

Networking Testbed, Supported by
Energy Scavenging
Paul Wright and students

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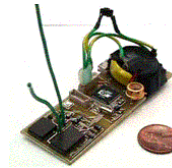
Operating system (TinyOS) allows ad hoc networking (Culler)



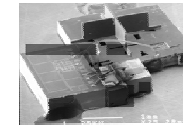
MVS - 60's



DOS / Windows - 80's



TinyOS - 2002



TinyOS - 2004

Energy source for supporting the nodes (Wright)

Traditional Batteries



Solar



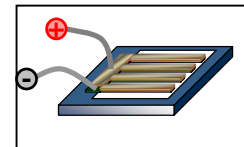
Vibration 2002

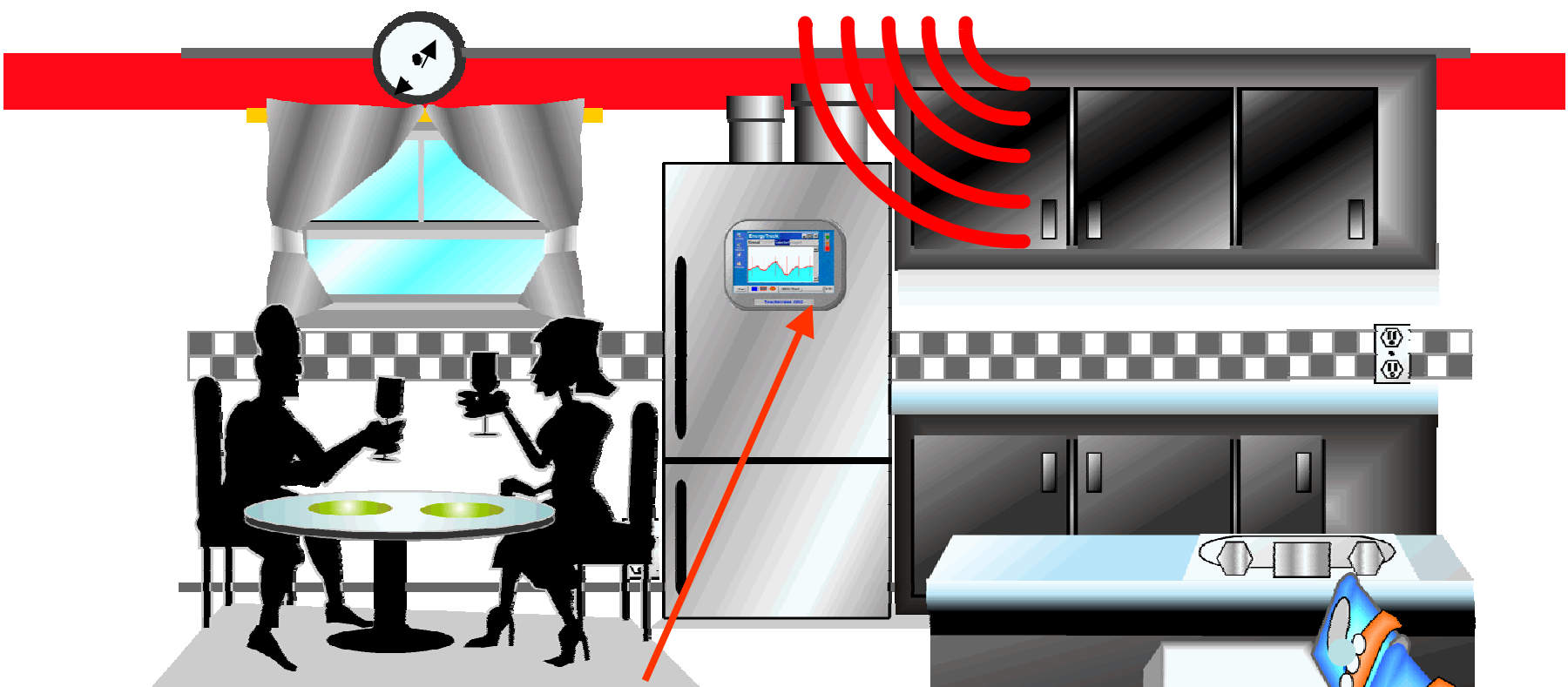


