

The logo for enerpak™ is rendered in a red, lowercase, sans-serif font with a white outline. The trademark symbol (TM) is positioned at the top right of the 'k'.

**enerpak™**

**Endless Power for Autonomous Devices**

**TPL, Inc.  
Fall, 2010**

The logo for enerpak™ is displayed in a red, outlined, lowercase sans-serif font. The background of the slide features a 3D grid of white spheres connected by thin lines, receding into the distance.

The Ultimate Power Management System

Maximizes Energy Extraction from Energy Harvesters  
and

Optimizes Charge Utilization to Power Autonomous Devices

Under all Operating Conditions

# EnerPak – SBIR Phase II Efforts

## ● Army – Completed December 2006

- “Power Supply for Meso Sensors”
- Development of EnerPak System

## ● DARPA – Completed Sept 2006

- “Power Supply for Meso-Sensors”
- Development of Supercaps & Tunable Vibration Harvester (WSU)

## ● Air Force – Completed Oct 2006

- “Advanced Supercapacitors for Micro-Power Supplies”
- Development of SC – Electrodes & Electrolytes

## ● NASA – Completed Dec 2007

- “Power for Vehicle Embedded MEMS Sensors”
- Energy Harvesters Evaluation, Coin Cell SC, System Performance

## ● Air Force – Completed April 2008

- “ $\mu$ PowerChip – Power for Microsystems with Extended Missions”
- EnerPak System Development

# The Complexities of EH-Powered WSN\*

## ● Power Supply Characteristics of Energy Harvesters

- Low
- Variable
- Intermittent
- Unpredictable

## ● Power Demand Modes of Wireless Sensor Networks

- Sleep
- Data Acquisition
- Data Processing
- Node-to-Node  
Communications
- Data Transmission

