Energy Harvesters and Energy Processing Circuits

Yogesh Ramadass

Texas Instruments

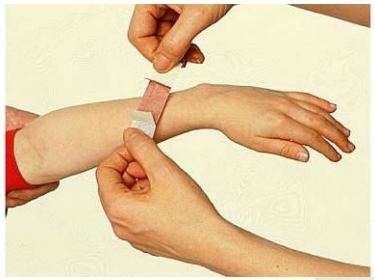
Trends in low-power electronics

Increasing Energy Criticality

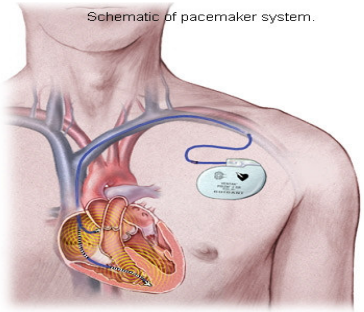
Portable Computers

Handhelds

Wearable Devices



Implantables

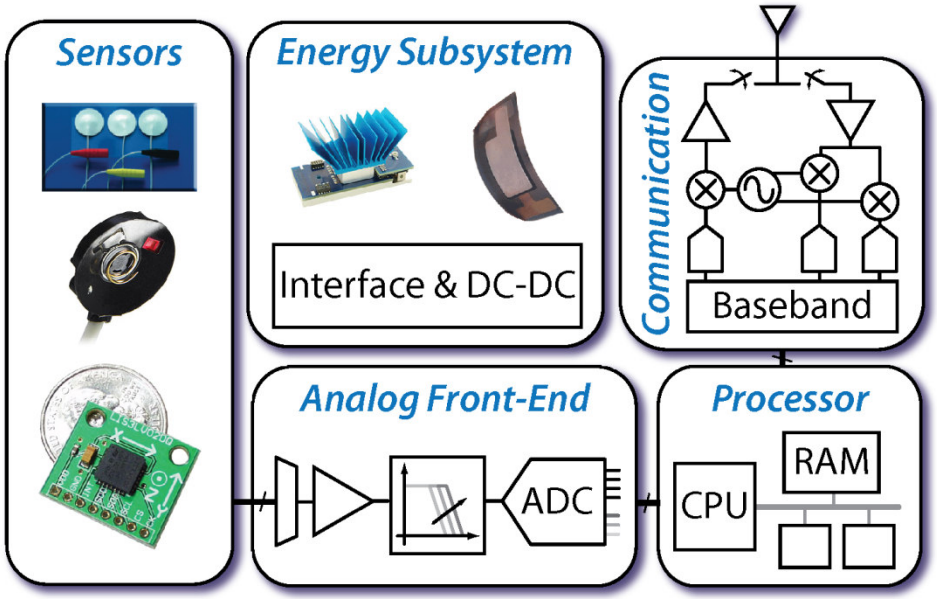


Sensor Networks

- Issues - Size, weight, operating lifetime
- Energy efficiency of IC's is crucial

Sensor Node for Monitoring

Component	Power	Comments
Inst. Amplifier [Verma, VLSI09]	3.5µW	1V V_{DD}, 1.3µVrms input referred noise
ADC [Agnes, ISSCC08]	3.8µW	1V V_{DD}, 100kS/s, 9.4ENOB
16b µ-cont [Kwong, ISSCC08]	2.72µW	0.5V V_{DD},128kb SRAM, 100kHz
Radio [CC 2550]	33.6mW (active)	3V V_{DD}, 2.4GHz, -12dBm P_{OUT}

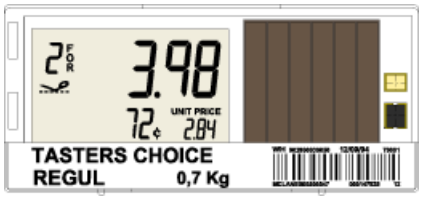


- Power consumption of building blocks steadily decreasing
- Low voltage operation, multi-cores, local processing of information, aggressive duty cycling