Vibration 2003



Vibration 2004



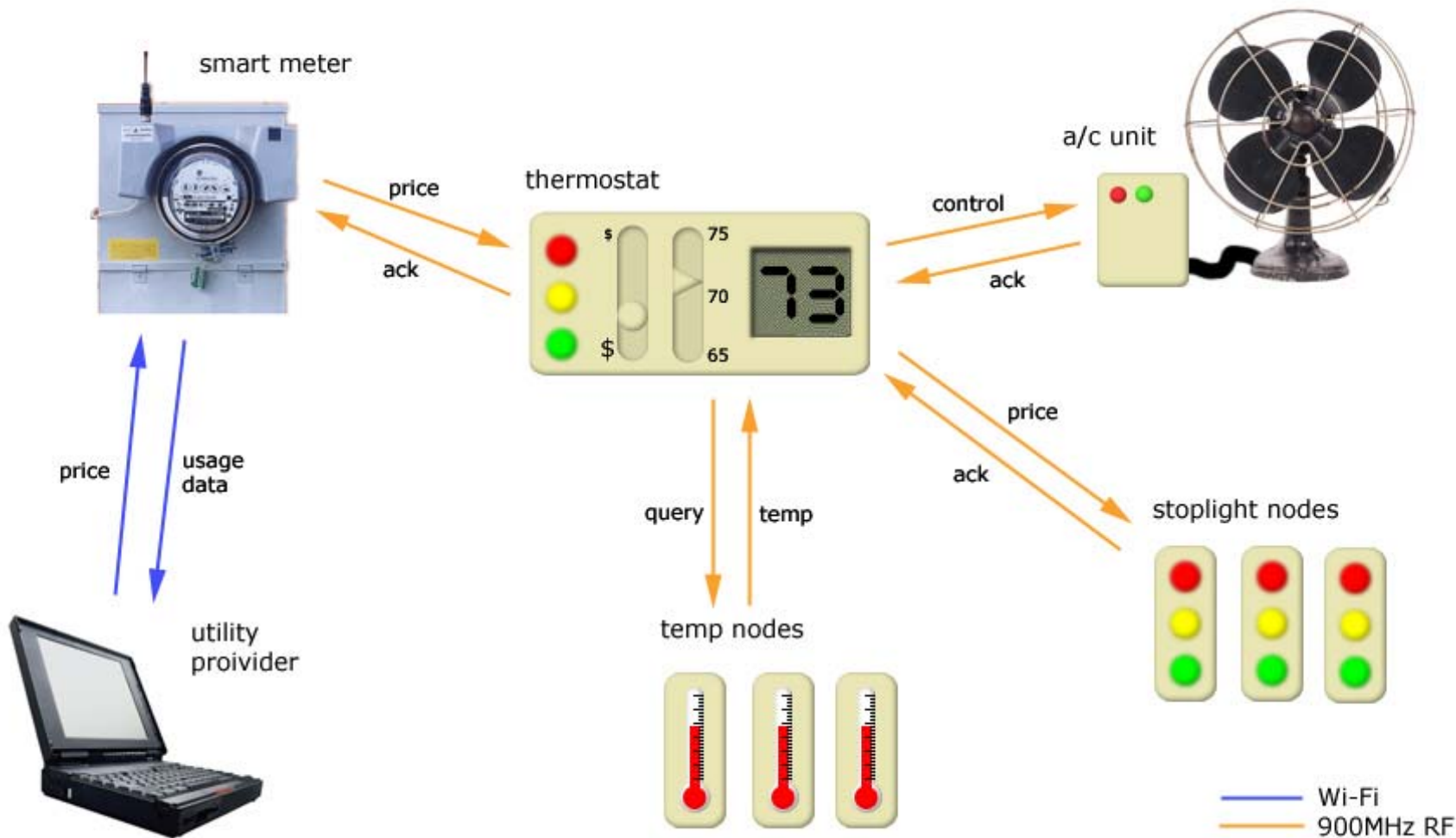


Networking of 3 main devices

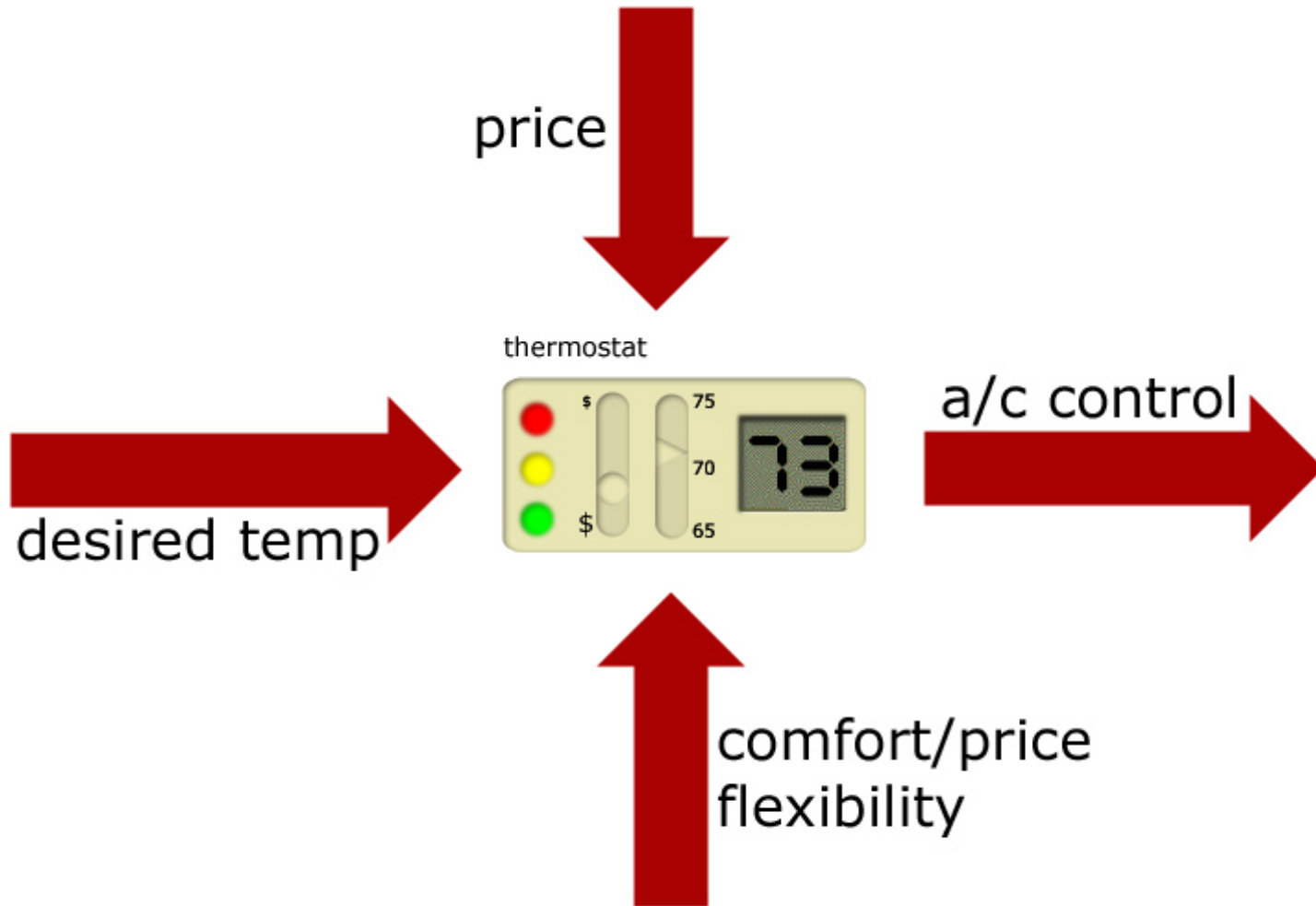
1. A New Style Thermostat (and/or TouchPad) receives information on price. It can display cost and demand. Then users can adjust their usage profile on AC and appliances. (Arens/Auslander)
2. A New Style Meter will convey usage/charge/quality back to Supplier (White)
3. TempNodes supported by scavenging (Wright)
4. Wireless systems (Rabaey/Culler)