\*An example of a challenging autonomous device

# A Versatile Power Management System is Needed

- Power Supply Characteristics of Energy Harvesting Devices

- Low
- Variable
- Intermittent
- Unpredictable



- Power Demand Modes of Wireless Sensor Networks

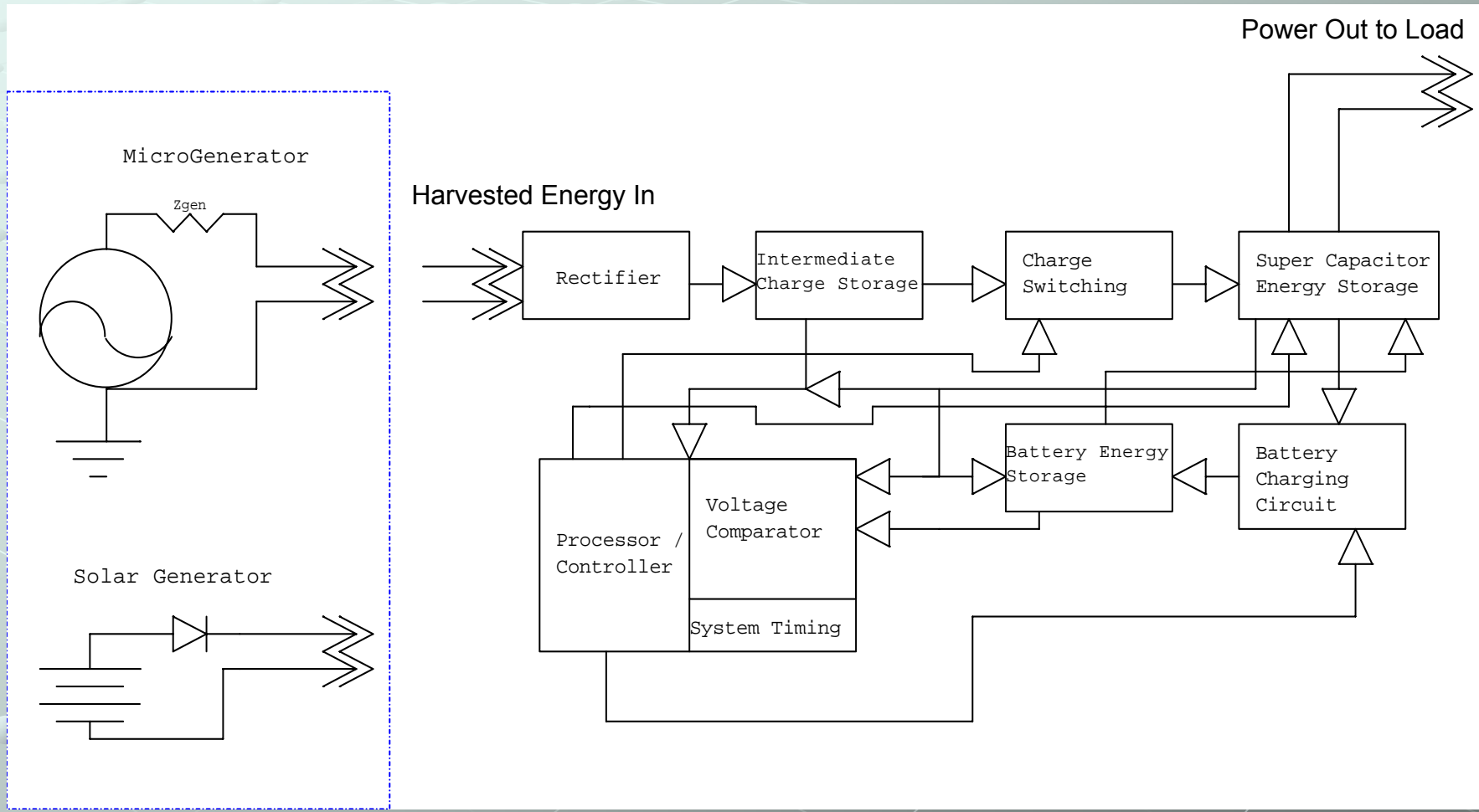
- Sleep
- Data Acquisition
- Data Processing
- Node-to-Node Communications
- Data Transmission

**Specifically Designed to Fill the Space  
Between  
Energy Harvesters and Autonomous Devices**

# Attributes of enerpak™

- Compatible with Wide Range of EH Outputs
- Optimizes Energy Extraction – Always Operates at EH Peak Power Output Conditions
- Charging Electronics & Energy Storage Device Combination Allows Charging at Very Low Power Levels
- Represents an “Always On” Power Supply
- Use of Supercaps for Load Requirements (Pulse Power) Provides Lifetimes of Hundreds of Thousands of Cycles
- Pulse Charging of Lithium Polymer Battery Increases Capacity Retention
- Pulse Charging of Lithium Polymer Battery Extends Lower Operating Temperature

# Schematic of the enerpak™



# enerpak™ Microcontroller

- Continuously monitors the state of charge of Harvester, Charge Pump, Battery and Supercaps
- Directs Charge Flow
  - Harvester – Direct to Supercap or to Charge Pump/then SuperCap
  - Supercaps – In Parallel, to Load; in Series, to Battery
  - Battery – Recharge Supercaps

# enerpak™ Charge Pump

- Continuously responds to the state of charge of Harvester and Supercaps

- Primary Functions

- Dynamically matches Harvester impedance to extract charge at maximum power output
- Dynamically controls charge delivery to the Supercaps based on rate of voltage increase

