State of the art in human powering of devices

9 November 2010

1st Energy Harvesting Research Theme Workshop

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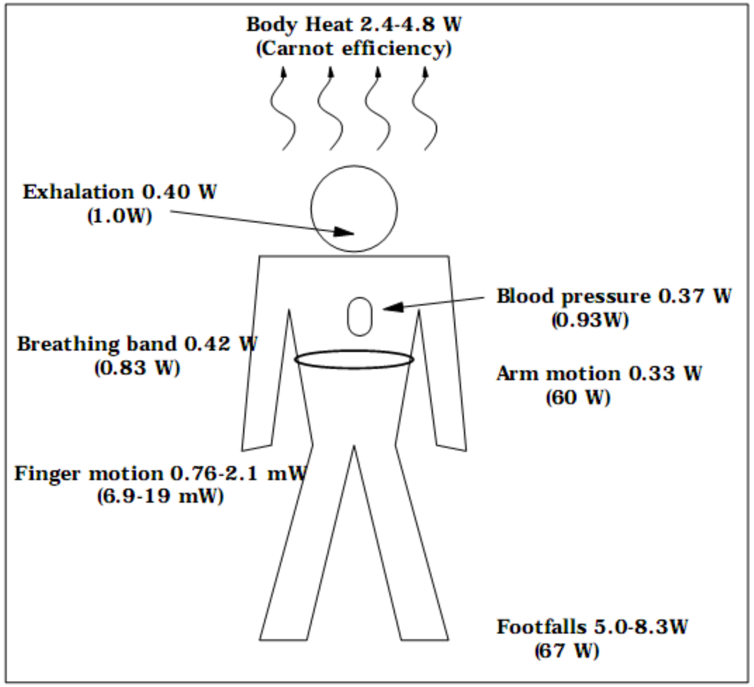
Available human power sources for energy harvesting

Table 1: Human energy expenditures for selected activities. Derived from [137].

Activity	*Kilocal/hr*	*Watts*
sleeping	70	81
lying quietly	80	93
sitting	100	116
standing at ease	110	128
conversation	110	128
eating meal	110	128
strolling	140	163
driving car	140	163
playing violin or piano	140	163
housekeeping	150	175
carpentry	230	268
hiking, 4 mph	350	407
swimming	500	582
mountain climbing	600	698
long distance run	900	1,048
sprinting	1,400	1,630



Possible power recovery from body-centered sources.
Total power for each action is included in parentheses

Human Generated Power for Mobile Electronics
Shad Starner Joseph A. Paradiso

Sources of power…from humans

- Thermal
- Mechanical
- Biochemical

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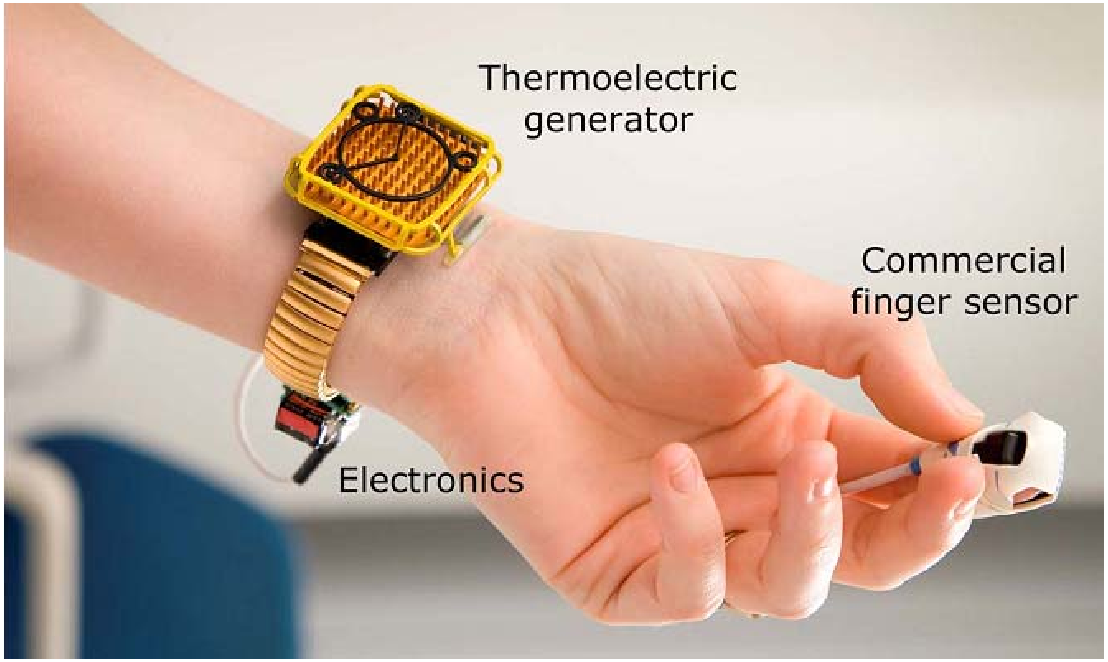
Thermoelectric body powered pulse oximeter

- Thermal energy harvesting is usually achieved through the thermoelectric effect, which requires a thermal gradient, and this is best achieved in the form of a wearable device



– output of a relatively active adult body is around 100W

– realistic capture, with commercial thermoelectrics ~ 1mW

– good for maybe PDA etc

Seiko Thermic watch, a commercially available timepiece (www.seikowatches.com).

