Development of Net Zero Energy Wireless Sensor Networks using Ultrathin, Flexible Supercapacitors

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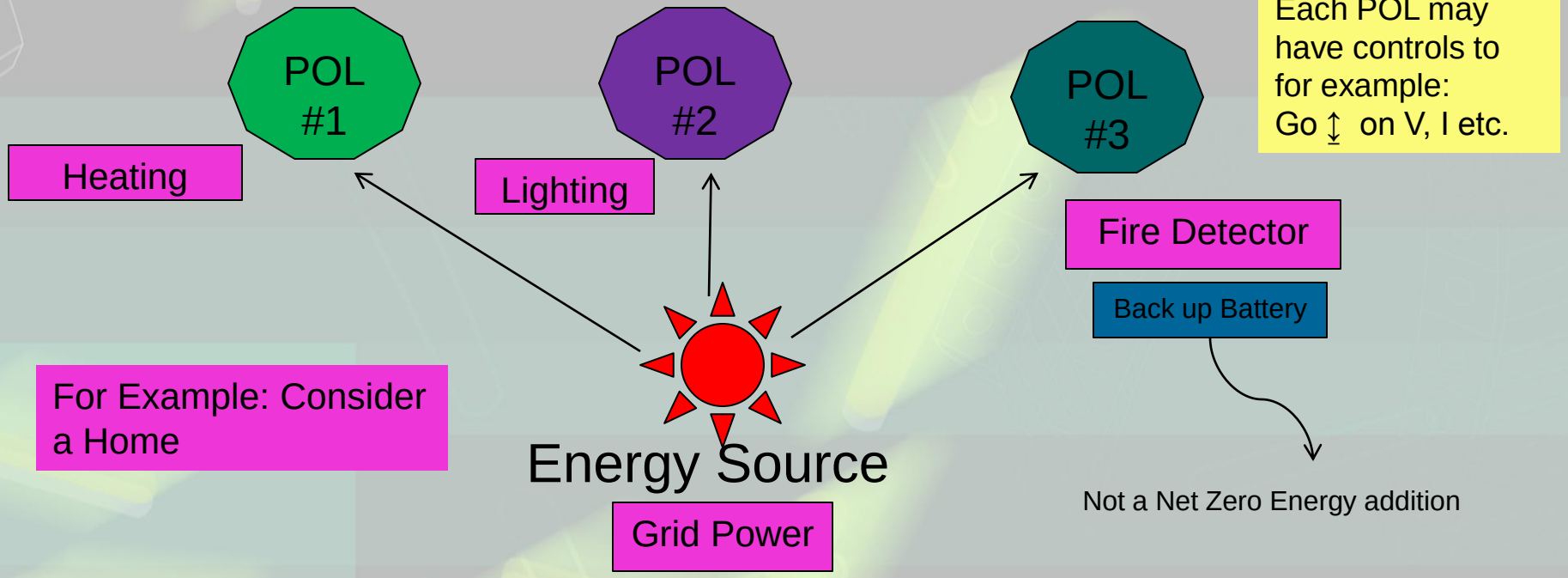
Understanding "Net-Zero" Energy Use
An Example

- In general, energy use can be understood by "breaking down" to various "Points of Load" connected to an energy source.



Net Zero Energy devices/components/networks do not add to the load.

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Net-Zero Energy components/devices/networks

Have no energy of their own

Do not add to the load (energy used)

