Energy Harvesting: Past, Present and Future

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Kilby Labs, Texas Instruments

05/29/2018

Self-Powered Applications

Low data rate, low duty cycle, ultra-low power

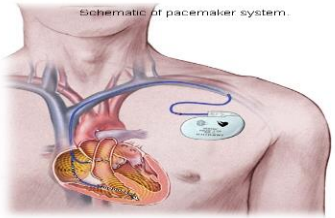
Solar Keyboard

Electronic Shelf Labels

Self-powered switches

Convenience

Occupancy Sensor



Implantables

Pipelines

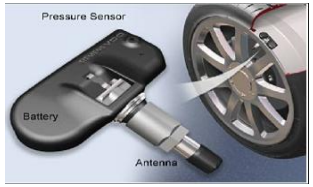
Oil Rig

Home/Industrial Automation

Smoke Detector

Structural sensors

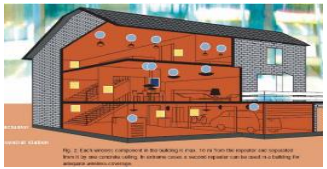
Hard to Reach



TPMS

Texas Instruments

Why cant a battery solve the problem

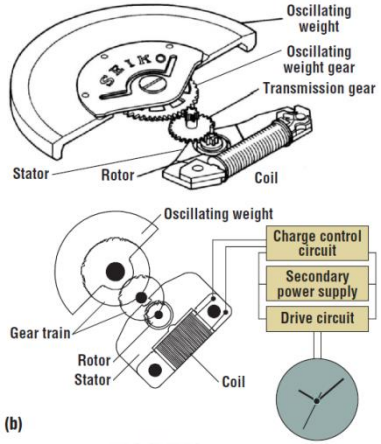


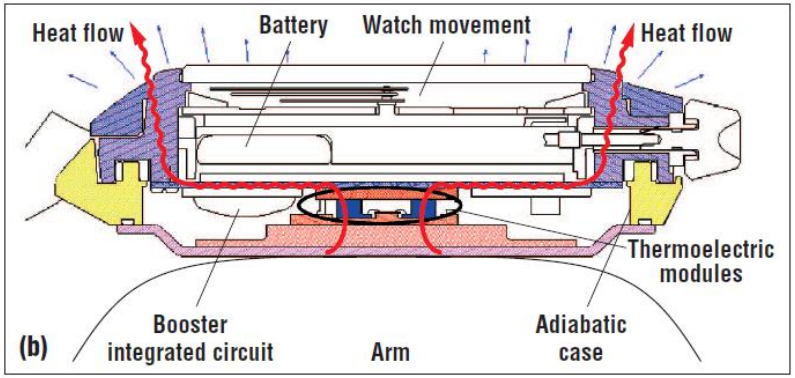
225mAh, 20¢

Operational cost over the product lifetime

	Battery Powered	Harvester Assisted
Life	10 years	10 years
Average Current	10uA	5uA
Years/battery	2.5	5
No. of batteries	4	2
Cost of battery + Cost to replace	$3	$3
Lifetime cost / node	$9	$3
Cost over 100 nodes	$900	$300

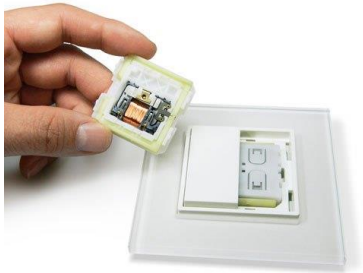
Energy harvesting systems – then

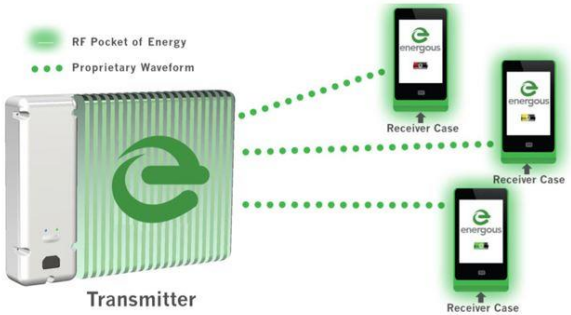




Watches, switches, calculators

Energy harvesting systems – now





Mechanical, Thermal, RF

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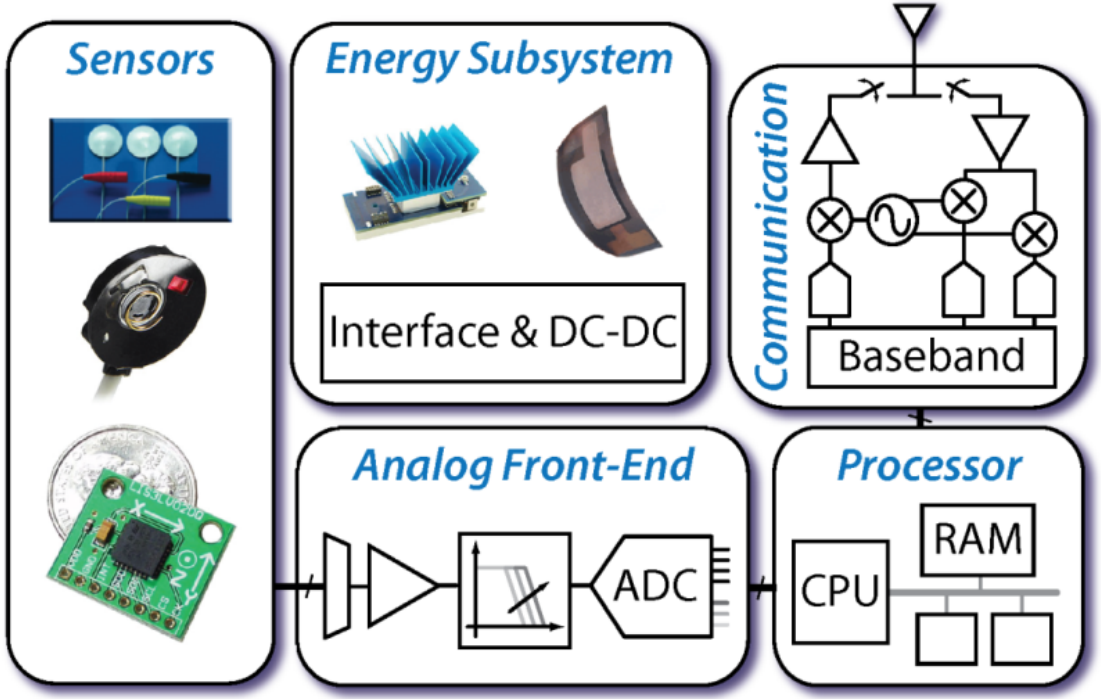
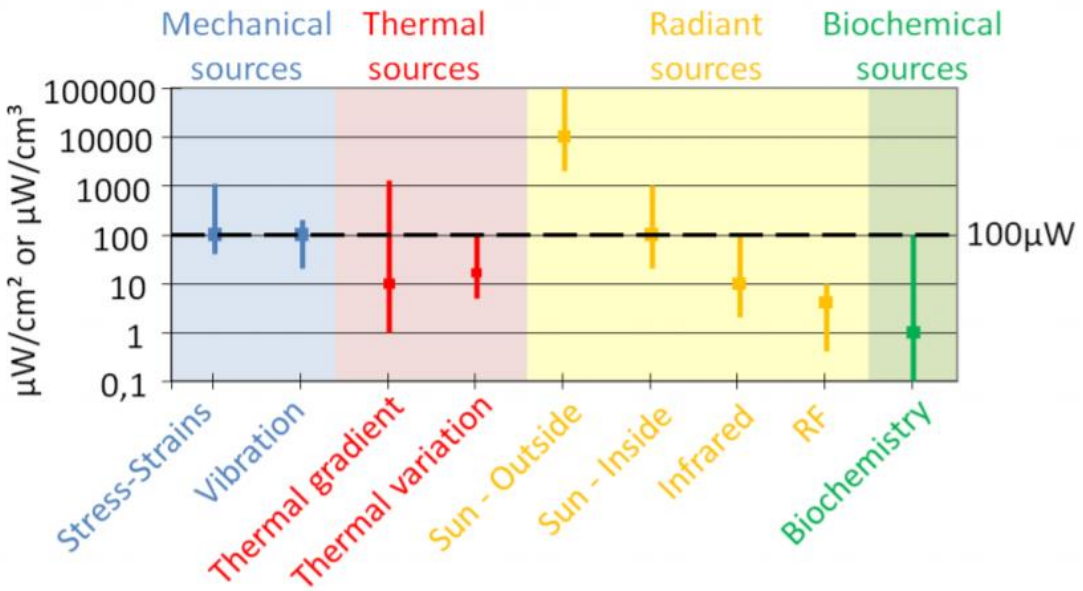
The Node