“Network communication testbed”

Dan Hooks, Nate Ota, Will Watts, Andrew Redfern



Control logic



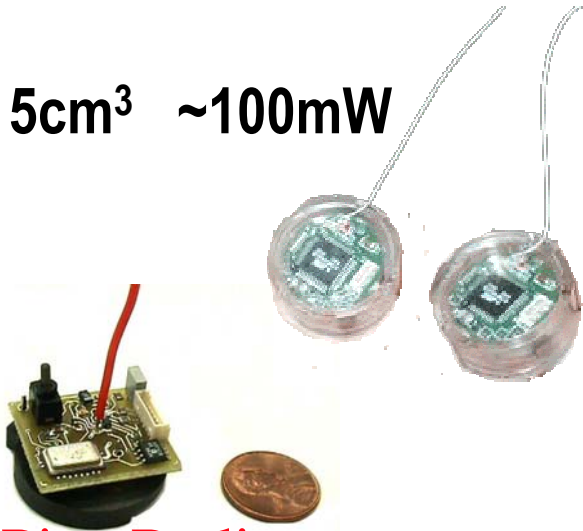
Pause: A light-hearted view of DR @ 74°C

Personal Choices	Two Cost Levels	Fan (or AC)	Averaged Room Temperature, T_{AVE}
Mr. Rich – Donald Trump	20 ¢ /kwhr	On	$\Sigma (T_1 \text{ to } T_5) / 5 = T_{AV}$
Mr. Grad Student – Nate Ota	\$1.00 /kwhr	Off	
Mr. Middle Class – Paul Wright			

<p>1. Donald @ 20¢ = Fan on =</p> <p>2. Donald @ \$1.00 = Fan on =</p>	<p>The first graph shows a horizontal red line at 74° on a vertical axis labeled T° and a horizontal axis labeled time. The second graph is identical, also showing a horizontal red line at 74°.</p>	<p>“Mr. Cool” (@74 or less)</p>
<p>3. Nate @ 20¢ = Fan on =</p> <p>4. Nate @ \$1.00 = Fan off =</p>	<p>The first graph shows a horizontal red line at 74° on a vertical axis labeled T° and a horizontal axis labeled time. The second graph shows a horizontal red line at 74° that then rises linearly to 80° on a vertical axis labeled T° and a horizontal axis labeled time.</p>	<p>“Mr. Sweaty” (@>>>80)</p>
	<p>The first graph shows a horizontal red line at 74° on a vertical axis labeled T° and a horizontal axis labeled time. The second graph shows a horizontal red line at 74° that then rises linearly to 77° on a vertical axis labeled T° and a horizontal axis labeled time. The third graph shows a horizontal red line at 74° that then rises linearly to 77° and continues as a high-frequency sawtooth wave on a vertical axis labeled T° and a horizontal axis labeled time.</p>	<p>“Mr. OK” (@77)</p>

Three enabling technologies for such a testbed

2 - 5cm³ ~100mW

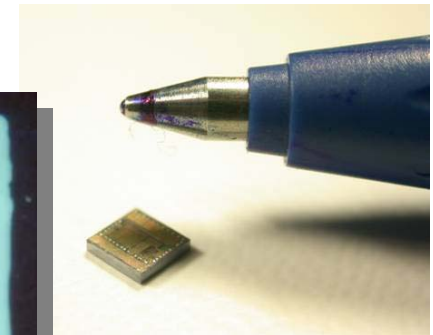
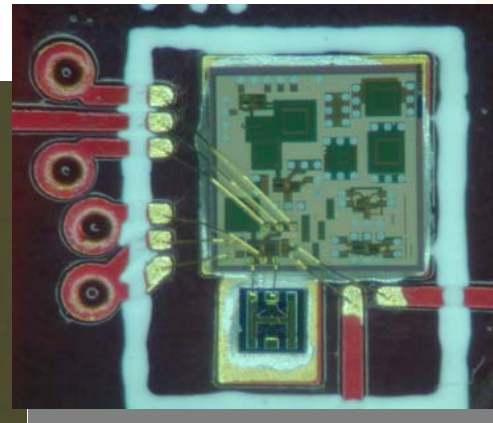
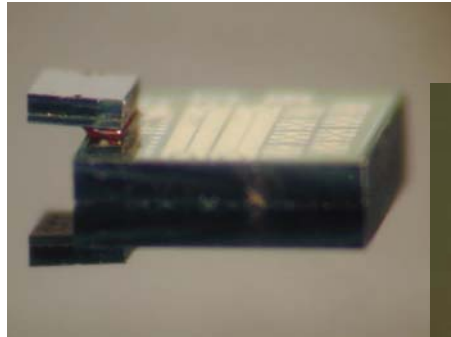