Operate by harvesting energy that was previously being wasted

more efficient energy use

do more with same energy use

reduce carbon footprint

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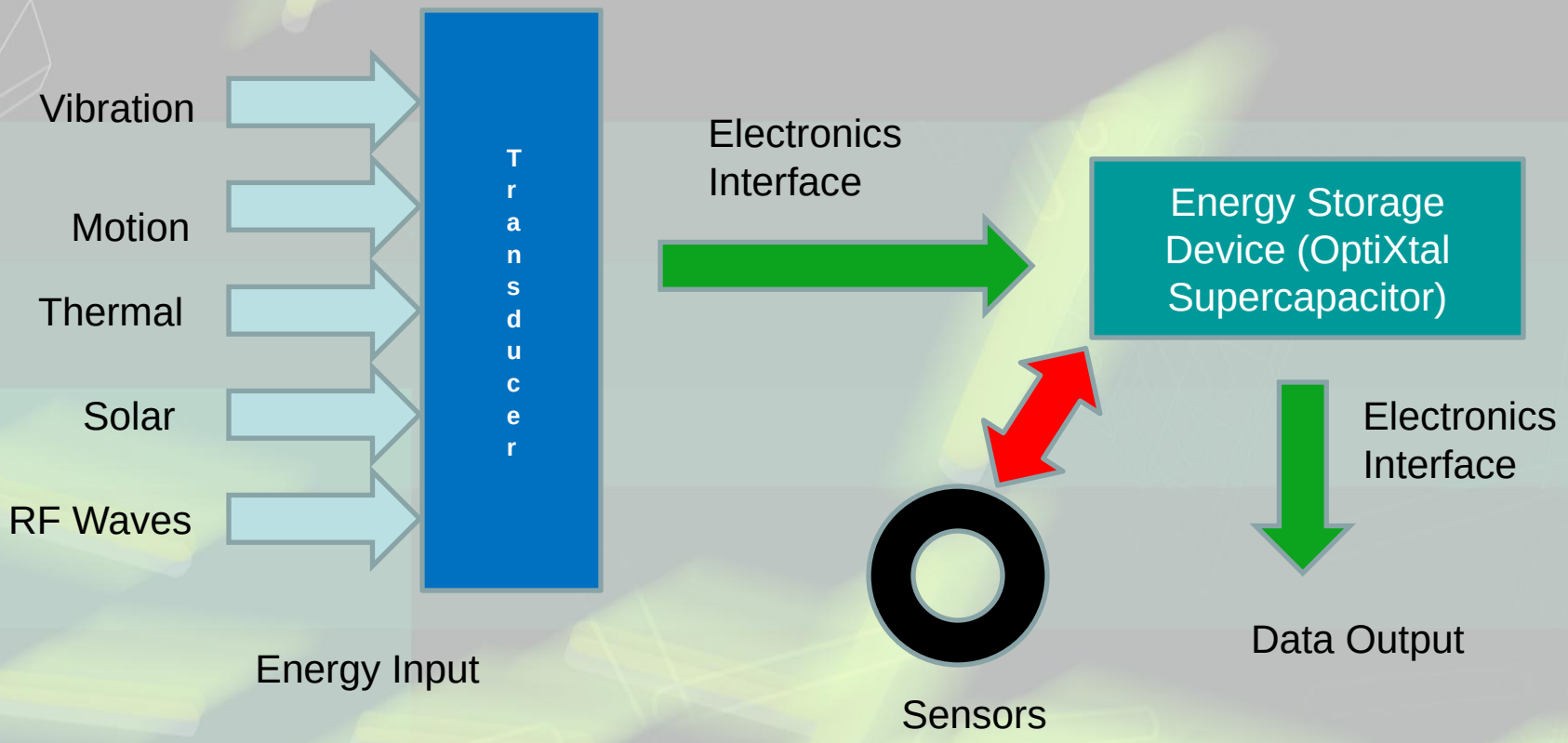
Energy Harvesting Block Diagram



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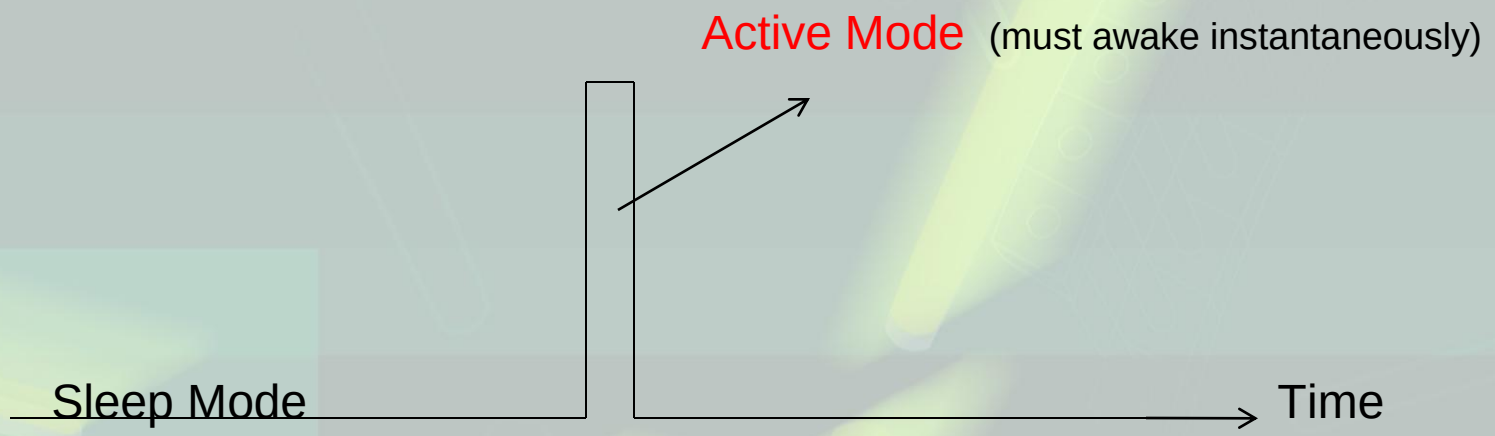
Applications where Supercapacitors rule