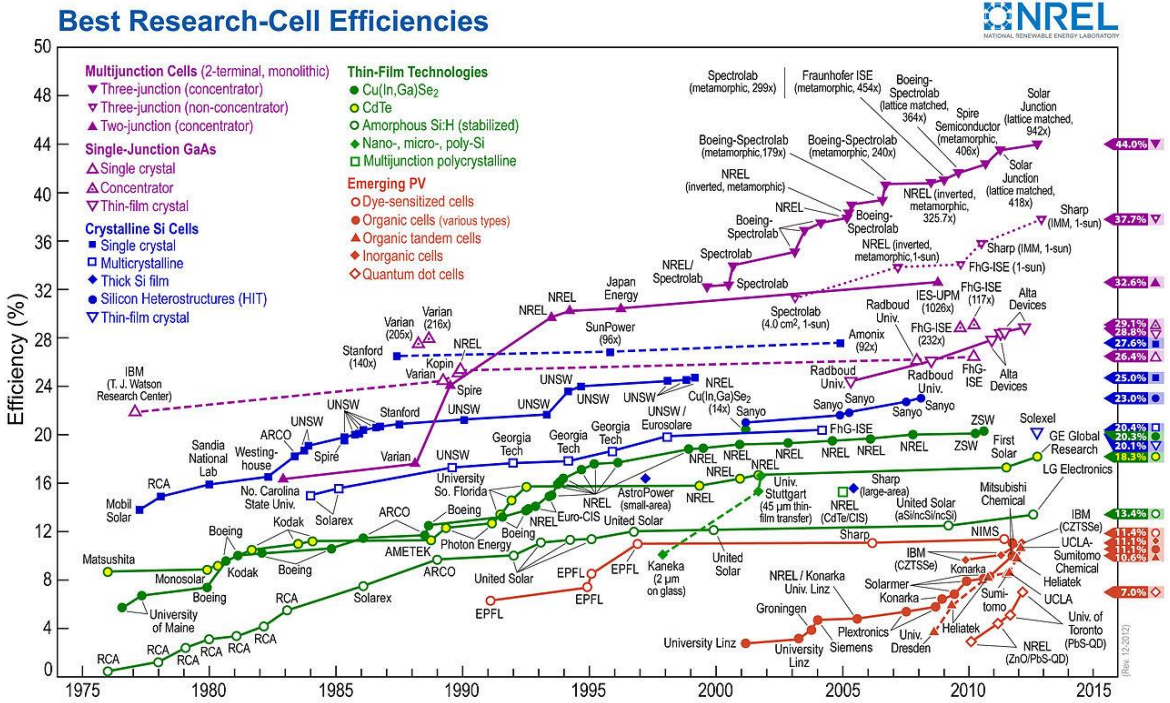

Sensors
Energy Subsystem
Interface & DC-DC
Communication
Baseband
Analog Front-End
ADC
Processor
CPU
RAM

Energy Harvesters



Source: S. Boisseau et. al, Electrostatic conversion for vibration energy harvesting, Open Access

Improvement in Solar Harvesters



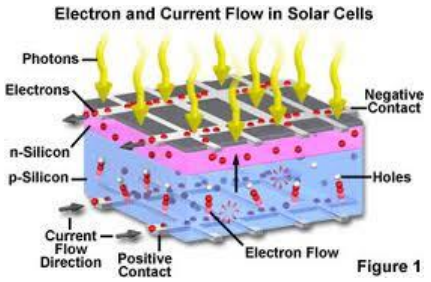
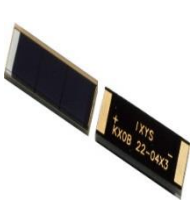
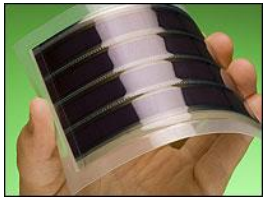


Figure 1

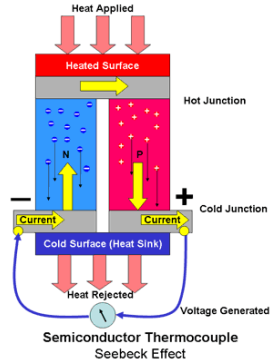




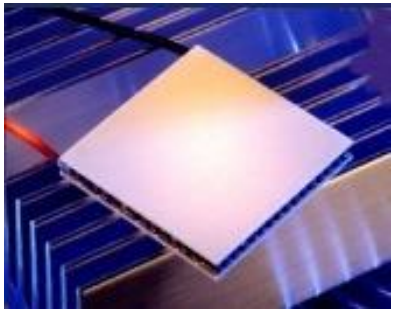
- *Crystalline → Amorphous/Multi-junction → Flexible/DSSC*
- Improvement in efficiency, ability to conform to different shapes

