Energy Harvesting For Zero Power Wireless Networks

Roger Roisen

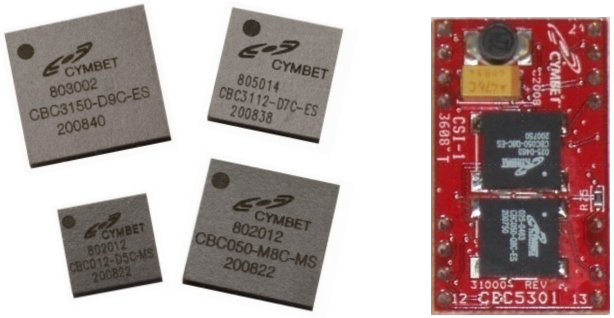
Agenda

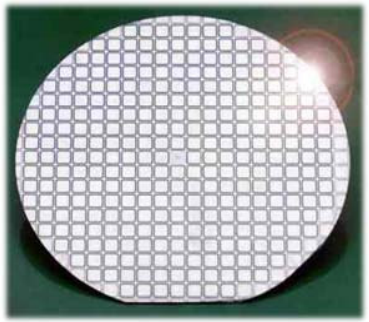
Solid-State Energy for Energy Harvesting

- 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 in RF Systems
- Transducer Selection and Design Considerations
- Summary

Cymbet's Business:
Solid-State Energy Solutions

- Established in 2000:
  - 38 employees (mostly technical)
  - Captive fab with Class 100 clean room
- 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





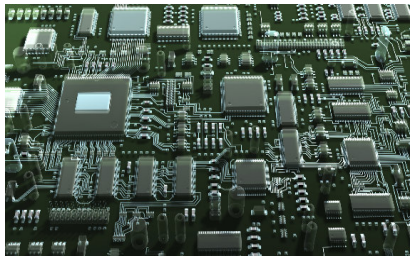
IC Packaging, Bare Die & Modules

EnerChips for Energy Harvesting and Back-up Power

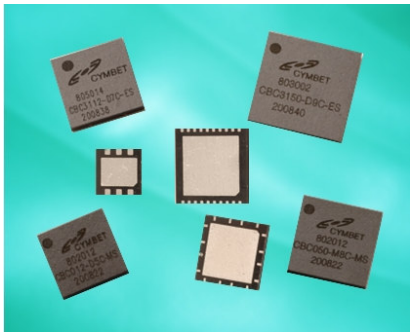
EnerChip products enable two important market solutions:

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

Back-up Power Solutions



Energy Harvesting Devices



EnerChip Product Family

EnerChip™ Construction

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

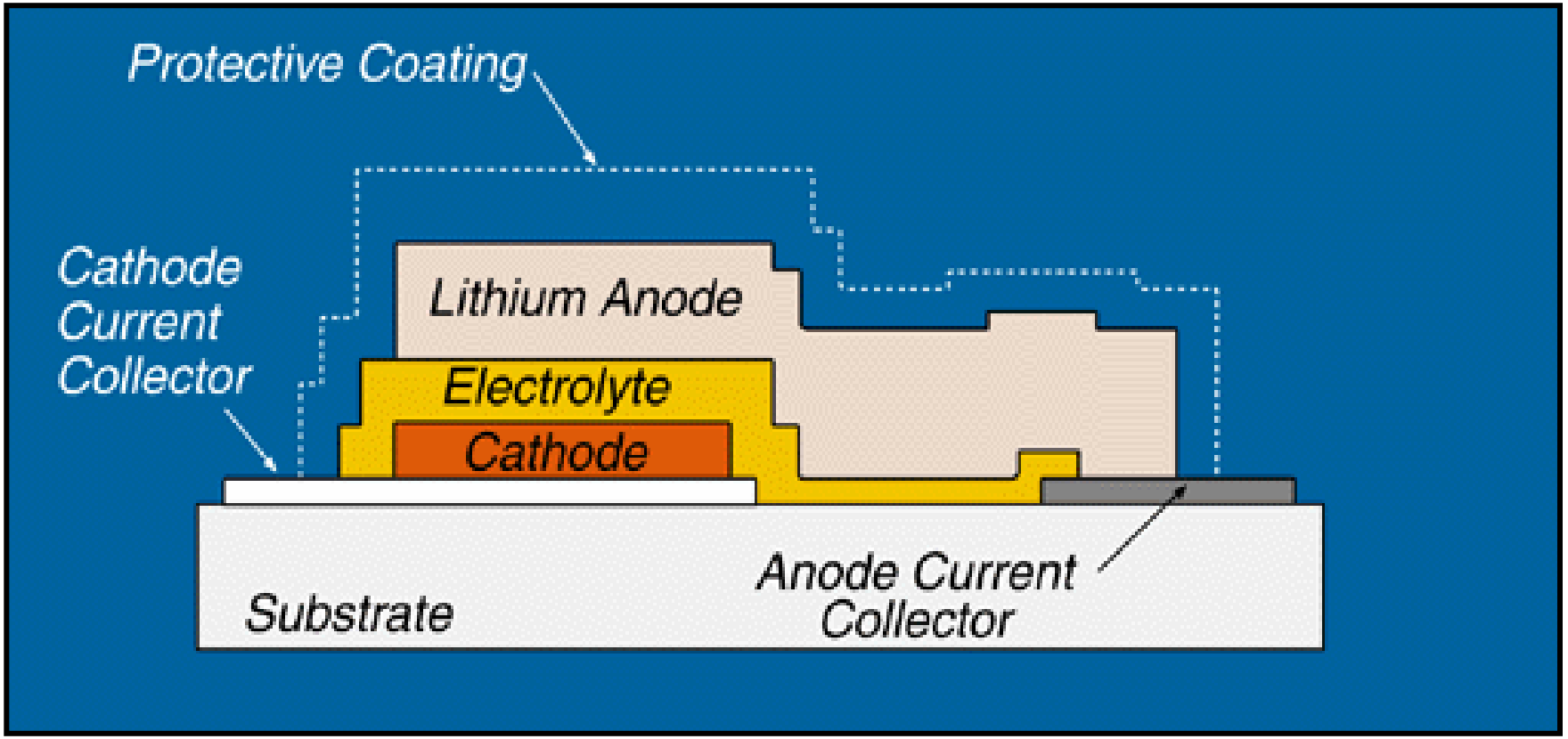
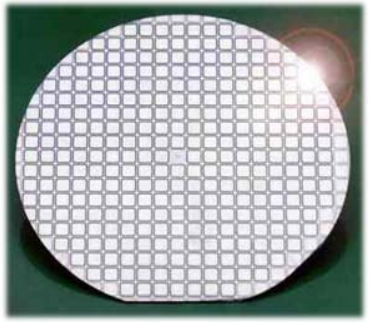