Duty Cycle (Awake time %) < 0.1%



During Sleep Mode: Trickle charge Supercapacitor by harvesting ambient energy

During Active Mode: Discharge the supercapacitor to output information

Low Energy Density is not an impediment, but (you will see that) Form Factor is critical

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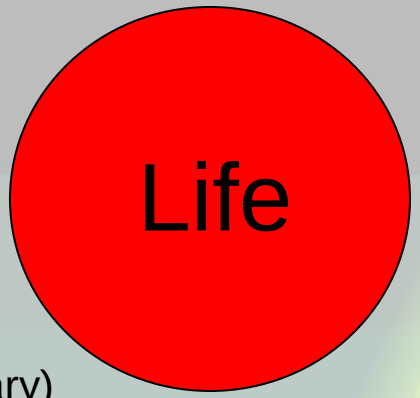
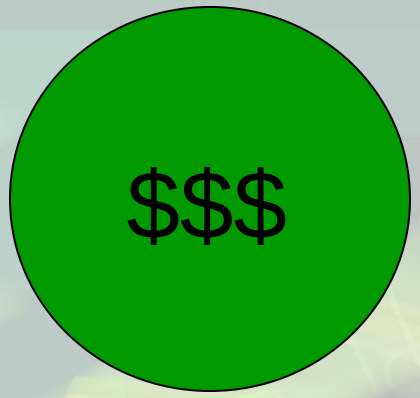
This Technology Can be deployed in Three Broad Areas

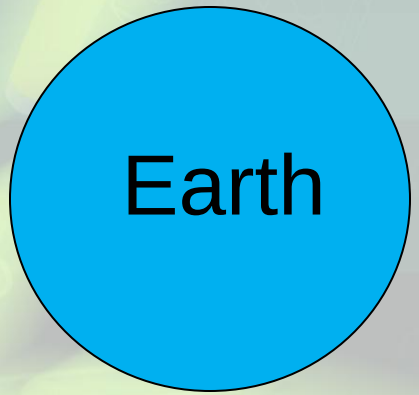


•Automobile Safety (V2V Communication)
•Terrorism Prevention
•Medical Equipments/Devices
•Infrastructure

Applications: (Industrial, Civil, Military)

•Efficient Buildings
•Efficient Autos
•Efficient Machineries





•CO_2 emission
•Less natural resource consumption
•Less noise/heat

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The Focus of Today's Presentation

- Example of Net Zero Energy Networks in Commercial Buildings
  - Easy, cost effective and fast way to reduce greenhouse gas emissions and save money
  - Retrofit existing buildings or add in to new buildings (LEED Certification?)
- Infrastructure Monitoring
  - Second example of the applicability of this technology
  - Proves robustness

OptiXtal's Supercapacitors unique properties that made this possible

- Form Factor
- Ultrathin, flexible
- Small Size (as small as 8 mm x 12 mm x 0.8 mm)
- Low leakage current
- Low cost

Facts About Energy Use in Commercial and Industrial Facilities in the US

Combined number of commercial buildings (4.8 million) and industrial facilities (350,000) in the United States: over 5 million

Combined annual energy costs for U.S. commercial buildings ($107.9 billion) and industrial facilities ($94.4 billion): $202.3 billion

Combined percentage of U.S. greenhouse gas emissions generated by commercial buildings (17 percent) and industrial facilities (28 percent): 45 percent

Portion of energy in buildings used inefficiently or unnecessarily: 30 percent

Source: http://www.energystar.gov/ia/business/challenge/learn_more/FastFacts.pdf

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10% improvement in efficiency and/or reduction in unnecessary use

in Commercial and Industrial buildings:

- Money saved : **$20 billion**

- Greenhouse gas emissions reduction ≈30 million vehicles

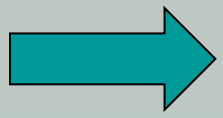
(*Number of registered automobiles in Illinois, New York, Ohio, and Texas combined: ≈30 million vehicles*)

How easy is it to achieve 10% improvement in efficiency and reduction in unnecessary use?