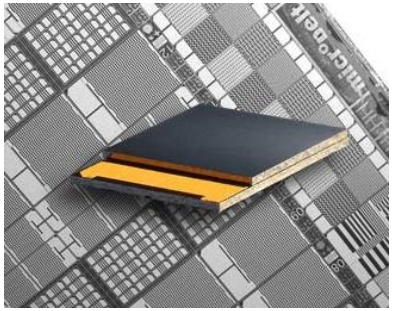
Source: L. Kazmerski, National Renewable Energy Lab, Dept. of Energy

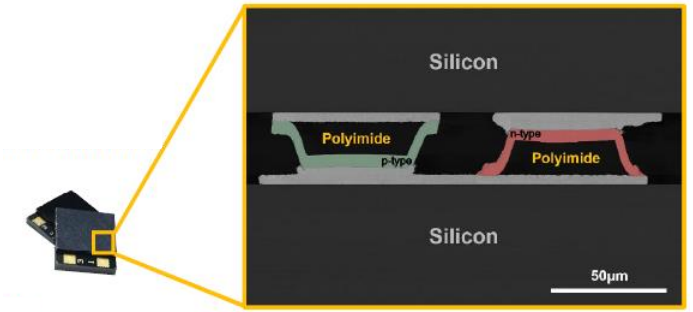
Improvements in Thermal Harvesters



Semiconductor Thermocouple
Seebeck Effect


Tellurex

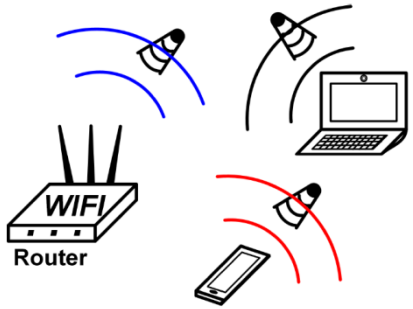

Micropelt



ADI

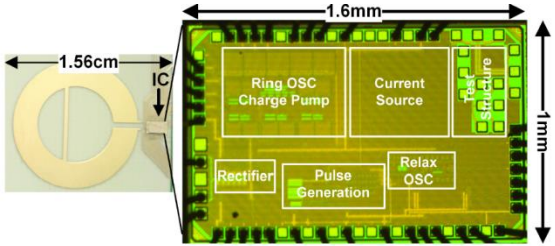
- *Bulk → Micro-machined → Chip-scale*
- Improvement in thermal resistance and material properties

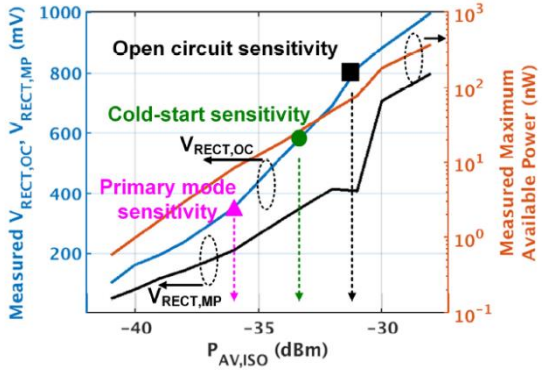
RF Energy Harvesting



Energous

d	$P_{AV,ISO}$	
0.5m	-14dBm	40µW
1m	-20dBm	10µW
3m	-30dBm	1µW

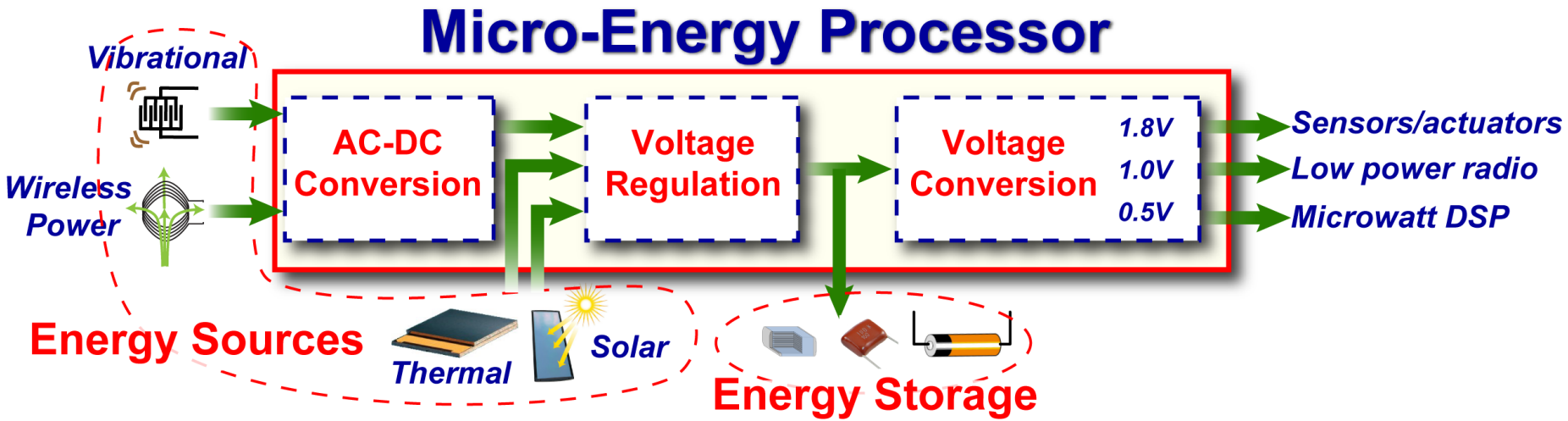




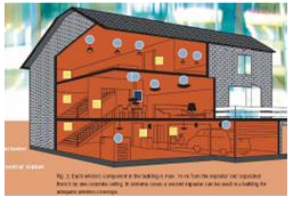
[K. Sadagopan, ISSCC, 2018]

