

Energy Harvesting For Zero Power Wireless Networks

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Agenda

Solid-State Energy Solutions



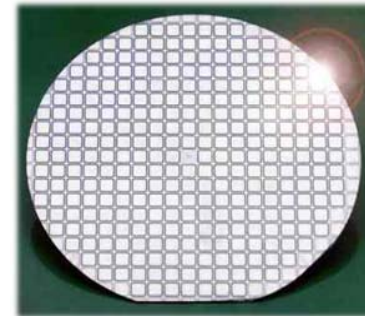
- Introduction to Cymbet
- Applications for Thin Film Batteries
- EnerChip™
 - Battery Construction
 - Battery Packaging
 - Electrical Characteristics of Battery
- EnerChip CC3150
 - Backup Applications
- Energy Harvesting
 - Self Powered RF Evaluation Module
- Low Power RF Systems
- Design Considerations for Low Power
 - Radio specifics
 - Estimating power requirements RF Systems
- Transducer Selection and Design Considerations
- Summary

Cymbet's Business:

Solid-State Energy Solutions



- Established in 2000:
 - 38 employees (mostly technical)
- Cymbet has 40 patents applied/granted including DOE technology licenses
- Component packaged device:
 - Solid-state batteries on silicon
 - Thousands of recharge cycles
 - Low self-discharge, flat voltage profile
 - IC processing, packaging, reflow tolerant
 - Enables high-volume SMT manufacturing
- Environmentally-friendly:
 - No harmful chemicals, RoHS
- EnerChips can be integrated with ICs
- Enables permanent, self-powered systems



IC Packaging &
Bare Die

Cymbet Widely Recognized as an Industry Innovator



2009 Best Enabler Award
for Green Engineering
EnerChip EH Demo Kit



Best of Sensors Expo
2008 Gold Award



2009 Most Innovative
Renewable Energy Award
EnerChip EH Module



Frost and Sullivan 2008 Best
Practices Award for
Innovation in Battery
Technology



2009 Editors Choice for
EnerChip CC



Tekne 2008 Award Winner for
Best Small Advanced
Manufacturing Company



2009 Readers Choice for
EnerChip EH Solar
Energy Harvesting



Embedded Computing Design
Editors Choice Award 2008

Cymbet EnerChip™:

Integration Drives Low Cost & High Volume



Embedded power at chip level or as SMT component:

- ✓ *Thousands of cycles*
- ✓ *SMT-compatible*
- ✓ *Reflow tolerant (260°C)*
- ✓ *RoHS compliant*

- ✓ *Fast recharge*
- ✓ *Low profile*
- ✓ *Eco-friendly*
- ✓ *Low self-discharge*

Many Applications in High Growth Markets

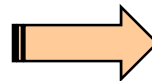
- ✓ *Real-time clocks*
- ✓ *Microcontrollers*
- ✓ *NVSRAM*
- ✓ *Supply supervisors*



- ✓ *Wireless sensing*
- ✓ *Energy harvesting*
- ✓ *Holding time/memory*
- ✓ *Medical devices*

Enabler of Energy Harvesting

- ✓ *Solar*
- ✓ *Thermal*
- ✓ *Motion/Vibration*
- ✓ *Electromagnetic*



- ✓ *Permanent sensors*
- ✓ *Process and control*
- ✓ *Active RFID*
- ✓ *Medical devices*

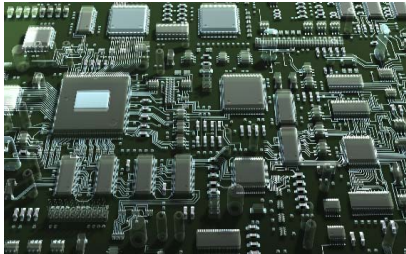
EnerChips for Energy Harvesting and Back-up Power



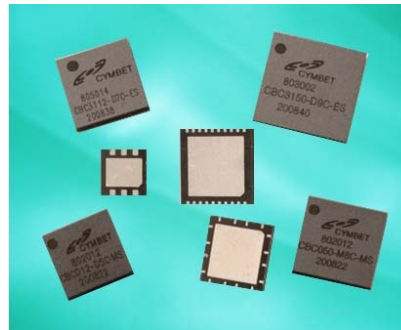
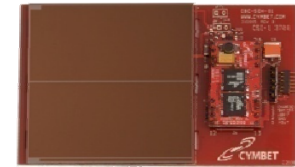
EnerChip products enable two important market solutions:

- **Permanent, Self-Powered Wireless Sensors**
- **Drop-in Back-up Power w/Battery Management**

Back-up Power Solutions



Energy Harvesting Devices



EnerChip Product Family

Typical Markets and Applications



Applications

- RTC back-up
- Microcontroller keep-alive
- SRAM – non-volatility
- GPS – Warm Start
- Power mgm't systems
- Transition power
- Point-of-load power
- Energy harvesting
- Wireless sensors & Data logging

End Equipment

- RAID controllers
- Point-of-sale terminals
- Copy and FAX machines
- Medical and test equipment
- Embedded systems
- PCMCIA cards
- Blade servers
- Networking & hubs
- Test equipment
- SmartCards
- PDAs & SmartPhones
- PABX systems
- GPS Navigation
- Industrial control
- Handheld/portable devices
- Consumer devices
- Thermostats
- Set-top boxes
- Appliances
- Wireless sensors
- Single-board computers
- Digital cameras
- Consumer radios/clocks
- Utility meters

EnerChip™ Construction



Single 6-Pin or 16-Pin SMT DFN/QFN Package

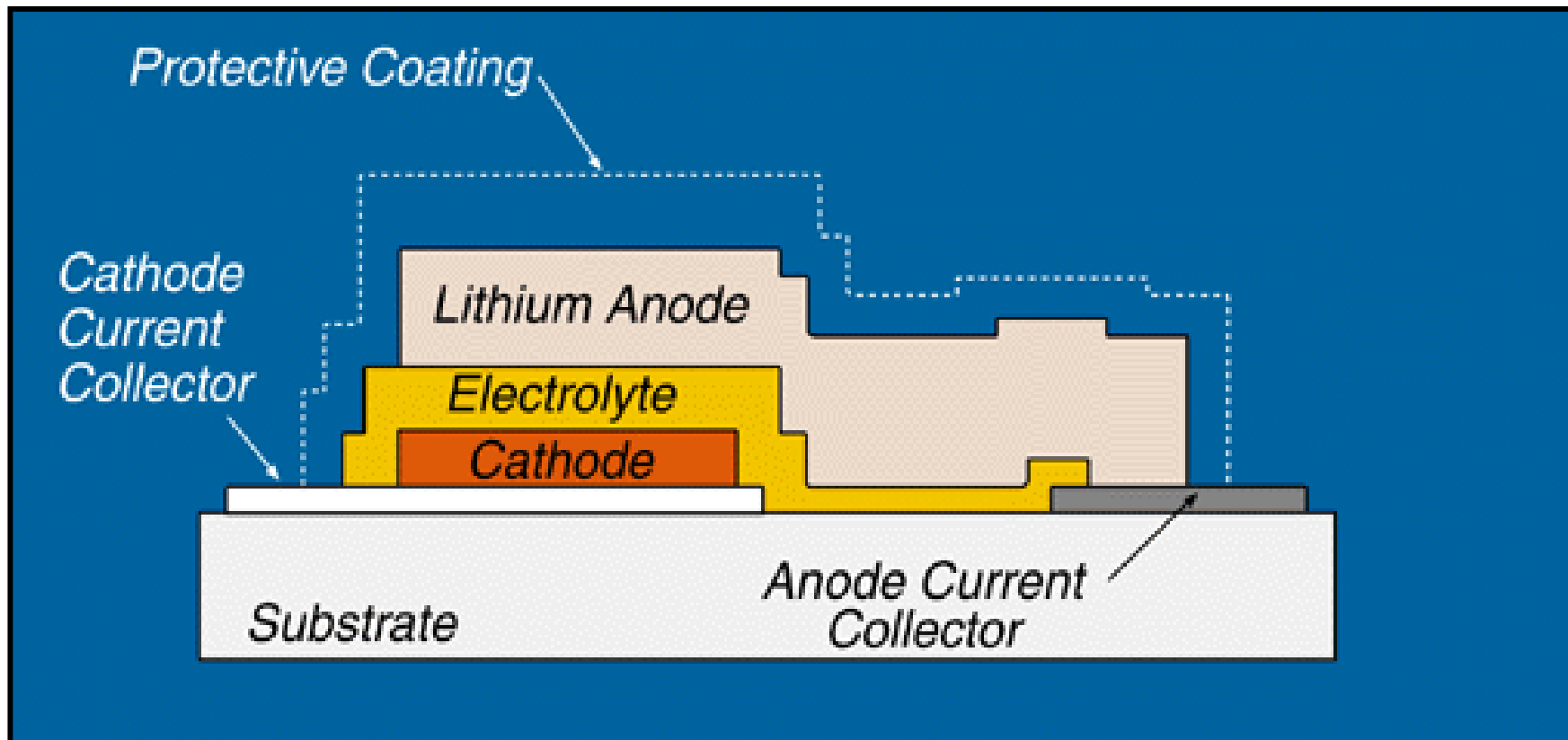
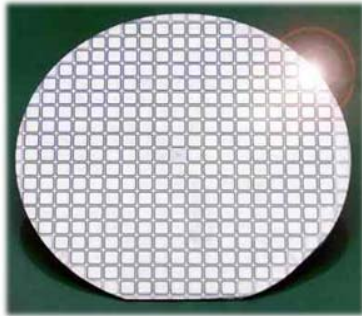