1. Tiny OS



2. Pico Radio

1cm³ or less and 10-50μW

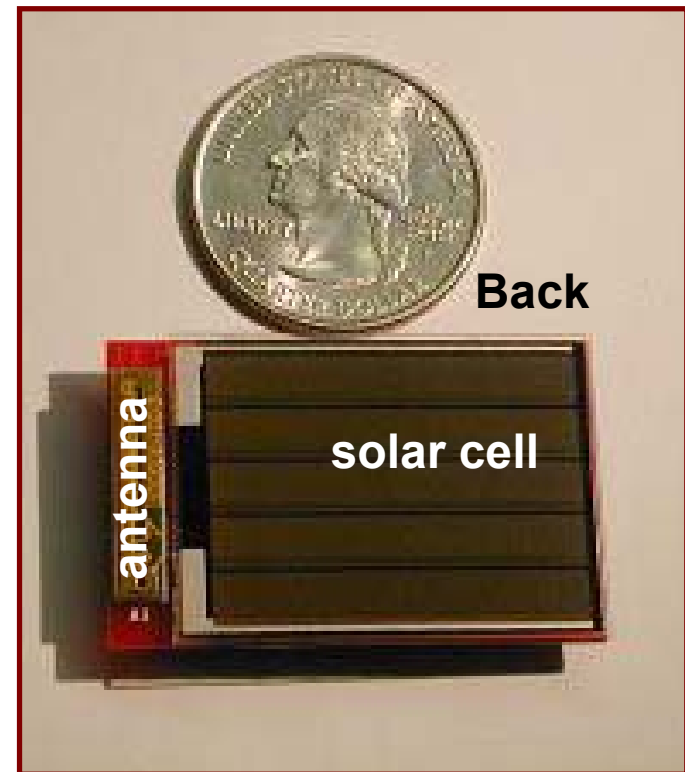
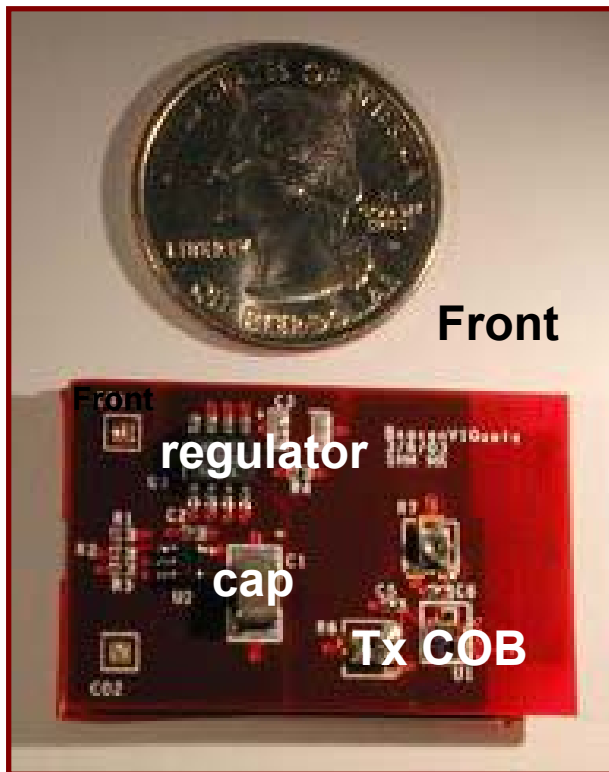


Source: Jan Rabaey

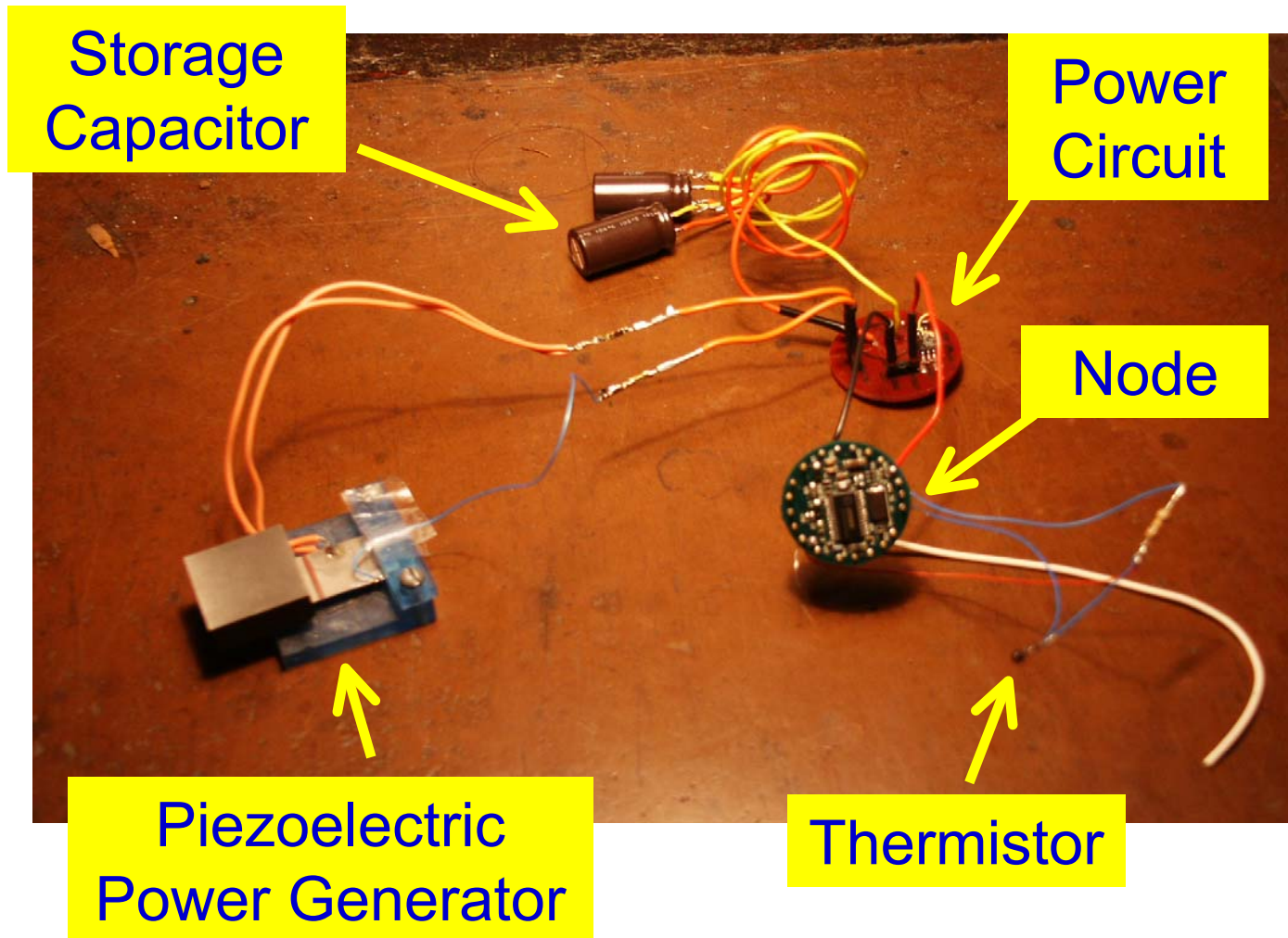
3. Energy Scavenging Methods for the Nodes in the Testbed