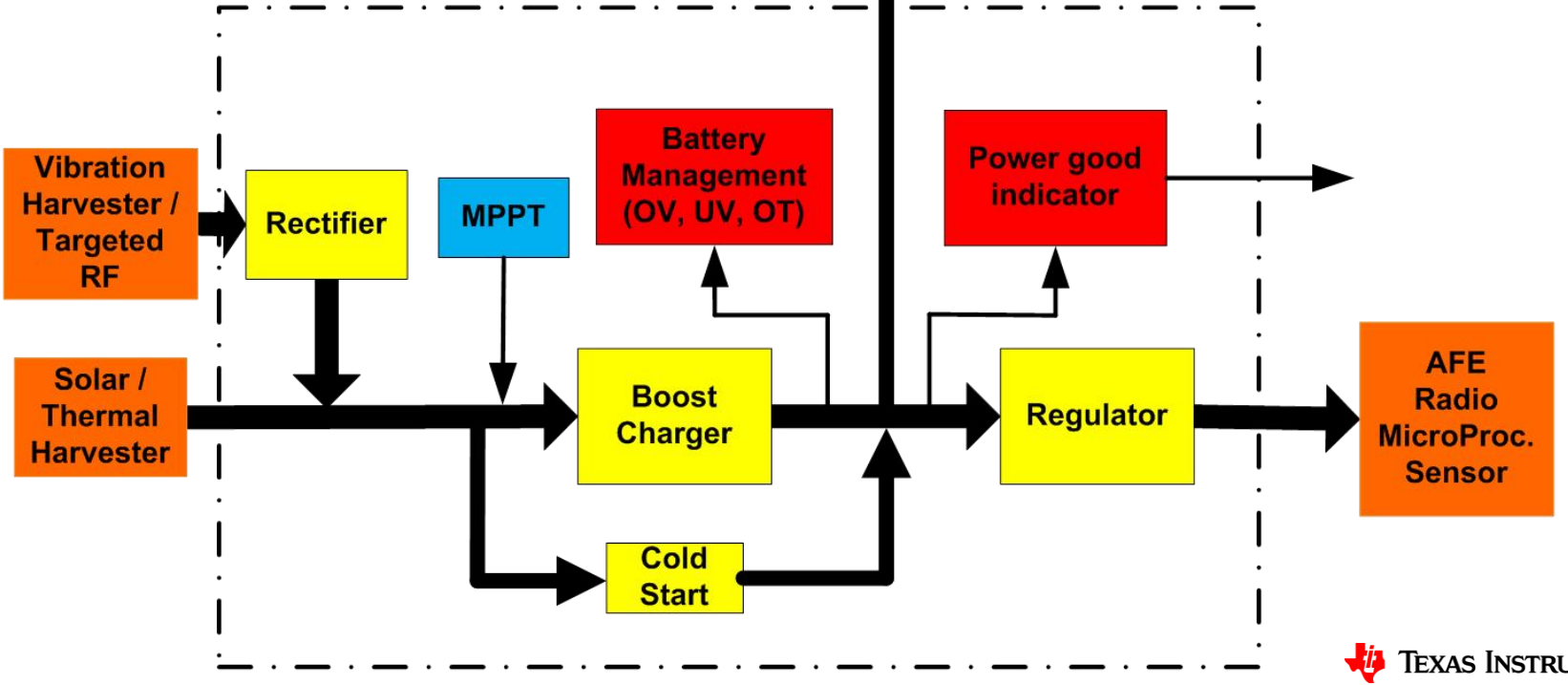
- Potential to be always ON → Reach inaccessible areas
- Influx of startups and mainstream commercial companies adopting technology

Energy Management Unit for IoTs / Wearables



Energy Management Unit for IoTs / Wearables

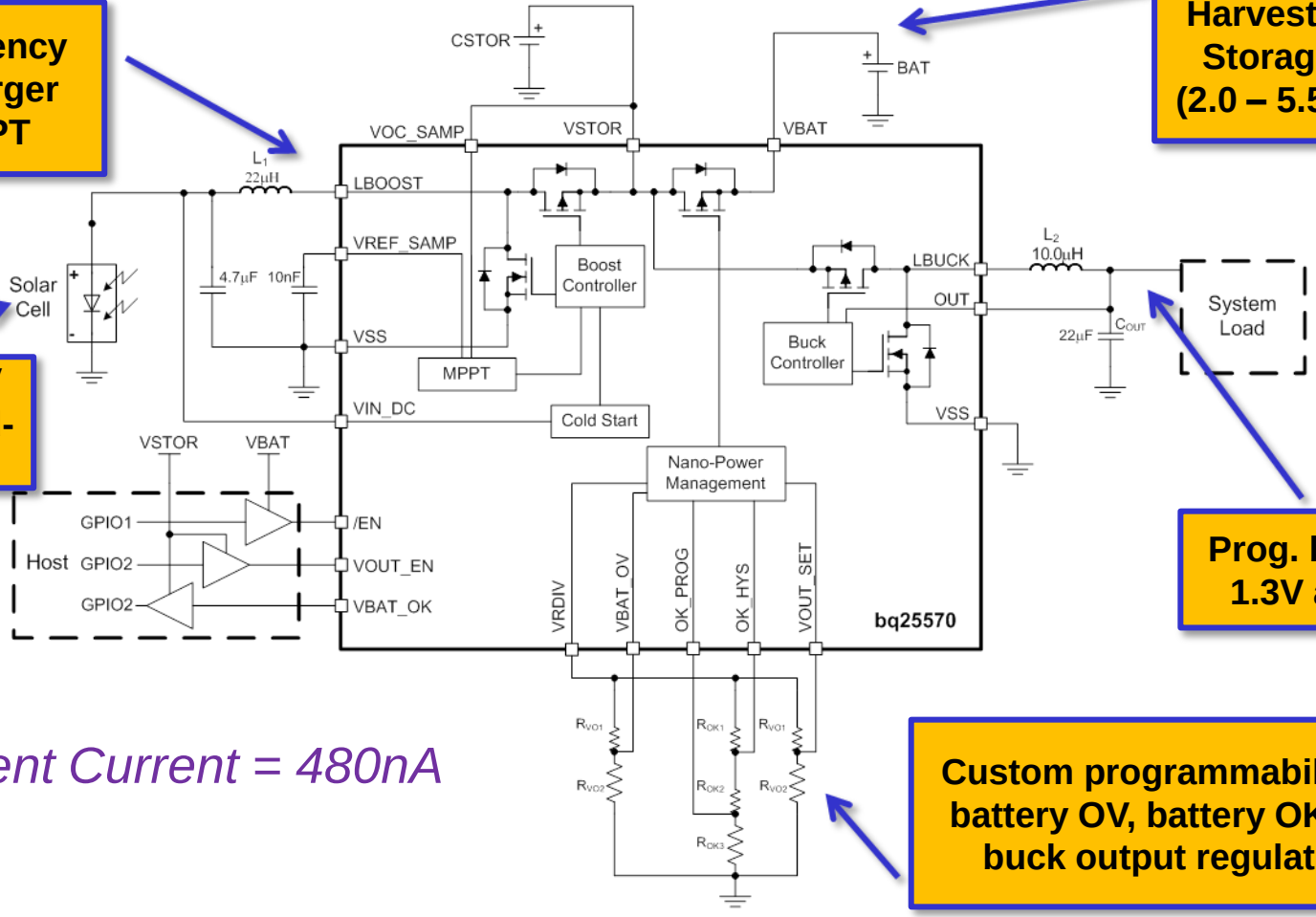




Commercial Energy Mgmt. IC -BQ25570

High efficiency boost charger with MPPT

Harvester Storage (2.0 – 5.5V)



