2 Y_o$
- Damper force < F or no movement
- Maximum work per transit $W = Fz_o = m\omega^2 Y_o z_o$
- Maximum power $P = 2W/T \quad = m\omega^3 Y_o z_o/\pi$



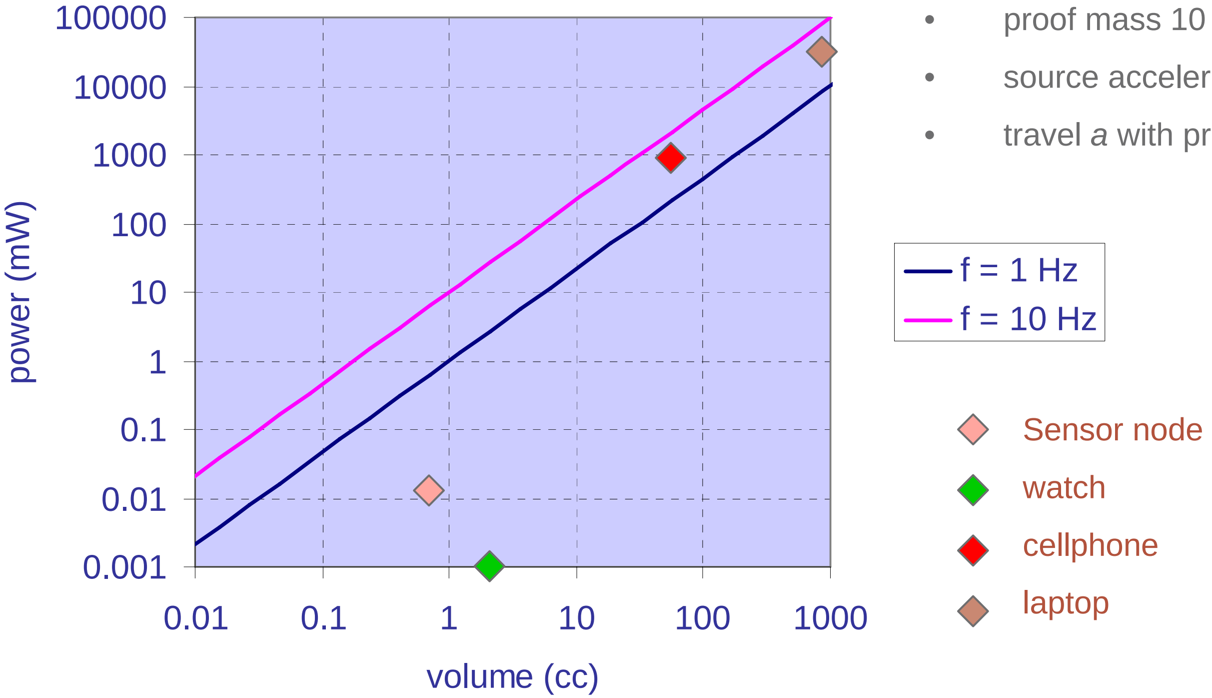
damper implements energy conversion

Power Density

- Maximum power $P = m\omega^3 Y_o z_o/\pi$: proportional to Volume and to z_o
- Therefore P_{max} proportional to $V^{4/3}$
- Scales badly into MEMS domain



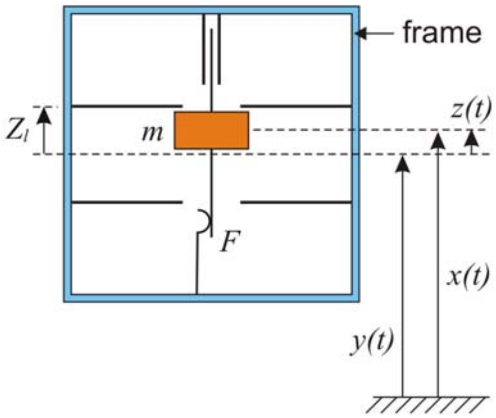
Achievable Power Relative to Applications