Simply Turning off unneeded lights

Automatic Dimming of lighting in Daylit Spaces

Manual Dimming of lighting according to Personal Preferences



Savings of 0.5 Quadrillion BTUs per year

or 14% of annual energy use for Lighting in Commercial Buildings.

or 7% of annual energy used in commercial buildings

(assuming that building energy costs are equally shared by lighting and HVAC (Heating, Ventilation and Cooling))

Typically, Lighting constitutes 30%-50% of a building's energy use

To Get to 10% savings, we will need to save an additional 3% from contributions to HVAC costs.

Source: US Patent 7 884 727 B2

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Reducing unneeded HVAC Costs and Other Savings

- Allowing unoccupied rooms to get cooler in winter and warmer in summer
- Additional reduction in energy consumption > 3%

  Realistic expected total savings : HVAC ≈ 5%-10%

  Lighting 5%-10%

  Total Savings = 10% – 20 %

  Note: This data is for Commercial Buildings
- And what if residential buildings are also included? Double The Savings.

Residential buildings use 21 % of the U.S. total energy, while commercial buildings use 19 %

Energy use in buildings costs ≈$400 Billion/year

DOE's multi-year plan for the three components of the Buildings Regulatory Program: Appliance and Equipment Efficiency Standards, ENERGY STAR, and the Building Energy Codes Program (2006).

We estimate total savings of ≈ $40 Billion per year in the US alone!

(And a Big reduction in Greenhouse Gas Emissions)

Clearly there is a big market for intelligent building control and automation

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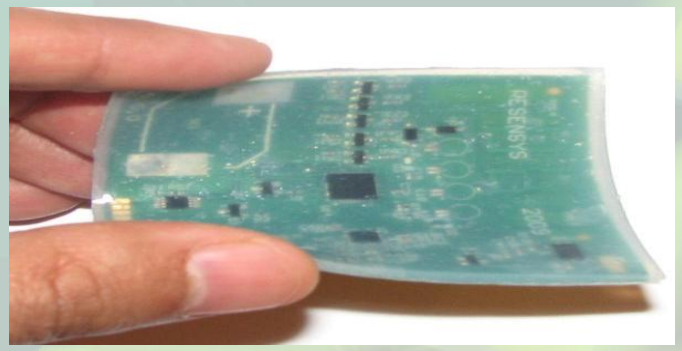
What is GreenPatch?

Device used for monitoring and optimization of among other things, building energy usage

- ✓ Wireless operation
- ✓ Detecting Occupancy/motion
- ✓ Measuring energy usage per zone (lighting, HVAC, temperature)
- ✓ Providing energy saving recommendations
- ✓ Micro-actuating: sending automated commands to turn on/off lighting, HVAC

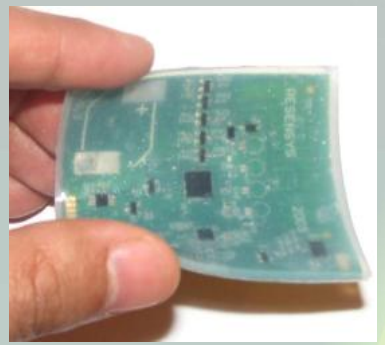


GreenPatch for building energy efficiency

Technical Specifications

Mechanical

- Thin film sensors, mechanically flexible
- Thickness: 1.2-2mm
- Weight: 9.1g
- Minimal installation effort
- Easy retrofit to existing infrastructure



Measurements

- Temperature
- Light intensity
- Air flow
- Strain (force)
- Vibration
- Motion

Energy

- Harvest ambient light
- Store in OptiXtal's Supercapacitors
  - Supercapacitor life – 500,000 cycles (battery is 500)
  - No need to change batteries
  - Can be deployed in remote/harsh locale
  - High pulse current capability of supercap (> 1A) – signal transmission range can exceed 0.5 -1 mile
- Guaranteed energy availability in sensors, over 45 hours dark time
- Need 1 GreenPatch per 100-200 Sq. Ft.