100mV to 4V VIN with cold-start circuit

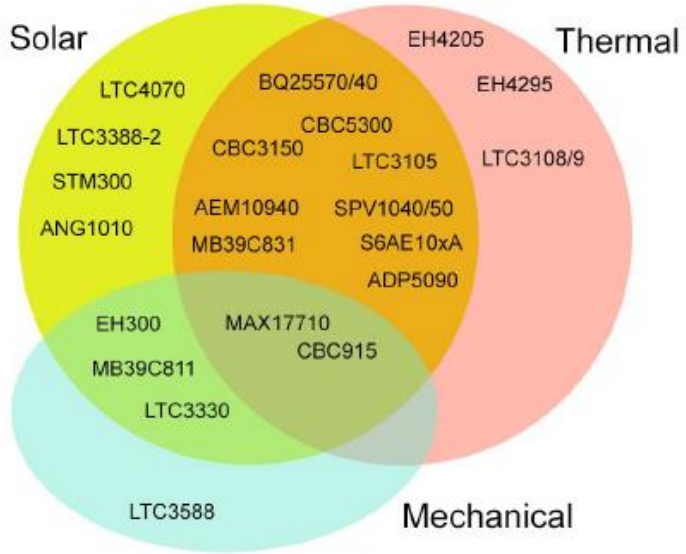
Prog. between 1.3V and 5V

Quiescent Current = 480nA

Custom programmability for battery OV, battery OK, and buck output regulation.

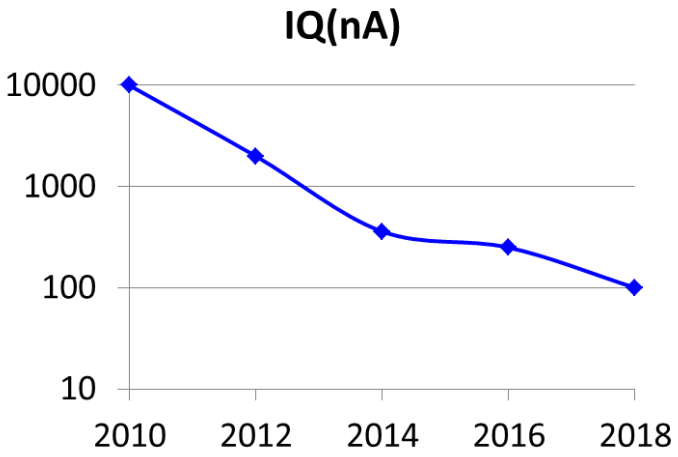
NTS

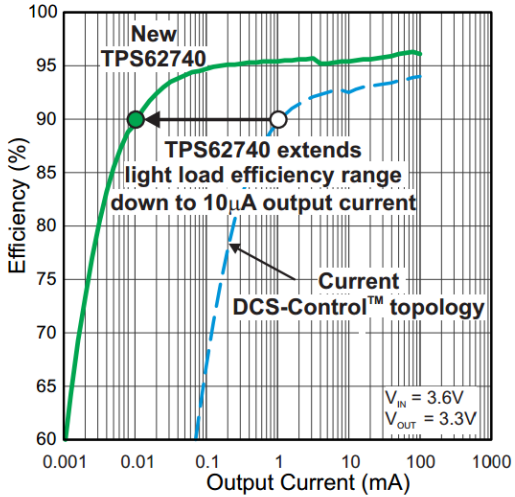
Commercial Energy Management ICs

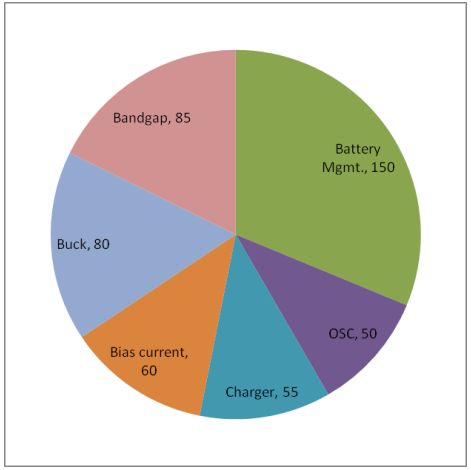


Source: Ilika

Improvements in IQ and low current efficiency





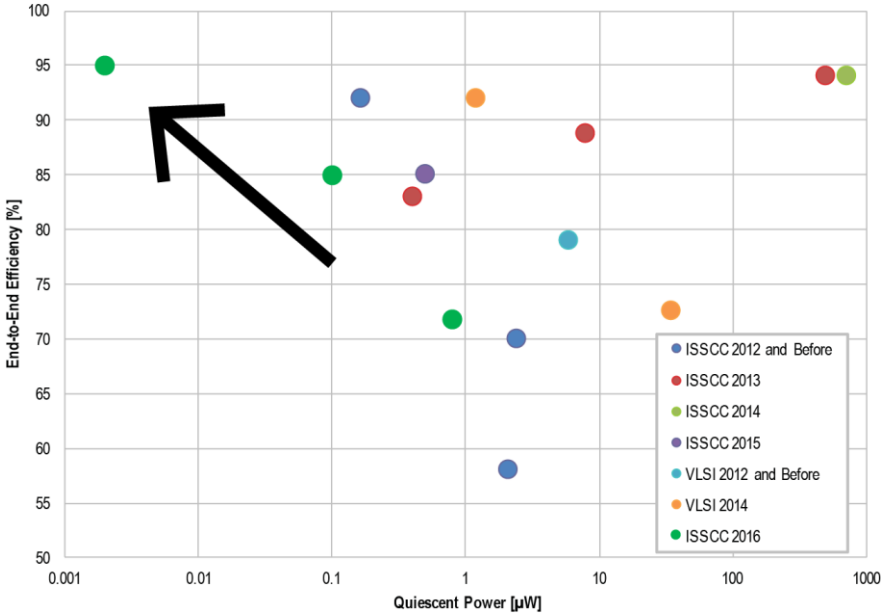


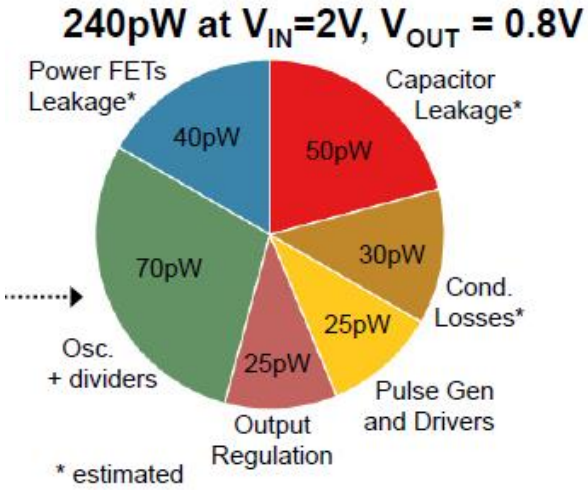
BQ25570

- IQ and efficiency numbers have significantly improved both in commercial parts and academic publications

