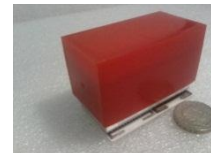
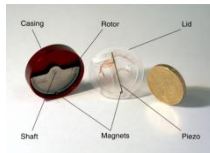


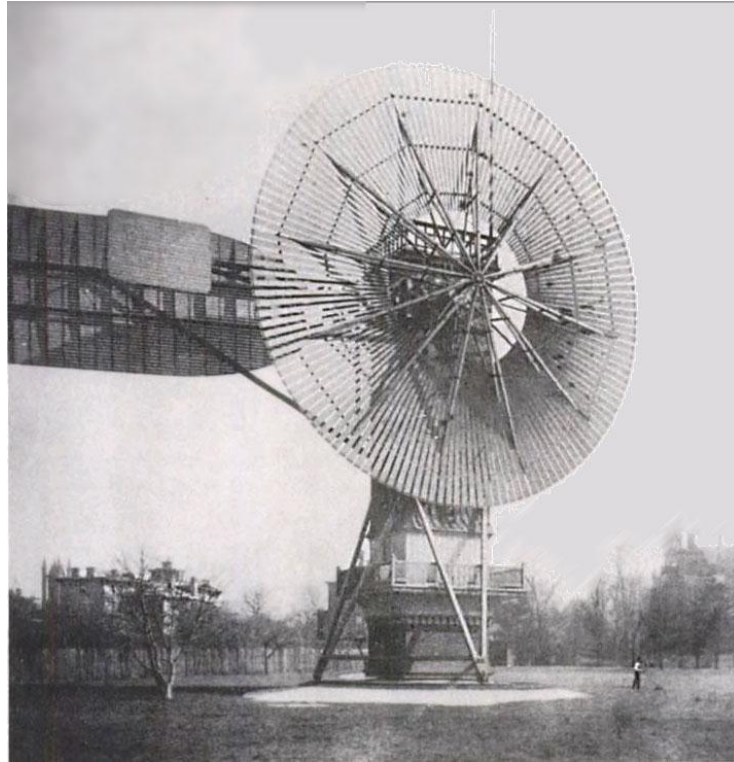
ENERGY HARVESTING FROM MOTION FOR AUTONOMOUS DEVICES

ERIC YEATMAN

DEPARTMENT OF ELECTRICAL ENGINEERING
IMPERIAL COLLEGE LONDON



HOW DO WE GENERATE POWER?



FROM MOTION

HOW IS HARVESTING DIFFERENT?

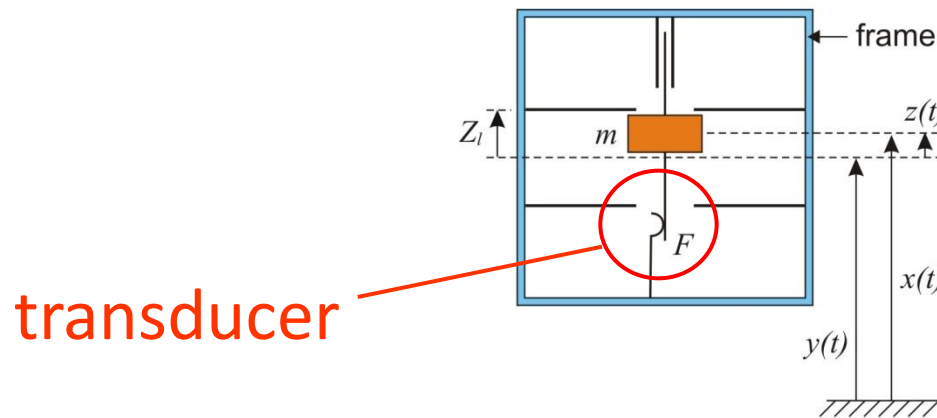
- Local generation for local use
- Miniaturisation



- Generator not necessarily anchored to ground

INERTIAL ENERGY HARVESTERS

- Mass mounted on a spring within a frame
- Frame attached to moving “host” (person, machine...)
- Host motion vibrates internal mass
- Internal transducer extracts power