Image Courtesy DOE-ORNL

EnerChip™ Assembly Process

EnerChip Wafer

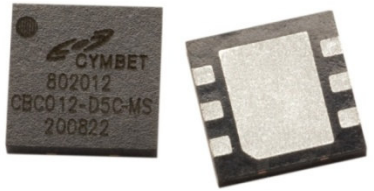


Diced

EnerChip Die

Packaged

EnerChip Package



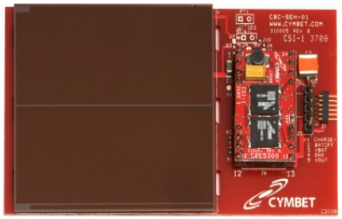
Tape & Reel

To Surface Mount Machine

To Reflow Solder

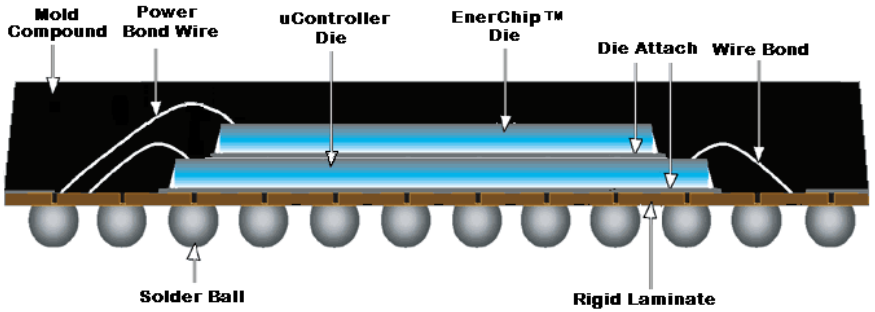
Final Assembly

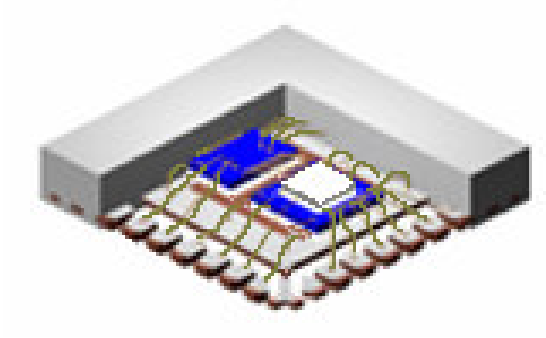
EnerChip on Board



EnerChip™ Embedded

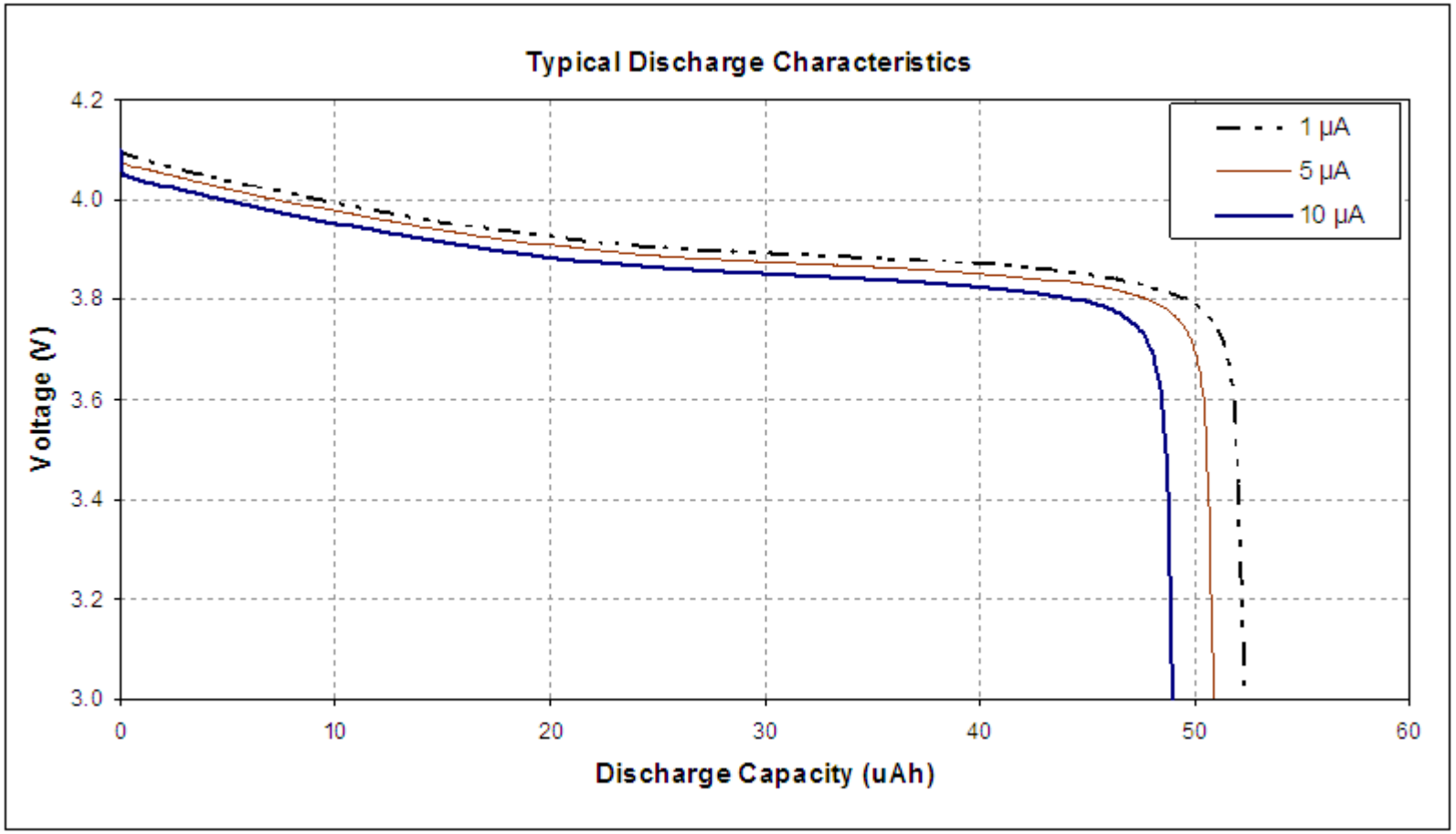
- Solid-State EnerChips enable embedded back-up batteries in uControllers & RTCs:





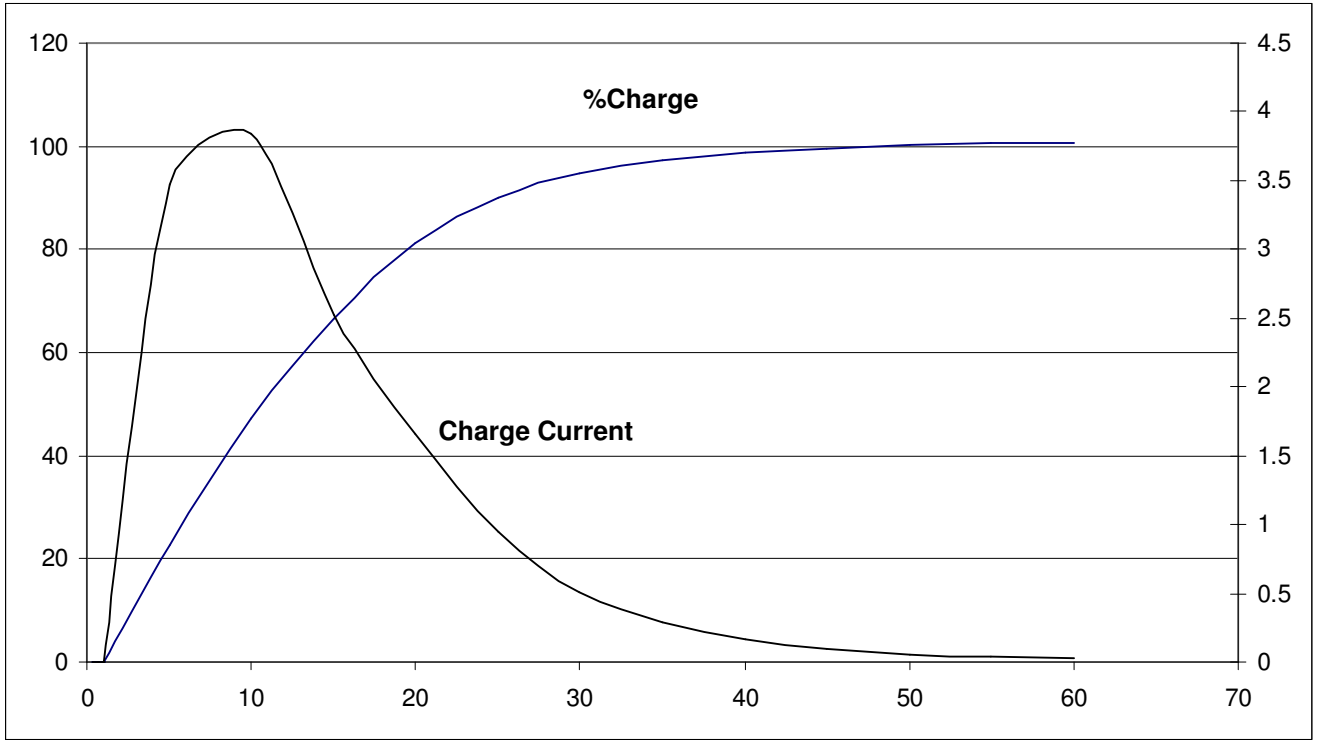
- Power Management packaged with EnerChip