Energy Harvesting from the body

Inertial Devices

Electromagnetic Scavenging

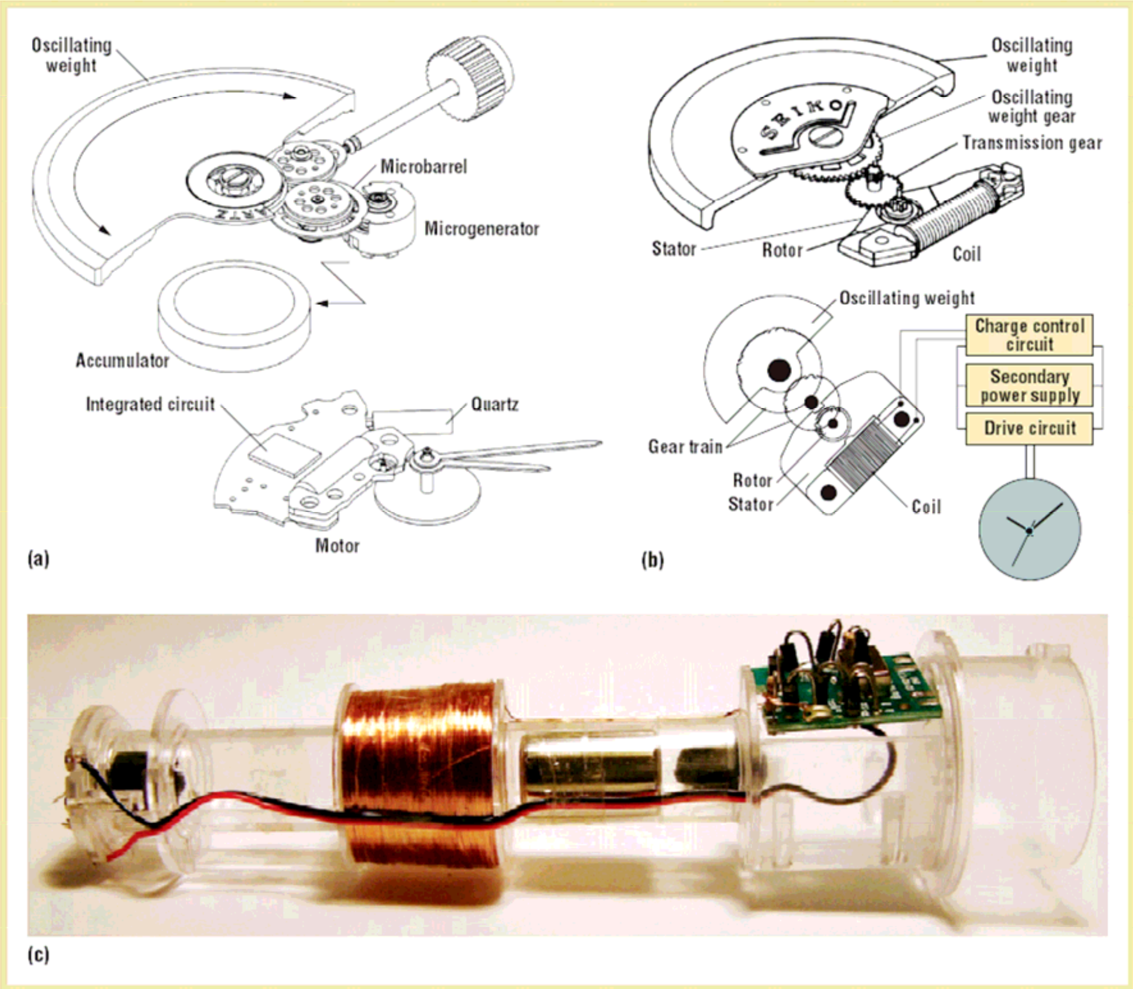
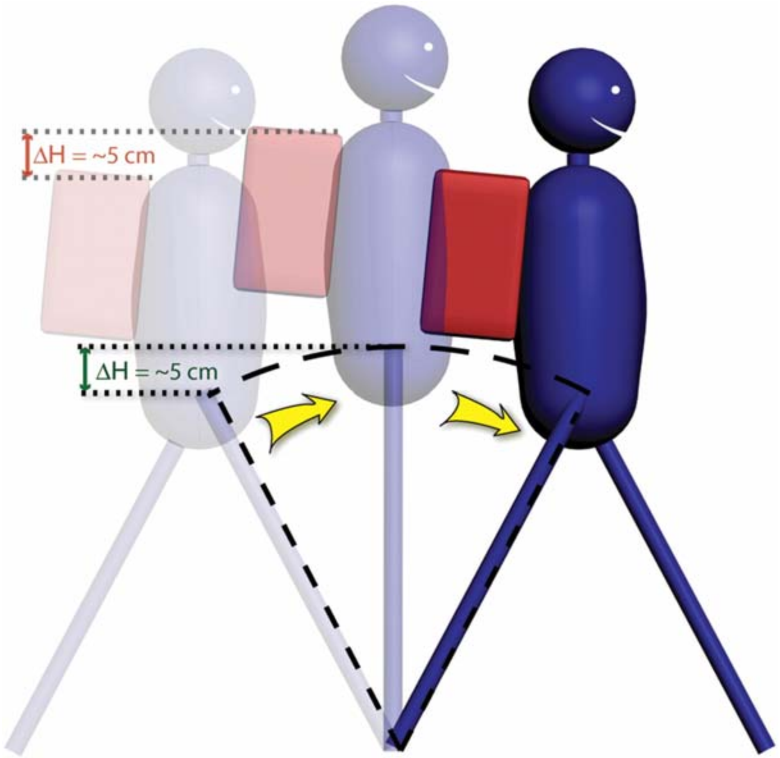


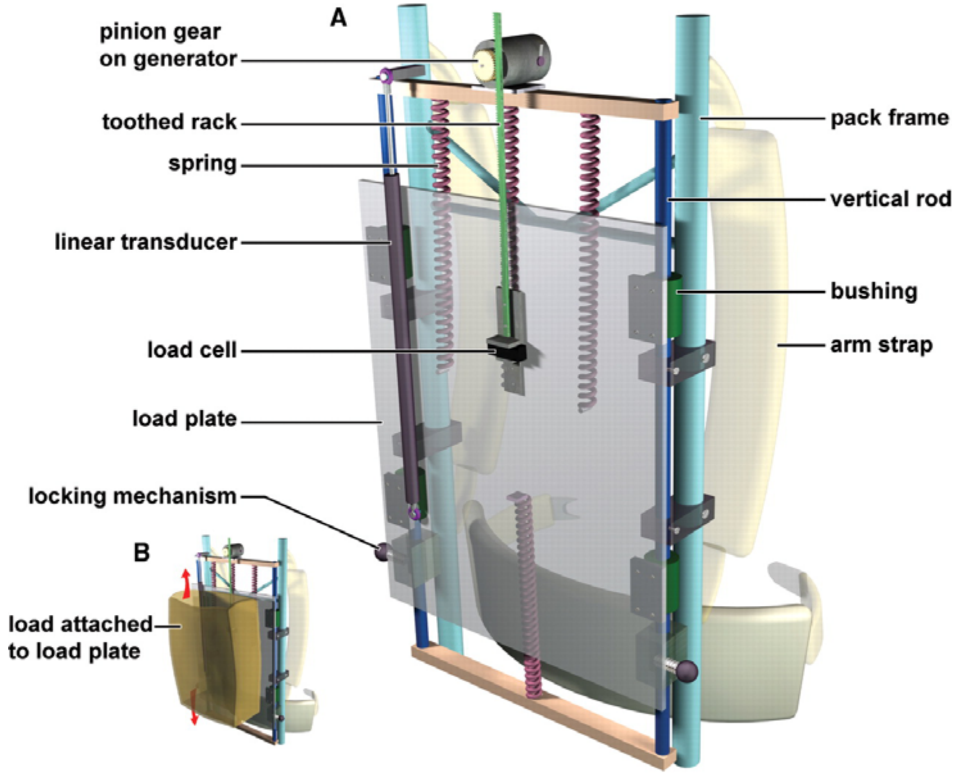
Figure 3. Commercial inertial-power scavengers. Two mechanisms for self-winding electric watches—(a) the ETA Autoquartz design

- An oscillating weight (selfwinding mechanism in a traditional watch) transmits the mechanical energy to the micro-generator through the microbarrel.
- The generator converts this mechanical energy into electrical energy and stores it in an accumulator.