ELECTROSTATIC HARVESTERS

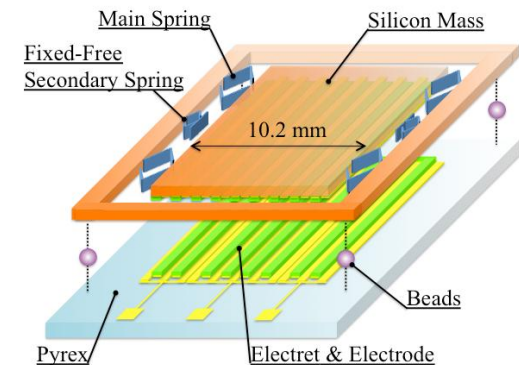
- Variable capacitor: simple structure
- Needs priming, or electret
- Hard to get high force plus good travel range: limits power



He C., Kiziroglou M.E., Yates D.C., Yeatman E.M., *IEEE Sensors Journal*, 11(12), (2011), 3437-3445 Stark B.H., *Microsystem Technologies*, 12, (2006), 1079-1083.



OMRON / IMEC Harvester



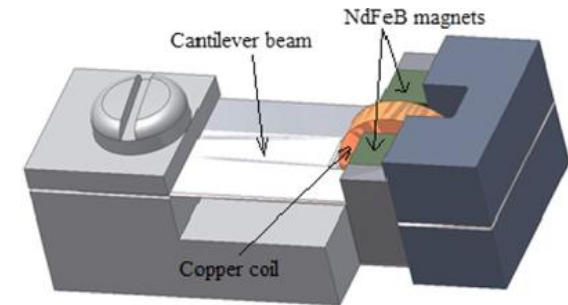
K. Matsumoto, K. Saruwatari, Y Suzuki, *Proc. PowerMEMS 2011*, Nov 15-18, Seoul, Korea, 2011.

ELECTROMAGNETIC HARVESTERS

- Coil and magnet- like conventional generators
- Don't miniaturise well – coil losses
- Small low frequency motion limits output voltage: hard to rectify



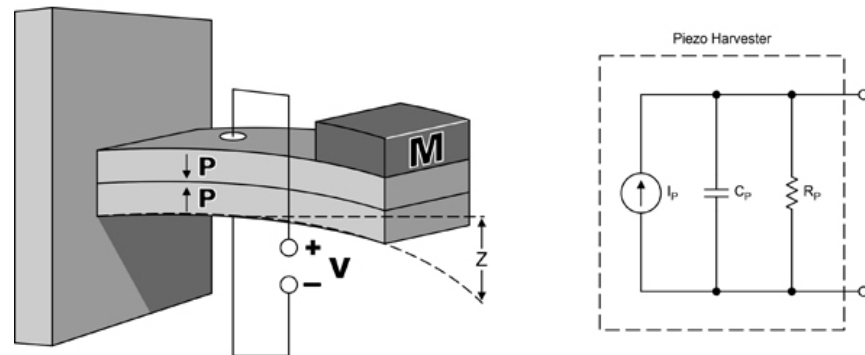
Univ. of Freiburg



Univ. of Southampton

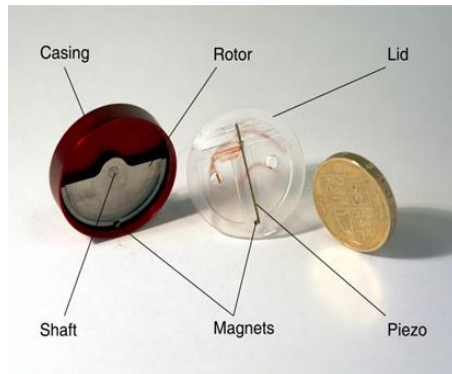
PIEZOELECTRIC HARVESTERS

- Need piezoelectric material
- Good output voltage even at low frequency
- Weak electromechanical coupling: needs high Q operation