Self-Powered Applications

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

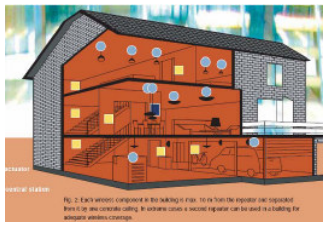
Solar Keyboard



Electronic Shelf Labels

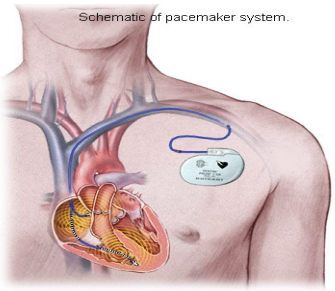
Self-powered switches

Convenience



Occupancy Sensor

Environmental Awareness



Implantables

Pipelines

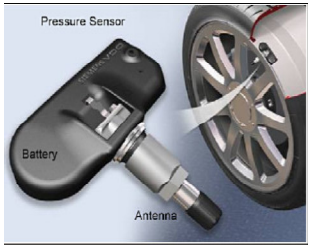
Oil Rig

Smoke Detector

Structural sensors

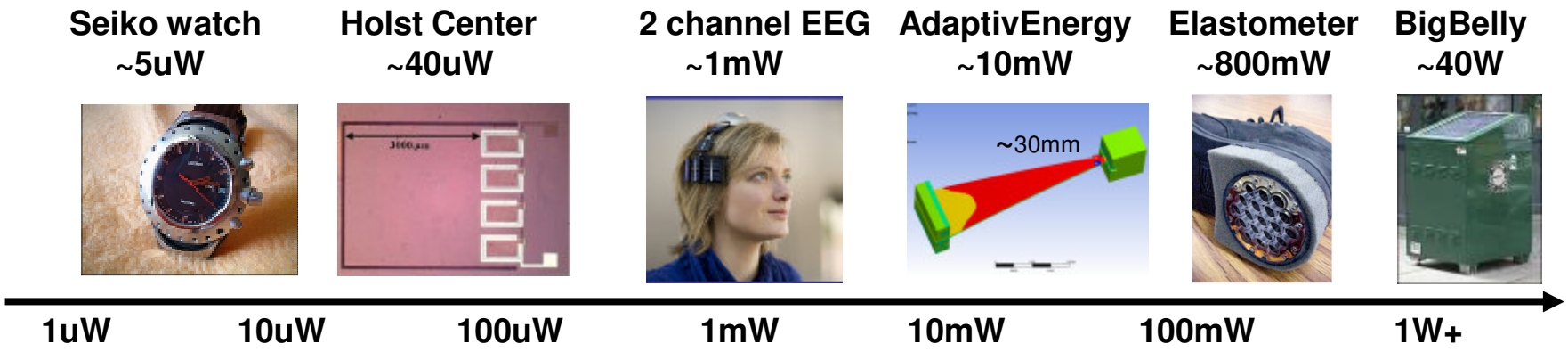
Hard to Reach

TPMS

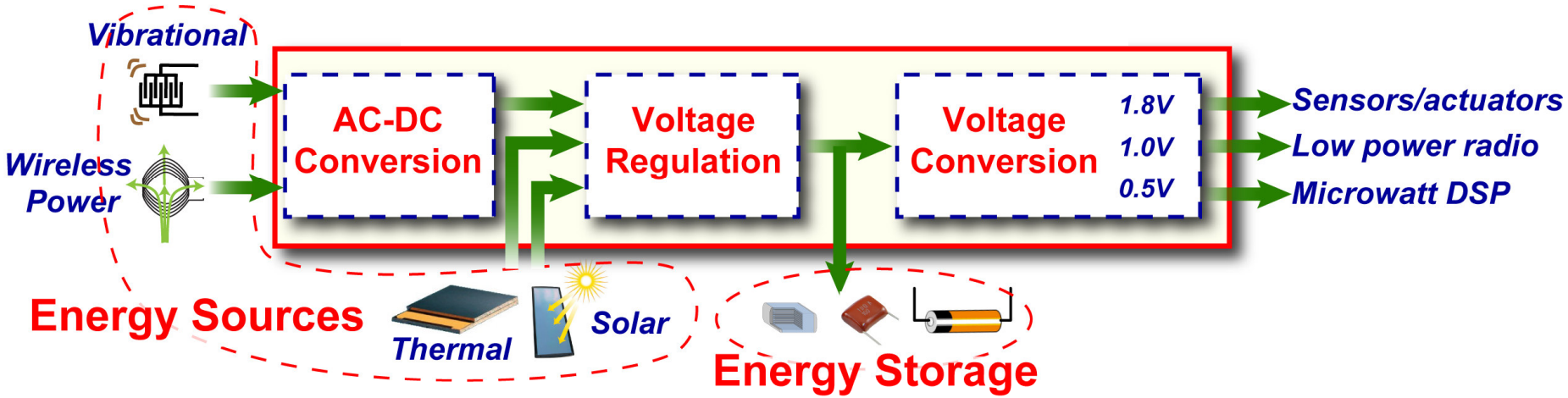


Energy Harvesting Sources

Energy Source	Characteristics	Efficiency	Harvested Power
Light	Outdoor Indoor	10~24%	10 mW/cm^2 10 µW/cm^2
Thermal	Human Industrial	~0.1% ~3%	60 µW/cm^2 ~1-10 mW/cm^2
Wireless	Near field Far field	> 60% < 1%	1-10 mW/cm^2 <10 µW/cm^2
Vibration	~Hz–human ~kHz–machines	25~50%	~4 µW/cm^3 ~800 µW/cm^3