Energy Harvesting Backpack

- **Electromagnetic generator**
- **Max Output ~ 7W**
- **Carrying 38kg**





Science 9 September 2005: Vol. 309. no. 5741, pp. 1725 - 1728

Energy Harvesting from the body

Direct Force Devices

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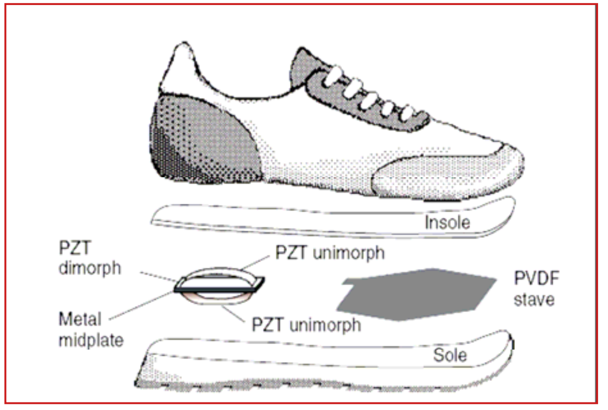
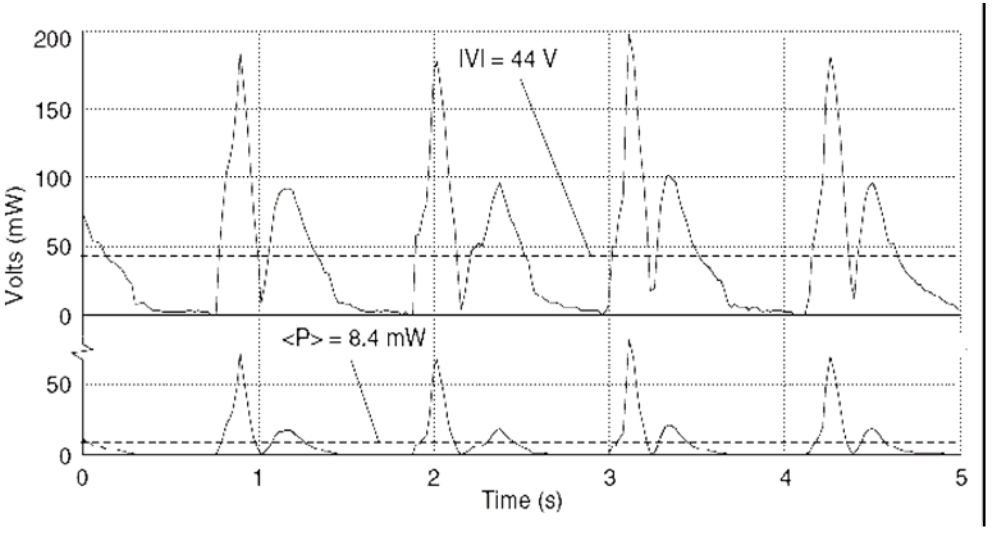
Energy harvesting from Walking



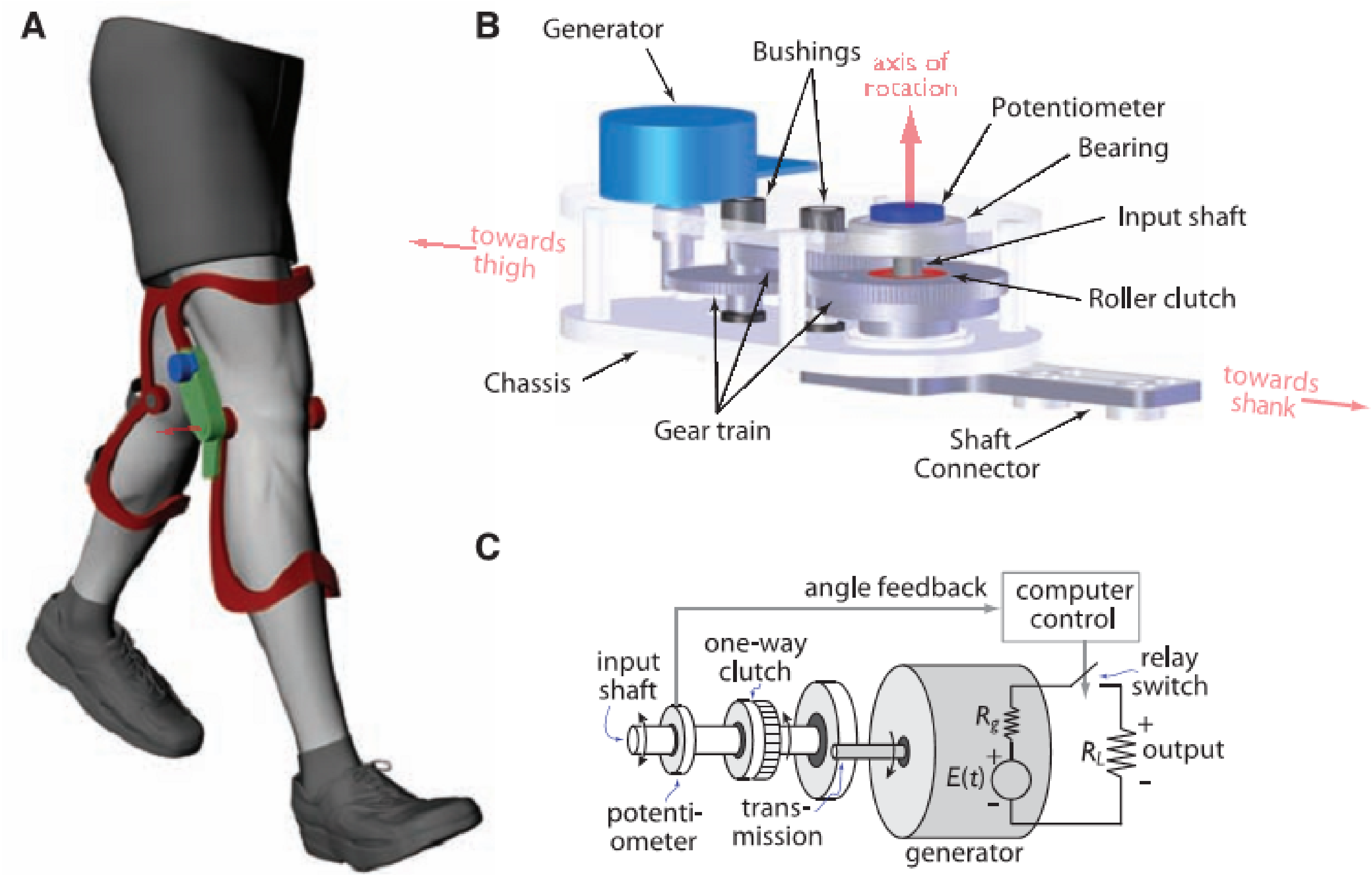
Shoe-mounted energy scavenger*



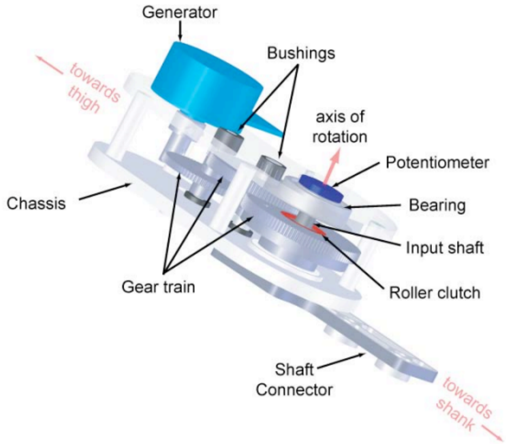
Example of the generated voltage and power*

**) Nathan S. Shenck, Joseph A. Paradiso, "Energy Scavenging With Shoe-Mounted Piezoelectrics", Publications IEEE, 2001*

Energy from human mobility...concepts



Energy harvesting from Walking



"Generative Braking" concept similar to KERS type regenerative braking
Muscle producing +ve work for 1 W mechanical needs 4W metabolic (3W heat)
Stretching muscle –ve work 1W mechanical needs 0.83W metabolic (1.83W heat)

•Donelan, J.M.; Naing, V.; Li, Q.;BIOMECHANICAL ENERGY HARVESTING, pages 39-44, Proceedings Power MEMS, 2008