Flat Discharge Voltage Profile



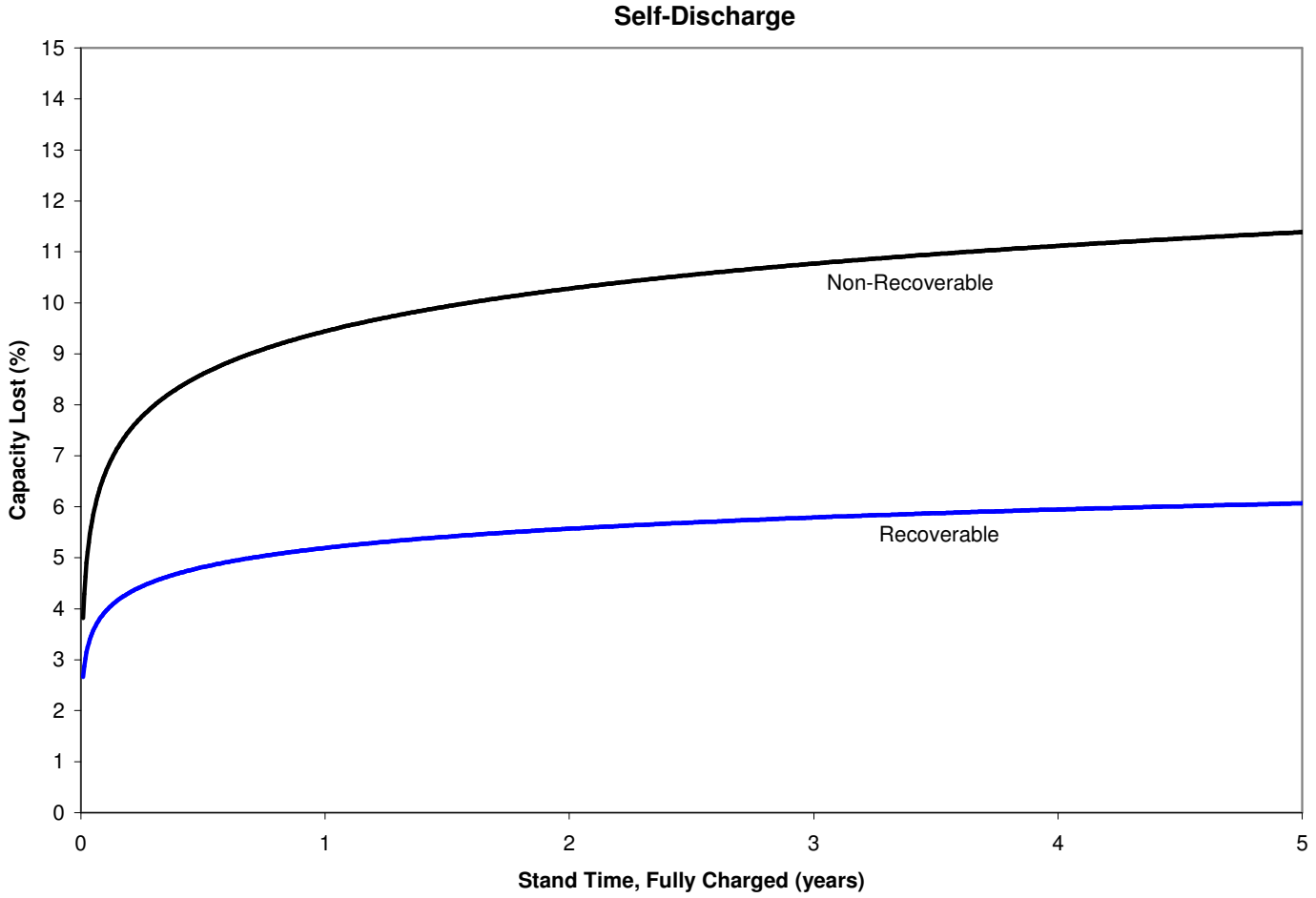
Fast Recharge Specifications

Charge Current & Charge Capacity vs. Charge Time

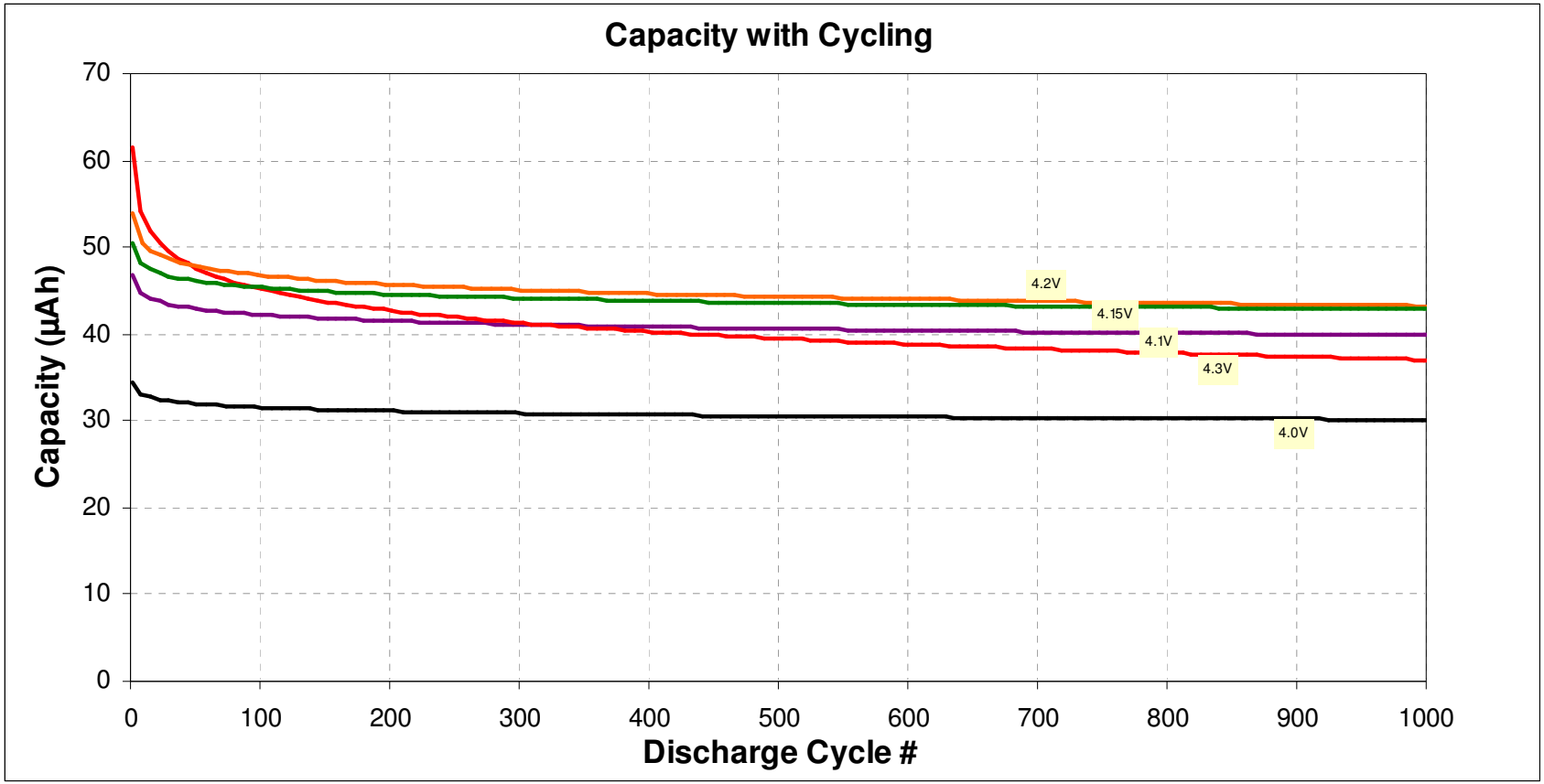


Time (minutes)

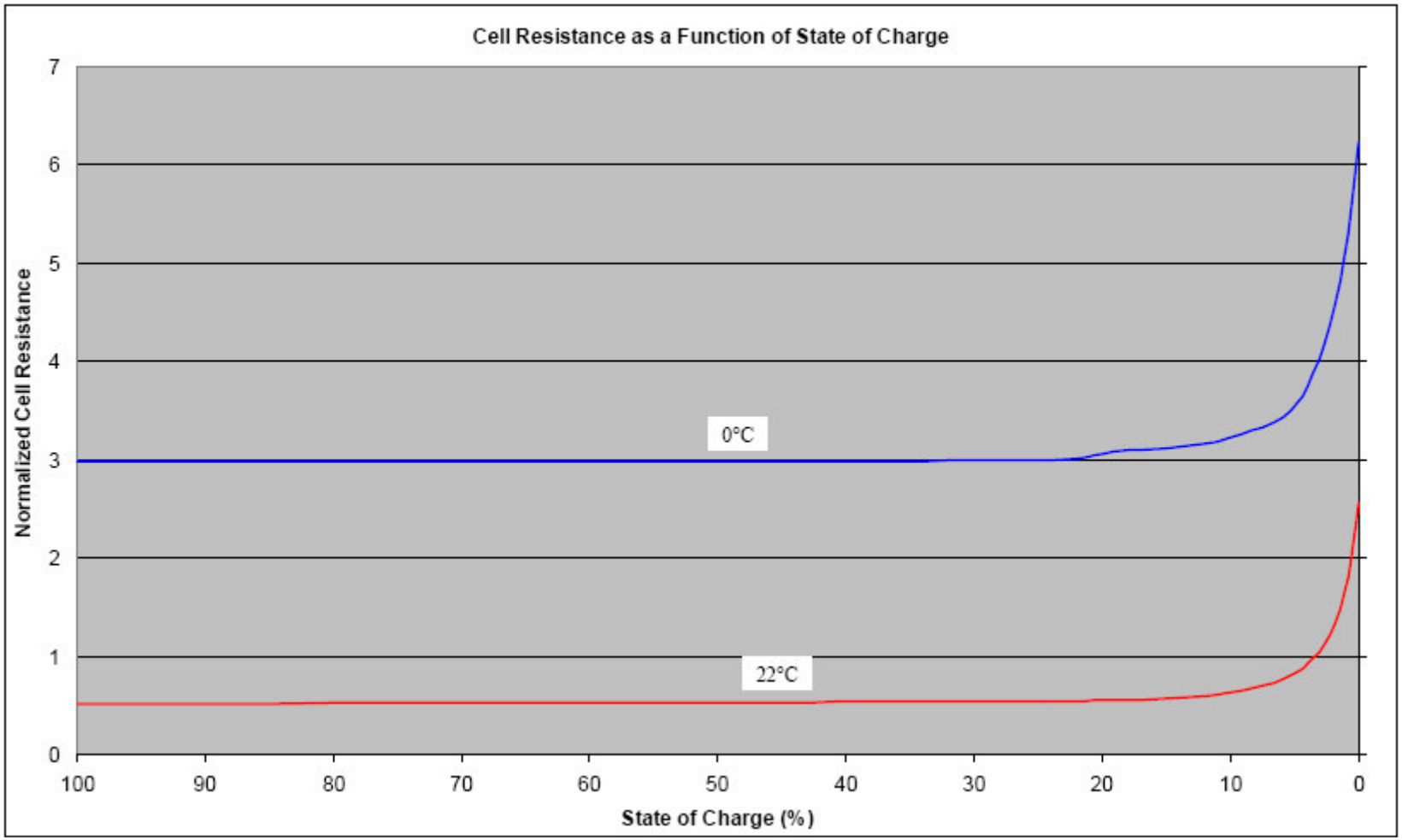
Low Self Discharge



Stable Capacity over Cycle Life



Stable Cell Resistance



Back-Up Power Solutions:
Addressing Customer Needs

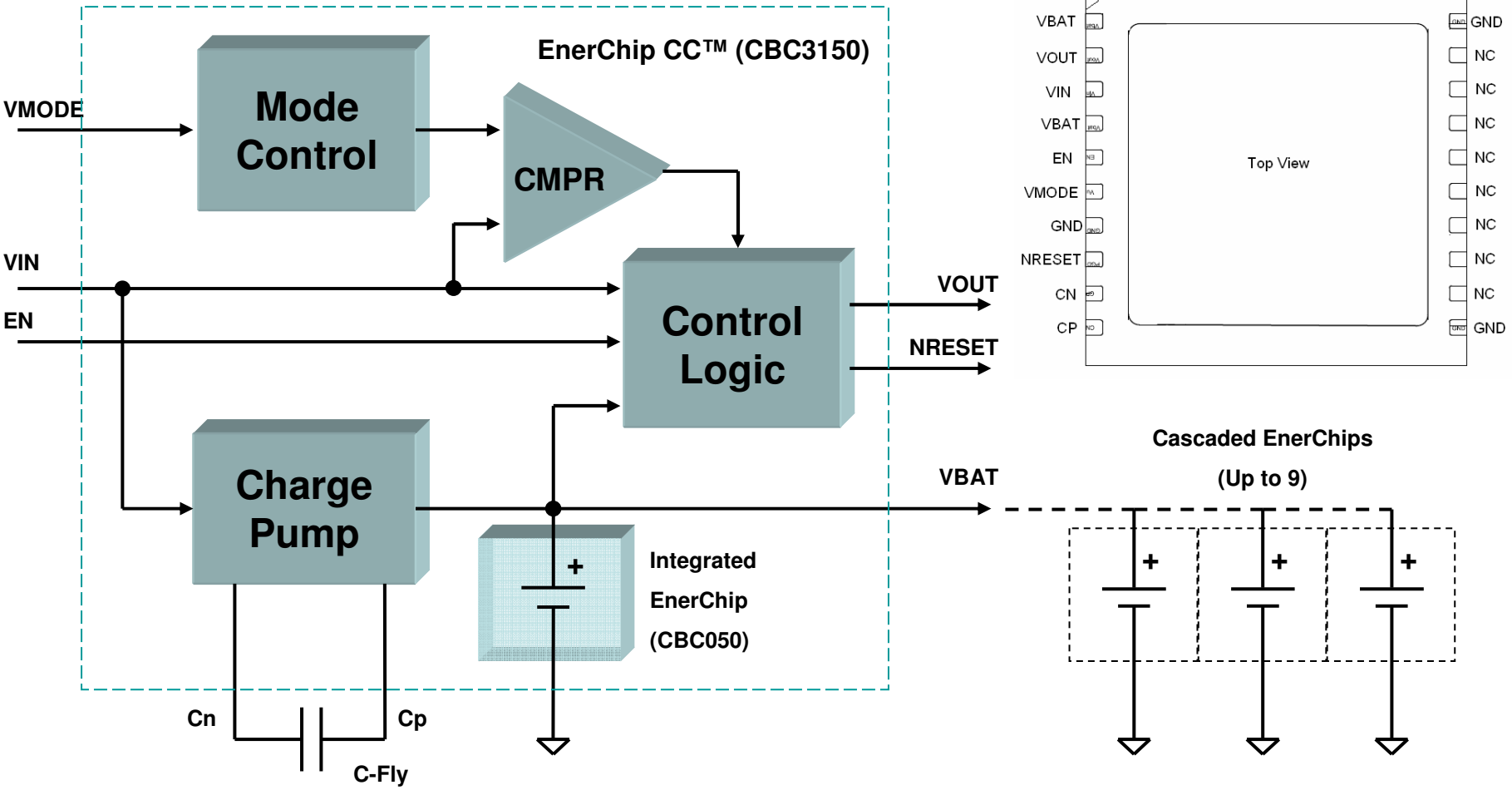
- Designers need a reliable energy storage device with:
  - Thousands of recharge cycles
  - Surface Mount Technology Packaging and Process
  - Reflow Tolerant
  - Low self Discharge
  - Flat output voltage profile
- They need to manage input power, manage the battery and control output power
- The ideal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