- Commercial switching converters and LDO's with IQ<100nA will soon be available

Improvements in IQ and low current efficiency



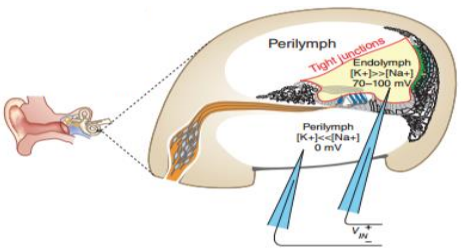


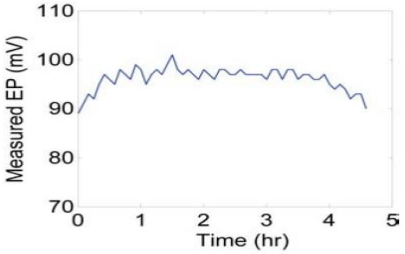
A. Paidimarri, ISSCC 2017

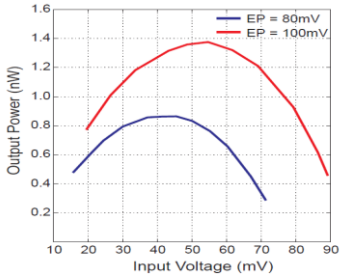
- Academic publications are trending towards <10nW of quiescent power while pushing end-to-end efficiency to > 90%

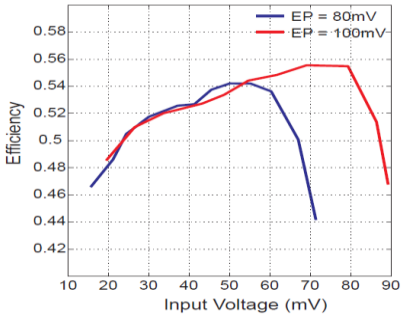
Source: ISSCC 2017 trend charts

Tapping Potentials within the body

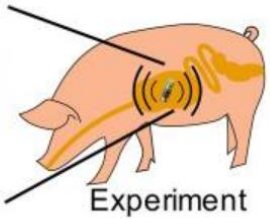


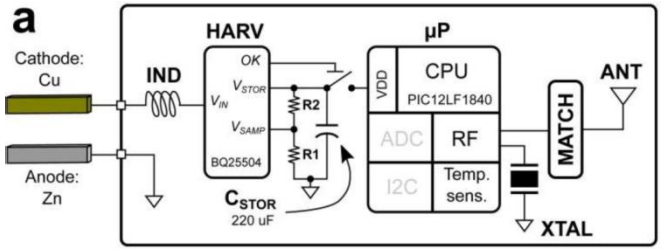


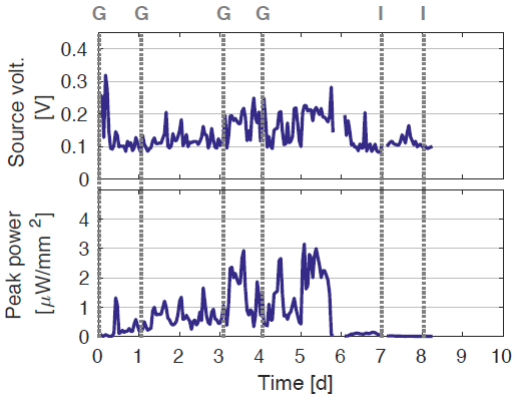




EndoCochlear Potential *[P. Mercier, Nature Bio, 2012]*





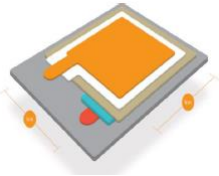


[P. Nadeau, Nature Bio, 2017]

Bio-Galvanic Cell

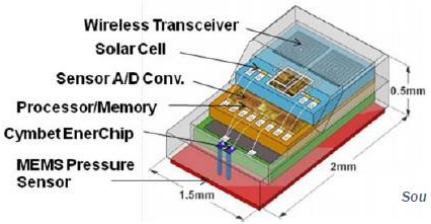
Texas Instruments

Storage Technologies



Leakage current level	Yearly loss	
1nA	10μAh	← Solid state batteries
10nA	100μAh	← Pulse caps
100nA	1mAh	← PMIC
1μA	10mAh	← Supercaps, coin cells

	Conventional Li-ion	Supercapacitors	Solid State Batteries
Trickle-charging/ Low Leakage	✗	✗	✓
5,000 cycles+	✗	✓	✓
Ultra-compact	✗	✗	✓
Safety Profile	✗	✓	✓
Capacity	✓	✗	✗
Power	✗	✓	✓
Biocompatible	✗	✗	✓

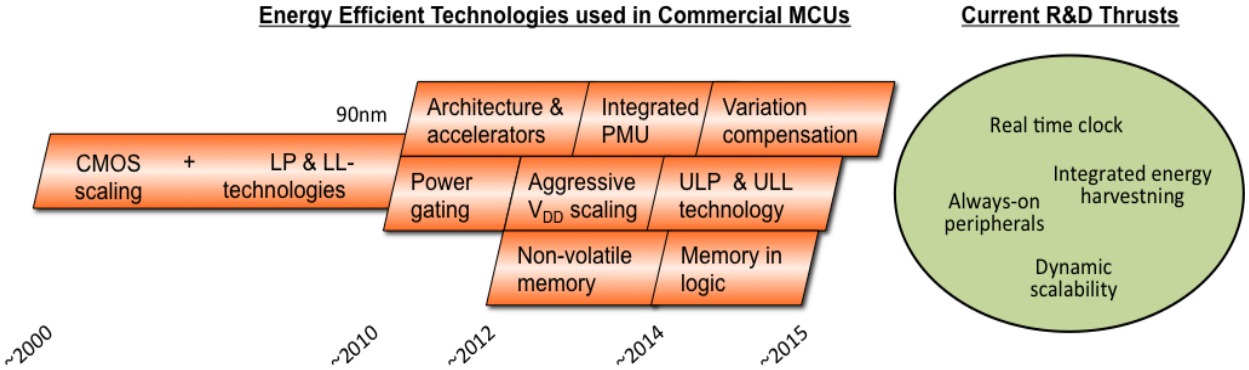


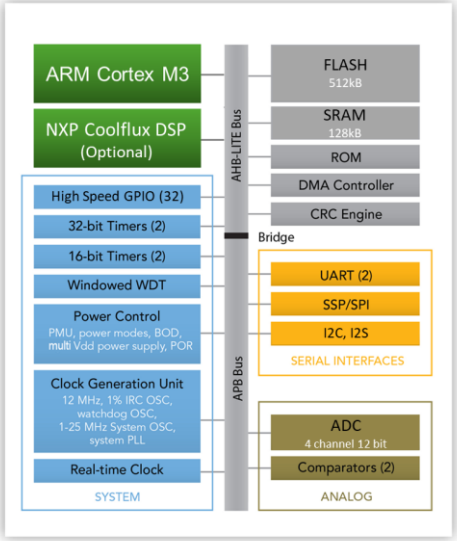
G. Chen, ISSCC 2011

- Low leakage solid-state batteries present attractive choice for long-term operation
- Ultra-thin with ability to be integrated with IC's enable small form factors