•www.bionicpower.com

Knee-mounted energy scavenger*

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Energy harvesting from Walking

•*www.bionicpower.com*
• *8-14W power from comfortable walking pace (2 devices)*
•*1.5m/s on level ground*

Knee-mounted energy scavenger*

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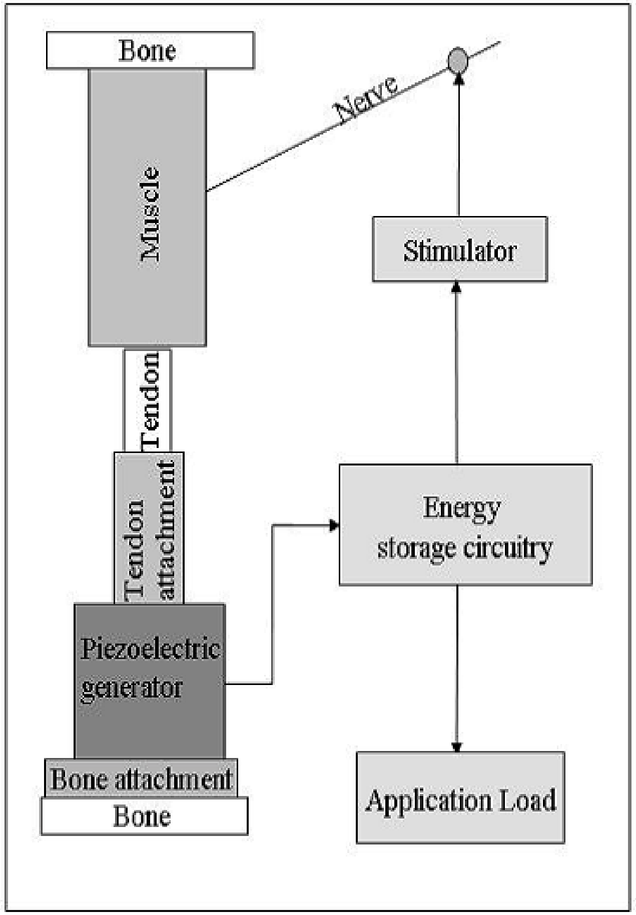
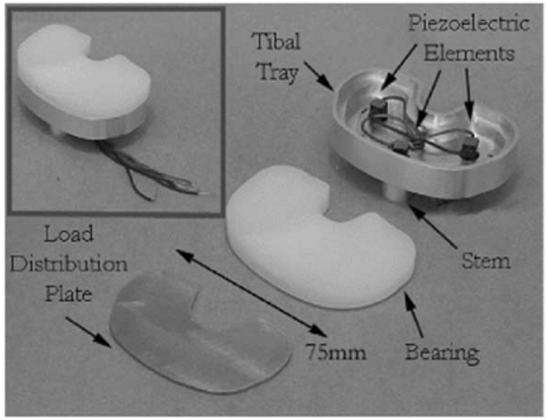
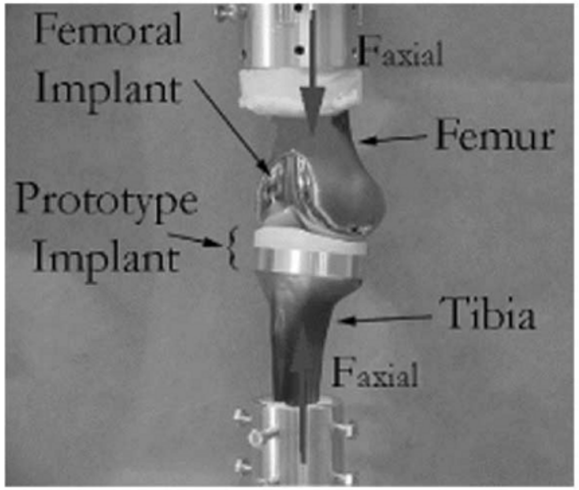
Energy harvesting from Walking: Implantable Device



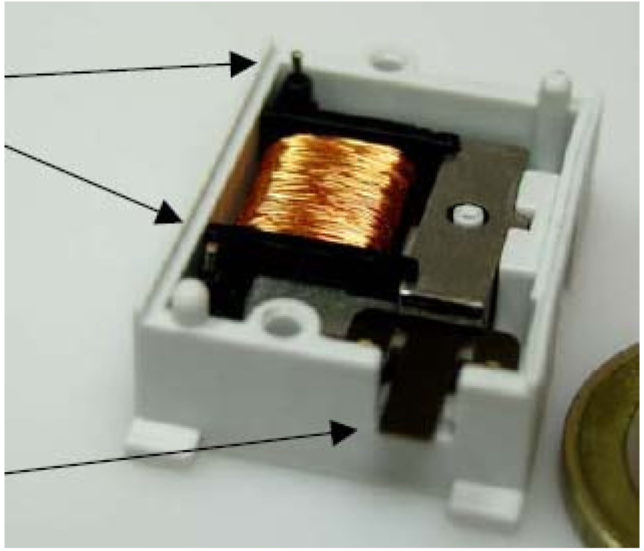


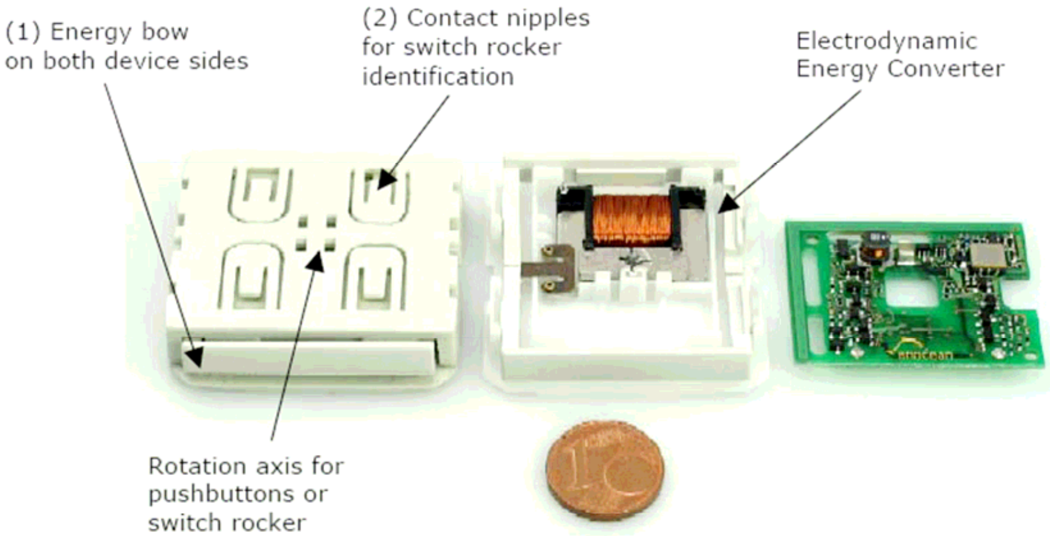


Biomechanical amplifier, where a piezoelectric device is attached between two points such that muscle contraction generates a force and thus an electrical charge. Energy is needed to stimulate the muscle, but predictions are that the harvested power of 690microW far exceeds the stimulus power of 46microW.

Platt, S. R. Farritor, S. Garvin, K. Haider, H.," The use of piezoelectric ceramics for electric power generation within orthopedic implants." Mechatronics, IEEE/ASME Transactions on, 2005. **10**(4): p. 455-461.