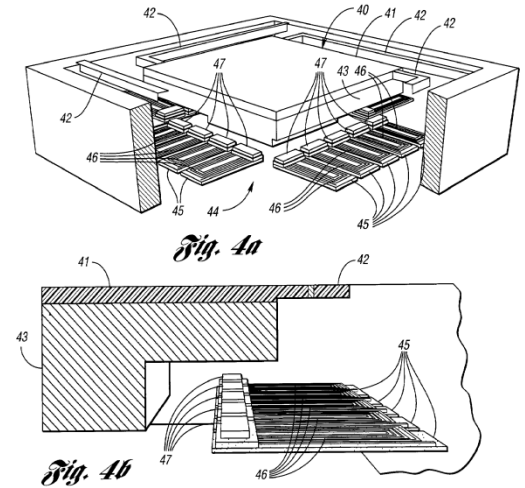
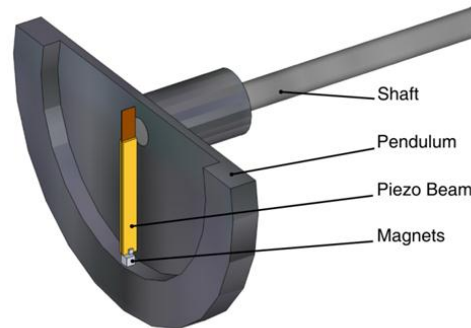


FREQUENCY UPCONVERSION

- Convert from low frequency, low Q input to higher frequency, high Q transducer oscillation
- Improves coupling for piezoelectrics
- Improves output voltage for electromagnetic devices



P. Pillatsch, E.M. Yeatman and A.S. Holmes, PowerMEMS 2013, London, Dec 3-6, 2013.



Kulah & Najafi, patent filing 2005

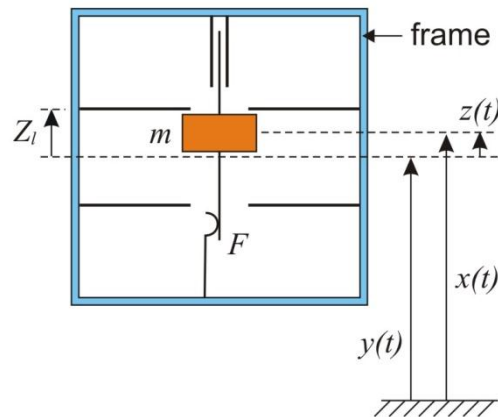
How Much Power?

World generation capacity	4 terawatts	10^{12}
Power station	1 gigawatt	10^9
House	10 kilowatts	10^4
Person, lightbulb	100 watts	10^2
Laptop, heart	10 watts	10^1
Cellphone	1 watt	10^0
Wireless sensor	1 milliwatt	10^{-3}
Wristwatch	1 microwatt	10^{-6}
Cellphone signal	1 nanowatt	10^{-9}

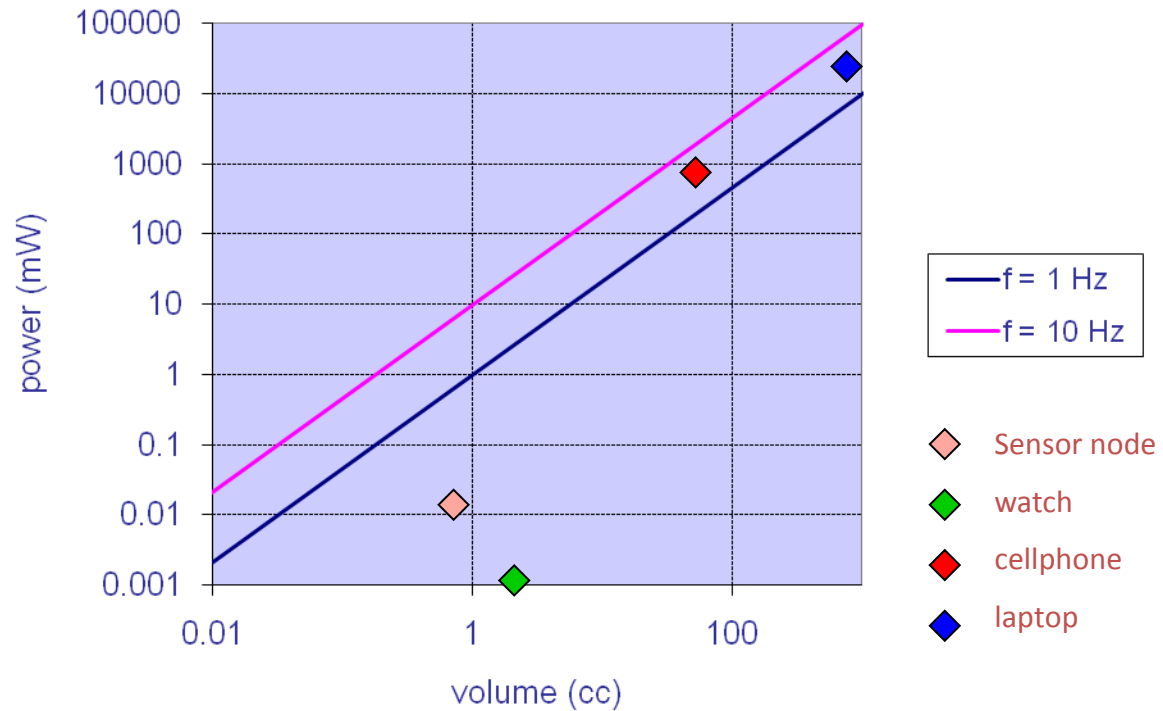
Inertial Energy Harvesters: Available Power