Image Courtesy DOE-ORNL

EnerChip™ Assembly Process



EnerChip Wafer



EnerChip Die

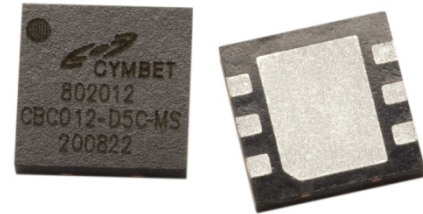


Diced



Packaged

EnerChip Package



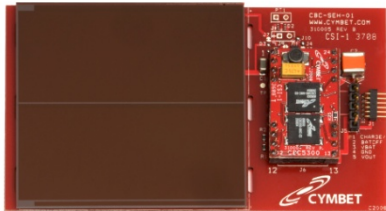
*To Surface
Mount Machine*



*To Reflow
Solder*



*Final
Assembly*

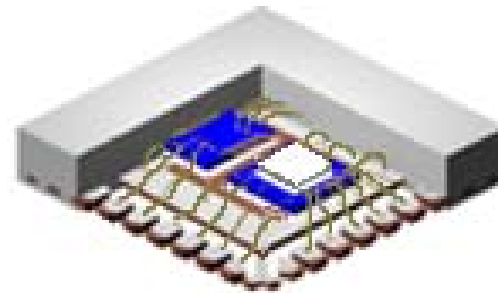
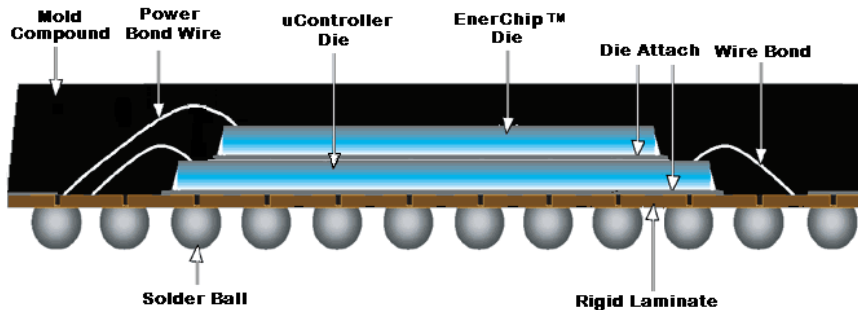


**EnerChip on
Board**

EnerChip™ Embedded

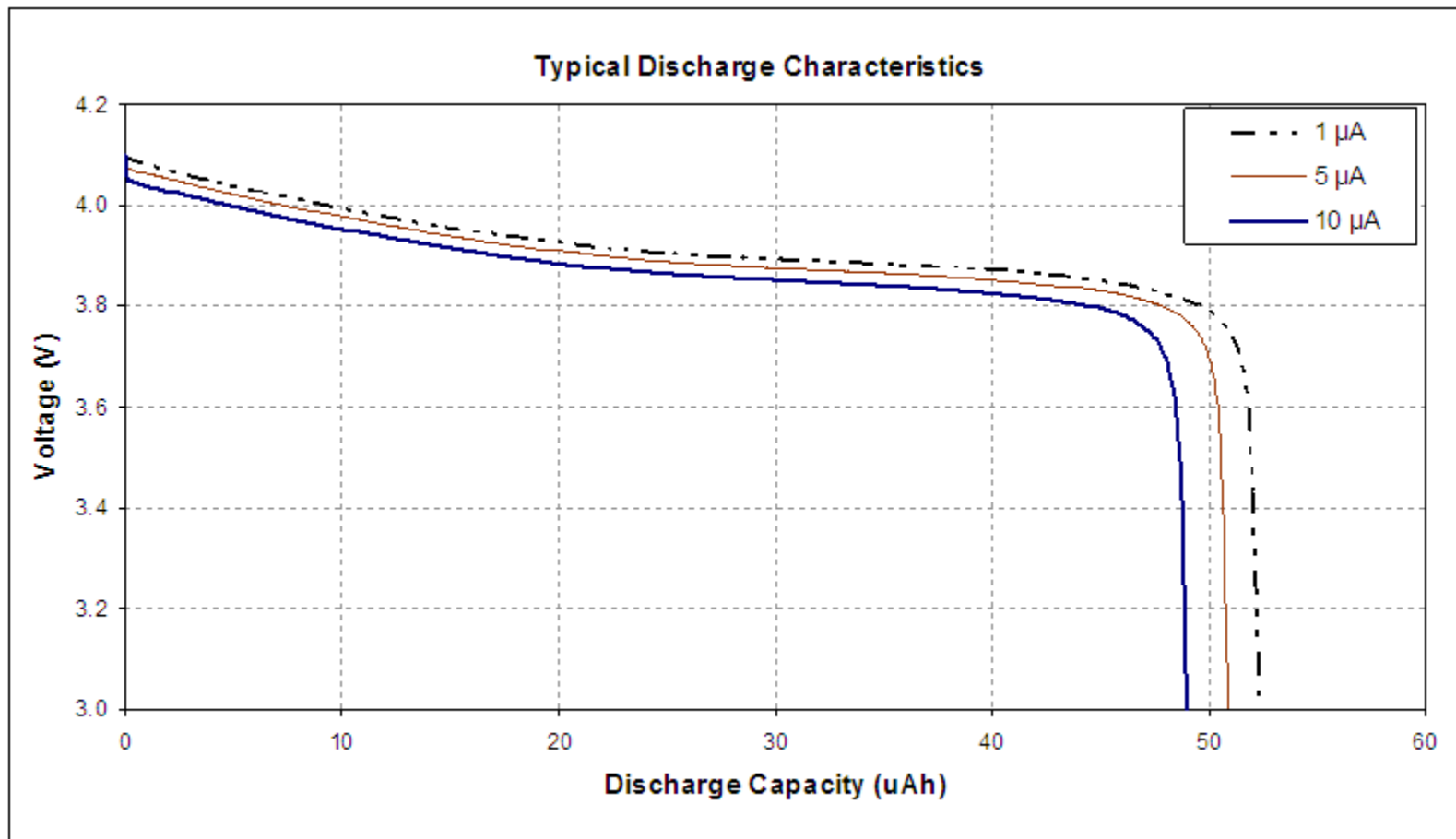


- Solid-State EnerChips enable embedded back-up batteries in uControllers & RTCs:



- Power Management packaged with EnerChip

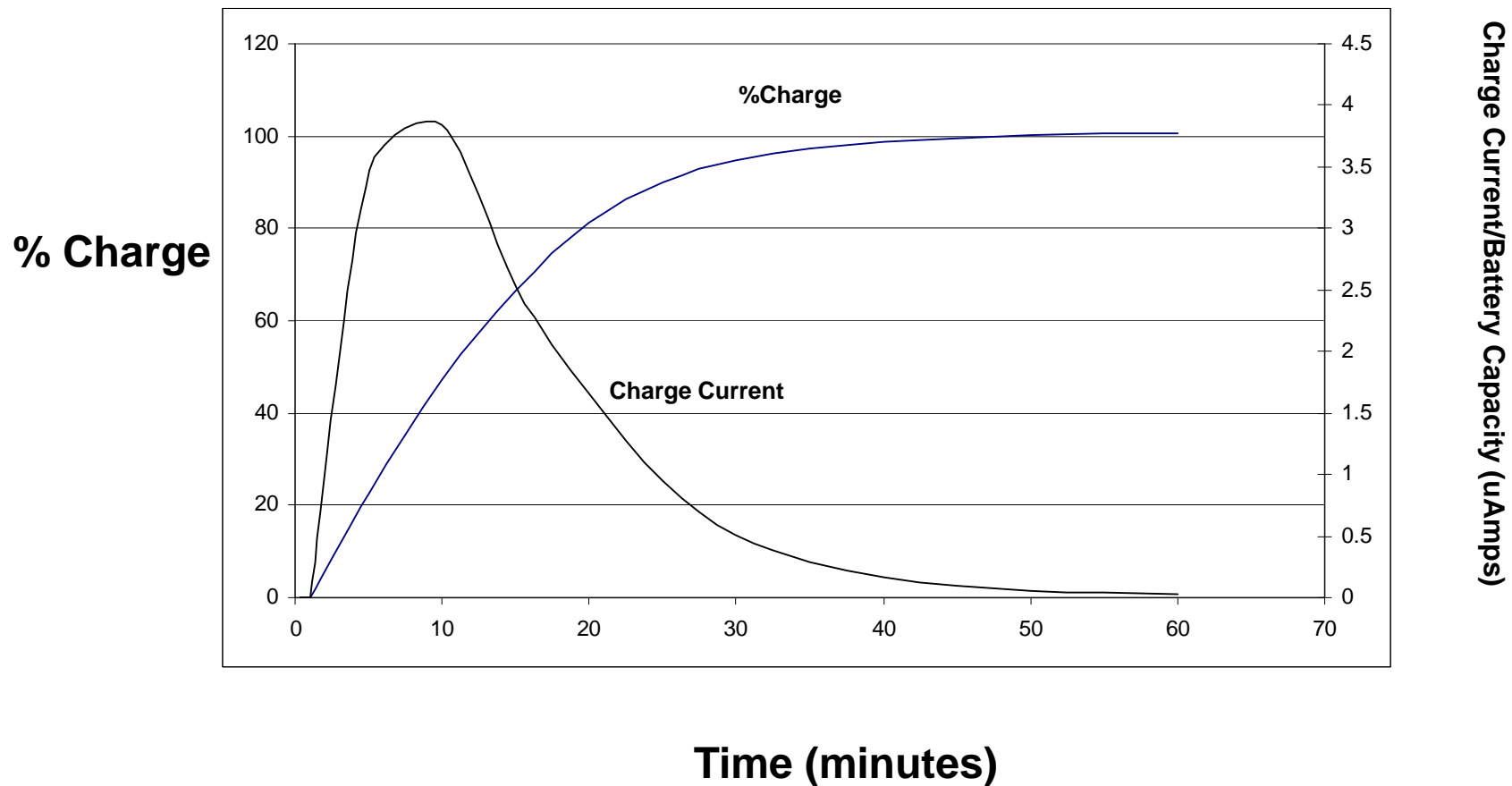
Flat Discharge Voltage Profile



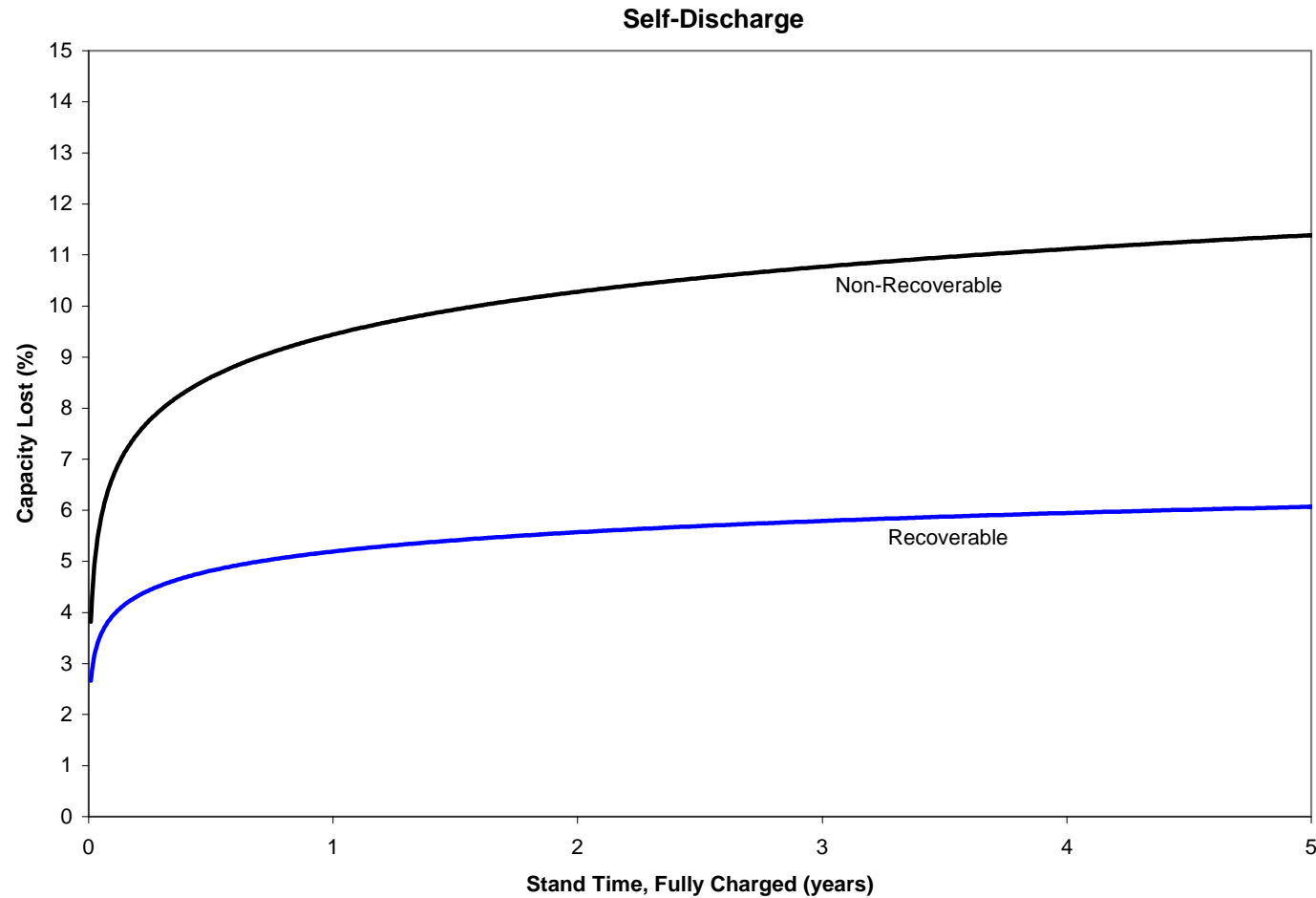
Fast Recharge Specifications



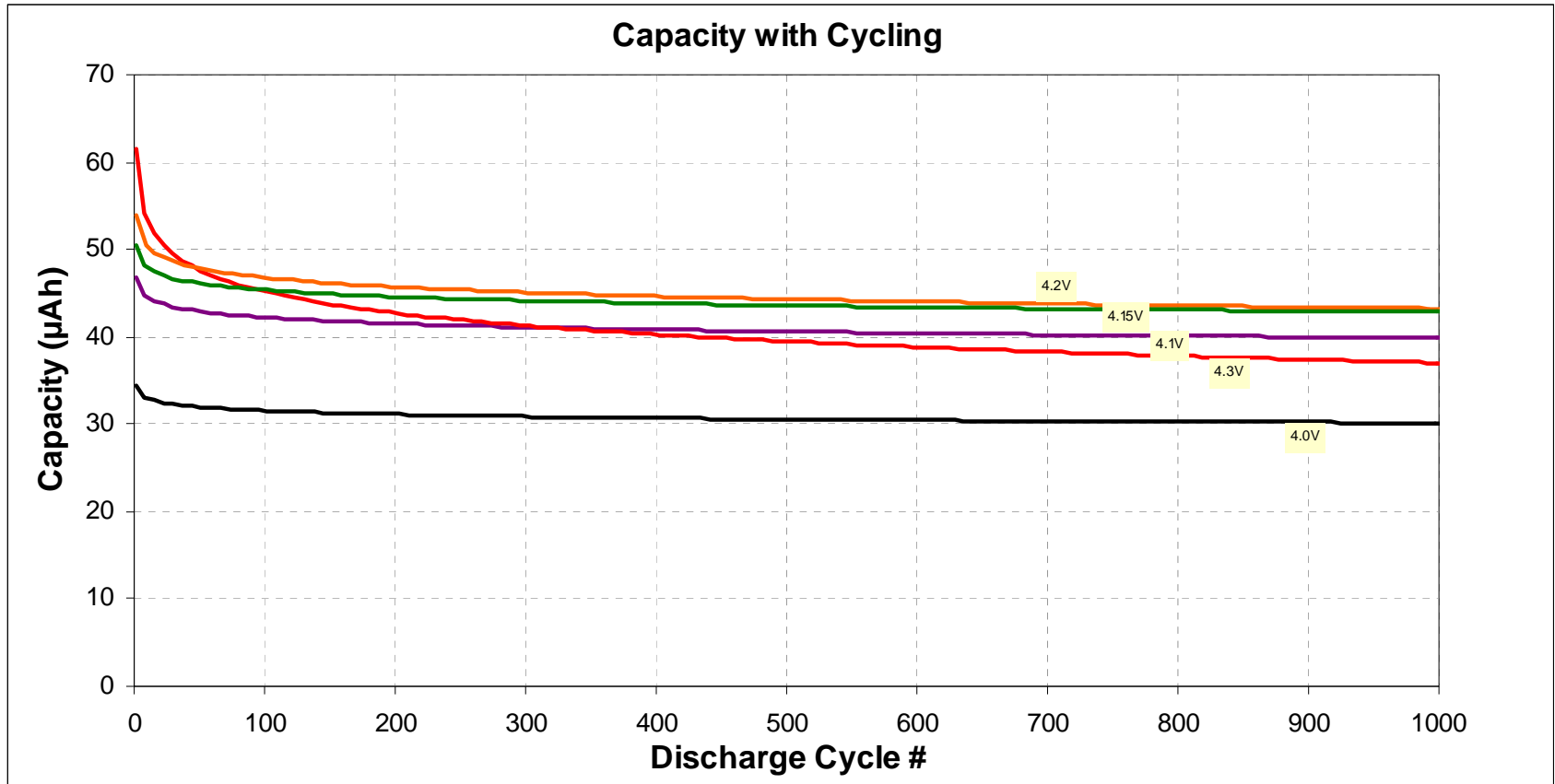
Charge Current & Charge Capacity vs. Charge Time