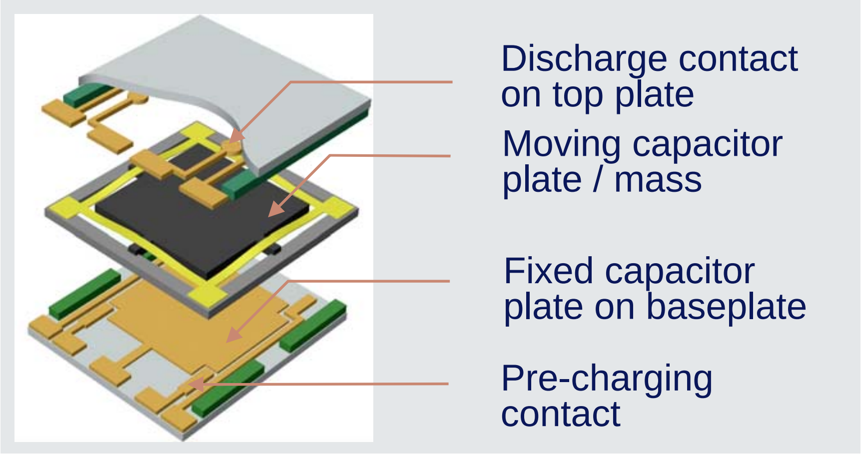


Plot assumes:

- proof mass 10 g/cc
- source acceleration 1g
- travel *a* with proof mass vol. a x a x a

Non-resonant Electrostatic device




Discharge contact on top plate

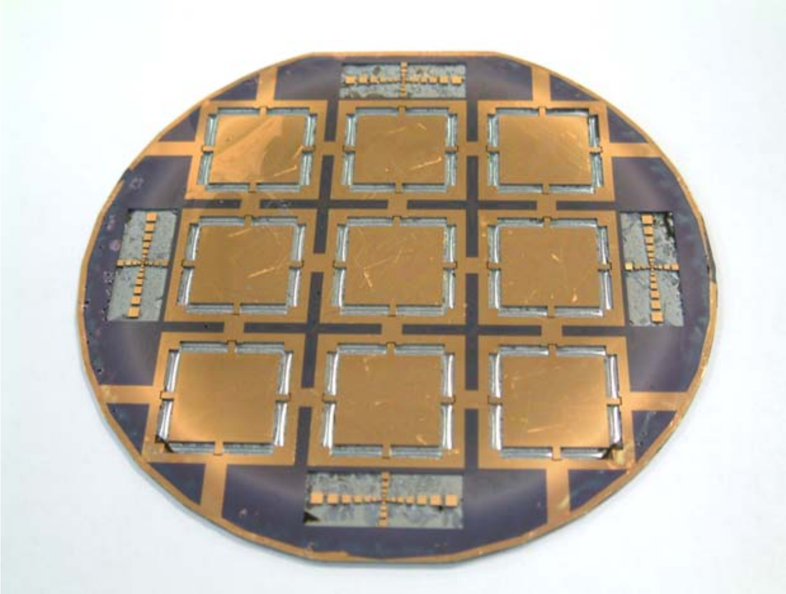
Moving capacitor plate / mass

Fixed capacitor plate on baseplate

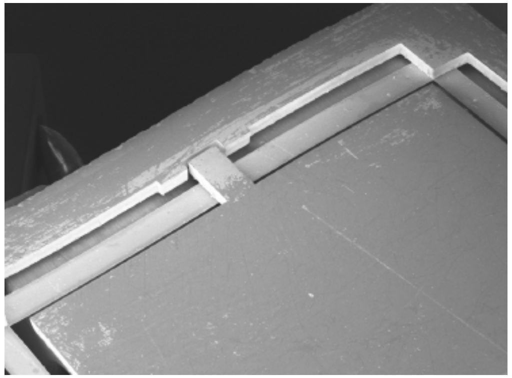
Pre-charging contact

- Capacitor pre-charged when mass is at bottom (max capacitance)
- Under sufficiently large frame acceleration, capacitor plates separate *at* ***constant charge***, and work is done against electrostatic force ⇒ stored electrostatic energy and plate voltage increase
- Charge is transferred (at higher voltage) to external circuit when moving plate reaches position of max displacement