assume:

- source acceleration amplitude a_0 and frequency f
- Proof mass m , max internal displacement Δz
- then maximum power $P = 2m\Delta z \cdot a_0 f$



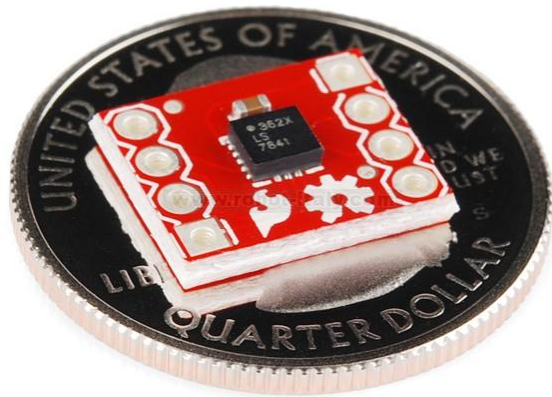
Inertial Energy Harvesters: Available Power



Plot assumes:

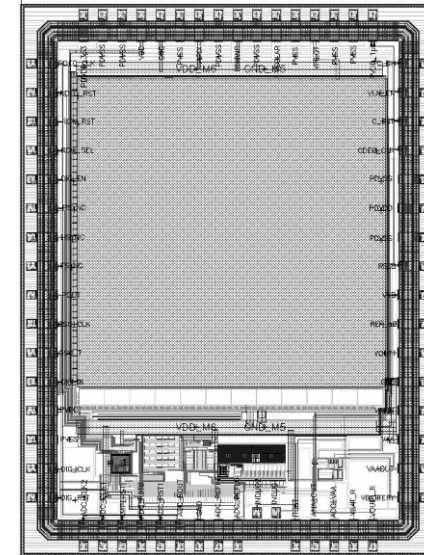
- proof mass 10 g/cc
- source acceleration 1g

Falling Sensor Power Requirements



Analog Devices ADXL362 3 axis accelerometer:

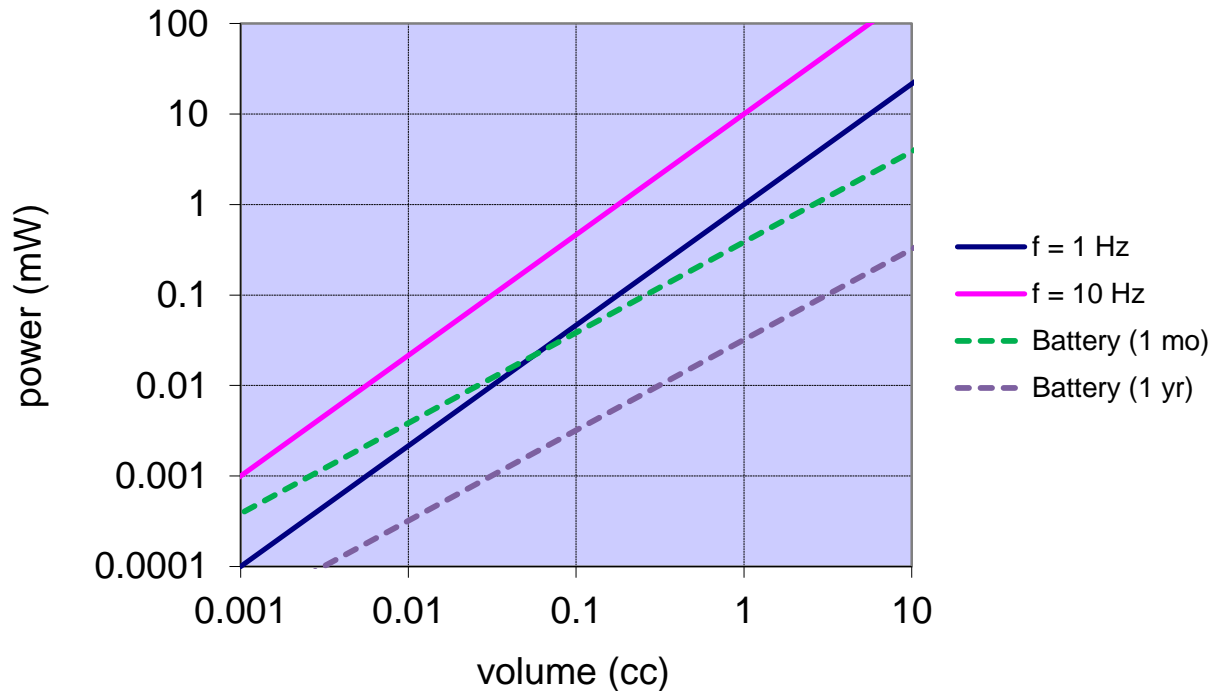
- less than 2 μ A at 100 Hz output data rate



Micropower CMOS imaging chip:

- 54 \times 50 pixels, 14 μ W at 7 frames per second
- S.U. Ay, IEEE Trans. Biomedical Circuits and Systems 6, 535-545 (2011).

Harvester Power Compared to Batteries



Plot assumes:

- proof mass 10 g/cc
- source acceleration 1g
- Li battery 1 kJ/cc

WHAT IS THE KILLER APP?

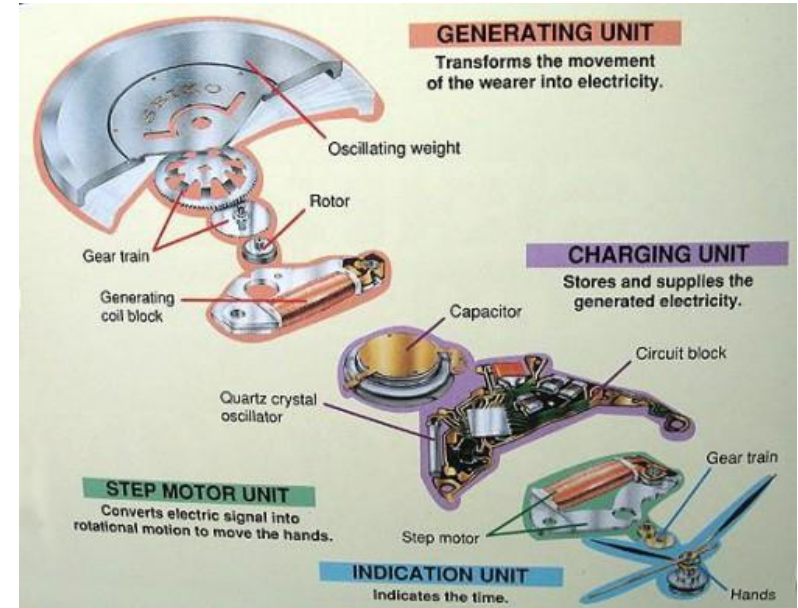
Tire Pressure Monitoring?