Source: Ilika

Improvements in Digital Loads



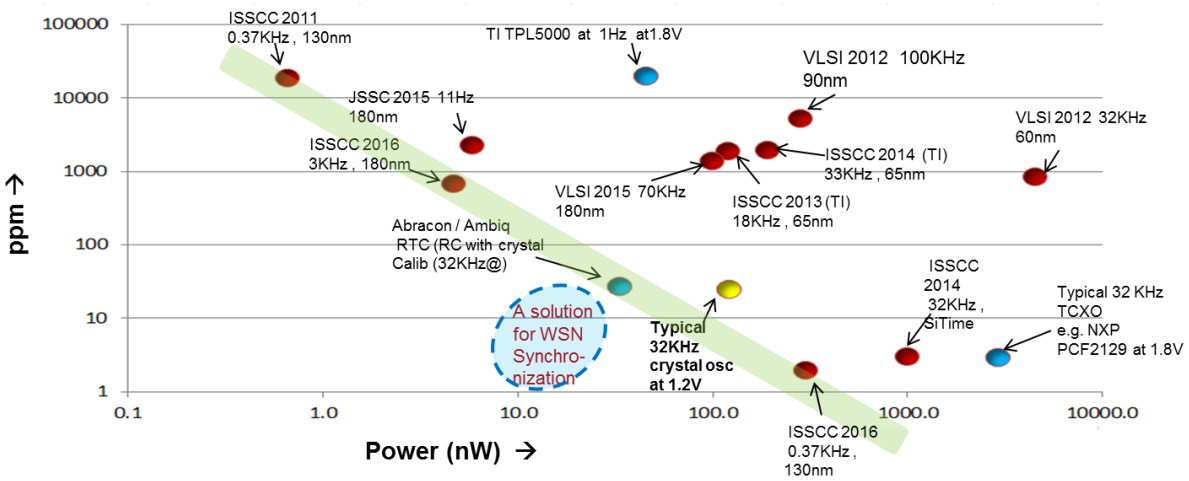


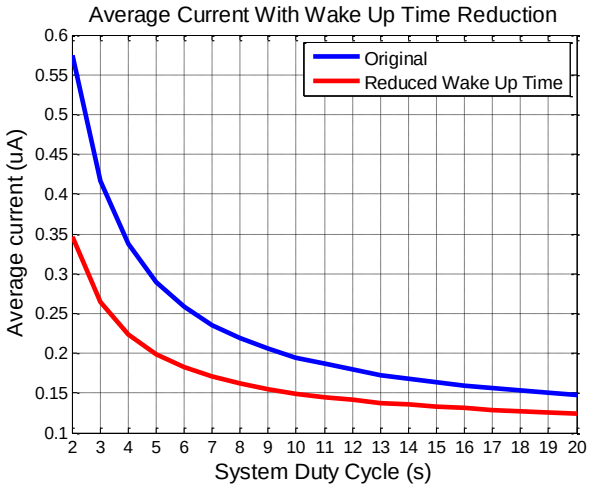
	Parameter	Core	Memory	Total	Units
64 MHz	Efficiency @ 3V	6	4	10	$\frac{uA}{MHz}$
5 MHz	Efficiency @ 3V	3	5	8	$\frac{uA}{MHz}$
Sleep w/ RTC on	Current @ 3V	0.2	0	0.2	uA

- Focus on dynamic scalability and efficient always-on peripherals, such as real-time clocks and wake-up sensors
- Asynchronous ARM Cortex M3 operating from 0.2V to 0.9V using on-chip voltage regulators
- Consumes 1.2uW at 200mV operation

Source: ISSCC 2017 trend charts, ETA Compute

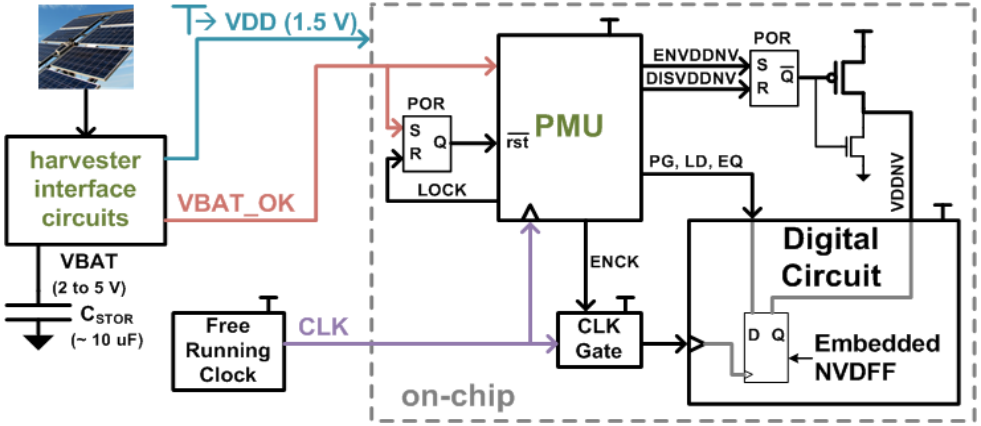
Improvements in Real-Time Clocks

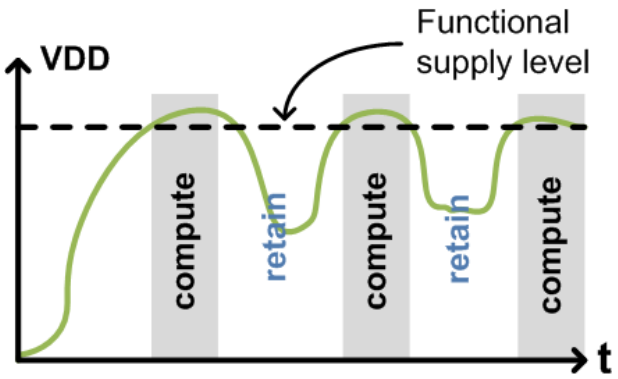


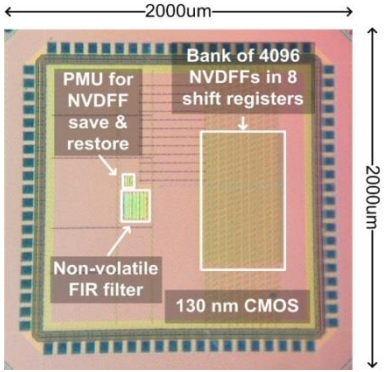


- Duty Cycled Sensors:
  - HDC1080 humidity + temperature sensor
  - Wake up time reduced from 2.5ms to 0.1ms
  - Power saving: 15% - 39%