Prototype MEMS Device

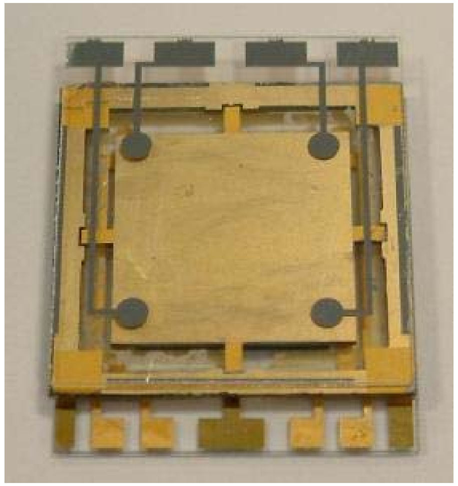


Generator dies on 4” dia. wafer



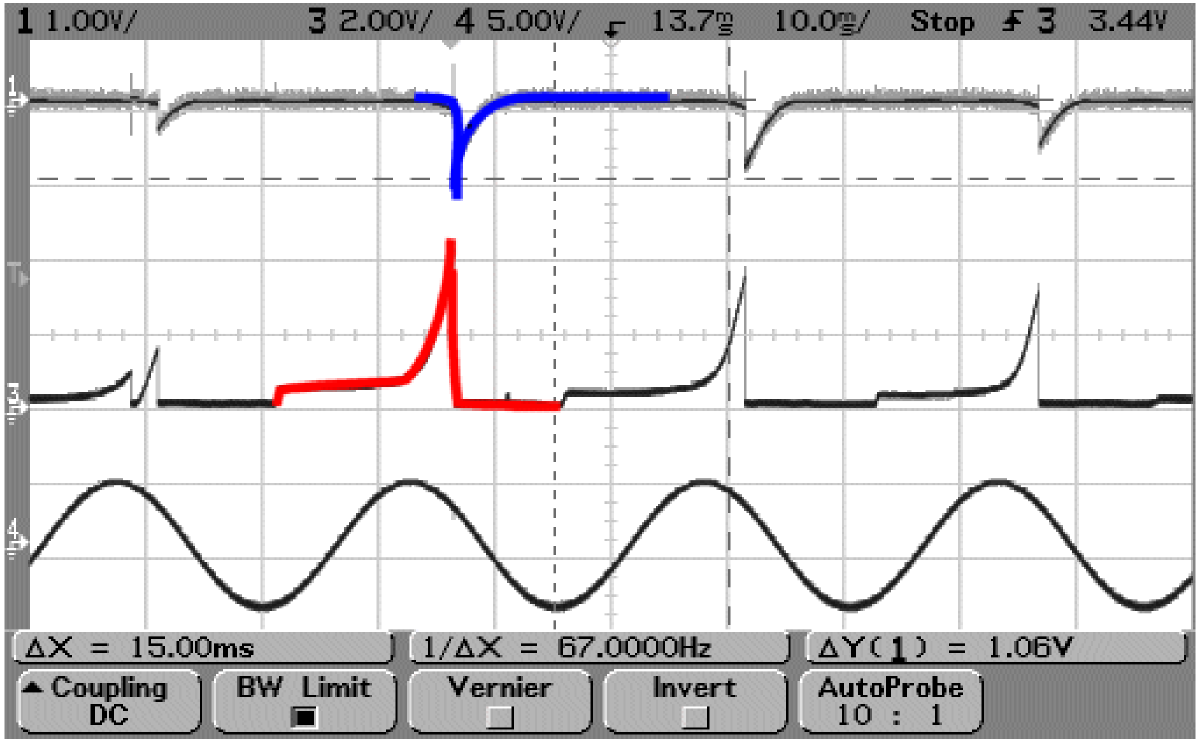
Detail showing deep-etched moving plate, and polyimide suspension

- Silicon mass formed by DRIE
- Polyimide suspension
- Glass top & bottom plates with electroplated gold electrodes