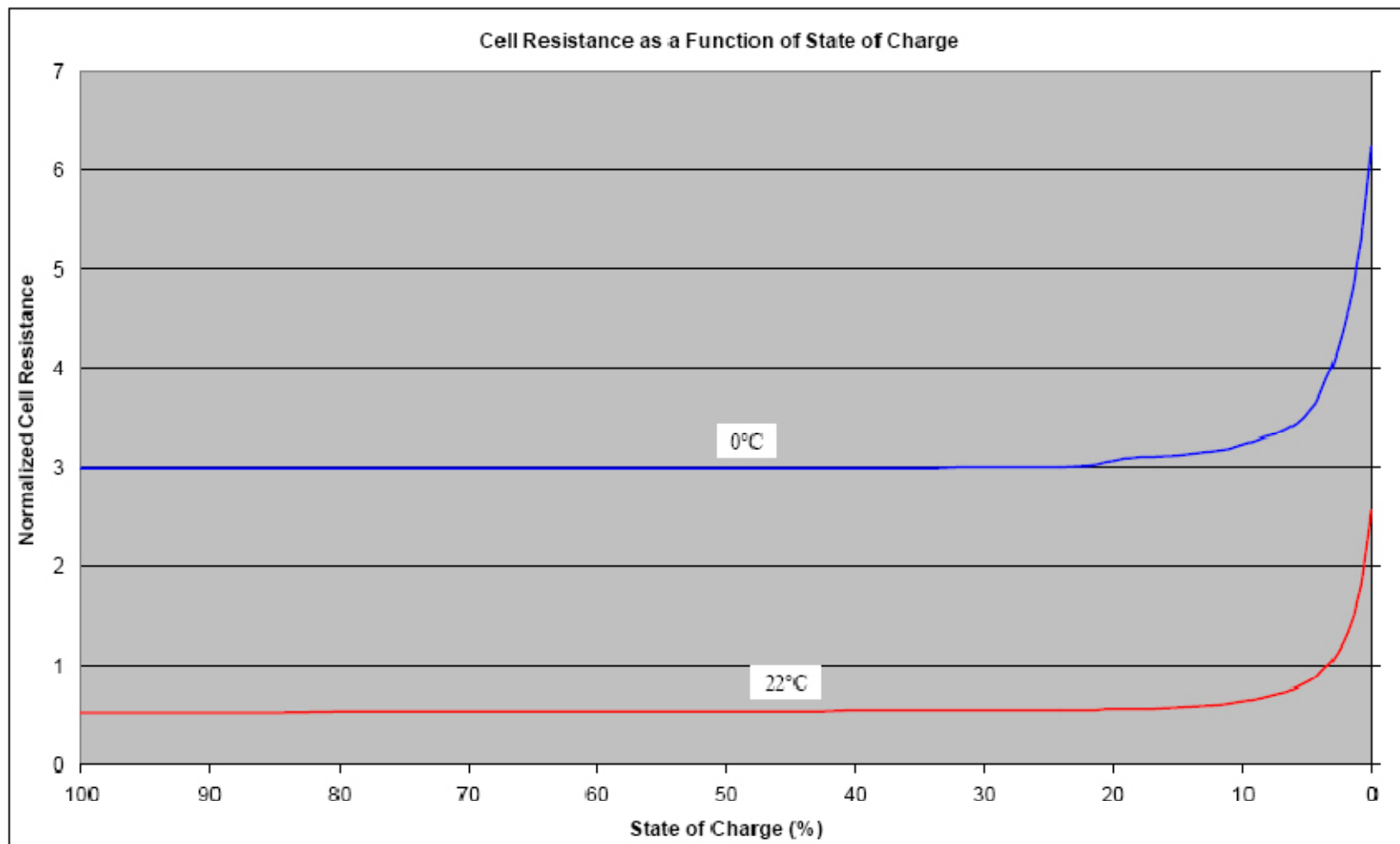
Low Self Discharge



Stable Capacity over Cycle Life



Stable Cell Resistance



Back-Up Power Solutions: *Addressing Customer Needs*



- Designers need a reliable energy storage device with:
 - Thousands of recharge cycles
 - Surface Mount Technology Packaging and Process
 - Reflow Tolerant
 - Low self Discharge
 - Flat output voltage profile
- They need to manage input power, manage the battery and control output power
- The ideal would be a “drop-in” power solution

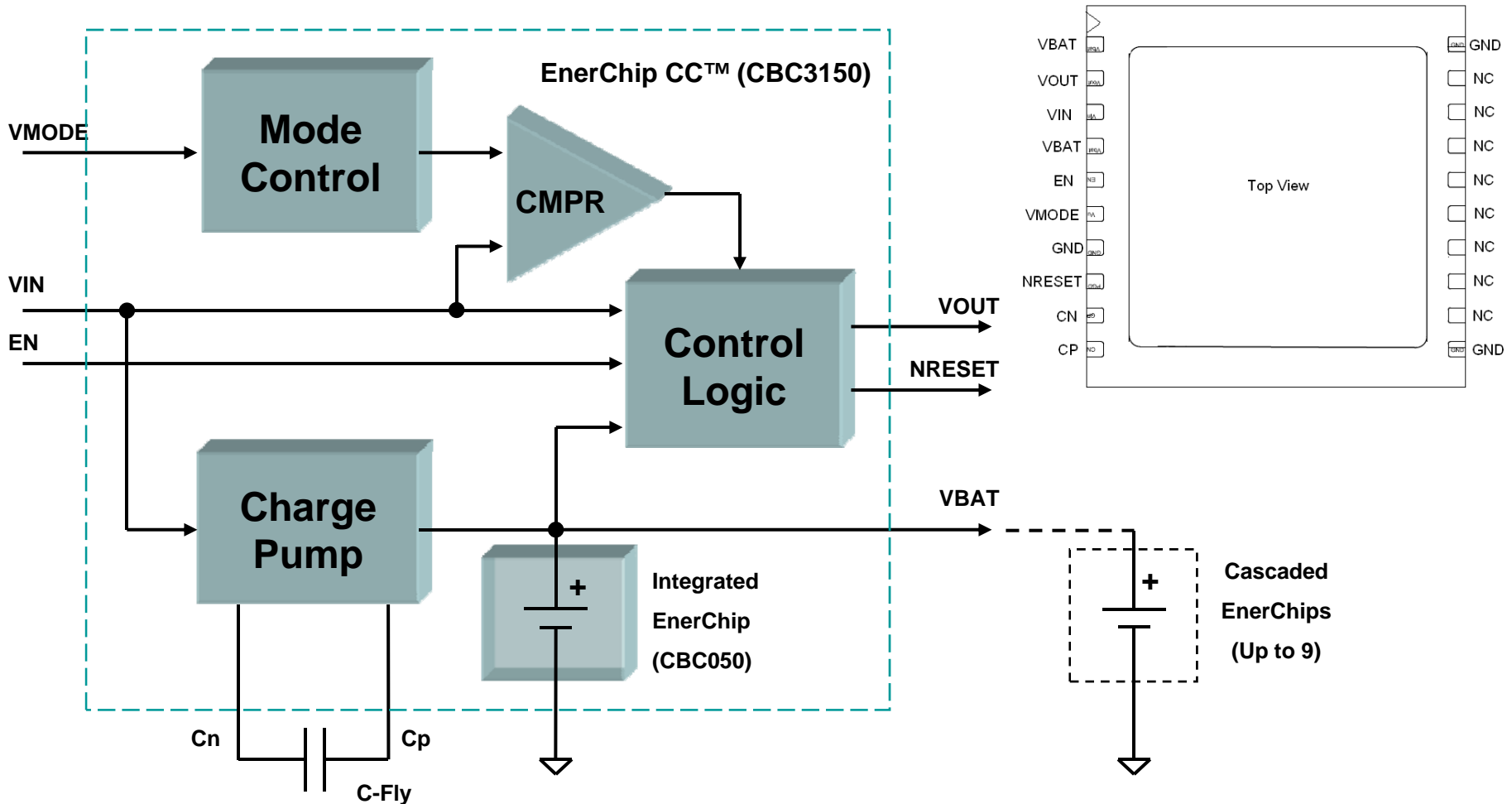
To meet these needs Cymbet has introduced the EnerChip CC with Integrated Battery Management

EnerChip™ CC with *Integrated Battery Management*

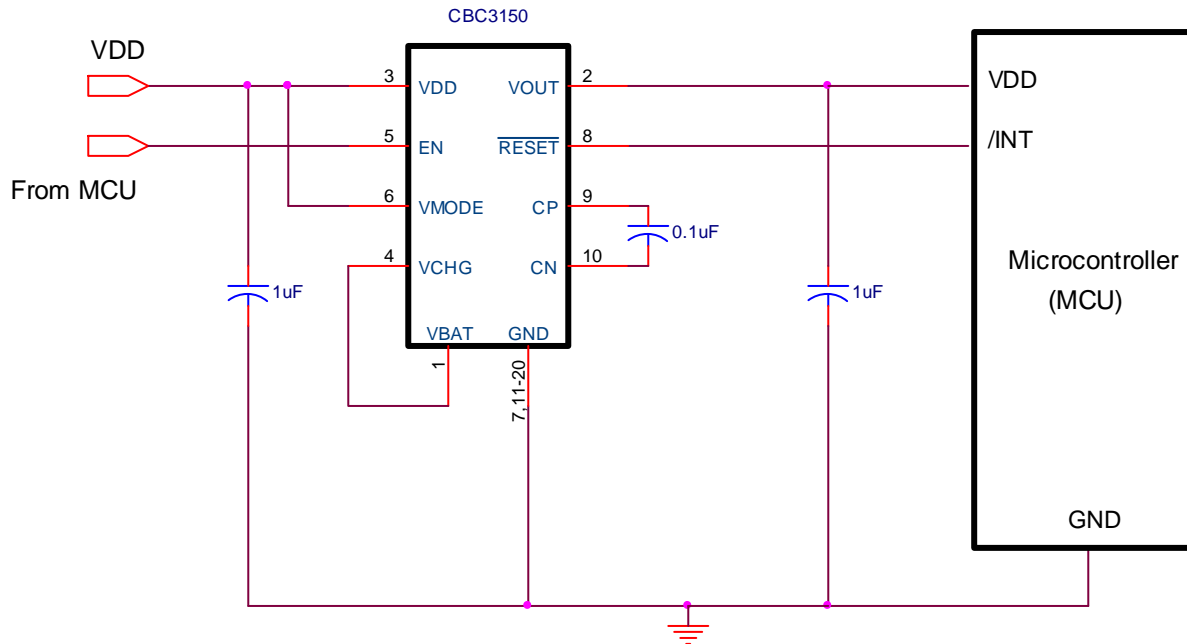


- Introducing the EnerChip CC:
 - EnerChip Energy Storage Device with Integrated Battery Management:
 - Charger and Supply supervisor management
 - High-efficiency boost converter & low-ripple charger
 - Configurable switch point to battery when input power fails
 - Provides supply voltage status signals for power management
 - Seamlessly enables EnerChip operation in 3.3V systems
 - Saves board space & assembly costs:
 - Replaces 2 ICs and over 20 discrete components:
 - 7x7mm or 9x9mm DFN plus only two external SMT caps
 - Part Numbers:
 - CBC3112-D7C & CBC3150-D9C
 - Evaluation Platform – CBC-EVAL-05

EnerChip CC Block Diagram



Microcontroller Backup Application



- Simple two wire microcontroller connection:
 - V_{OUT} connects to microcontroller's power pin – power to uP automatically switches when V_{IN} goes below user selected threshold
 - RESET/ connects to Microcontroller interrupt input indicates the MCU is running off the battery

Energy Harvesting: *Solving the Energy Storage Problem...*



- Energy can be harvested from almost any environment:
 - Light, vibration, flow, motion, pressure, magnetic fields, RF, etc.
- Energy Harvesting applications include:
 - Permanently powered wireless sensors,
 - Hybrid & Active RFID, data logging and access control
- Self-Powered Systems need reliable energy storage:
 - Energy Sources are not always available: (Solar @night, motor vibration at rest, air-flow, etc.)
 - Longer operating times – high-efficiency minimizes charge loss
 - Self-Powered allows remote locations & lower installation costs
 - High cycle life enables extended operation – fewer service calls
- Ideal solution is a highly-efficient, eco-friendly, energy storage device that can be cycled continuously for years

EnerChip™ EH modules allow designers to quickly adopt energy harvesting, save energy and improve performance