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GreenPatch Sensor Data Protocol

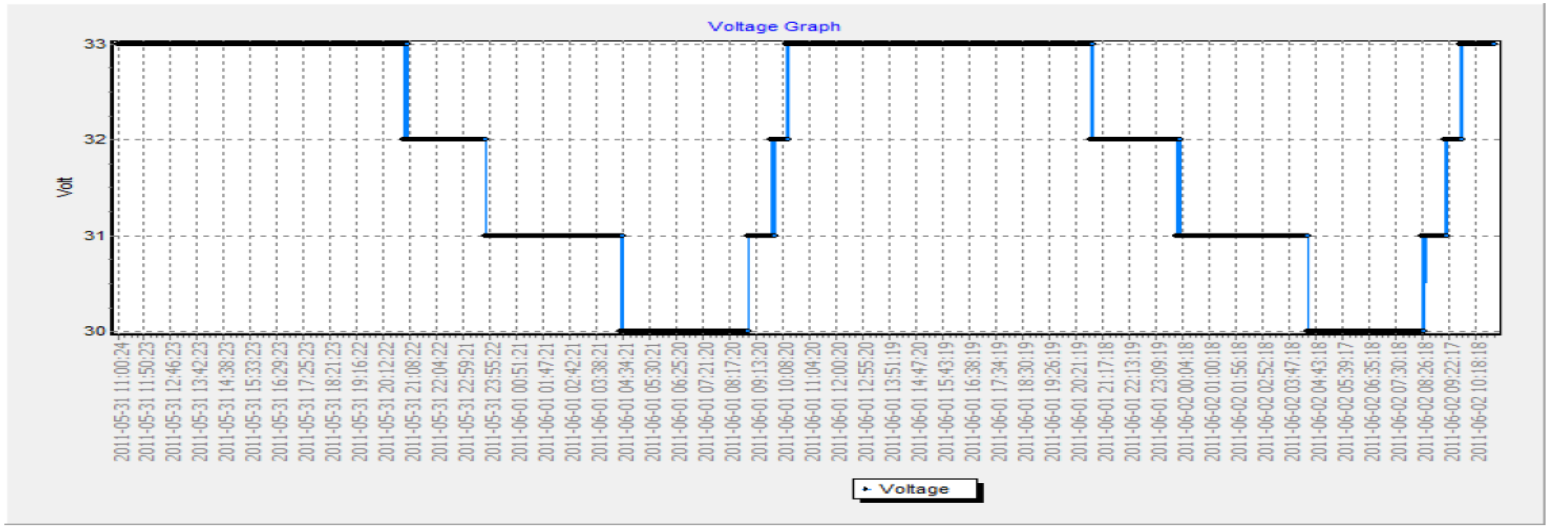
- The sensors stay in sleep mode most of the time - make one transmission of a 58 byte packet every 6 minutes to synchronize with a data collector /or whenever there is motion.
- The communication takes approximately 3-4 milliseconds and the transmit power is 100mW – active time = 4 ms/240 s x 100 = 0.002% (Sleep time = 99.998%)
- The sensors and supercapacitor field tested in a room with a window to outside -receive energy during the day and use the energy collected in the daytime during the dark hours- Dark time is about 14 hours

Field Test – Supercapacitor

- Two OptiXtal 1F, 2.7 V, ultrathin, flexible, supercaps in series
- Three 1.8V IXYS small solar cells used to charge the supercaps
- Protection circuit disconnects the solar cells from the system when the voltage across the supercaps reaches 3.3V

Room has window but no indoor light
Voltage measured over 2 days

Drops show energy depletion as a result of consumption and self discharge at night and increases show charging (in excess of consumption) by ambient light during day



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Analysis of the Performance of Supercap

- Charge/self discharge graph repeats over 48 hours
- Voltage drops from 3.3 V to 3 V at night (in decrements of 0.1V)
- At no time does the voltage drop below 3 V
- During the day, rapidly charges up to 3.3 V
- We calculate – can continue to operate for up to 45 hours with no sunlight (voltage will go down to 2V – sensors cannot operate below 2V)