# enerpak™ and Energy Harvesters

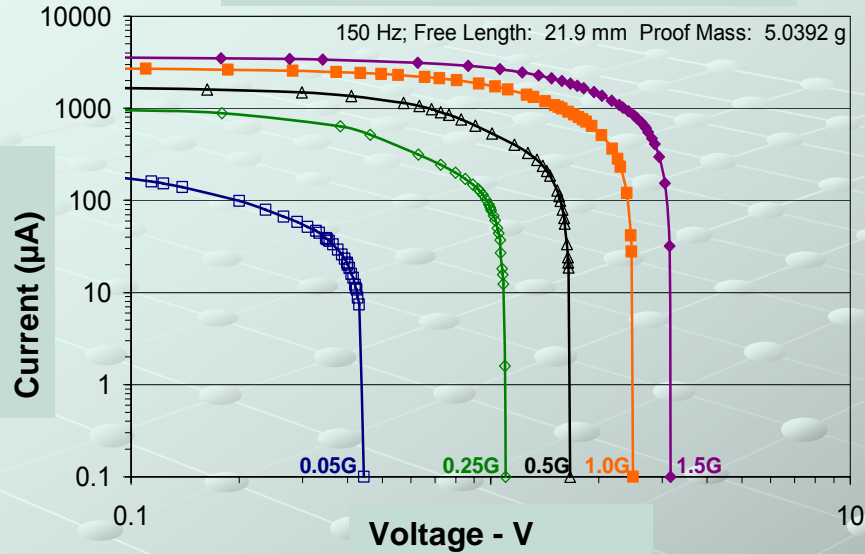
## Compatible with a Variety of Energy Harvester Outputs

- Photovoltaic
- Thermoelectric Generators
- Vibration Harvesters
- Radio Isotopes
- Fuel Cells

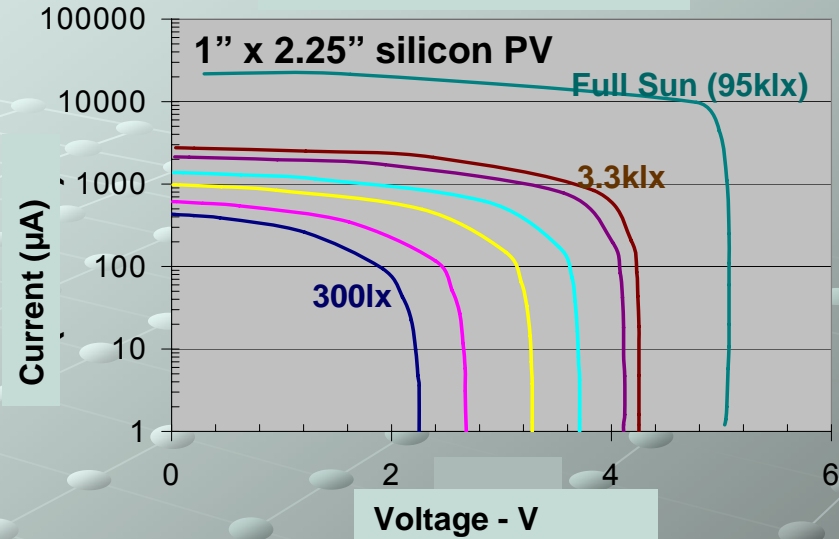
EH	Impedance	Voltage	Power
PV	Variable Low $K\Omega$ – $10s\ k\Omega$	DC 0.5-5V	$10\mu W$ -15mW
Vibration	Constant $10s\ k\Omega$ - $100s\ k\Omega$	AC $10s$ of V	$1\mu W$ -20mW
TEG	Constant $1\Omega$ - $100s\ \Omega$	DC $10s$ mV-10V	.05mW- 10mW