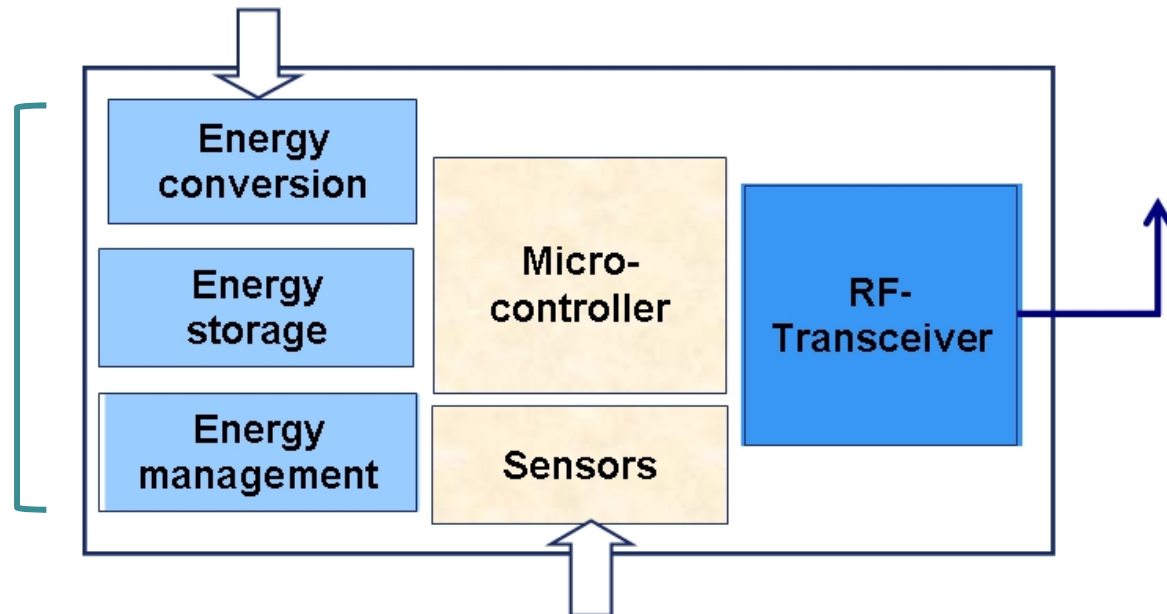
EnerChip EH is the Enabler of Autonomous Wireless Sensors



Self-Powered Sensor

Ambient Energy:
Motion, Vibration, Light, Temperature etc.

Cymbet's
EnerChips
provide these
functions



Temperature, Pressure, etc.

This could be co-packaged into a cost effective single chip solution!

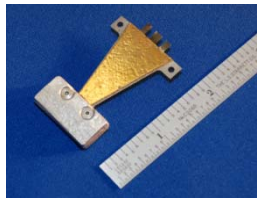
Energy Harvesting Transducers

EnerChip works with all...



<i>Energy Source</i>	<i>Challenge</i>	<i>Estimated Power</i> <i>(in 1 cm³ or 1 cm²)</i>
<i>Light</i>	Conform to small surface area Wide input voltage range	10μW-15mW (Outdoors: 0.15mW-15mW) (Indoors: <10μW)
<i>Vibrations</i>	Variability of vibration	1μW-200μW (Electrostatic: 50μW-100μW) (Electromagnetic: <1μW)
<i>Thermal</i>	Small thermal gradients	15μW (10°C gradient)
<i>Piezoelectric</i>	Capturing pressure or motion	~ 200μW
<i>RF & Inductive</i>	Coupling & rectification	Various

Source: EE Times

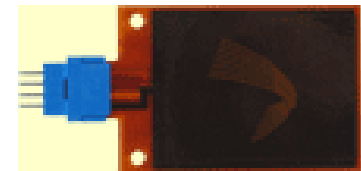


AdaptivEnergy – JouleThief™

Solar - Various

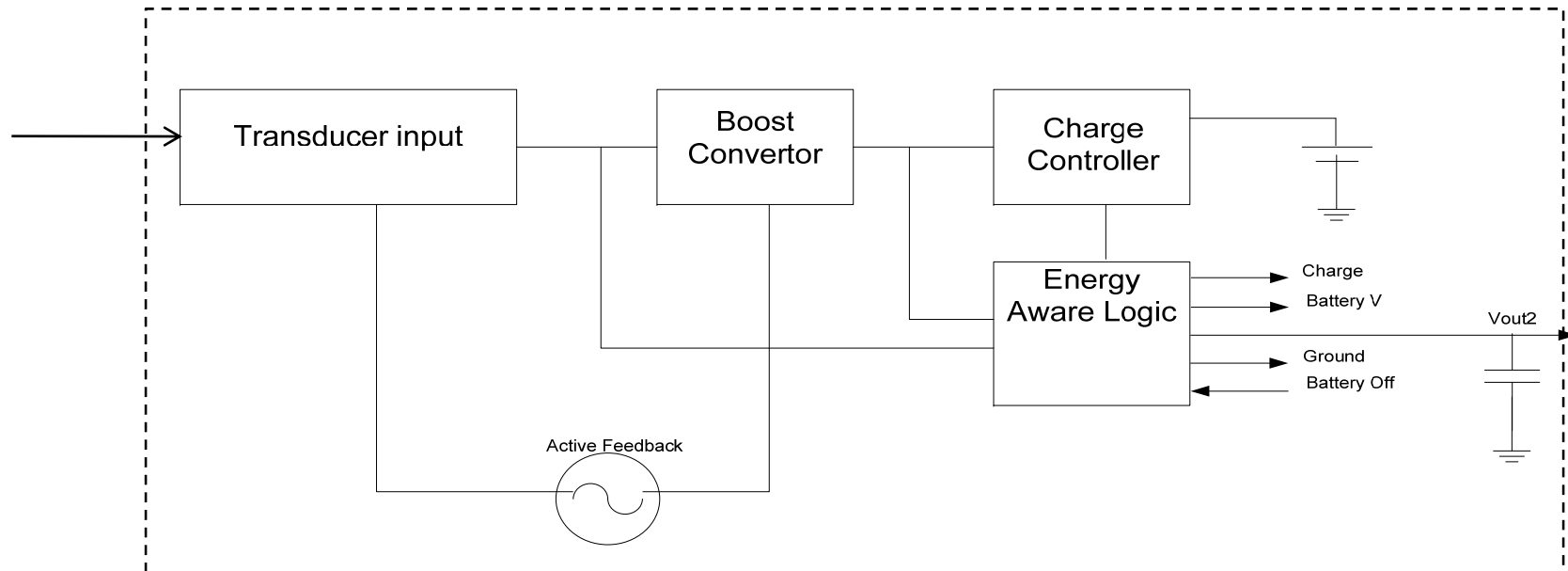


Peltier - Thermo Life



MIDE – Vulture™ Piezo

Energy Harvesting Power Module



- **I/O Pin Description:**

- Charge: Output - indicates that the batteries are being charged
- Battery off: Input – disconnects battery from charger
- Battery V: Output – raw battery voltage
- Ground : output - ground
- Vout2 : output – stepped down battery voltage for 3.3 volt systems

Transducer Interface & Tuning

- Energy Harvester Tuning:
 - Optimized for 50 to 4000 ohm impedance
 - Voltages at that impedance should be between 270mV to 1.5V
 - Nominal voltage and impedance is 800mV at 1000 ohms (min = 700mV)
- Find Transducer Peak Power:
 - Some manufactures will provide operating characteristics
 - To find the peak power:
 - Place a variable resistor across the transducer
 - Monitor voltage and current in resistive load
 - Sweep the variable resistor until you find the peak $I \cdot V$
 - This resistance is the ideal impedance for the energy harvesting module for peak power transfer
- Tune the energy harvesting module:
 - Find the optimal operating voltage for the transducer
 - Match the impedance for the transducer to the input stage

Applications: Medical Monitoring



- Wireless Patient Monitoring:
 - Rechargeable micro-power source powers wireless sensors
 - Eliminates wires & battery replacement
- Patient ID & Tracking:
 - Small size enables Active-RFID & RTLS
 - Utilize near-field recharging
- Smart Patches & Dressings:
 - Administer medicine & monitor wound condition -temp, moisture, PH, etc.



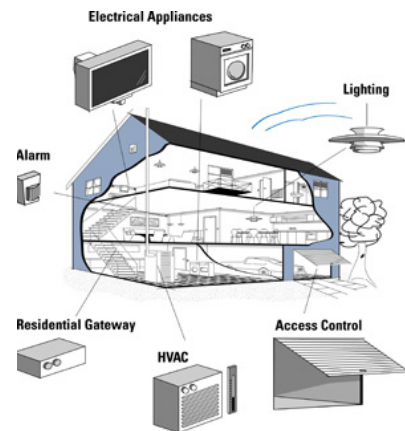
Applications: Business and Home Energy Management



- HVAC sensors – occupancy, temp, humidity, CO2
- Lighting Controls – Window light, room light, shade controls
- Security – occupancy, intrusion detect, motion sensors, noise sensors, proximity, etc.
- Utility monitoring, meter reading & off-peak control