Goals:

- 3a) Solar & 3b) Vibrational energy scavenging
- Push integration limits - limited by dimensions of solar cell

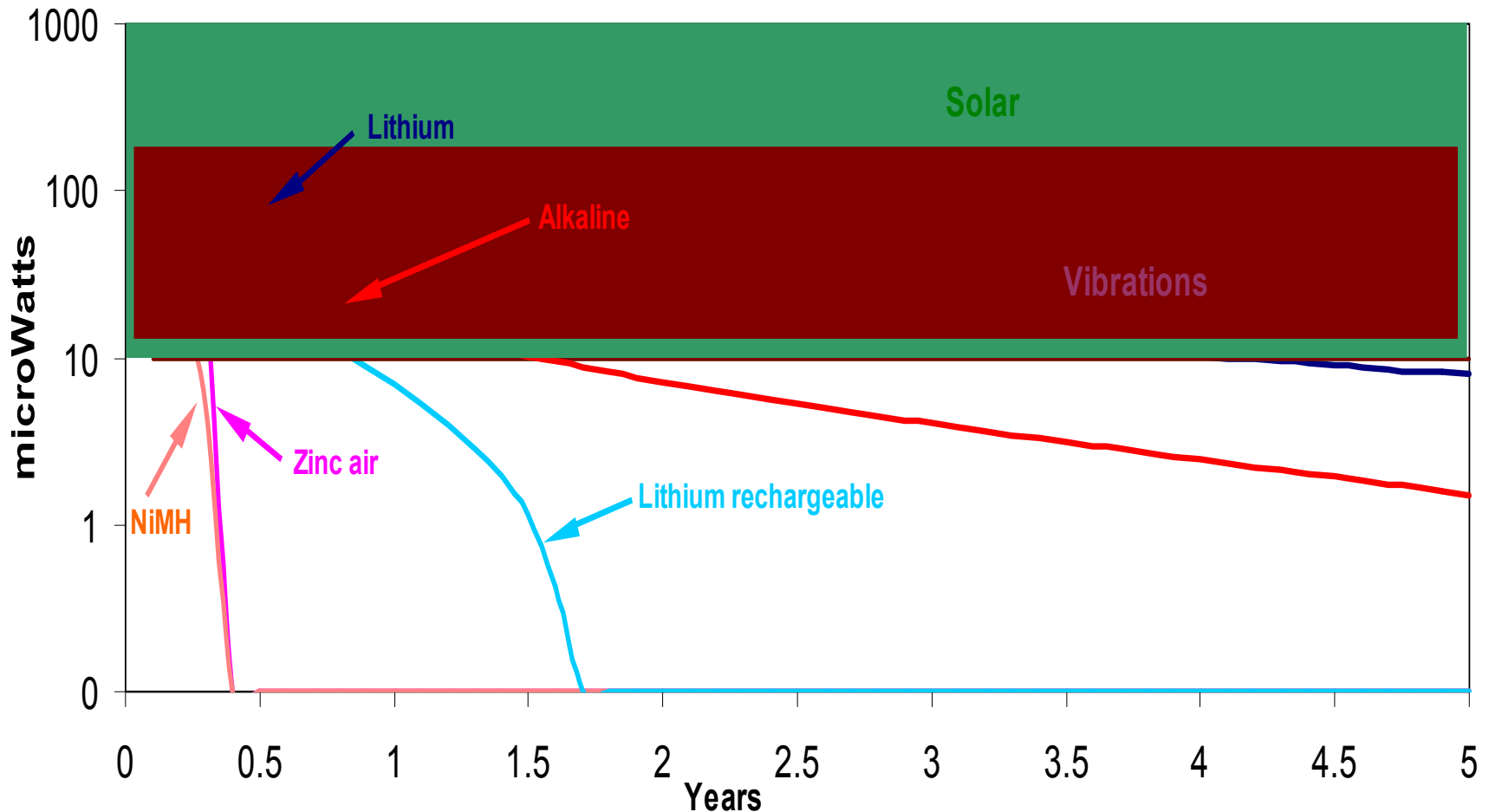


3b) Wireless Sensor Network (WSN) platforms Powered by Energy Scavenging



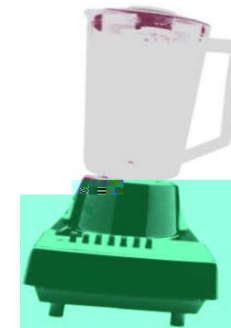
Battery, Solar, and Vibrational Energy

Continuous Power / cm³ vs. Life Several Energy Sources



Common Sources of Vibrations

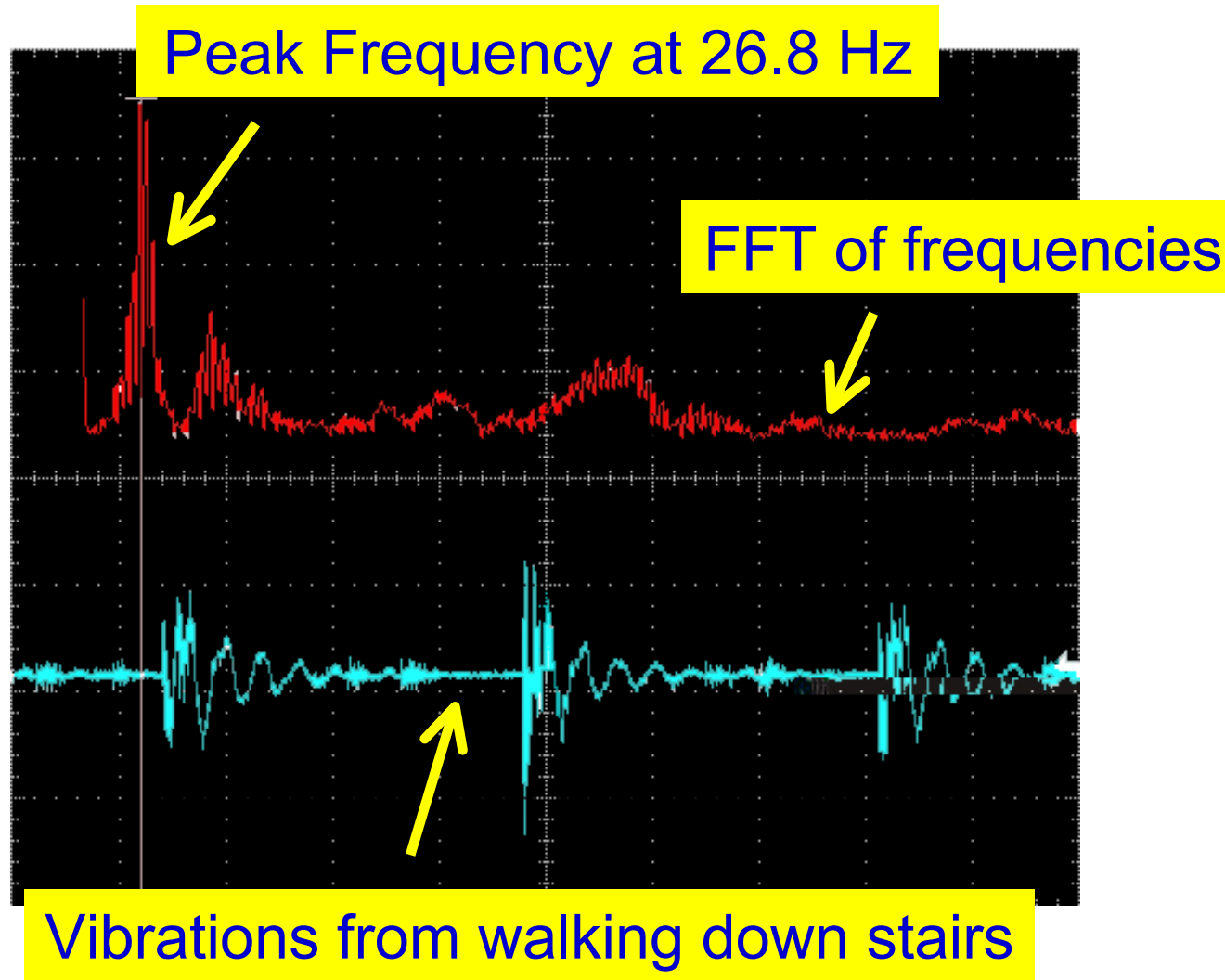
Vibration Source	Frequency of Peak (Hz)	Peak Acceleration (m/s ²)
Kitchen Blender Casing	121	6.4
Clothes Dryer	121	3.5
Door Frame (just after door closes)	125	3
Small Microwave Oven	121	2.25
HVAC Vents in Office Building	60	0.2-1.5