# Importance of Peak Power Output Matching Achieved Thru Dynamic Adjustment of Charging Module Impedance

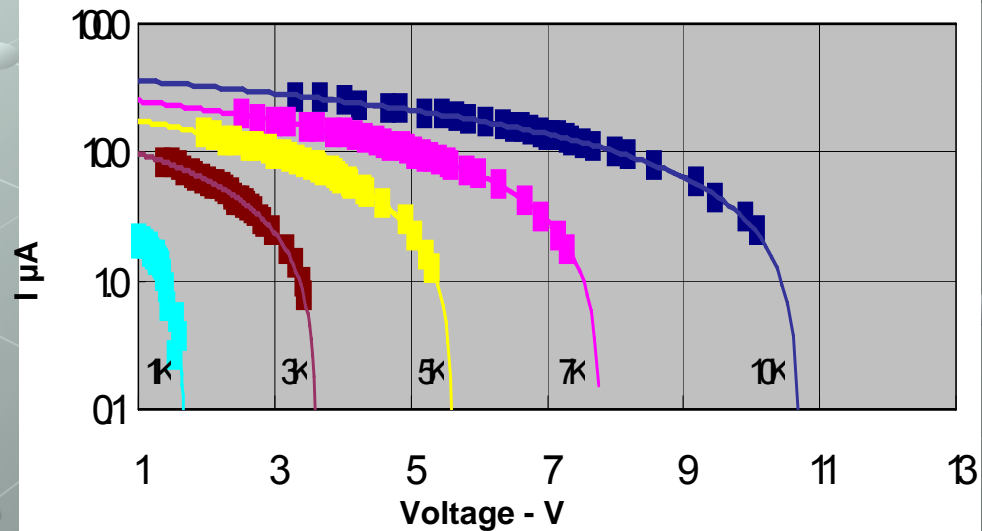
## Piezoelectric Vibration



## Photovoltaic Array



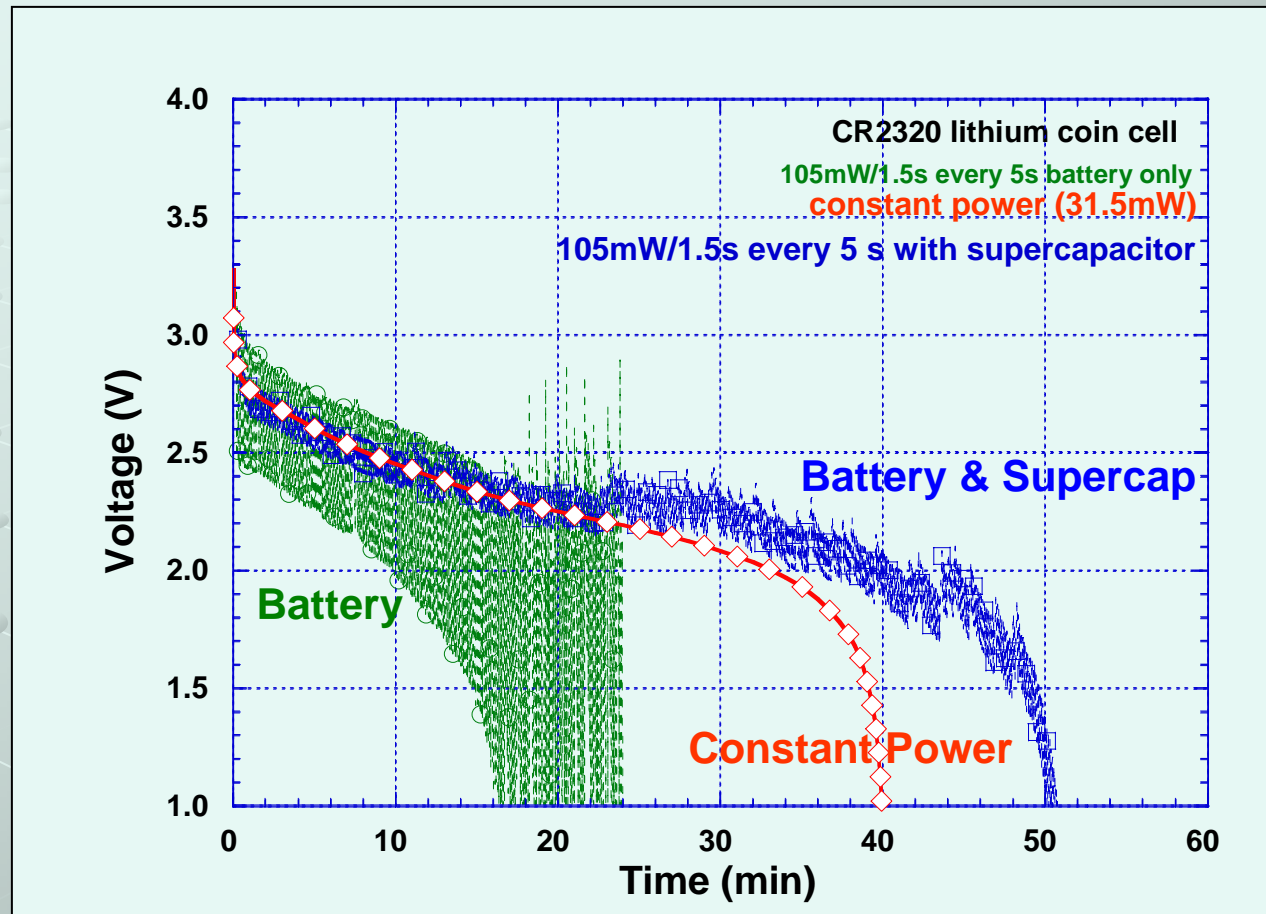
## Thermoelectric Generator



# Battery/Supercap Combination Exploits Storage Device Attributes

- **Supercapacitors = high specific power**
- **Batteries = high energy density**
- **Supercap serves as Initial Storage Reservoir**
- **Supercap provides pulse power to load**
- **Use of Supercap to Charge Battery  
(More Effectively Utilizes Available EH Energy)**