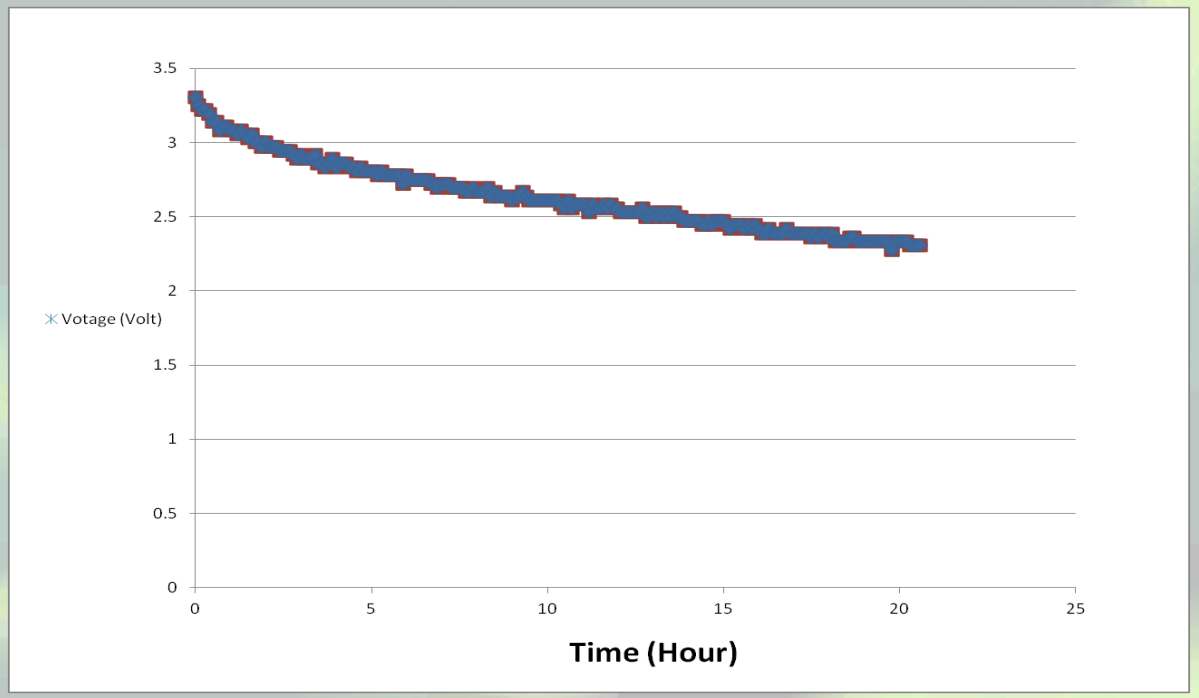
- Competitor's Supercapacitor dropped to 2.8V
  - Higher Leakage Current
  - Fewer hours of operation with no sunlight

Field Test–Motion Detector

- Two OptiXtal 1F, 2.7 V, ultrathin, flexible, supercaps in series
- Connected to a low power wireless sensor equipped with a low power motion detector device

Leakage current = 0.96 µA

Room with no window and no indoor light



Voltage at 10 hours	2.61111111
Voltage at 20 hours	2.33333333
Capacitance (F)	0.5
Current drawn from supercapacitor	3.858E-06
Consumption of sensor with motion detector	2.90E-06
Leakage	9.58E-07

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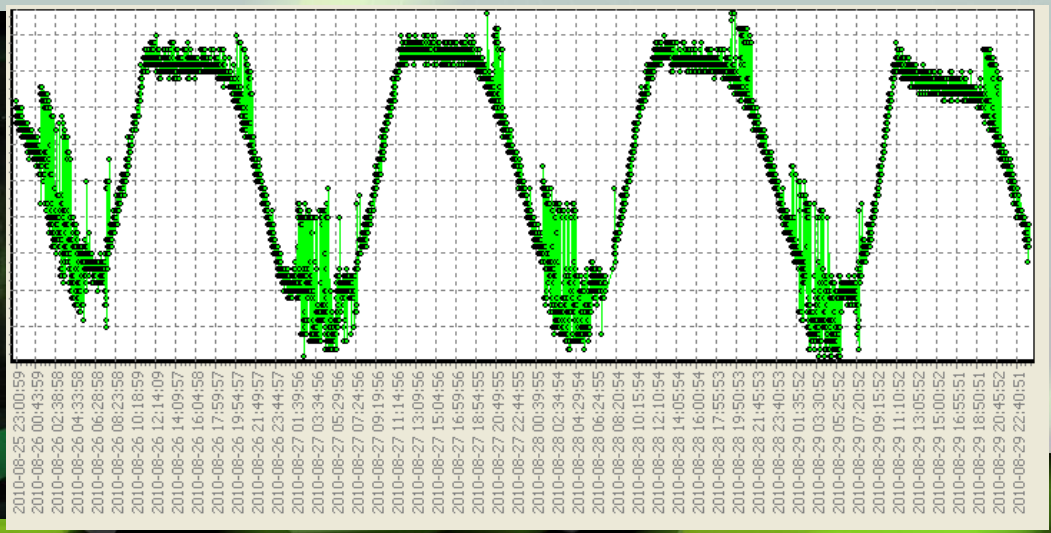
GreenPatch for Infrastructure