- Huge market
- Sensor inaccessible to vehicle power
- Batteries dominate today



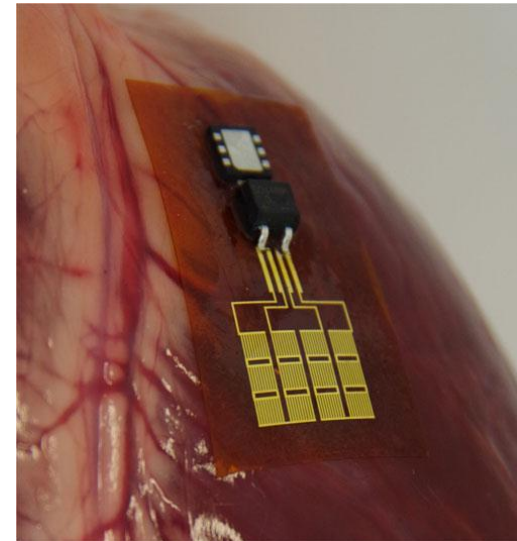
Watches?

- Huge Successful devices (e.g. Seiko)
- Peak power > 50 μW
- Electromagnetic: needs gear train to increase speed (& voltage), good bearings
- Precision mechanics, not MEMS: expensive
- Smart watches much higher power?



Implanted Medical Devices?

- Batteries undesirable
- Avoid surgery for replacement
- Higher cost toleration
- Reliability crucial!!



Nano-generator, U Illinois

Machinery?

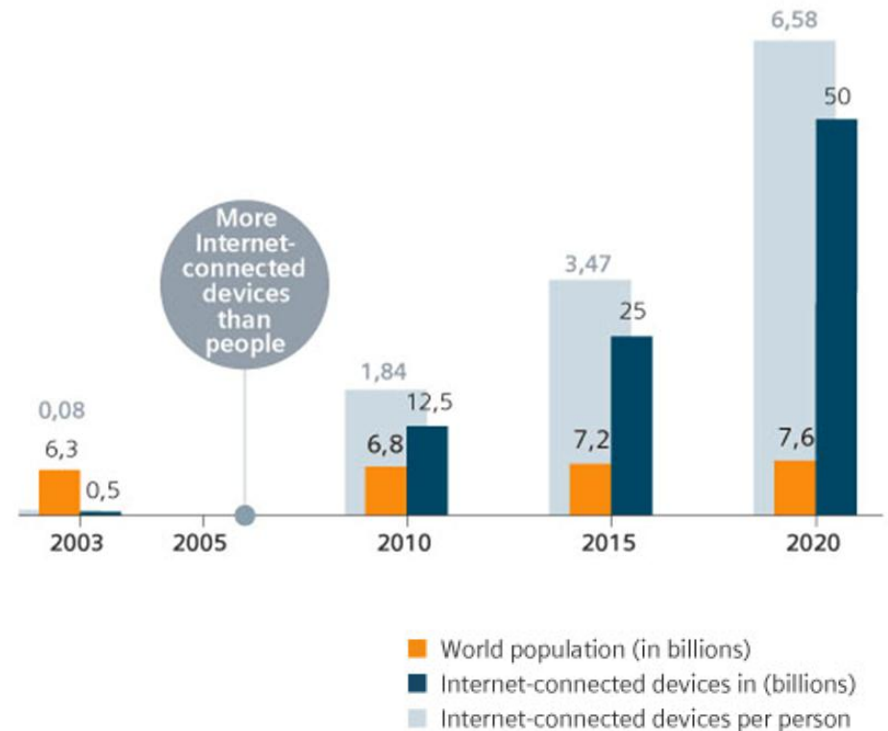


Internet of Things?

- A Trillion sensors!
- Battery replacement / charging impractical
- Variety of size and power requirements



Harvester powered radio location beacon



What Are The IoT Apps For Motion Harvesters?

THINGS THAT MOVE



THINGS THAT MOVE



THINGS THAT MOVE



THINGS THAT MOVE



THINGS THAT MOVE



THINGS THAT MOVE



THANK-YOU!

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Support: EPSRC, Digital City Exchange project