- **Battery Serves as Primary Storage Reservoir and  
Supercap Recharge Source**
- **Pulse Recharging of Battery Increases Operating Life  
and Operating Temperature Range**

# Attributes of the Battery/Supercap Combination



- Supercap far more efficient in delivering pulse power

# Charging the Li Polymer Battery From the Supercapacitor

## ● Charging Requirements

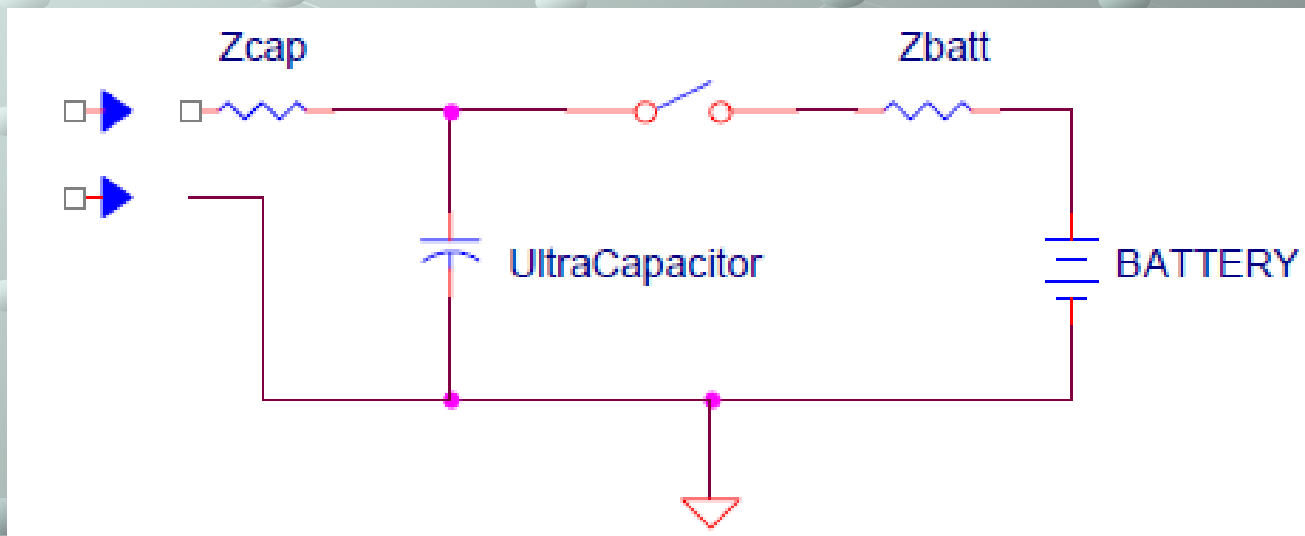
- Charging current must be sufficient to maintain charging voltage
- Charging current cannot overpower the battery
- Charging voltage must be greater than present voltage in battery