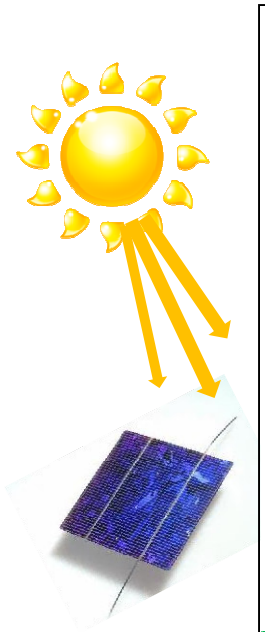


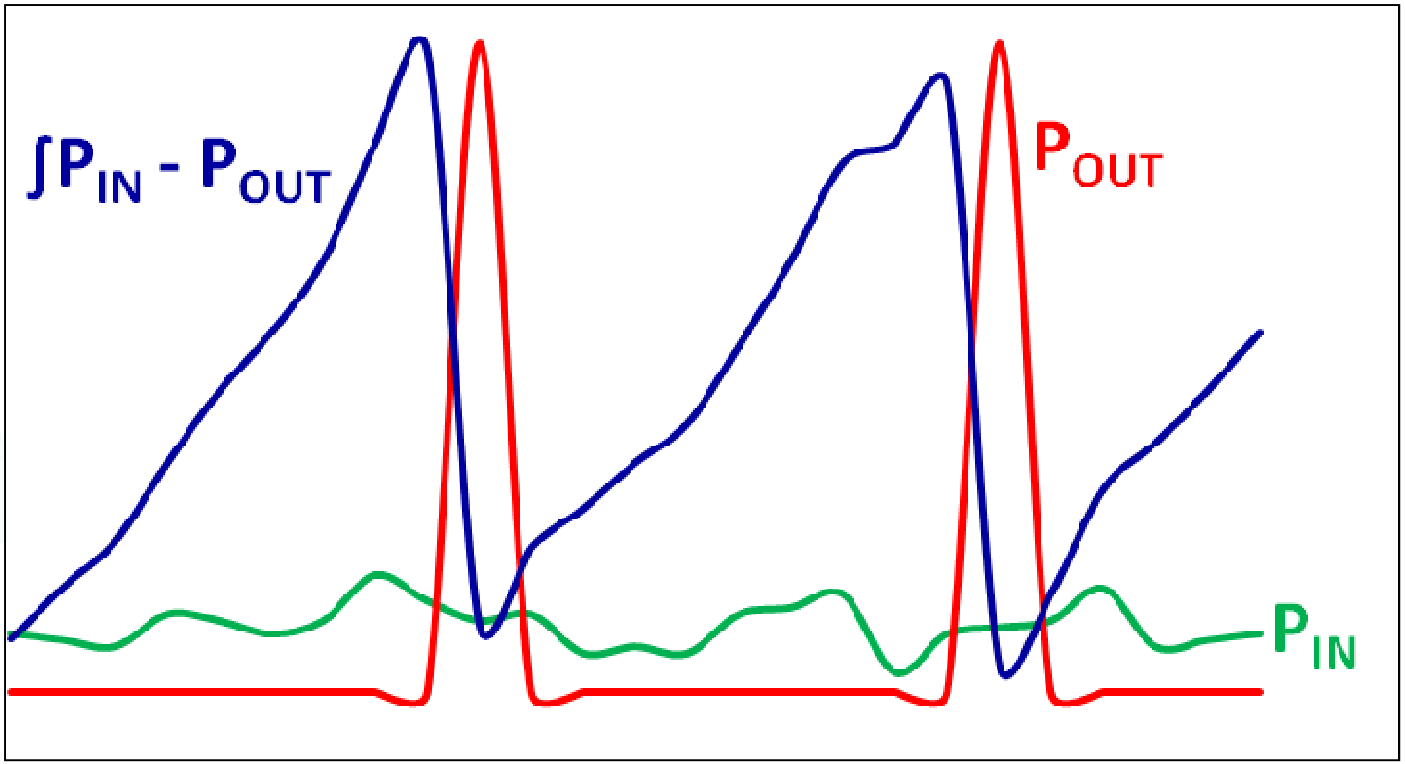
Energy Processor



- Low-power applications → less than 10mW
- Efficiency of power delivery – a key bottleneck
- Amount of power obtained – better metric for energy harvesters