Electromagnetic Remote Transmitter





Mechanical dimensions: .... 33.3 x 22.0 x 10.8 mm

Actuating force / travel: .... 2.1±0.5 N / 2.0 mm

Switching cycles (up or down): .... >60.000 at 25°C

Operating temperature: .... +5 up to +65 °C

Output pulse: T (rise time) .... Typical 1,4 ms

Output pulse: U_{END} (voltage in the capacitor at the end of the energy pulse) ..... Typical 5 V ± 25%

http://www.enocean.com/

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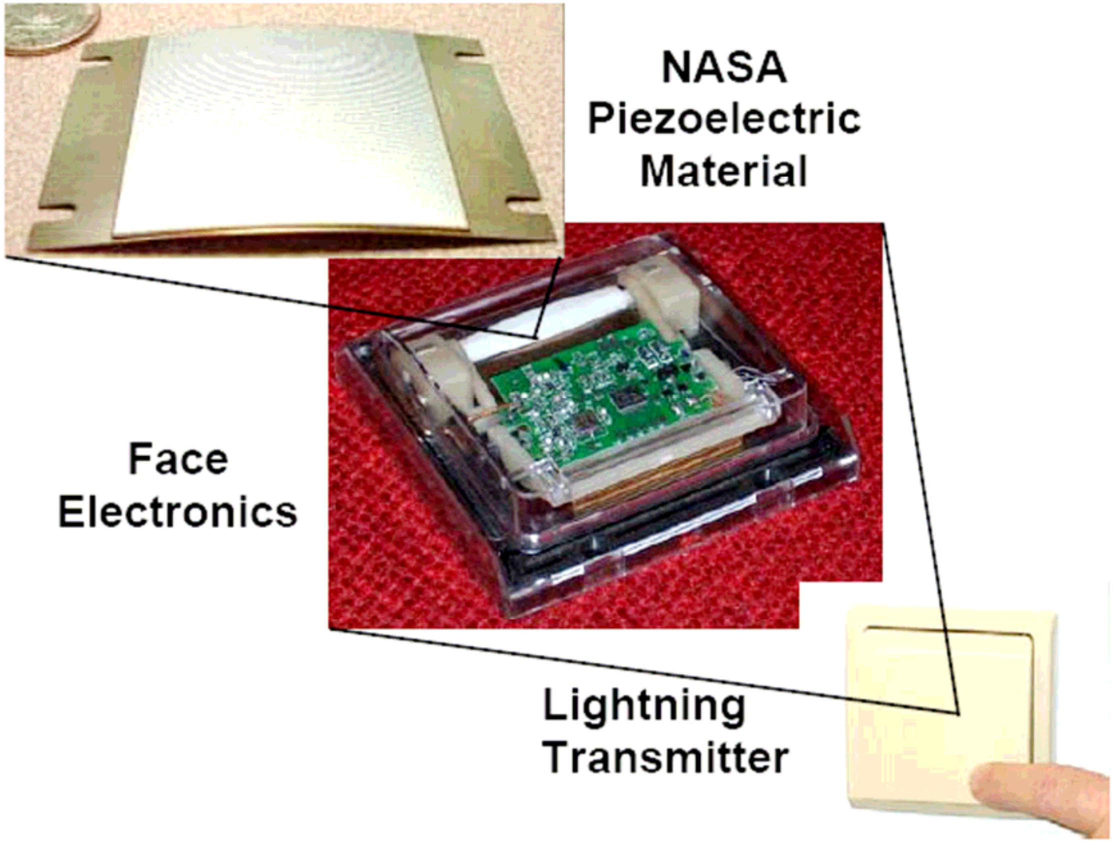
Piezoelectric Remote Transmitter



Lightning Switch wireless Transmitters (what look like the switches) use NASA space technology to generate their own electricity whenever the Transmitter button is pushed.

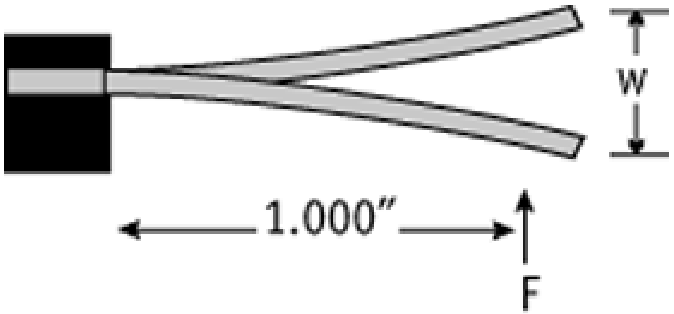
http://www.lightningswitch.com/

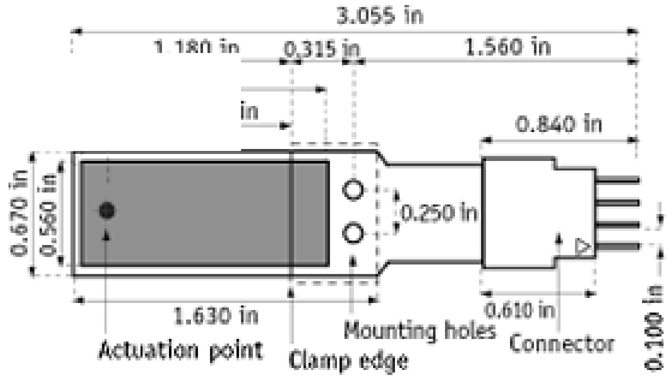
Piezoelectric Remote Control

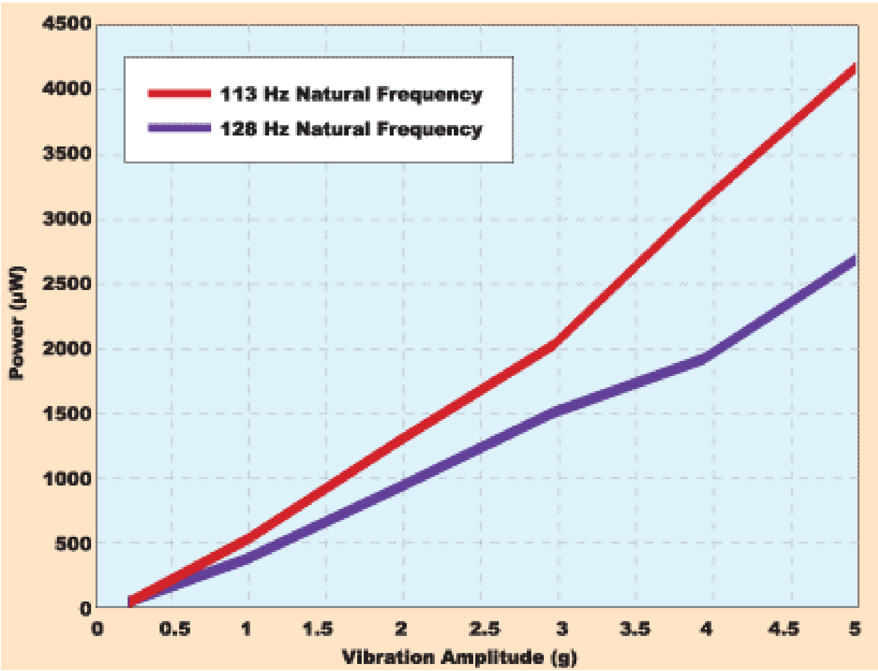
Worlds first batteryless infrared remote controller

www.arveni.fr

Piezoelectric vibration energy harvester (Volture)