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

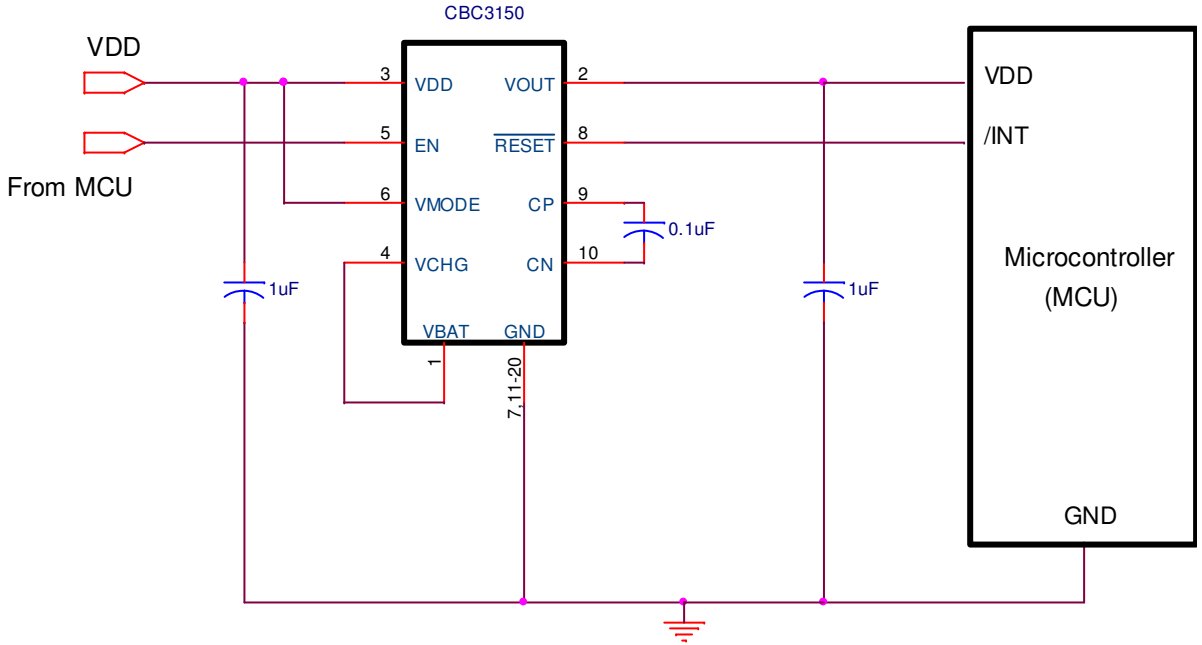
EnerChip™ CC with
Integrated Battery Management

- 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 VIN goes below user selected threshold
  - RESET/ connects to Microcontroller interrupt input indicates the MCU is running off the battery

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

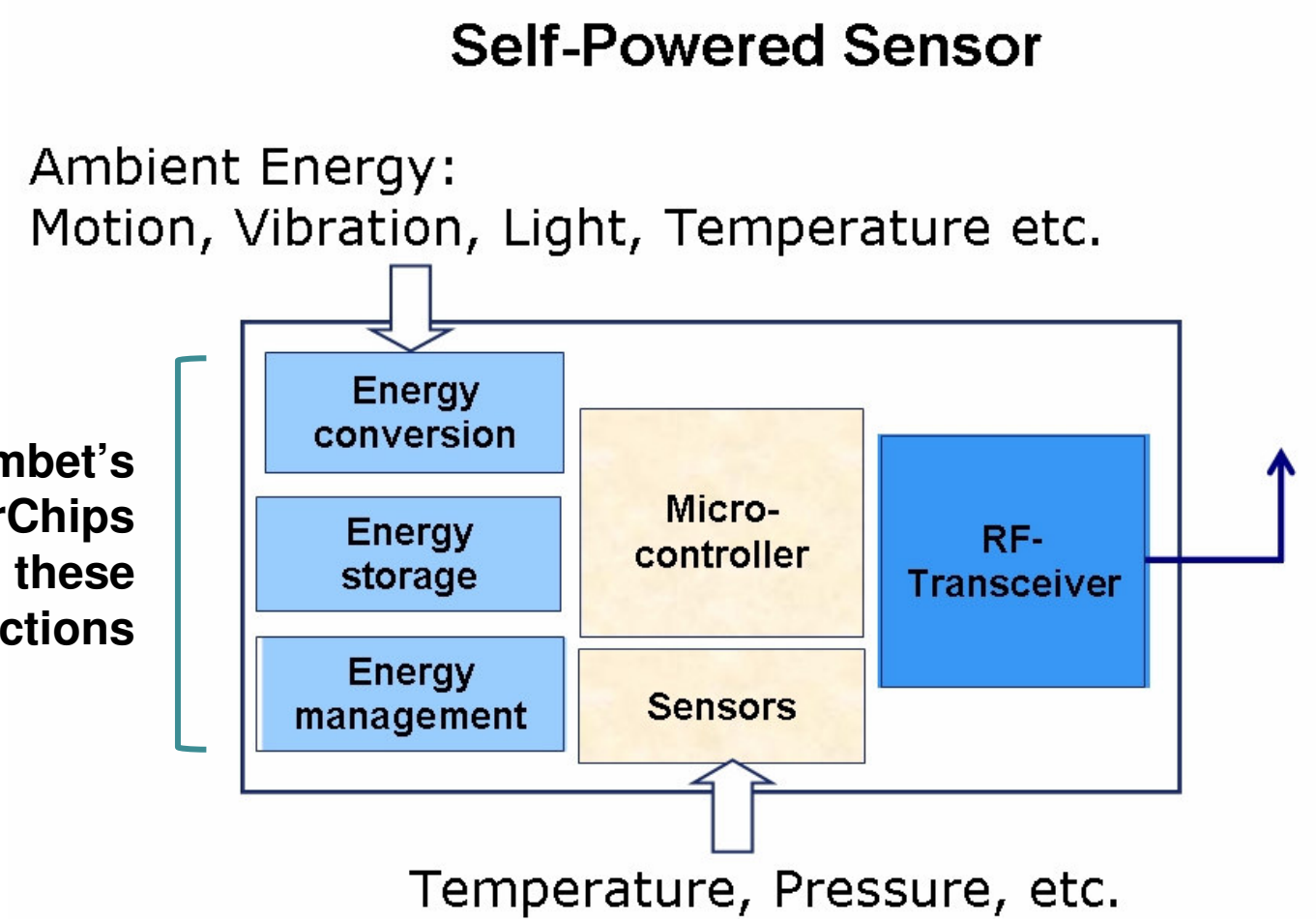
- RAID controllers
- Point-of-sale terminals
- Copy and FAX machines
- Medical and test equipment
- Embedded systems
- PCMCIA cards
- Blade servers
- Networking & hubs
- Test equipment
- SmartCards
- PDAs & SmartPhones
- PABX systems
- GPS Navigation
- Industrial control
- Handheld/portable devices
-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

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



Cymbet's EnerChips provide these functions

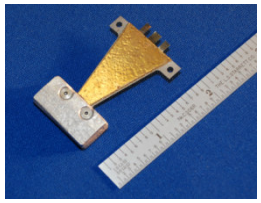
This could be co-packaged into a cost effective single chip solution!

Energy Harvesting Transducers

EnerChip works with all…

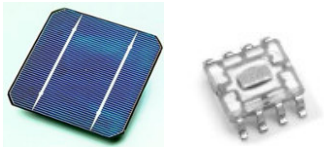
Energy Source	***Challenge***	***Estimated Power*** *(in 1 cm^3 or 1 cm^2)*
Light	**Conform to small surface area** **Wide input voltage range**	**10µW-15mW** **(Outdoors: 0.15mW-15mW)** **(Indoors: <10µW)**
Vibrations	**Variability of vibration**	**1µW-200µW** **(Electrostatic: 50µW-100µW)** **(Electromagnetic: <1µW)**
Thermal	**Small thermal gradients**	**15µW** **(10℃ gradient)**
Piezoelectric	**Capturing pressure or motion**	**~ 200µW**
RF & Inductive	**Coupling & rectification**	**Various**