Example: Wireless Lighting Control

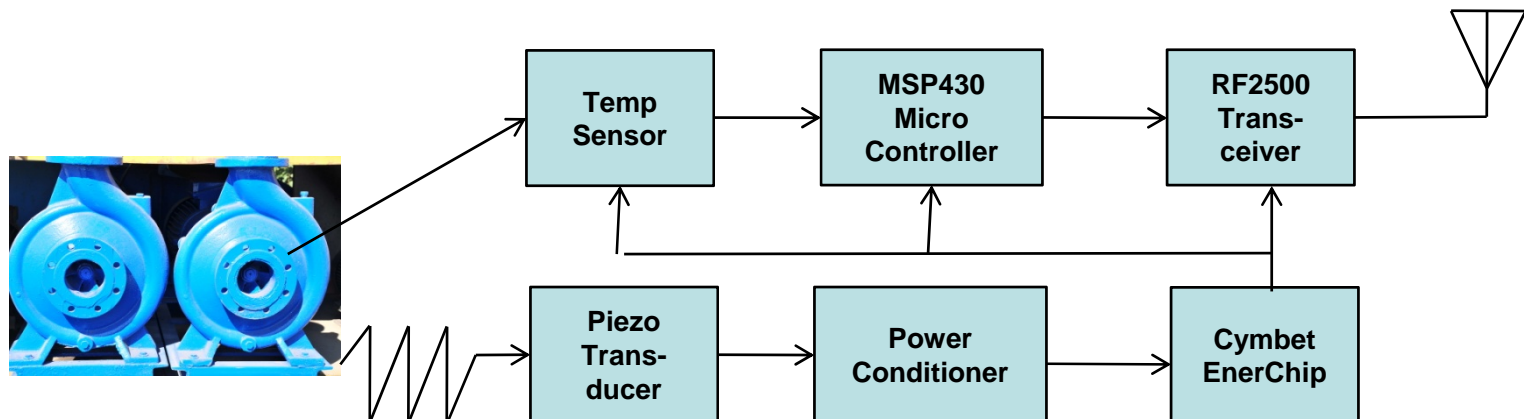


Example: Home Automation

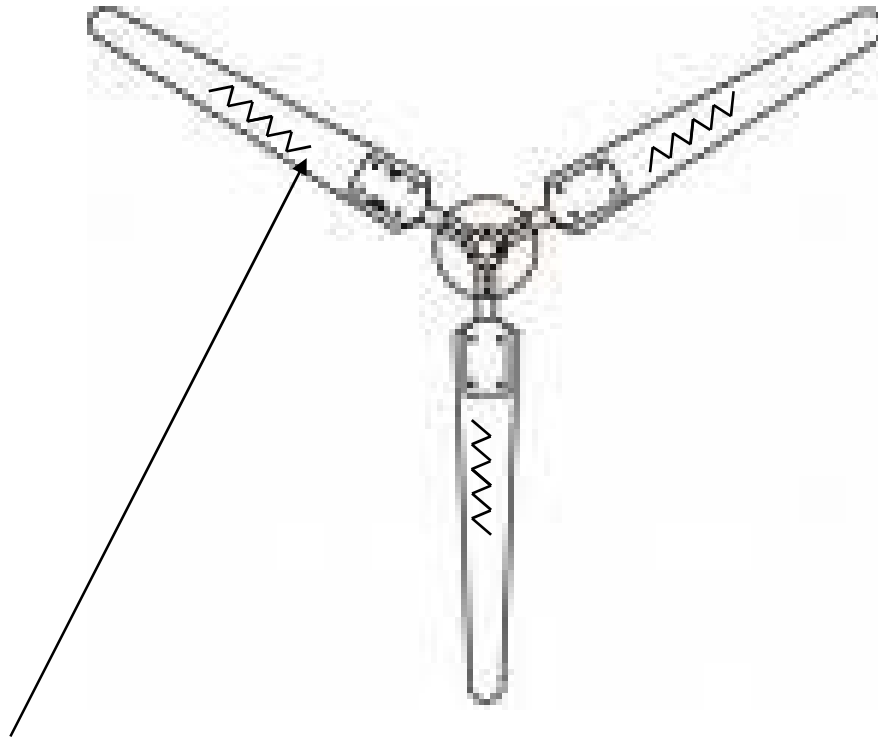
- Applications:
 - Building Energy Management Systems
 - Access and Security
 - Systems Integrators
 - Home Networks
 - Smart Utility Meters

- Electric Motor Sensor:

- Utilizes Energy Harvesting, Wireless Networking & Mixed Signal microcontroller & temperature sensor
- Piezo Transducer converts vibration to energy to power sensor system and recharge the Cymbet Battery
- MSP430 monitors bearing temperature & reports to access point
- Uses SimpliciTI protocol for connection
- EnerChip provides power to sensor when Vibration stops



Mechanical Fatigue Monitoring using Energy Harvesting



- Piezo Elements for Both Power and Sensor
- Solar Could be used for Power Optionally

Applications: Wind Turbine Stress and Fatigue Monitoring



Radio transmits data to controller

Piezo or Solar element in each blade

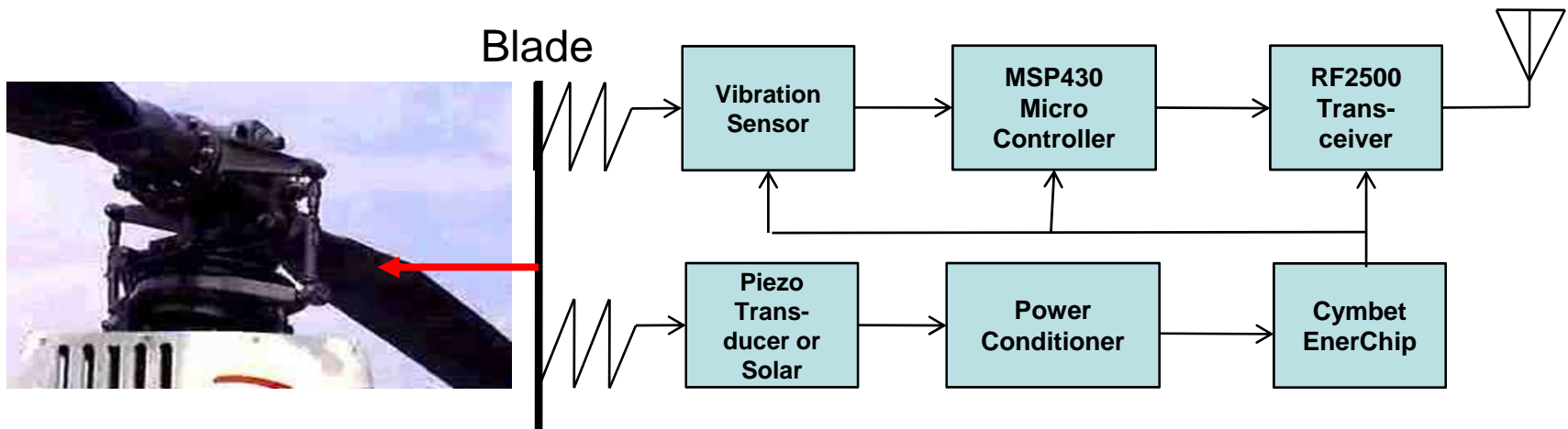
See footage of windmill destroyed:

<http://www.youtube.com/watch?v=CqEccgR0q-o&feature=related>

Applications: Helicopter Blade Fatigue Monitoring



- Propeller Blade Integrity Monitoring:
 - Utilizes Energy Harvesting, Wireless Networking & Mixed Signal Microcontroller & A/D Signal conditioning
 - Piezo Transducer converts vibration to energy to power sensor system and recharge the Cymbet Battery
 - MSP430 monitors stresses & reports to access point
 - Uses SimpliciTI protocol for connection
 - EnerChip provides power to wireless sensor when Vibration stops

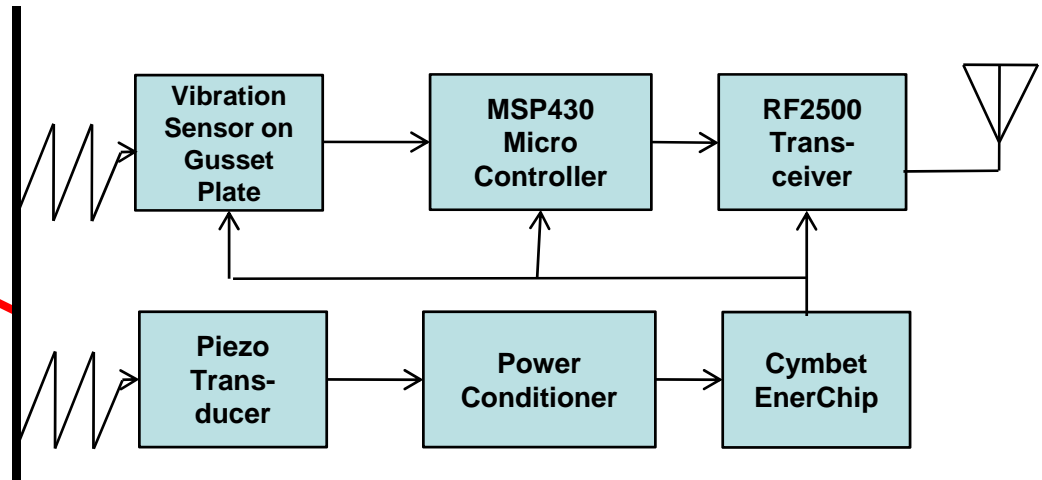
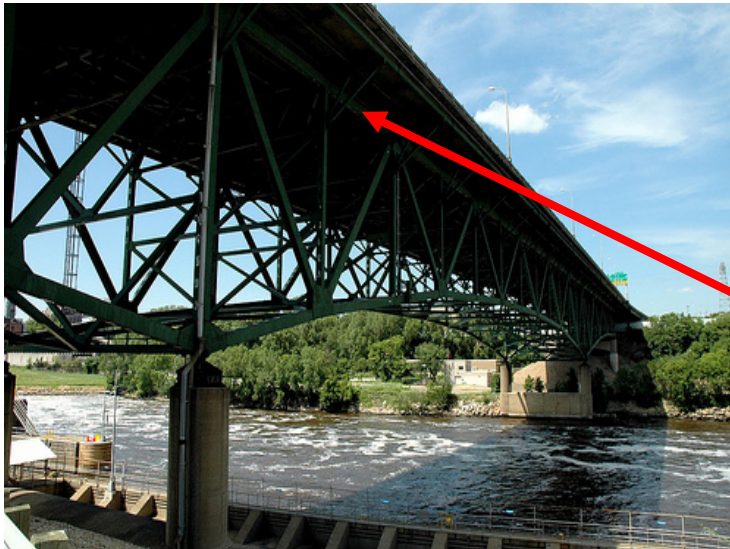