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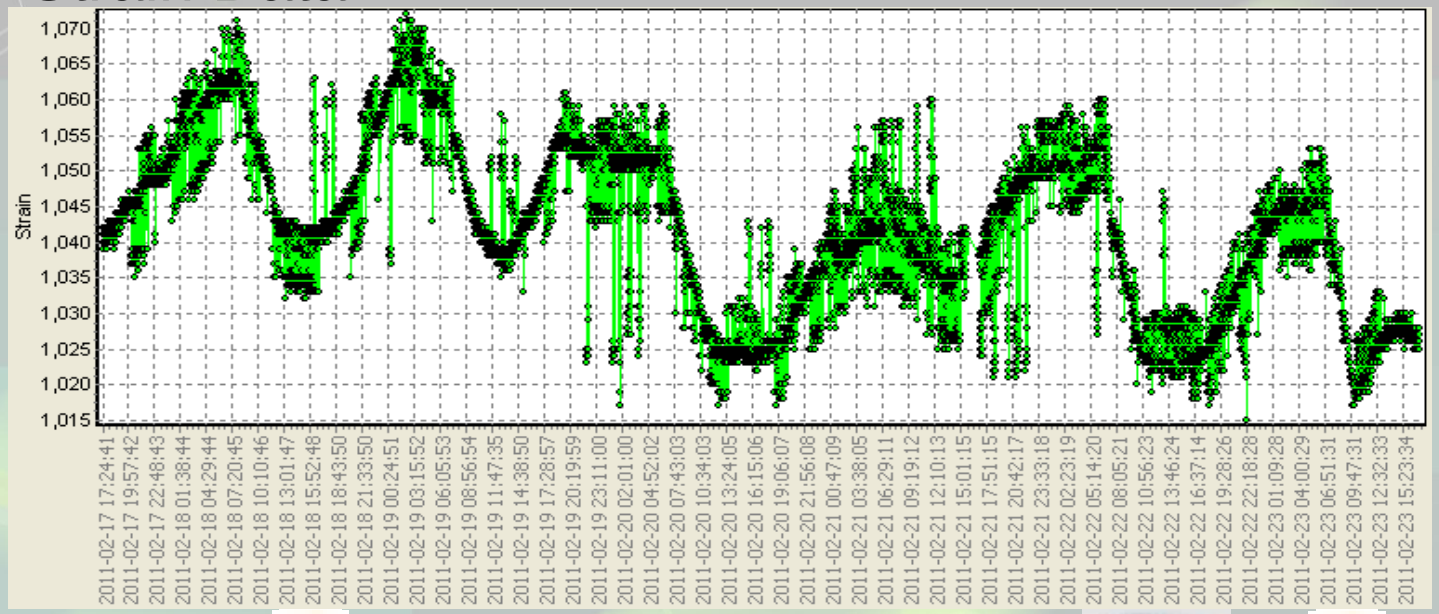
Robust Weather-Proof Operation

A seven-day strain graph of a GreenPatch installed on Northwest Branch bridge on **Capital Beltway (I-495).** Data collected from 2/17/11 to 2/23/11.

Strain Data



2/17 2/18 2/19 2/20 2/21 2/22 2/23

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Conclusions

- OptiXtal Supercaps have been integrated into Resensys' GreenPatch to create a net zero energy wireless motion sensing, advisory and actuating system
- Easy to install, flexible patch can generate energy savings of up to 40% - pays for itself
- Sensors are asleep more than 99% of the time
- Solar cells harvest energy from ambient light and store them in supercaps
- Supercaps can provide power to the sensor for up to 45 hours in the absence of ambient light (voltage will go down to 2V)
- Similar smart monitoring can also be implemented in any sensor technology that enhances safety, economy and environment

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Thank you

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