## ● Charging Feasibility Direct from Harvester

- Often difficult to meet charging current requirements

## ● Charging Feasibility from Supercapacitor

- Charging current can be controlled
- Charging voltage can be controlled



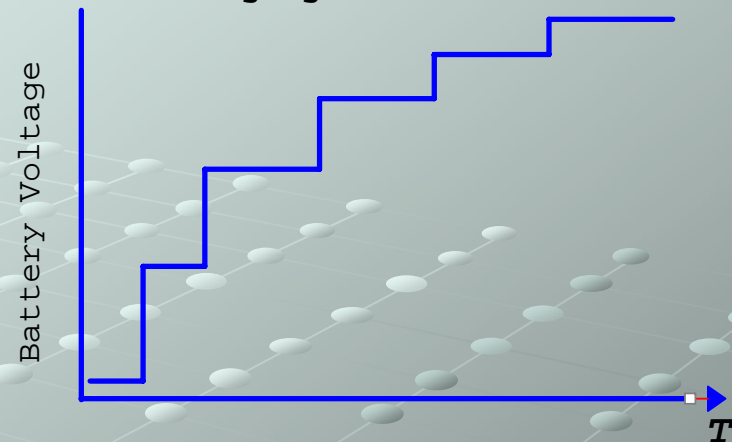
# Pulse Charging the Li Polymer Battery

At low harvested power input, it is not feasible to charge a Li polymer battery with the conventional CC/CV charging profile.

Pulse charging the battery is an effective approximation to the Li Polymer conventional charging profile.

In the charge cycle, at the constant current – constant voltage transition point, as the voltage of the battery increases, the charge current decreases in an exponential fashion.

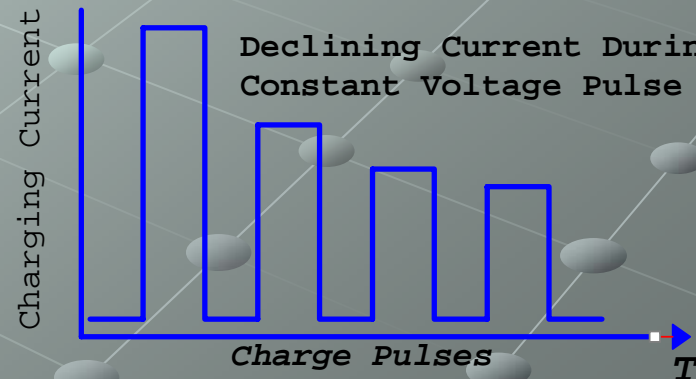
Voltage Profile With Pulse Charging At Constant Current