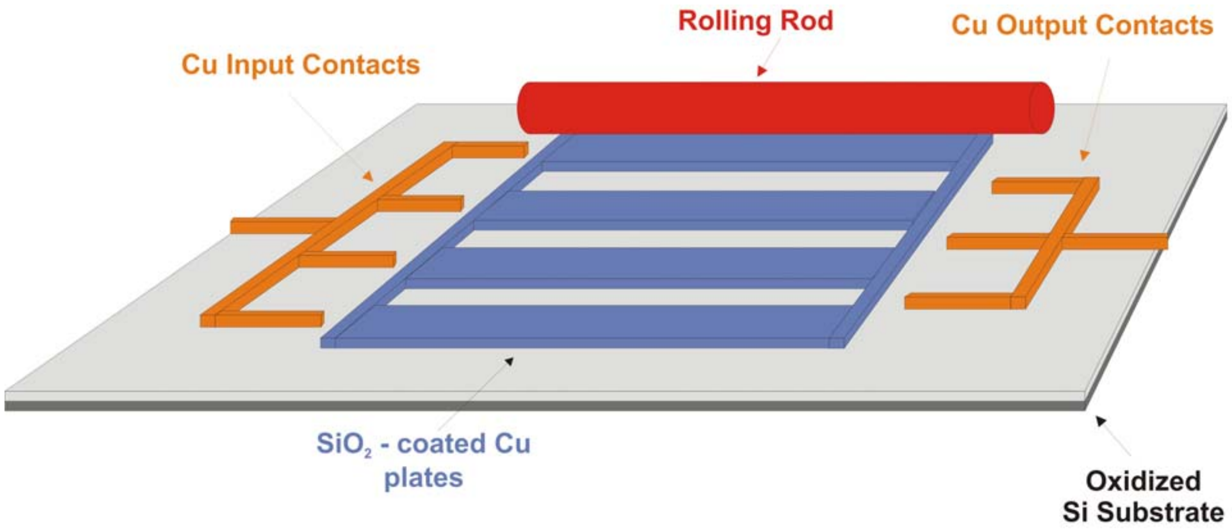
Assembled generator

Measured Performance



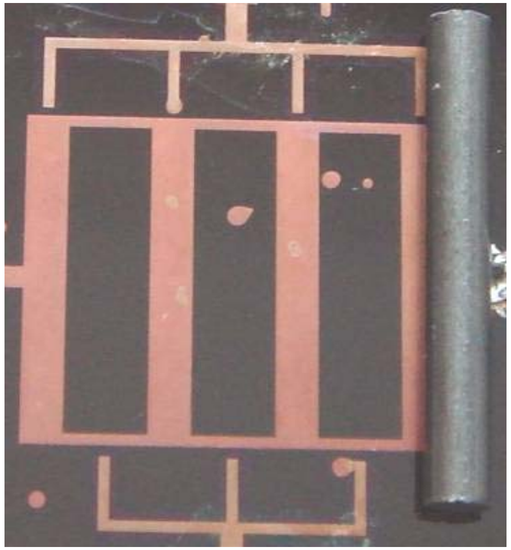
- Voltage probe has input impedance >10^{12} Ω and dynamically measures voltage on capacitor
- Net power in this experiment: 2.2 μW

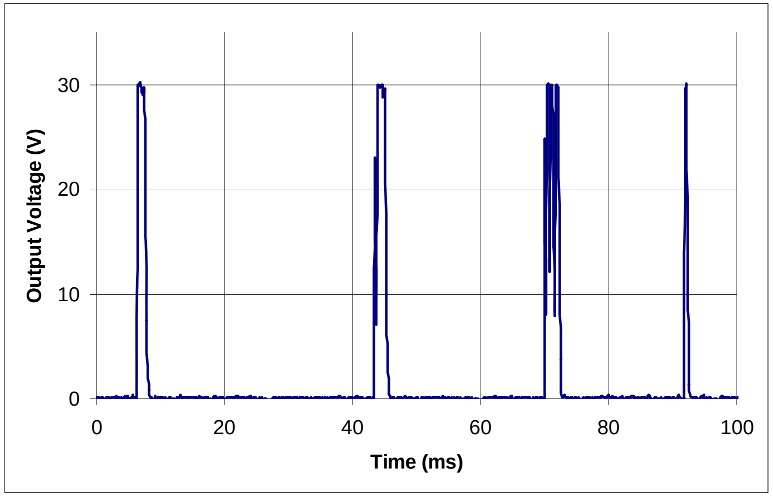
Alternative Structure



- Rolling proof mass external to device
- Multiple output pulses per transit
- Increase mass and travel range