Wooden Deck with People Walking	385	1.3
Bread Maker	121	1.03
External Windows (size 2ftx3ft) next to a Busy Street	100	0.7
Notebook Computer while CD is Being Read	75	0.6
Washing Machine	109	0.5
Second Story of Wood Frame Office Building	100	0.2
Refrigerator	240	0.1



Wooden Stairs



Power generator must match peak frequency of vibration source for max power output



Bender Design



40V peak-to-peak
output from bender
when someone walks
down the stairs

Characteristics

- Piezoelectric: PZT
- Tungsten Alloy Mass: 52 g
- Beam Dimensions:

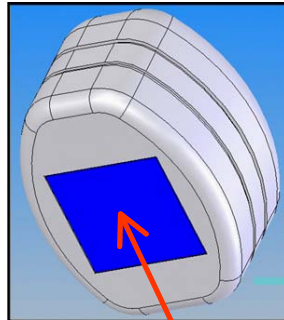
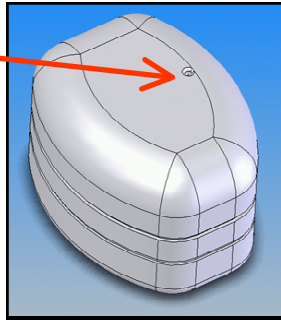
1.25" x 0.5" x 0.02"