Applications: Bridge Fatigue Monitoring



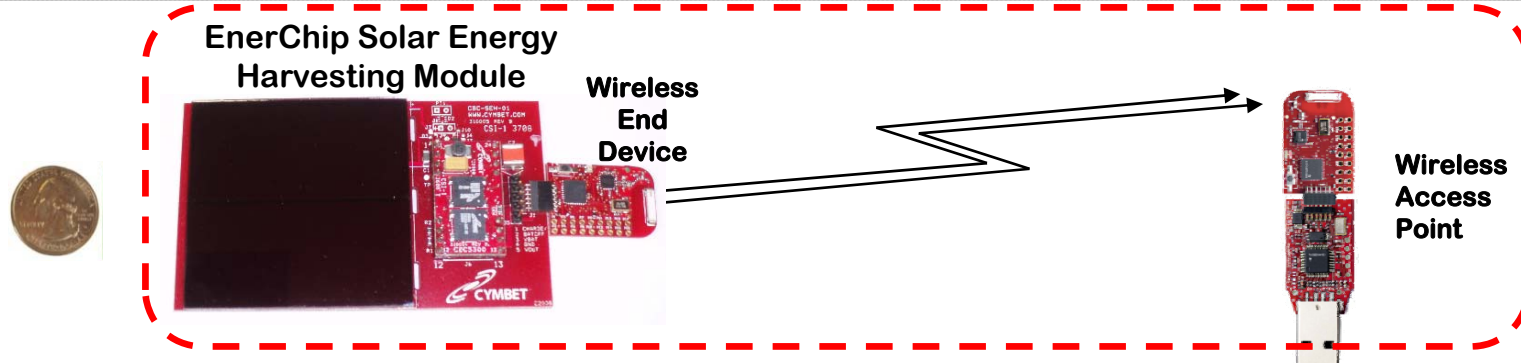
- Stress and Fatigue Monitoring Bridge Decks:

Gusset Plate

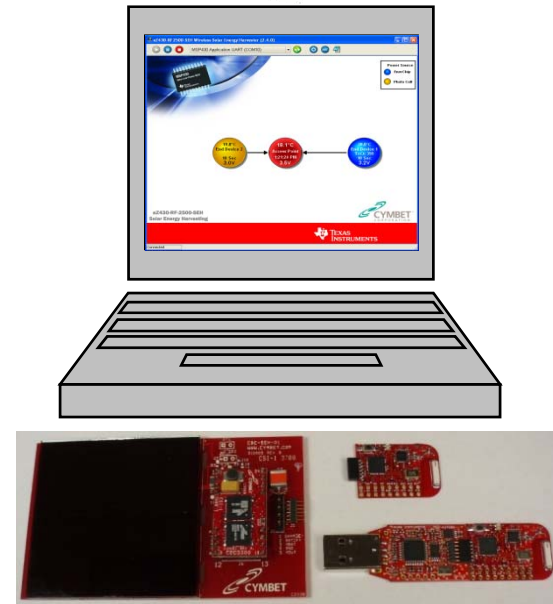


Self-Powered Wireless Sensor:

TI eZ430-RF2500-SEH Evaluation Kit



- Available as the TI eZ430-RF2500-SEH Evaluation Kit in January 2009
- Compact module with integrated solar cell
- Works in low light – down to 200Lux
- Low self-discharge enables high-efficiency
- No battery replacement or disposal; 10-year life
- Uses the EnerChip EH CBC5300 – Energy Harvesting Module
- CBC-EVAL-08 is Cymbet's version of Solar EH Board for generic Energy Harvesting designs

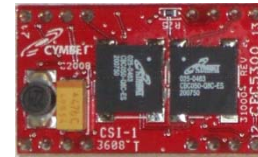


**TI's eZ430-RF2500-SEH
Evaluation Kit Contents**

EnerChip EH Products



- EnerChip EH Module – CBC5300:
 - Capacity = 100uAh, uses 2 CBC050s
 - Compatible with solar, inductive, piezo & thermoelectric transducers
 - No battery replacement or disposal; 10-year life
 - Provides control signals to enable “Energy Aware” sensor nodes
 - Low self-discharge enables high-efficiency
 - Order P/N: CBC5300-24C
- Solar Evaluation Board – EVAL-08:
 - Solar Energy Harvesting Demo Kit
 - Compact module with integrated solar cell array
 - Works in low ambient light:
 - Uses the EnerChip CBC5300
 - Adaptable to many sensors and wireless networks via Interface Header
 - Order P/N: CBC-EVAL-08



**CBC5300
Module**



**Interface
Header**

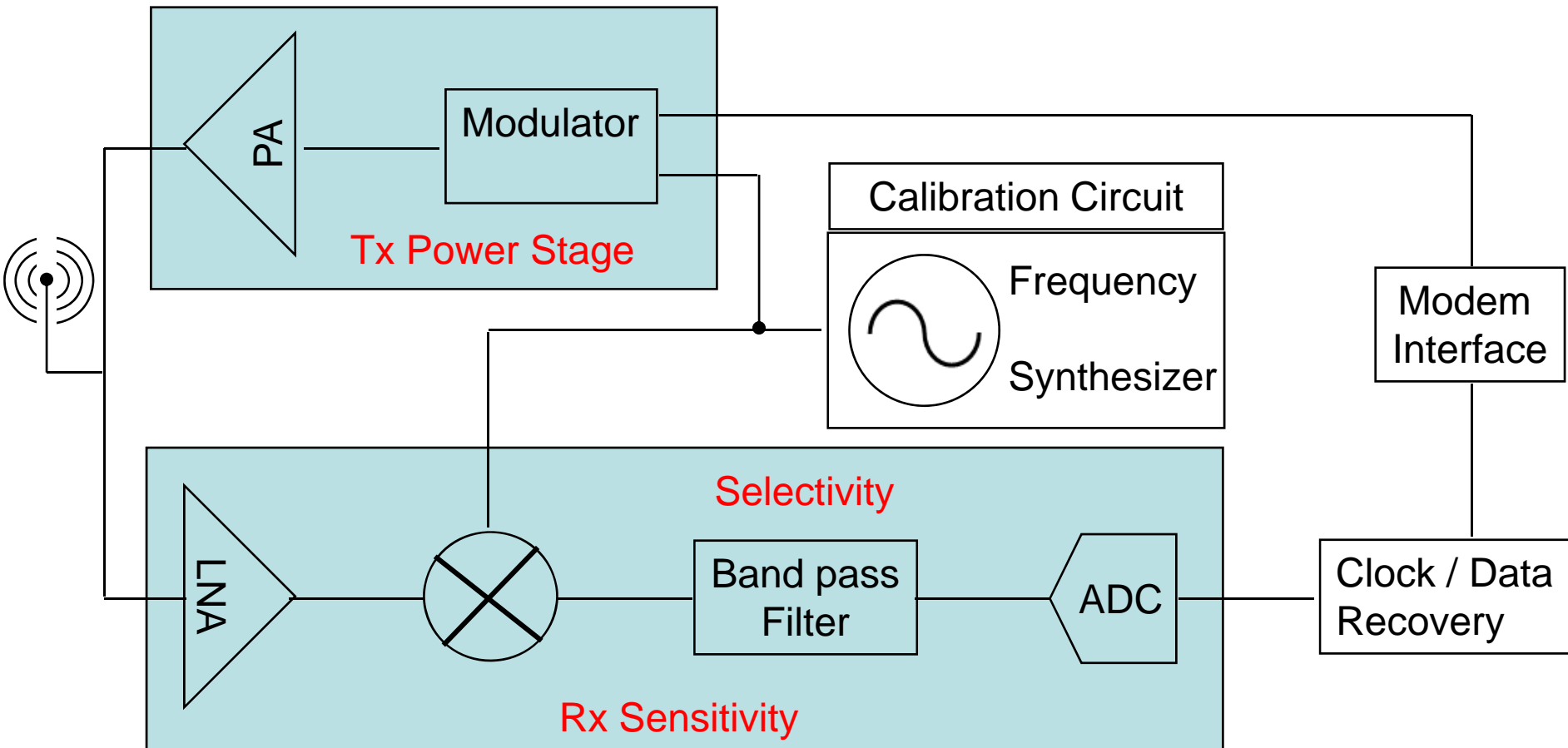
eZ430-RF2500-SEH

Electrical Characteristics

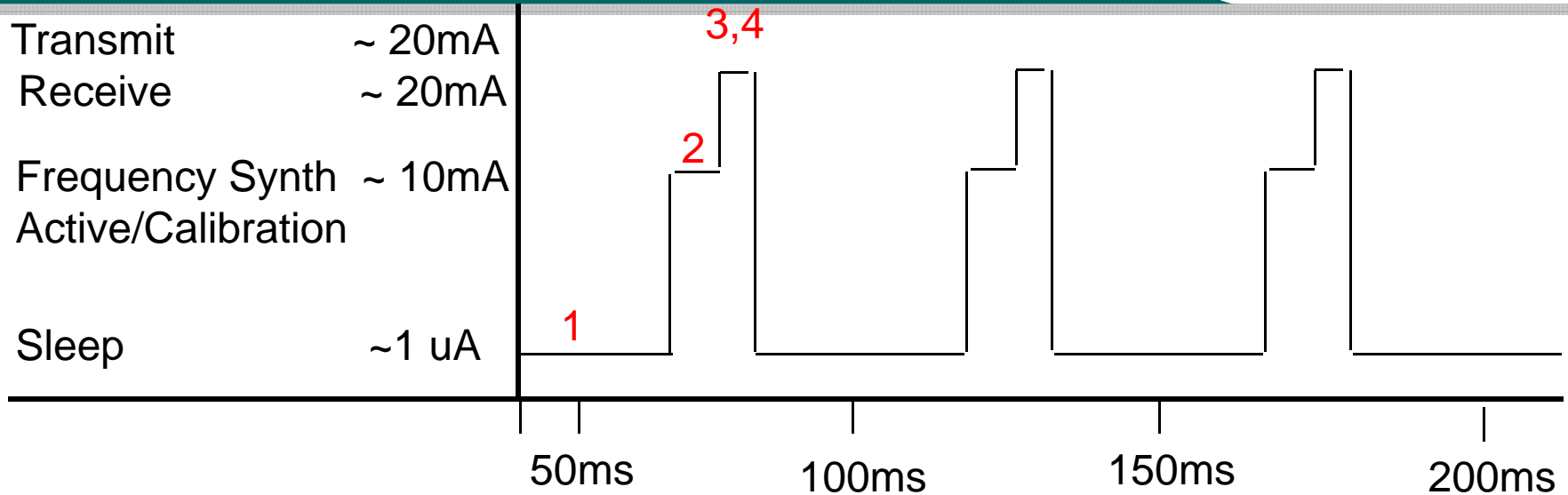


Parameter	Min	Typical	Units
Min input Lux	200		Lux
Full charge Lux	700		Lux
Load current (charging		20	uA
Load Current (not charging)		800	nA
Battery Charge Voltage		4.06	Volts
Battery Cutoff Voltage	3.0	3.3	Volts
UVLO Trip Select Voltage		0.7	Volts