Source: EE Times

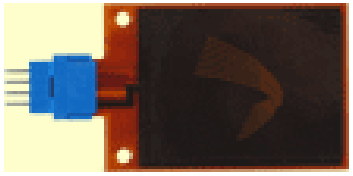


AdaptivEnergy – JouleThief™

Solar - Various

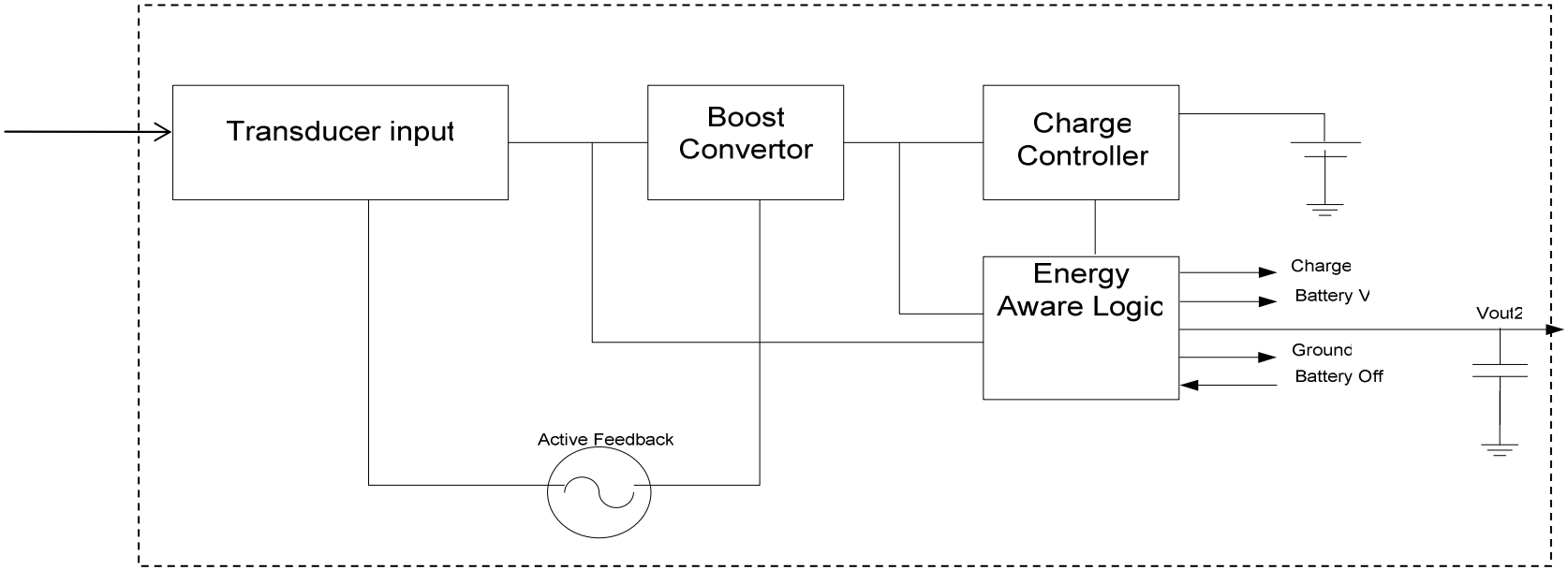


Peltier - Thermo Life



MIDE – Volture™ 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

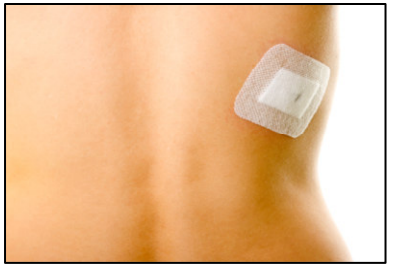
- Energy Harvester Tuning:
  - Optimized for 50 to 4000 ohm impedance
    - Voltages at that impedance should be between 270mV to 1.5V
  - Nominal voltage and impedance is 800mV at 1000 ohms (min = 700mV)
- Find Transducer Peak Power:
  - Some manufactures will provide operating characteristics
  - To 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*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: Turning Passive Tags Into Semi Passive Tags

- PaLFI Passive Low Frequency Interface Device TMS37157
  - Integrated battery less Half Duplex LF interface
  - 3-Wire SPI interface to any microcontroller
  - 121 Bytes free available EEPROM user memory
- Semi Passive Tags With Rechargeable Energy Storage
  - Utilizes CBC3150 for remote power to Tag
  - Ultra low current consumption
  - Allows for active data logging
  - Recharged when in proximity of LF field during data download with TI RFID Reader
  - When battery is drained, tag data can still be read through the LF field
  - Used in capsulated systems without power availability needing active sensors

Applications: Turning Passive Tags Into Semi-Passive Tags

- Passive PaLFI Functions
  - Data Logging, Line-End Programming, mailbox function, communication through MCU (read & write), passive wake-up via air or push button
  - Battery charge function
  - Secure and encrypted communication
- Semi Passive Tag Monitors Temperature Aberrations
  - Integrated power for tag allows for active temperature monitoring

Monitor temp. during shipment; read tag at destination

Semi Passive Tag

Application Schematic

DATA LOGGER:

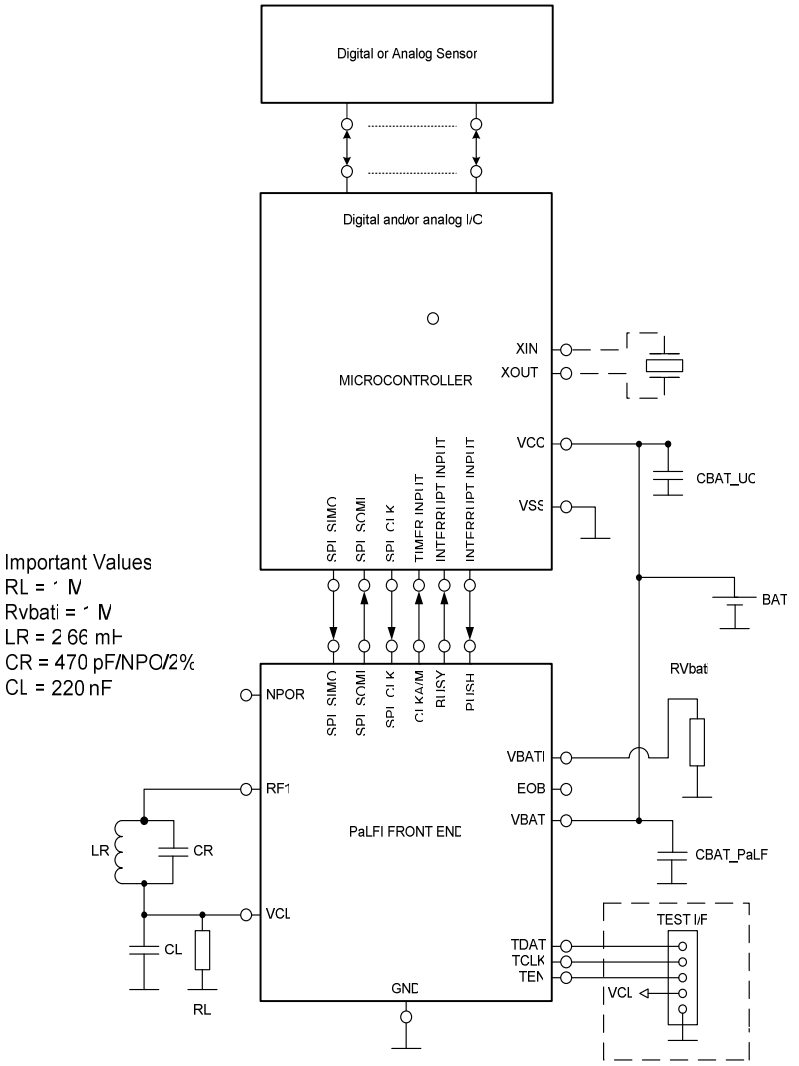
- Microcontroller directly connected to the battery
- Microcontroller is in Low Power Mode and performs measurements from time to time
- Measurement results are stored in EEPROM of the PaLFI device
- EEPROM of PaLFI could be accessed without battery support

RUN BY FIELD OPTION:

- Battery can be replaced by a capacitor
  → System performs measurement only if a LF field from a external reader is provided
- Measurement results is transferred over the LF interface

Application Examples:

- Sensors, Implantable Devices, Hearing Aids, Inventory Management, Asset Tracking, Start of active communication



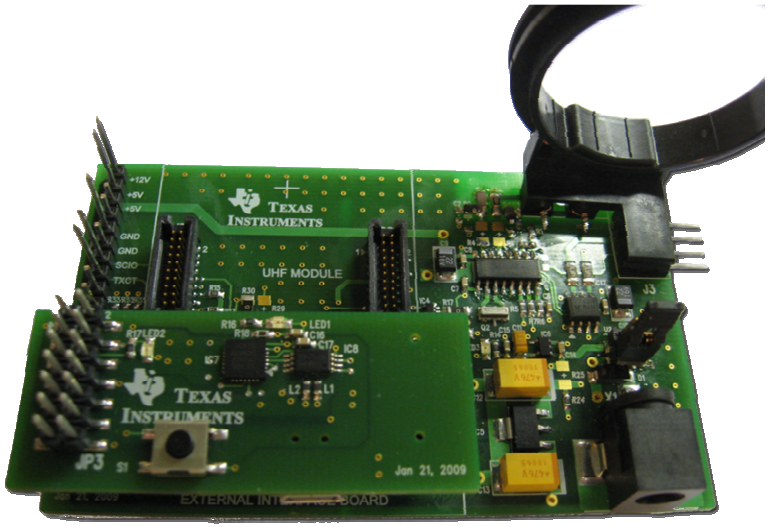
Semi Passive RF Tag Applications

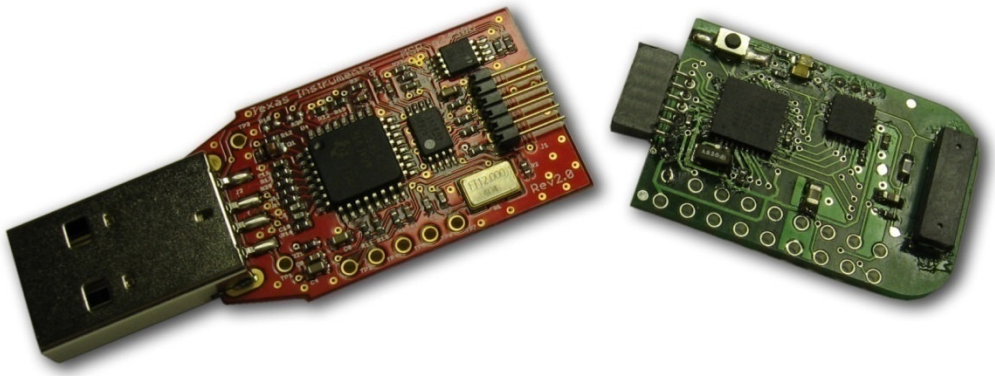
- Cold-chain time/temperature monitoring
- Smart patches – medical
  - Blood glucose monitoring
  - Body temperature
  - Moisture, pH, oxygen
- Service tags
  - Equipment calibration and servicing indicators
- Low duty cycle real-time locating systems

eZ430-PaLFI Development Kit

eZ430 - PaLFI

- **EVM for TMS37157 – PaLFI (Passive Low Frequency Interface)**
- **MSP430F2274 connected to the TMS37157 chip**
- **Demo system for PaLFI functions**
- **RFID Base Station (Reader) is supplied with the demo system**