Device size (in): 3.625 x 1.725 x 0.39

Device weight (oz): 2 oz

www.mide.com

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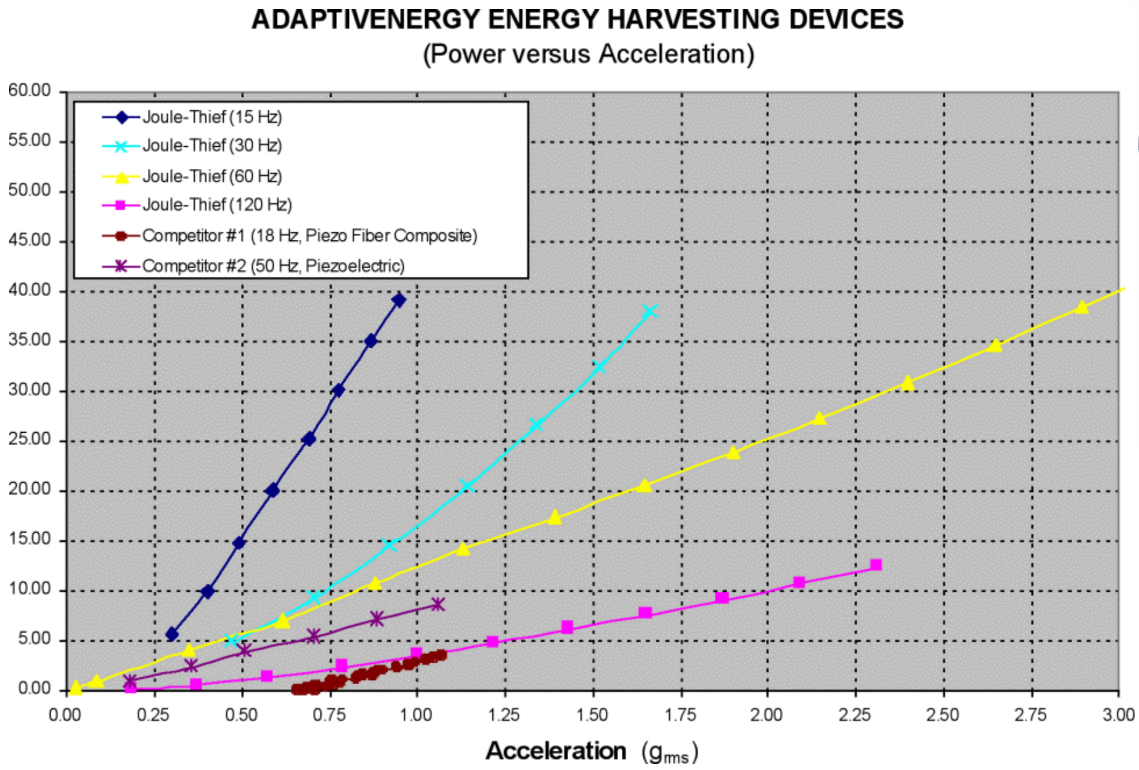
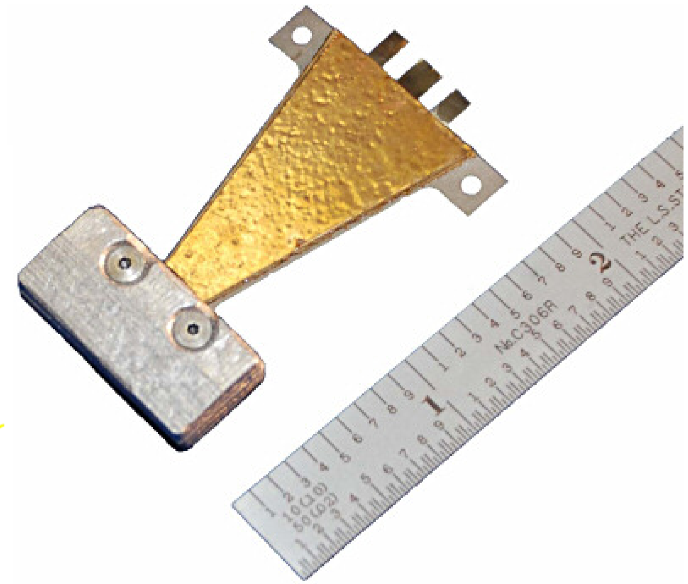
Piezoelectric vibration energy harvester (Joule Thief)





www.rlpenergy.com

Claim " *the highest output per unit volume energy harvester in the world*." (40mW)

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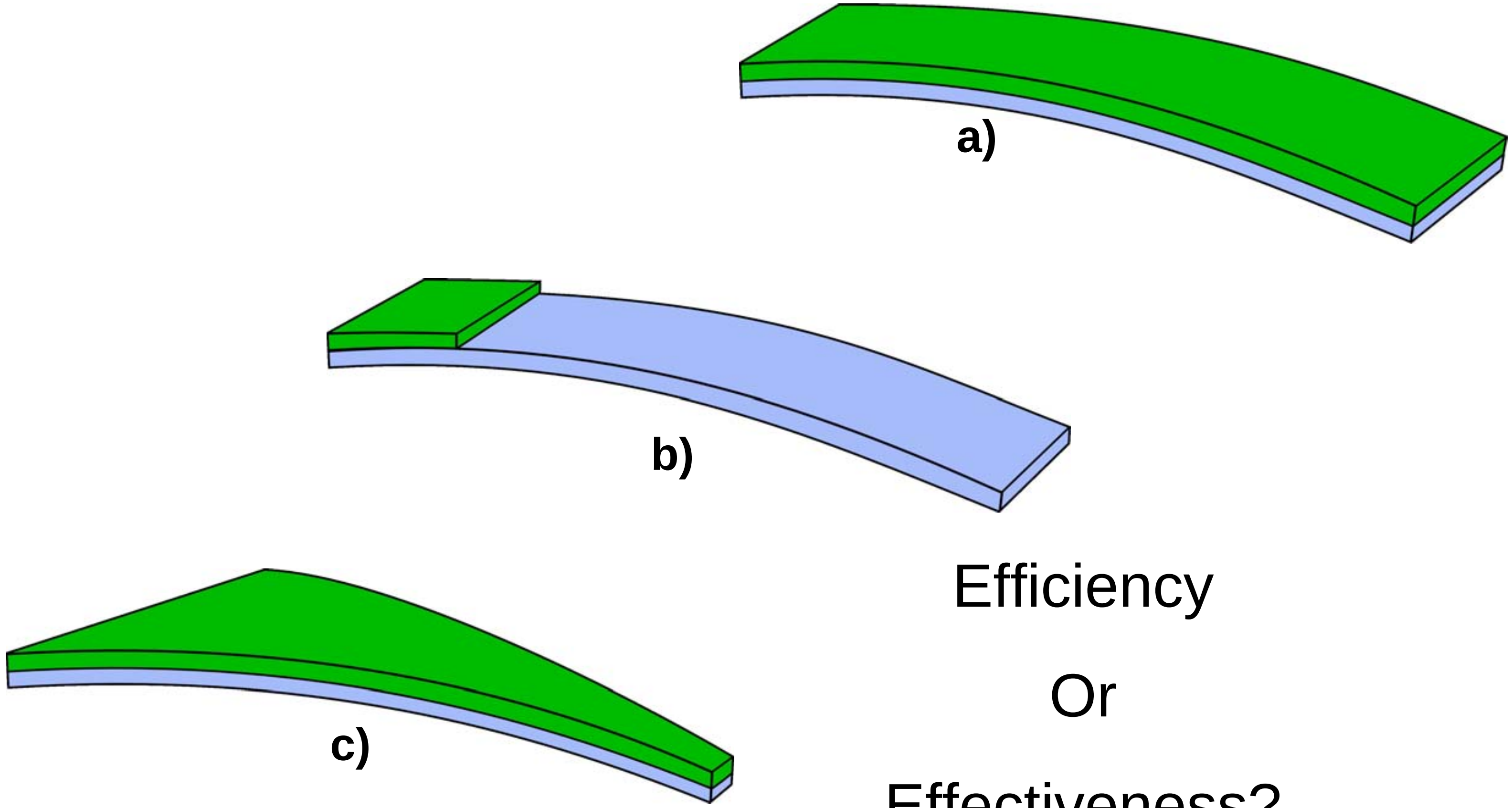
NPL – EH vibrational harvesting metrology