Typical Low Power Transceiver

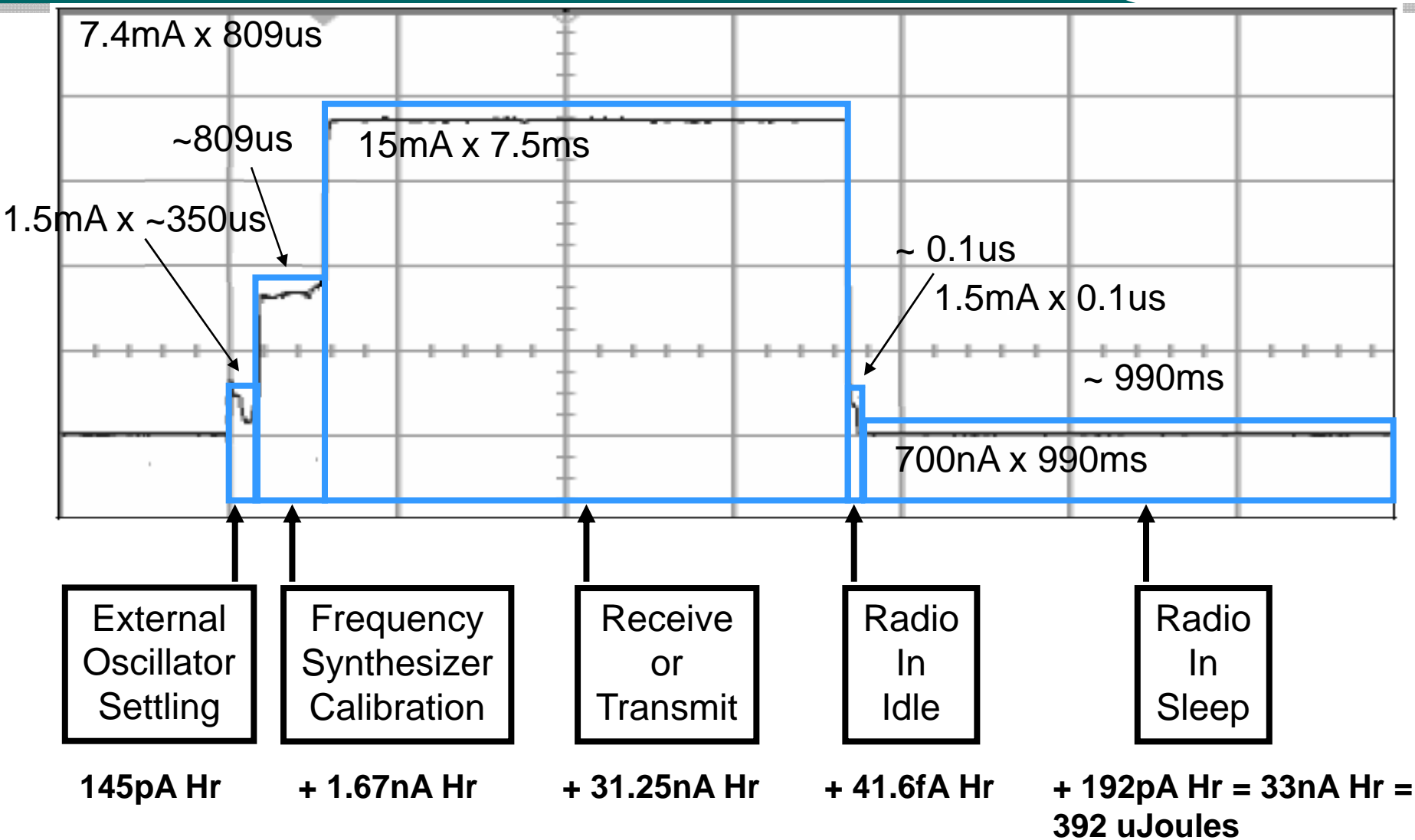


Wireless Transceiver Power Usage



1. Sleep current is an important number, but as important is the time in the duty cycle the transceiver is in the sleep mode
2. The Frequency Synthesizer's low power performance is measured in the settling time from sleep mode and how well it retains its accuracy (fewer calibration cycles required).
3. Receive Polling is a nice feature in a transceiver as long as the polling period is adequate to pick up the network's messages.
4. Transmit and Receive require the highest power usage. Network and data payload settings in the user's application can drastically effect power.

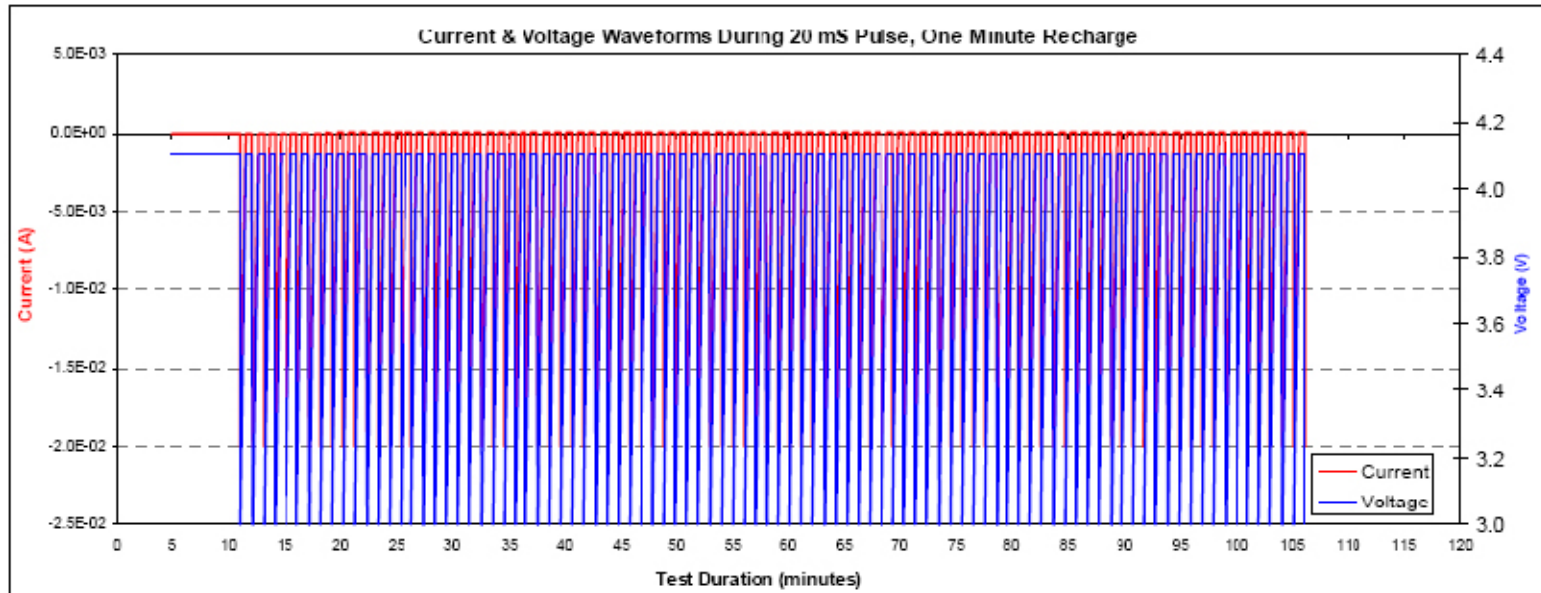
Calculating Energy Usage per Transmission



Pulse Capacitor Requirements

- Sizing of output capacitor depends on several factors:
 - Battery impedance
 - Battery voltage
 - Temperature
 - Pulse current amplitude
 - Pulse current duration
 - Allowable voltage drop during discharge
- Calculating output capacitor size:
 - $C = t / R * [-\ln (V_{min} / V_{max})]$
 - C= output capacitance
 - t = pulse duration
 - R= load resistance = $V_{out}(\text{average}) / I_{pulse}$
 - V_{min} and V_{max} are dependant on the minimum operating voltage of the external circuit
- Charge time determines maximum duty cycle:
 - Charge formula: $t = R * C [-\ln (1 - V_{min} / V_{max})]$
 - T = charging time
 - R = battery resistance
 - C = output capacitance

Pulse Current & Voltage Profiles During RF Transmissions



Energy Harvesting Summary



- Lower Cost Transducers and energy storage enable cost effective energy harvesting:
 - Solar
 - Piezo
 - Generators – spinning vanes – air – fluid - gasses
 - Thermal Electric
 - RF induction

CBC012 & CBC050 = Available Now
- Make your system “Energy Aware”
 - This will enable the most efficient use of available energy
 - Peak Power tracking and power factor correction designs will be the most efficient design

Flexible Solutions for Power Back-up and Energy Harvesting



Energy Harvesting



- EnerChip CC with Integrated Battery Mgmt



- EnerChip EH Module



- EnerChip EH for ANT



- EnerChip Solar Eval Kit



- TI Wireless EH Demo Kit

Back-up Power



- EnerChip 12µAh



- EnerChip 50µAh



- EnerChip CC 12µAh with Integrated Battery Mgmt



- EnerChip CC 50µAh with Integrated Battery Mgmt



- EnerChip CC Eval Kit

Summary



- The EnerChip is the next advancement in rechargeable micro-power sources:
 - Improved performance & new functionality
 - SMT Assembly, Reflow tolerant, & RoHS
 - Lower environmental impact
 - New approach to distributing energy at the chip, board and sub-system level
 - CBC012 & CBC050 = Available Now
- EnerChip CC with Integrated Battery Management
 - EnerChip CC sampling Q1 '09, Production Mid-Year
- The enabling technology for energy harvesting
 - New EnerChip EH Products available in Q1 '09
- Customer Online Tools:
 - Application Notes, Datasheets, Product Overviews, Eval Kits