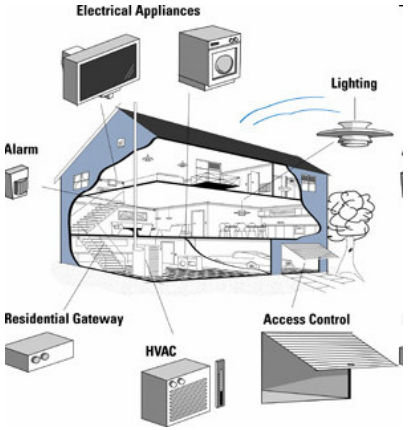




Applications: Business and Home Energy Management

- 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

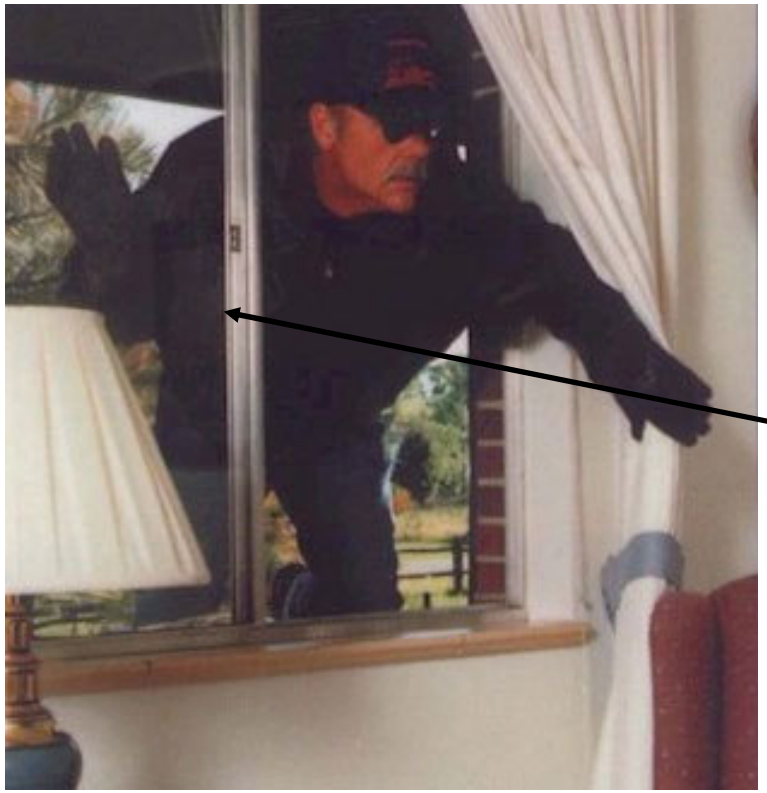
Example: Wireless Lighting Control

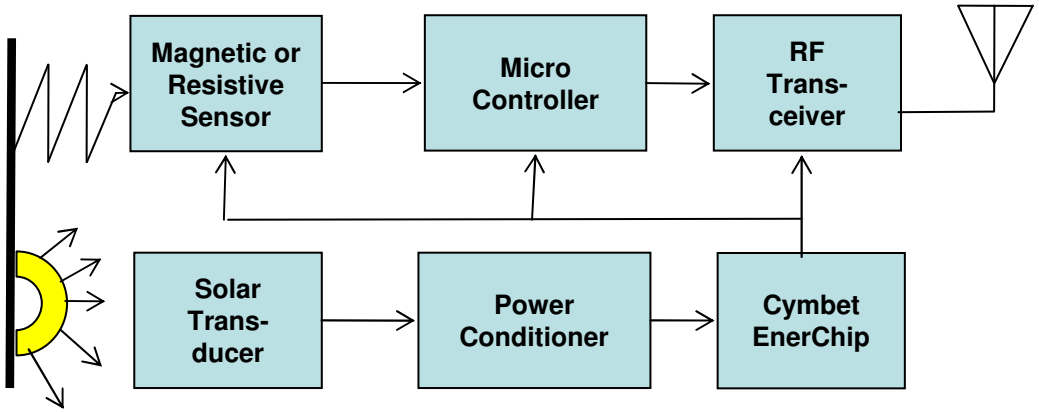


Example: Home Automation

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

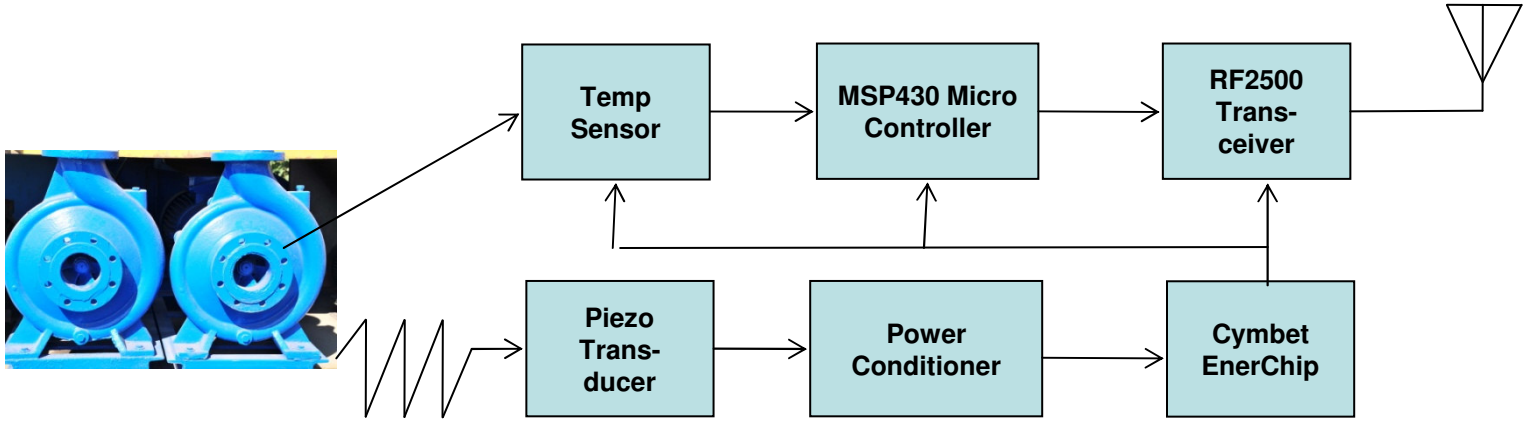
Applications: Alarm Systems



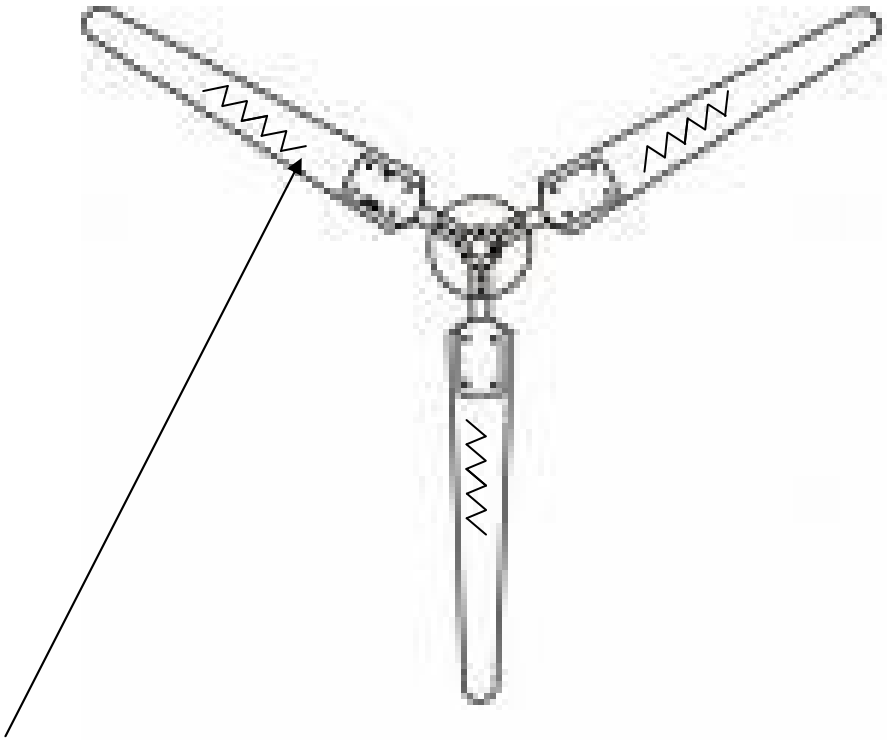


Applications: Industrial Sensing

- 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

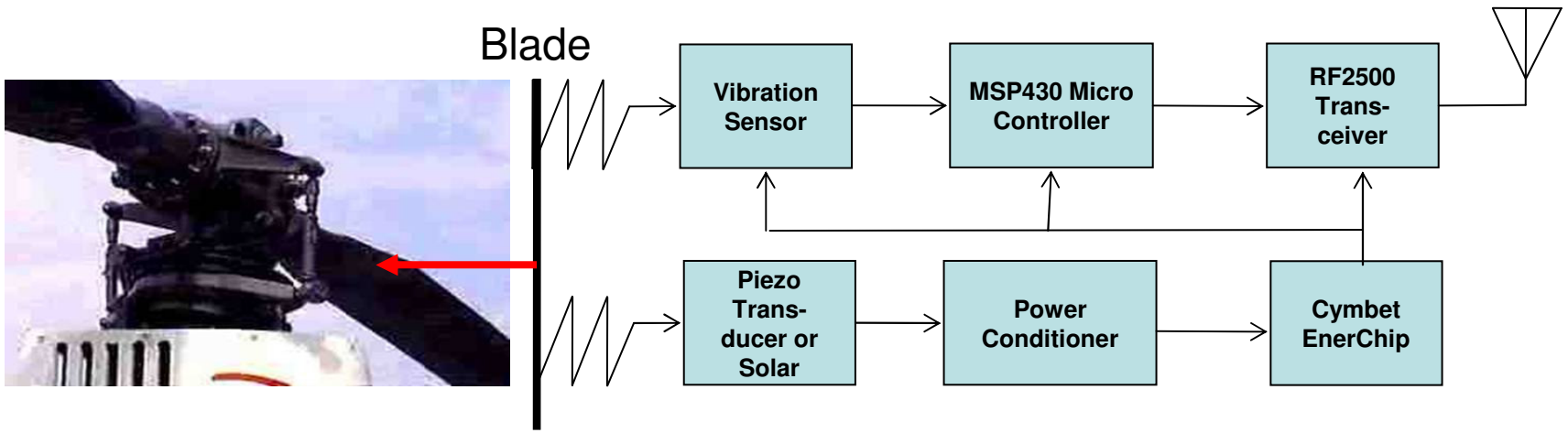
Piezo or Solar element in each blade

See footage of windmill destroyed:

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

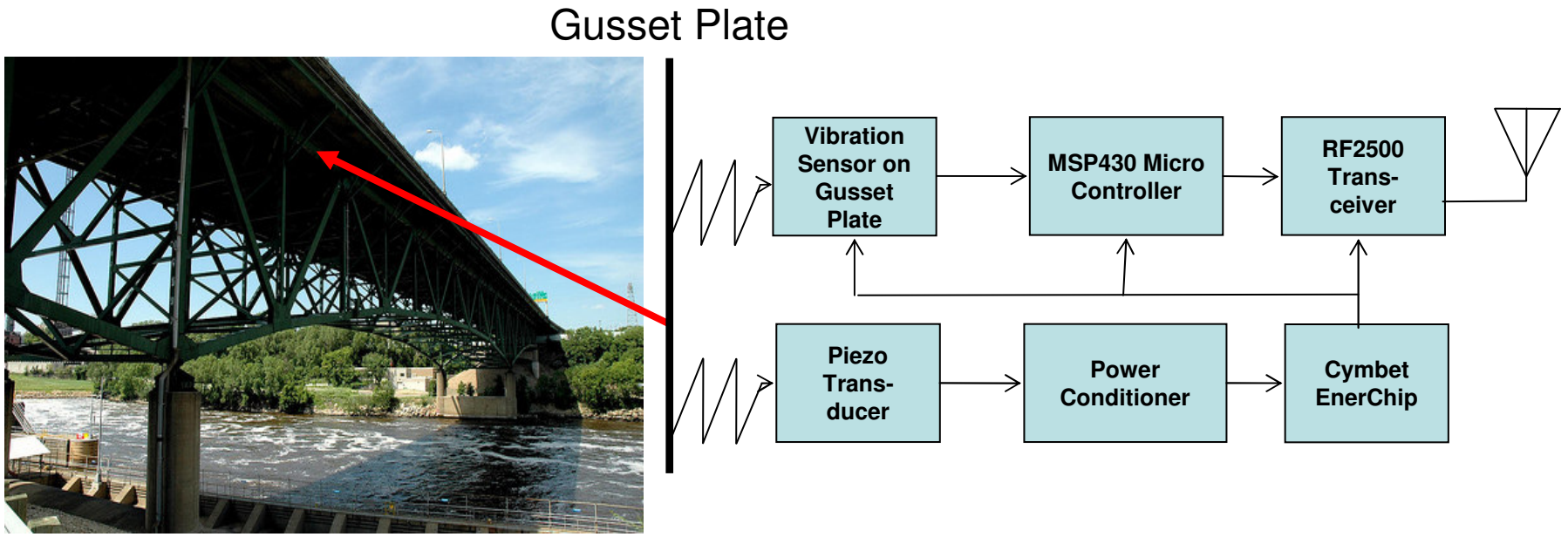
Applications: Helicopter Blade Fatigue Monitoring

- 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

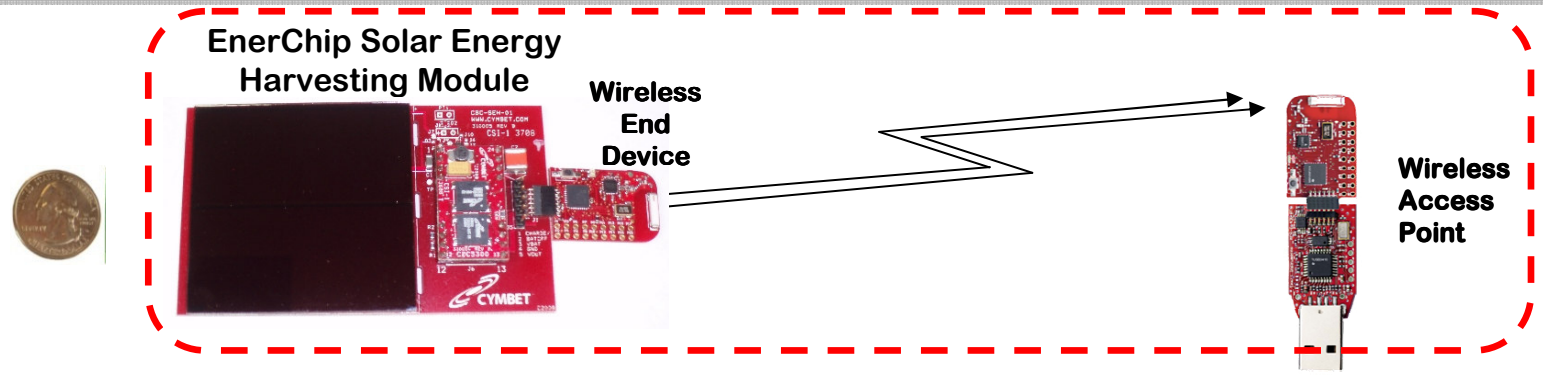


Applications: Bridge Fatigue Monitoring

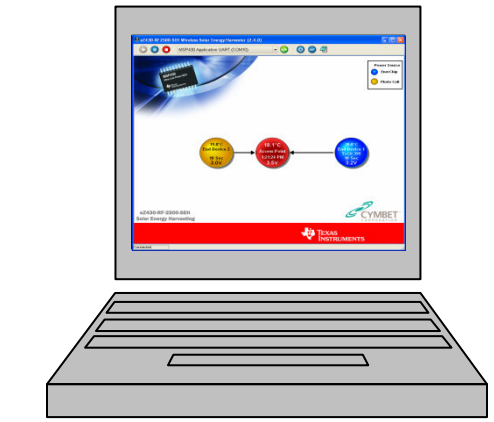
- Stress and Fatigue Monitoring Bridge Decks:

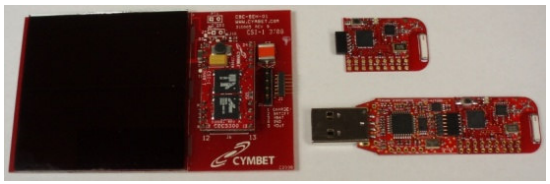


Self-Powered Wireless Sensor:
TI eZ430-RF2500-SEH Evaluation Kit



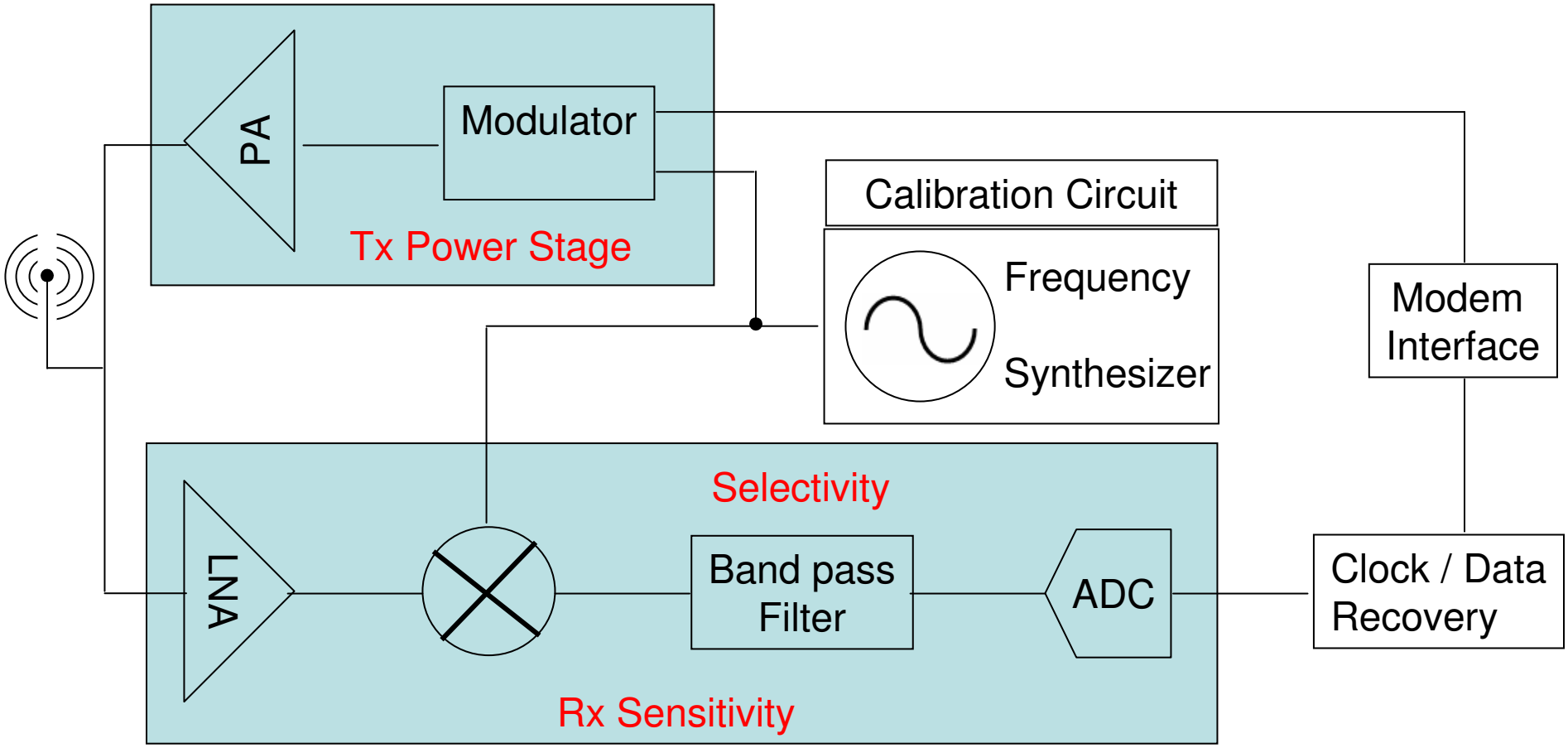
- Available as the TI eZ430-RF2500-SEH Evaluation Kit at TI e-store and distributors
- Compact module with integrated solar cell
- Works in low light – down to 200Lux
- Low self-discharge enables high-efficiency
- No battery replacement or disposal; 10-year life
- Uses the EnerChip EH CBC5300 – Energy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