Behavior

- Resonant Frequency: 26.8 Hz
- Power Output: 450 μ W

FDM Packaging

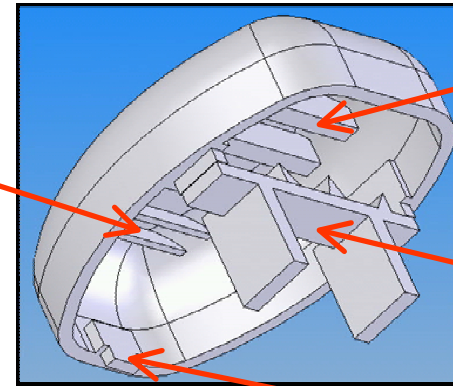
Temperature
Sensor Hole



Bender Platform

PCB Holder

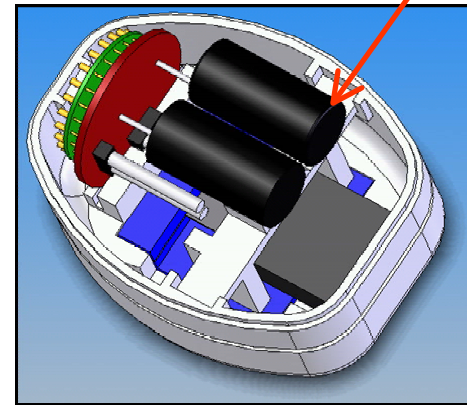
Upper Case



Capacitor
Holders

Bridge

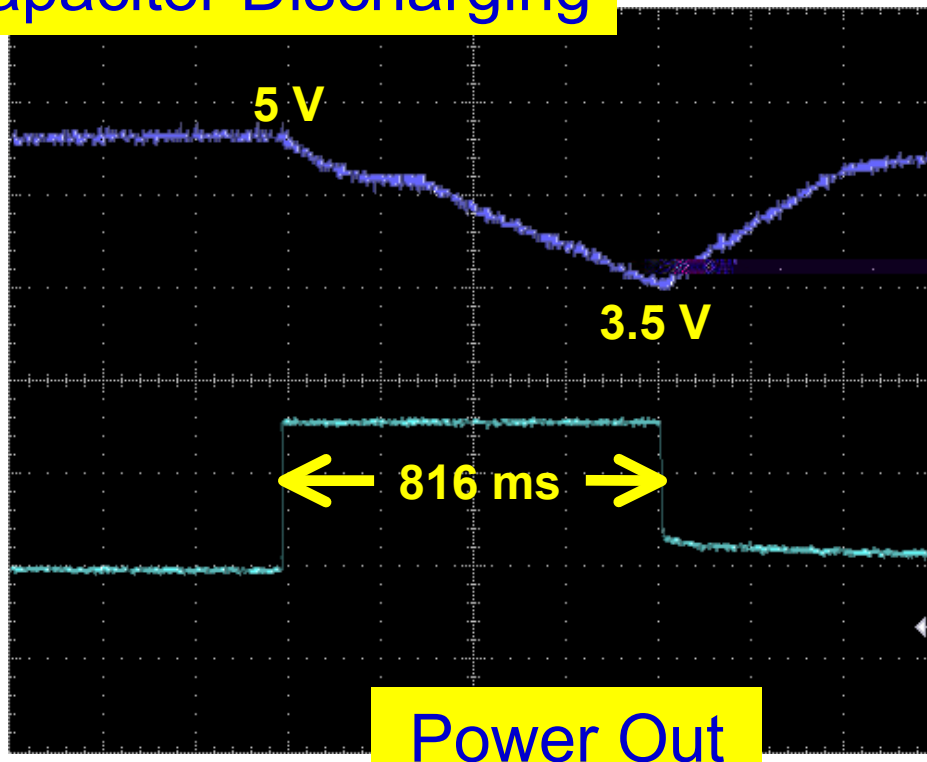
Lower Case



Case Tabs

Proof of Concept

Capacitor Discharging



```
/opt/tinyos-1.x/tools/java
FF FF 0A 7D 08 01 00 26 00 01 00 0B 02
FF FF 0A 7D 08 01 00 2C 00 01 00 0C 02
FF FF 0A 7D 08 01 00 34 00 01 00 0C 02
FF FF 0A 7D 08 01 00 3A 00 01 00 0C 02
FF FF 0A 7D 08 01 00 42 00 01 00 0C 02
FF FF 0A 7D 08 01 00 49 00 01 00 0C 02
FF FF 0A 7D 08 01 00 52 00 01 00 0D 02
FF FF 0A 7D 08 01 00 5A 00 01 00 0D 02
FF FF 0A 7D 08 01 00 61 00 01 00 0C 02
FF FF 0A 7D 08 01 00 6A 00 01 00 0C 02
FF FF 0A 7D 08 01 00 72 00 01 00 0C 02
FF FF 0A 7D 08 01 00 78 00 01 00 08 02
FF FF 0A 7D 08 01 00 81 00 01 00 08 02
FF FF 0A 7D 08 01 00 8A 00 01 00 0A 02

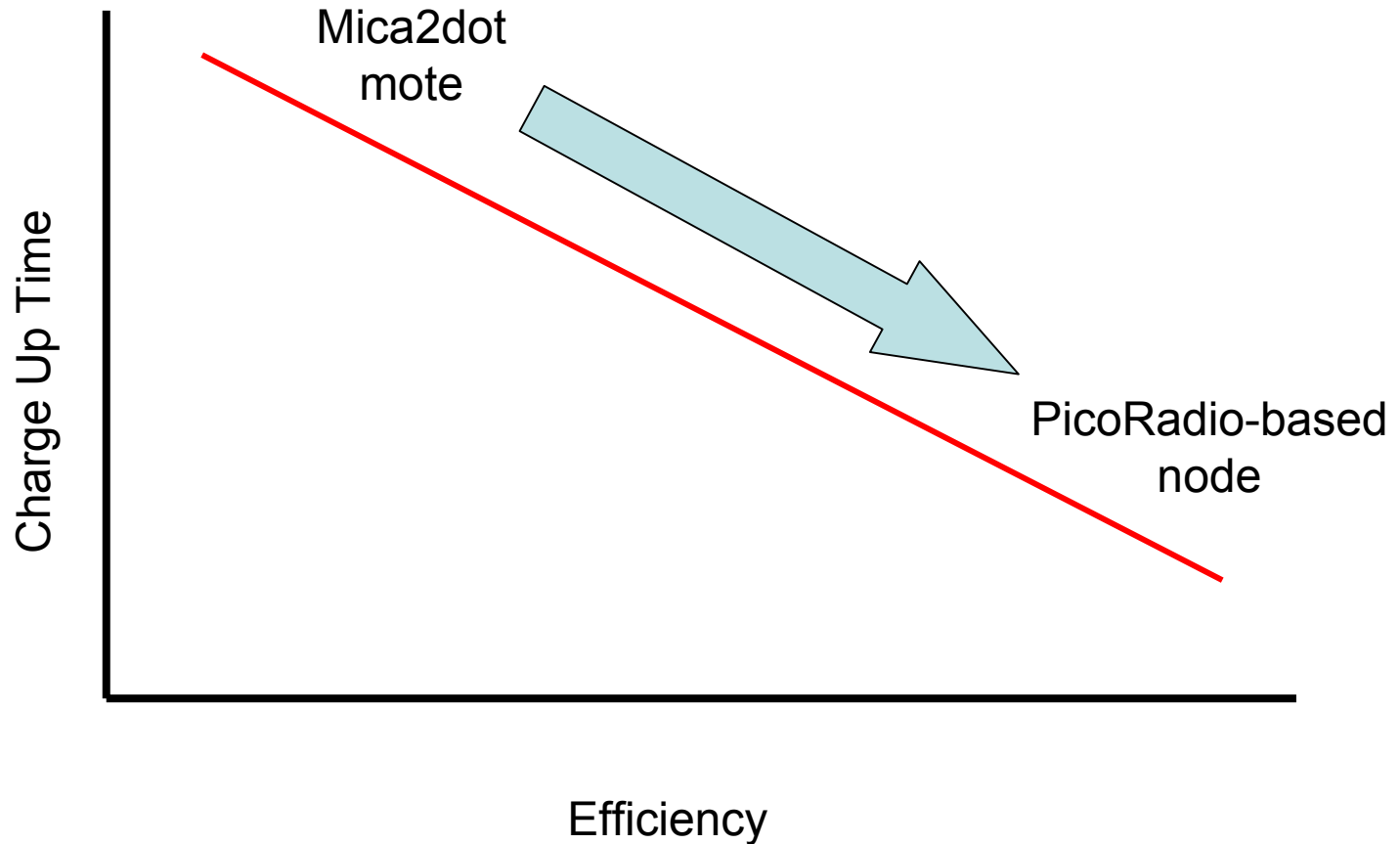
me@ELAINE /opt/tinyos-1.x/tools/java
$ java net/tinyos.tools.Listen
serial@COM1:19200: resynchronising

me@ELAINE /opt/tinyos-1.x/tools/java
$ java net/tinyos.tools.Listen
serial@COM1:19200: resynchronising
FF FF 0A 7D 08 01 00 01 00 01 00 09 02
FF FF 0A 7D 08 01 00 09 00 01 00 0A 02
```