Efficiency

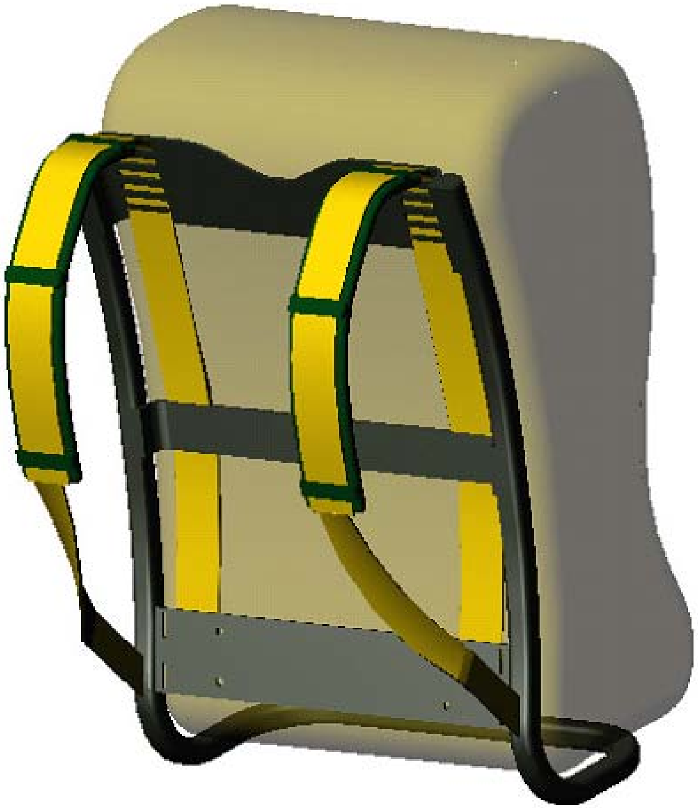
Or

Effectiveness?

Electro-Mechanical Impedance Matching

- Problem
  - Electromagnetic devices and most piezoelectric devices have a high modulus, compared with most of the body – so power transfer is difficult.
  - Challenge – to make or use materials that better match the stiffness of muscles and body tissue.
  - Extraction of energy must be considered at the beginning of design – as must energy storage

Mechanical Impedance Matching
Energy harvesting from Walking



- PVDF used as material for backstrap.
- Used proprietary rubber metal as contact material due maintain contact during large strains
- Output 46mW for 100lb load

J Granstrom, J Feenstra, H A Sodano
SmartMater.Struct. 16 (2007)1810–1820

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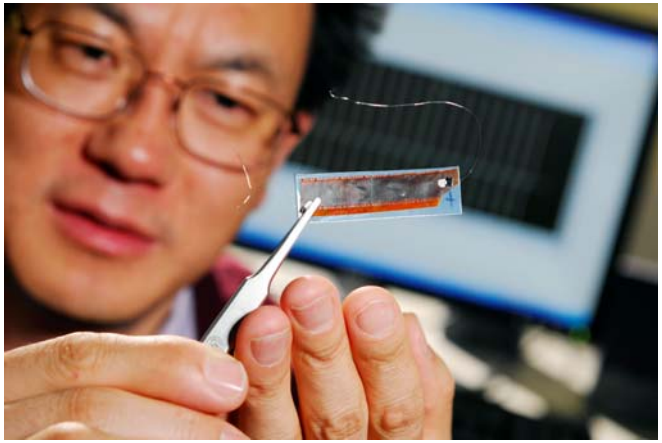
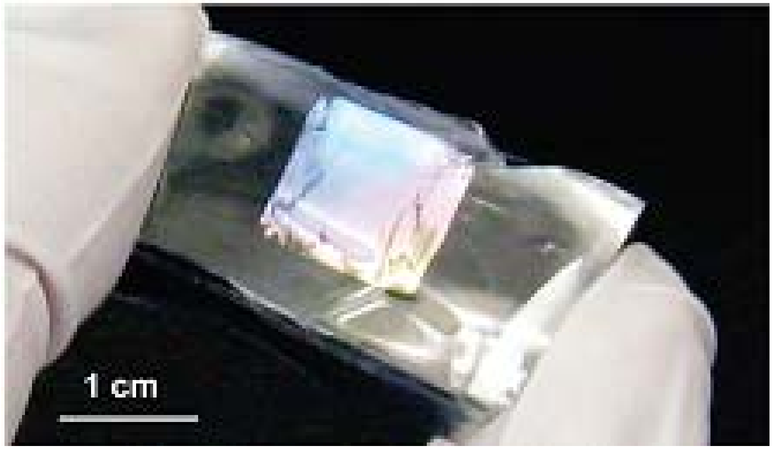


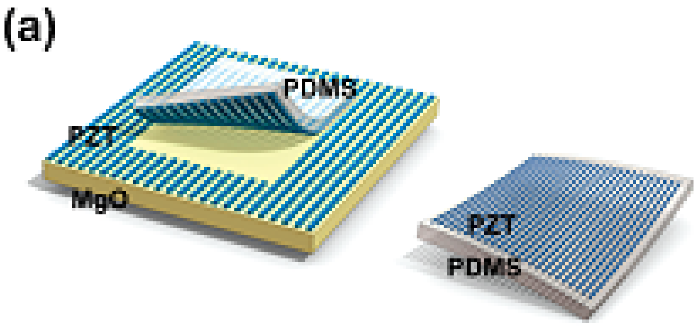
Georgia Tech Zinc Oxide nanowires

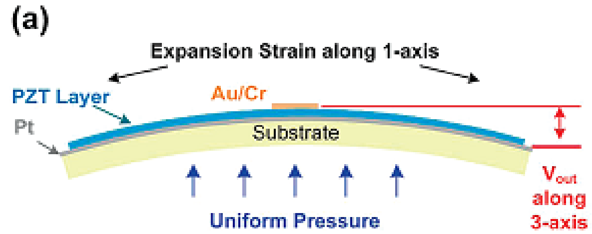
Turn away now for those of delicate disposition