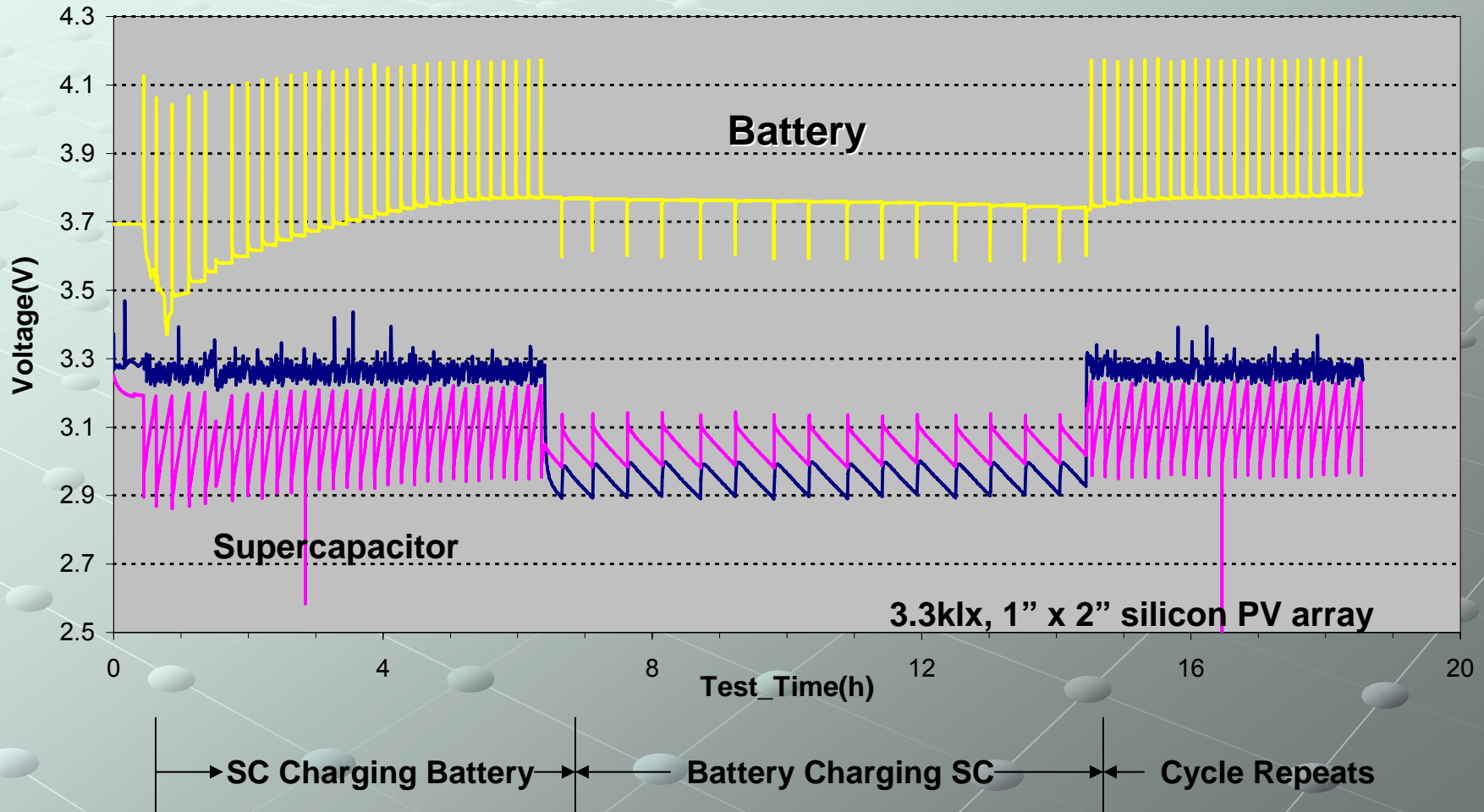
Constant Voltage Pulse Charging



Declining Current During Constant Voltage Pulse Charging



# EnerPak Provides Continuous “Day & Night” Power “Always On” Power



# Summary

- EnerPak makes energy harvested power a practical source of energy for autonomous devices
- EnerPak charging electronics allow safe and optimized charging of energy storage components at *very low power*
- EnerPak system performance optimizes the available power from harvesting throughout device load power cycles
- EnerPak power management system has resulted in a product that electrically looks like a battery:
  - Always on
  - Provides stable, regulated voltage
  - Can deliver power over the full range of levels demanded by wireless sensors and other self-powered devices
- EnerPak leverages and improves the stand-alone performance of lithium-polymer and other rechargeable batteries
- EnerPak can be discrete or semi-conductor solution