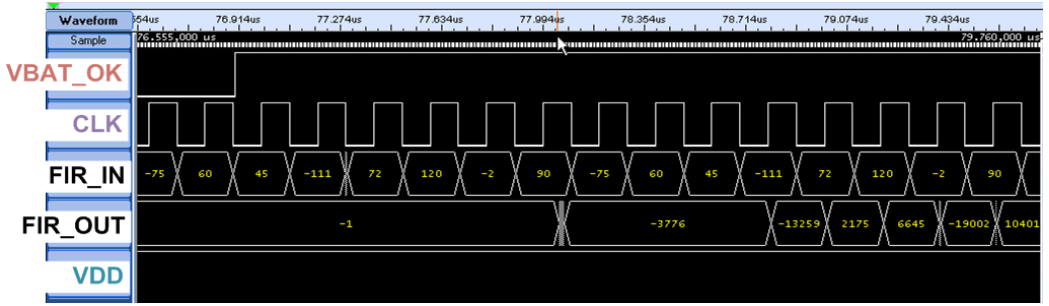
Computing Architecture with Energy Harvesting





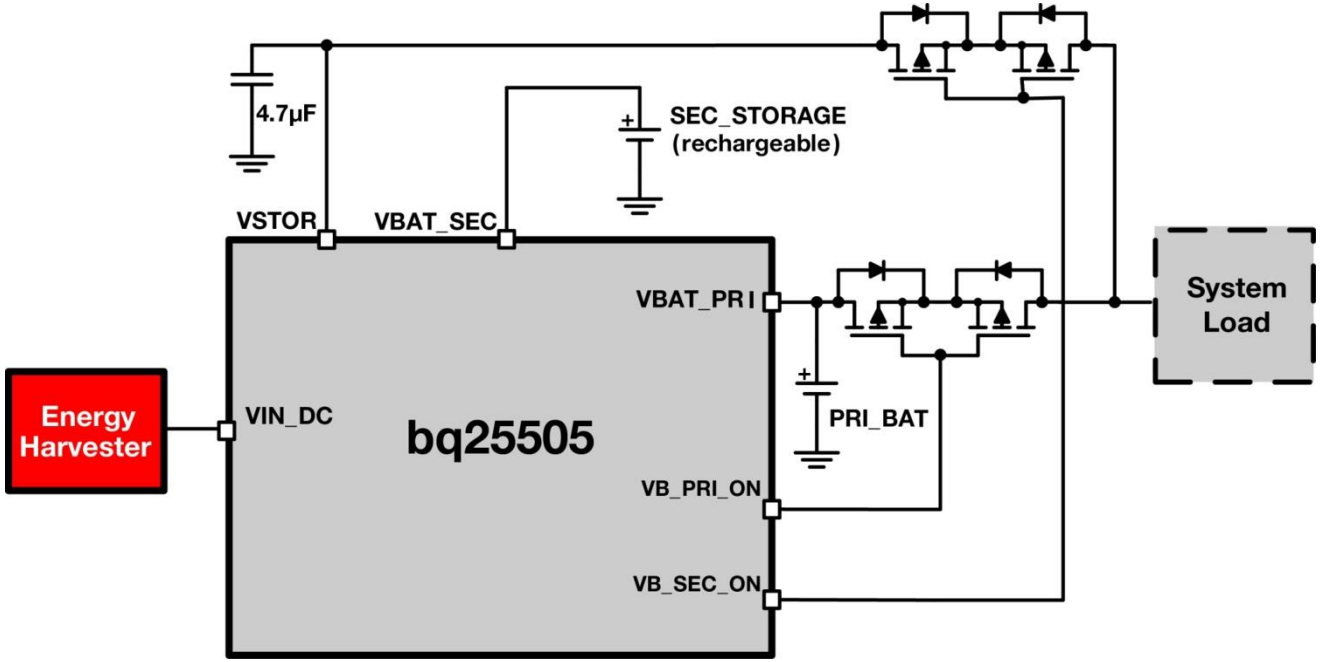


M. Qazi, ISSCC 2013



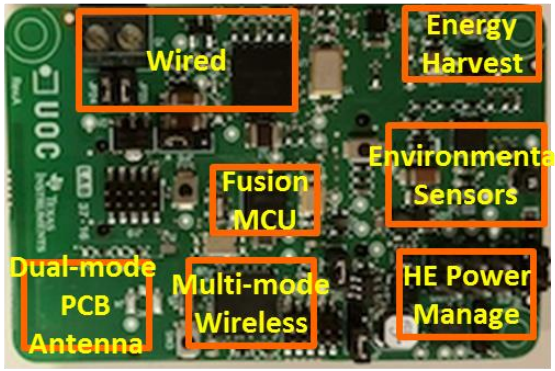
- Rapid transition from sleep to active

Energy Harvesting with Battery Backup

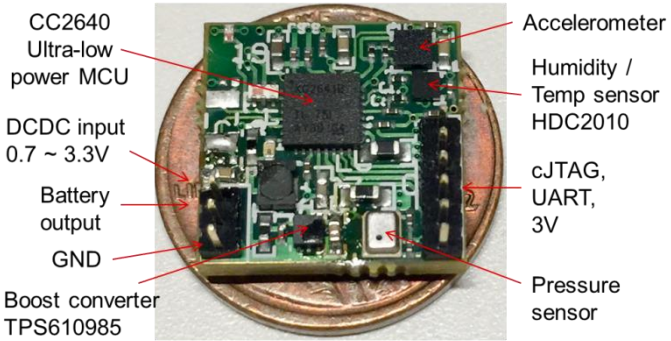


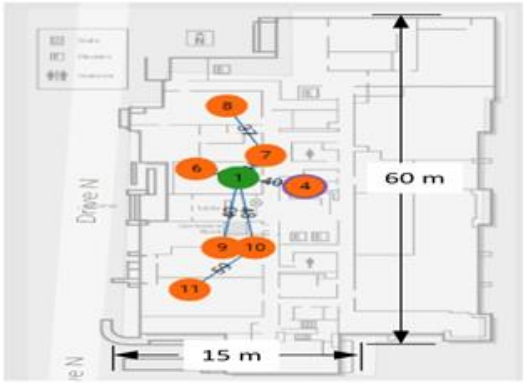
Autonomous handoff between primary and secondary storage

Energy Harvesting Platforms



- Wireless auto mesh
- Dual-mode PCB antenna (subGHz/2.4GHz)
- 10 years battery life
- Built-in environmental sensors (temp, humidity, light, accelerometer, pressure)
- Multiple standards: WiSUN, Thread, Zigbee, WHART, 6TiSCH
- Single HW for: node, mesh node and root node for GW
- Energy harvesting complemental to battery life
- Data logging and analytics in IBM Watson Cloud





Source: Texas Instruments

Summary

- Significant improvements in harvester technology, energy processing circuits and digital, wireless systems
- Cost-benefits exist in areas where it is expensive to replace batteries and where long lifetimes are paramount
- Specialized architectures are need of the hour to make the adoption of energy harvesting more widespread
- Emerging medical and home/industrial automation applications promise an exciting future for energy harvesting