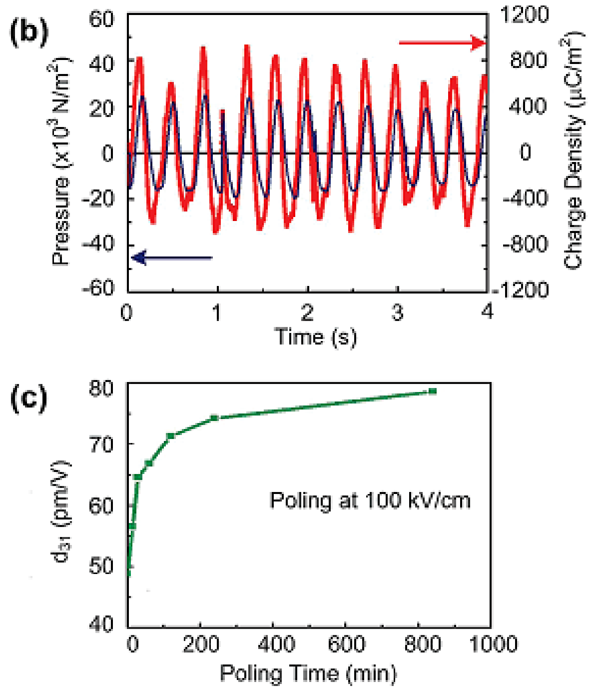
Mechanical Impedance Matching

PZT ribbons on rubber substrate









Piezoelectric Ribbons Printed onto Rubber for Flexible Energy Conversion
Yi Qi et al Nano Lett., 2010, 10 (2), pp 524–528

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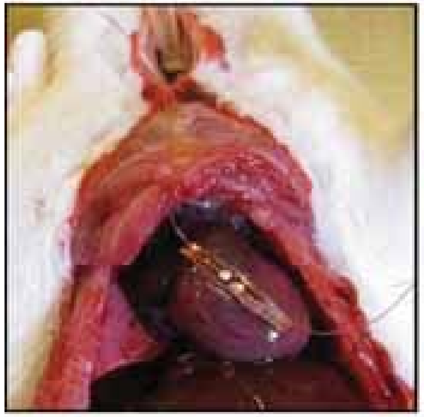
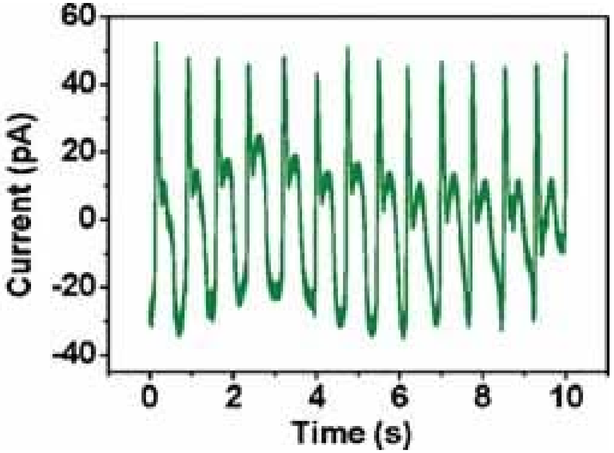
Mechanical Impedance Matching
Zinc Oxide Nanowires





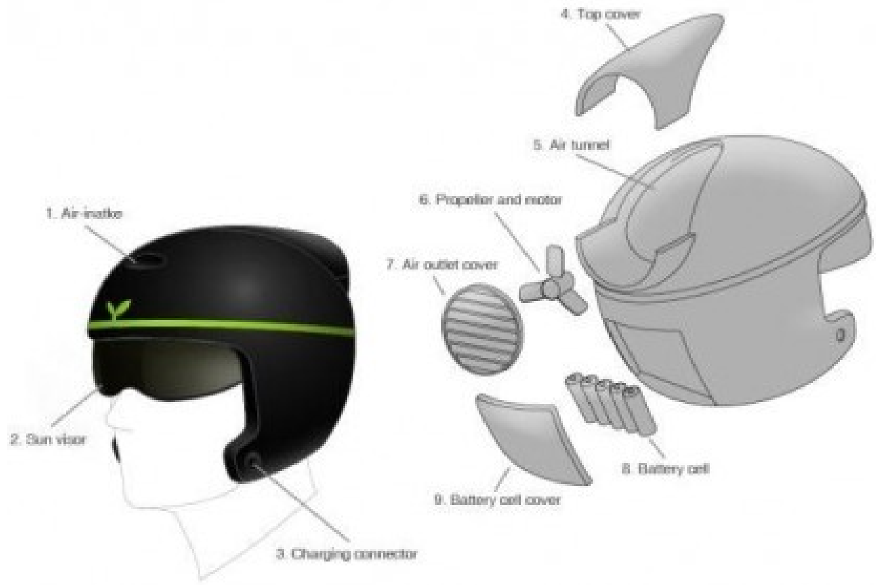
Wang and his team sealed zinc-oxide nanowires in a polymer. The polymer served as a shield to the rat's body fluids and to be a barrier to outside electrical sources. They then glued the 2 mm x 5 mm rectangular unit to the rat's diaphragm muscle. The breathing motion generated 4 picoamps of current at a potential of 2 millivolts. Even more power was generated when the unit was glued to the rat's heart: 30 picoamps at 3 millivolts.

Muscle-Driven In Vivo Nanogenerator
Zhou Li, Guang Zhu, Rusen Yang, Aurelia C. Wang, Zhong Lin Wang
Advanced Materials, 22, Issue 23, pages 2534–2537, June 18, 2010

Energy Harvesting by Design

There are many press reports concerning energy harvesting which begin as a design concept without much real engineering and physics backing, and are presented in the press and advertising with little or no peer review. In the long term this will damage the energy harvesting sector if too many of these ideas fail to deliver.

Wind Harvesting Helmet



NO – use an aerodynamic helmet and a wheel mounted dynamo

Image source: The Design Blog
Via Energy Harvesting Journal

Energy Harvesting Dancefloor

Little evidence that this concept works or is practical. Image probably artistic license.

"In Rotterdam, Club Watt also houses an energy harvesting dance floor which generates power for the clubs' lights, the average dancer making around 20 watts of electricity. That electricity is used to power the light show in and around the floor."

http://www.energyharvestingjournal.com/articles/energy-harvesting-dance-floors-00001613.asp

EURAMET
European Association of National Metrology Institutes

EMRP
European Metrology Research Programme
Programme of EURAMET

- Project JRP SRT-03 **Metrology for Energy Harvesting**

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- MIKES, Finland
- CMI, Czech Rep
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Piezoelectric and magnetic materials for energy harvesting

Conversion efficiency of microgenerators

Traceability for small non-sinusoidal signals

Figure of merit of thermoelectric reference material

Metrology for nanostructured thermoelectrics

- Traceability and scaleability – micro to nano
- Non-sinusoidal waveforms and non-linear devices
- Scanning probe microscopy for measurement of energy coupling
- Magnetic coupling / magnetostriction

Summary

- Expectations of energy harvesting must be realistic.
- Energy Harvesting Devices are already commercially available.
- Reduction of power requirements, particularly for wireless technologies has increased the opportunities for energy harvesting.
- Piezoelectric based energy scavengers offer very good performance in comparison to the other techniques especially in microsystem applications. But integration challenge!

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  - www.piezoinstitute.com
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- EMRP Metrology for Energy Harvesting - piezos & thermoelectrics
  - See http://www.euramet.org/index.php?id=a169jrps

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