Initial Prototype

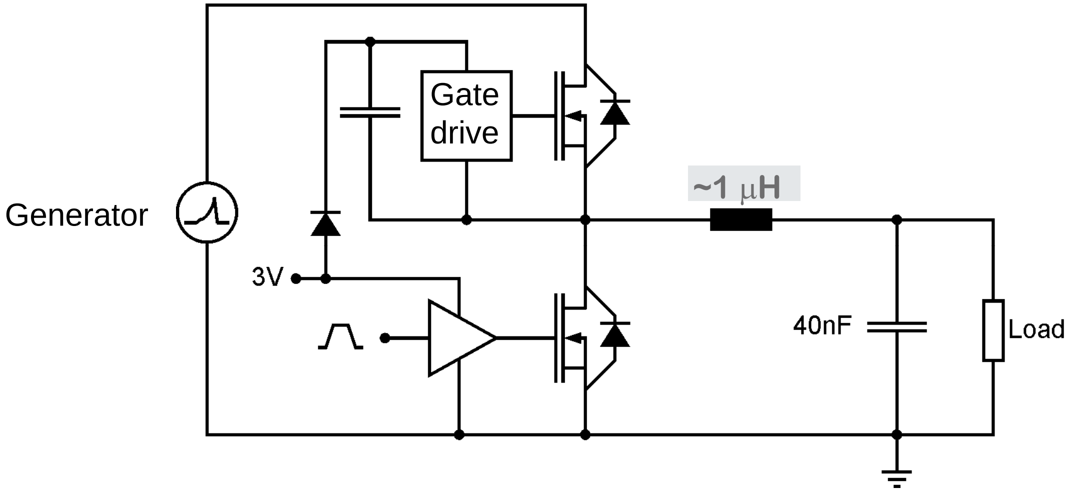




- 1 cm x 1 cm, 1 mm rod
- Power gain demonstrated
- Parasitic capacitances a significant challenge

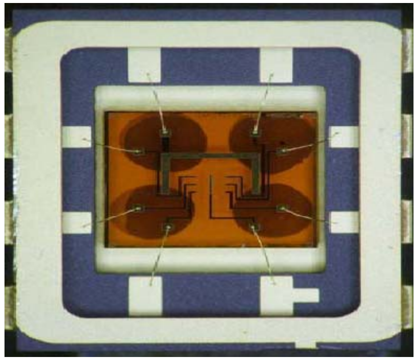
Power Processing for ES Generators

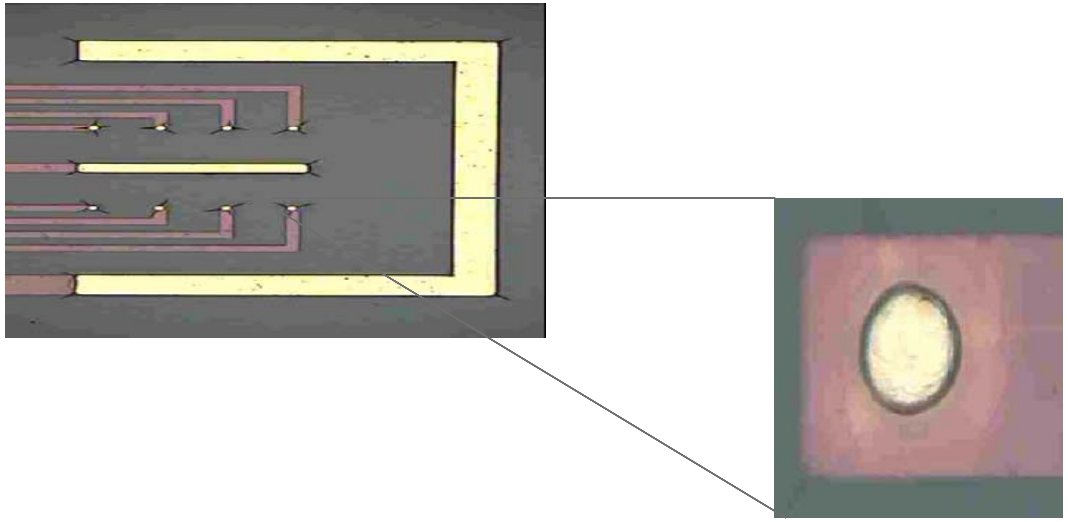
- Problem: convert generator output - small charge (nC level) at high voltage (100s of Volts) - to stable DC at e.g. 3.3 V
- Needs a conversion circuit with:
    - High stand-off voltage
    - Very low off-state leakage current
    - Very low off-state capacitance (“charge-sharing” problem)
    - Low on-state resistance
- Selected topology based on classic buck converter:



Potentiometric Sensors

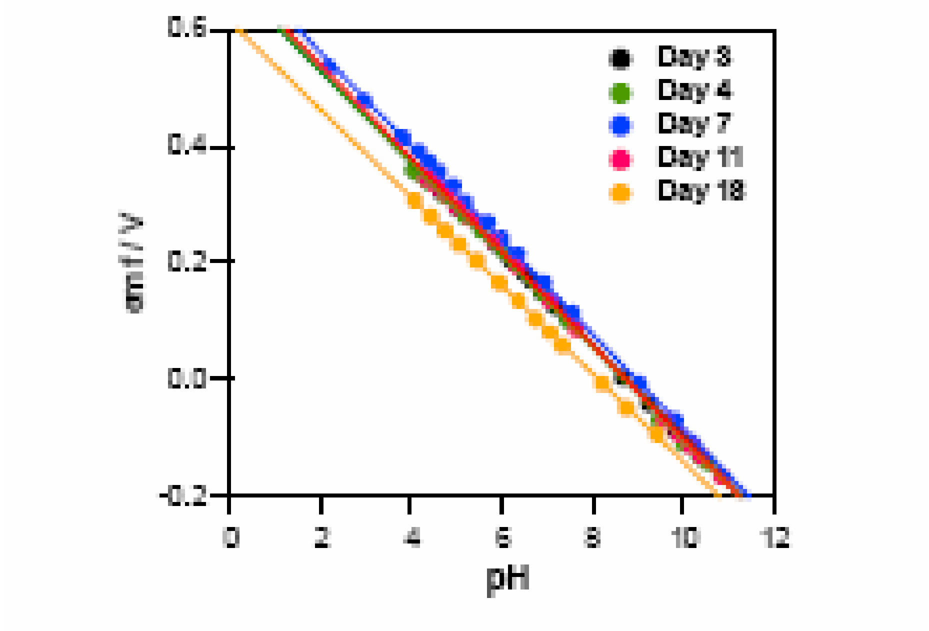
- Passive potentiometric sensor for pH monitoring
- pH indicator of tissue metabolism
- Metal-metal oxide thin film construction
- Highly miniature, arrays possible





Potentiometric Sensors

- Direct voltage output, high output impedance
- Convenient voltage range

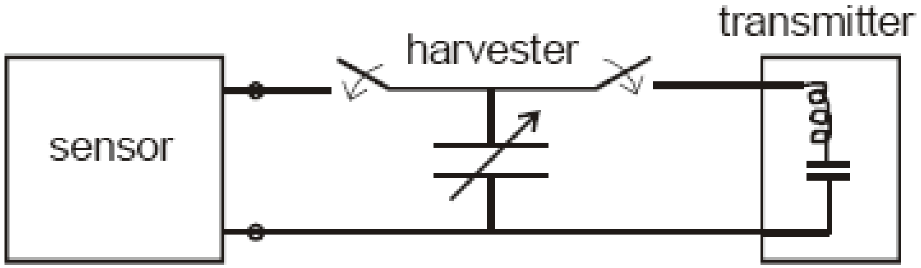


Signal Conditioning and Storage

- Analog-Digital conversion possible at very low power
- E.g. below 1 μW reported for 8-bit, 4 kS/s A-D
- Memory more power hungry, e.g. mW write power for flash memory
- However, average power ≈ 1 μW possible with very low duty cycle (low average data rate)

Alternative Architecture

- Direct wireless output of analogue sensor signal
- Motion energy harvester as energy amplifier
- Generates output pulses proportional to output voltage
- Dump pulses into resonant tank-circuit of short distance transmitter



Conclusions

- Potentiometric thin film sensors suitable for low-power, miniaturised sensing of physiological parameters
- Microwatt power levels available from mm-scale motion energy harvesting on or in body
- Microwatts sufficient for basic signal conditioning and storage
- Low duty cycles crucial
- Wireless data transfer either using power from host or direct harvester output