Results

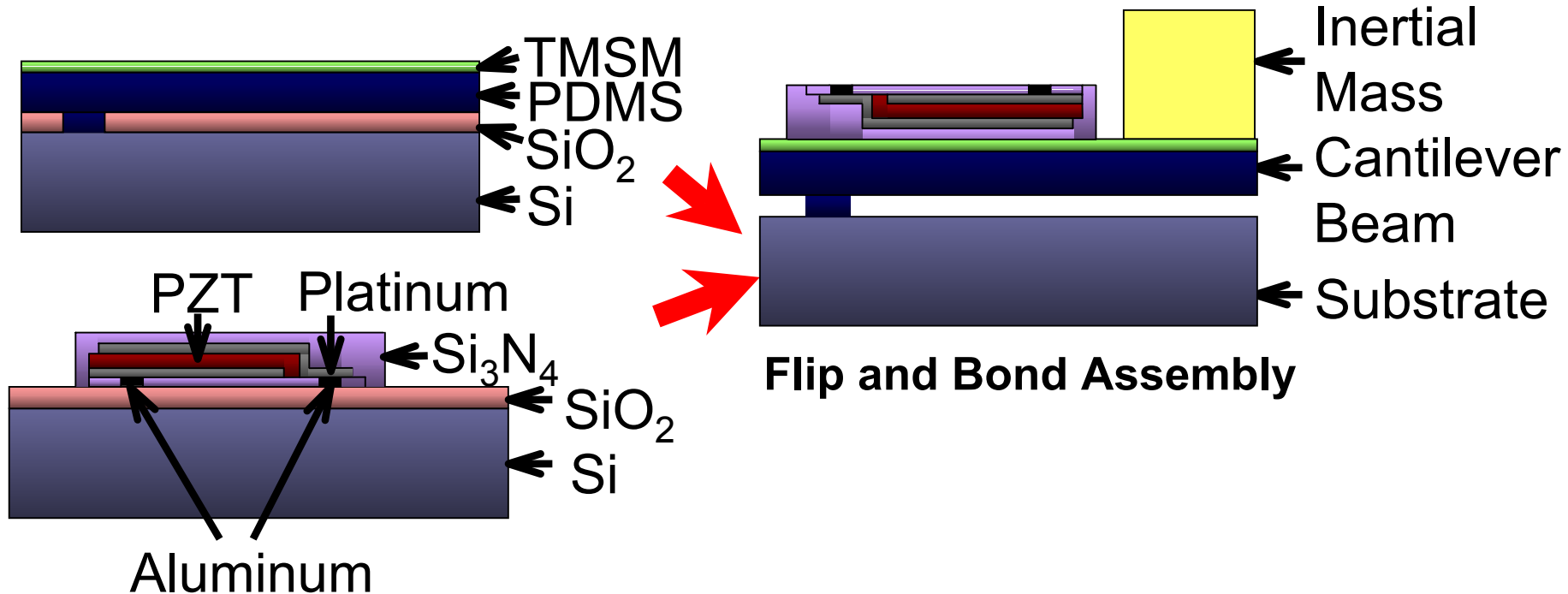
- 3.28 V for 816 ms
- 2 temperature readings transmitted

Next Steps



Next Steps

Design a variable resonant frequency MEMS bender which adapts to vibration sources with different peak frequencies.



“Network testbed & energy scavenging”

End/Summary/Questions/See Demo