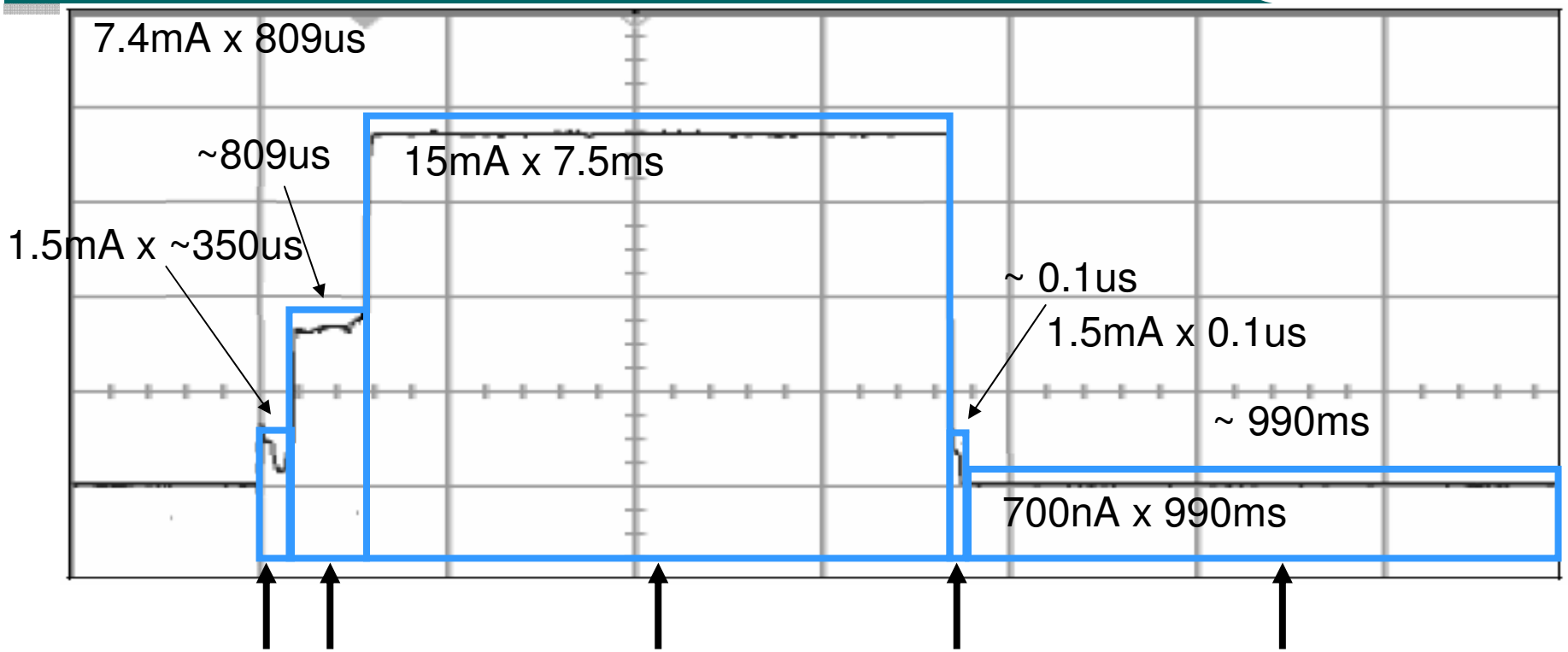


TI's eZ430-RF2500-SEH Evaluation Kit Contents

Typical Low Power Transceiver



Calculating Energy Usage per Transmission

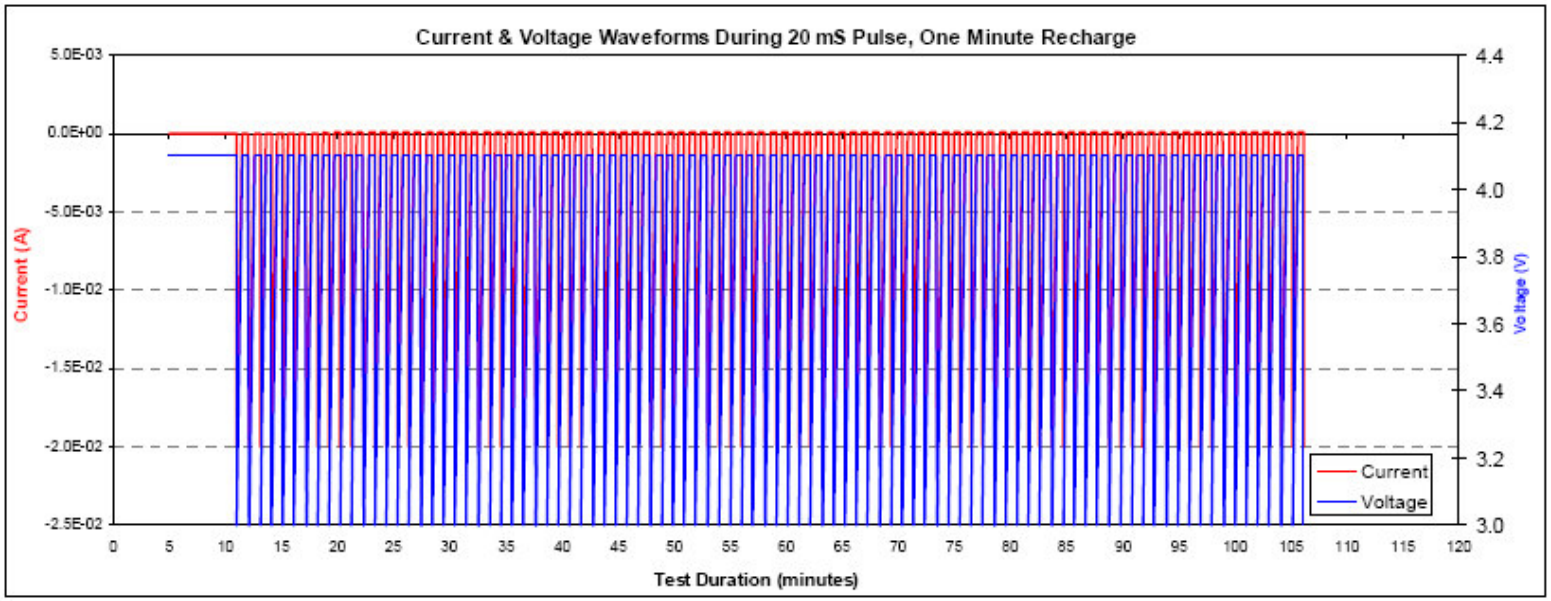


External Oscillator Settling	Frequency Synthesizer Calibration	Receive or Transmit	Radio In Idle	Radio In Sleep
145pA Hr	**+ 1.67nA Hr**	**+ 31.25nA Hr**	**+ 41.6fA Hr**	**+ 192pA Hr = 33nA Hr = 392 uJoules**

Pulse Capacitor Requirements

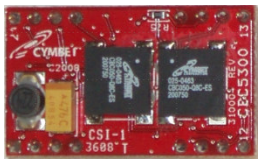
- Sizing of output capacitor depends on several factors:
  - Battery impedance
  - Battery voltage
  - Temperature
  - Pulse current amplitude
  - Pulse current duration
  - Allowable voltage drop during discharge
- Calculating output capacitor size:
  - C = t / R * [-ln (Vmin / Vmax)]
    - C= output capacitance
    - t = pulse duration
    - R= load resistance = Vout(average) / Ipulse
  - Vmin and Vmax are dependant on the minimum operating voltage of the external circuit
- Charge time determines maximum duty cycle:
  - Charge formula: t= R * C [- ln (1 – Vmin / Vmax)]
    - T = charging time
    - R = battery resistance
    - C = output capacitance

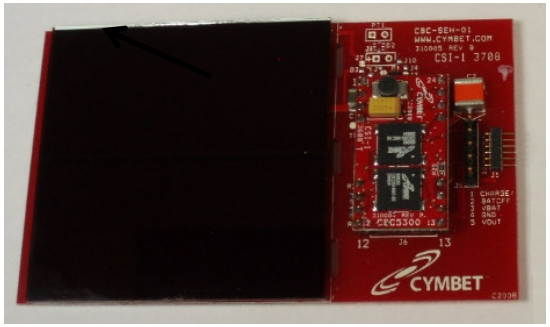
Pulse Current & Voltage Profiles During RF Transmissions



Technical Eval Kits to Create EH demos CBC5300

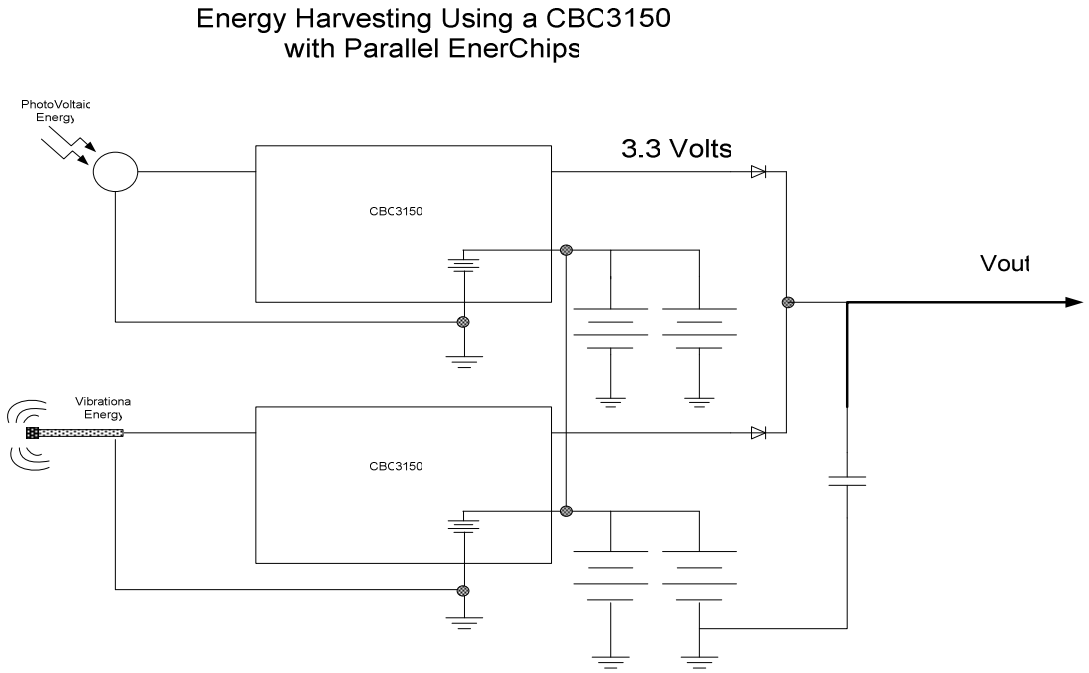
- EnerChip CBC5300 for EH product protoyping:
  - Capacity = 100uAh, uses 2 CBC050s
  - Compatible with solar, inductive, piezo & thermoelectric transducers
  - Provides control signals to enable “Energy Aware” sensor nodes
- EVAL-08 try out solar cells :
  - Solar Energy Harvesting Demo Kit
  - Compact 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
- Available at Digi-Key and Mouser





Technical Eval Kits to Create EH demos CC3150

- EVAL-05 for Solar Energy Harvesting
  - Uses EnerChip CC 3150
  - Can connect solar cell or Piezo or both for simple EH design



- Available at Digi-Key and Mouser

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

Presentation 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