Need for Energy Buffer

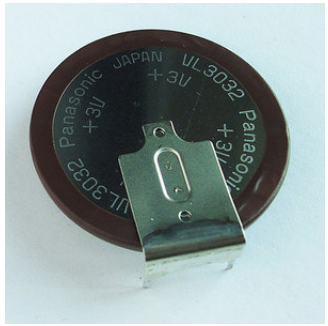




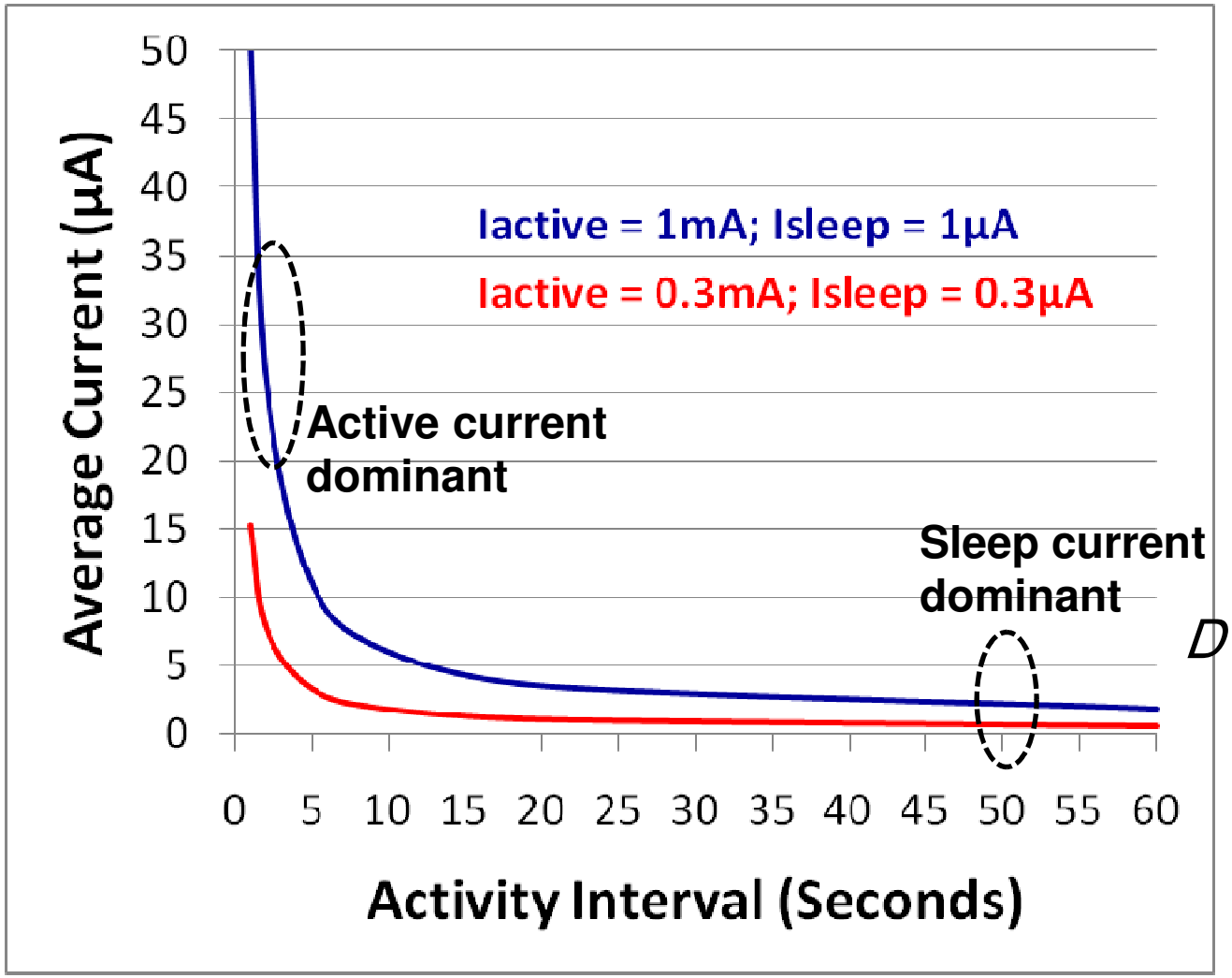
- Accumulate input power
- Provide peak output power
- Smooth out input, output power imbalances

Energy Storage Options

	Conventional Batteries	Thin Film Batteries	Supercaps
Recharge Cycles	100s	5k-10k	Millions
Self Discharge	Moderate	Negligible	High
Charge Time	Hours	Minutes	Sec-Minutes
Impedance	Low - High	High	Low
Physical Size	Large	Small	Medium
Capacity	0.3-2500mAH	12-2200µAH	10-100µAH



Duty Cycle Impact on Current

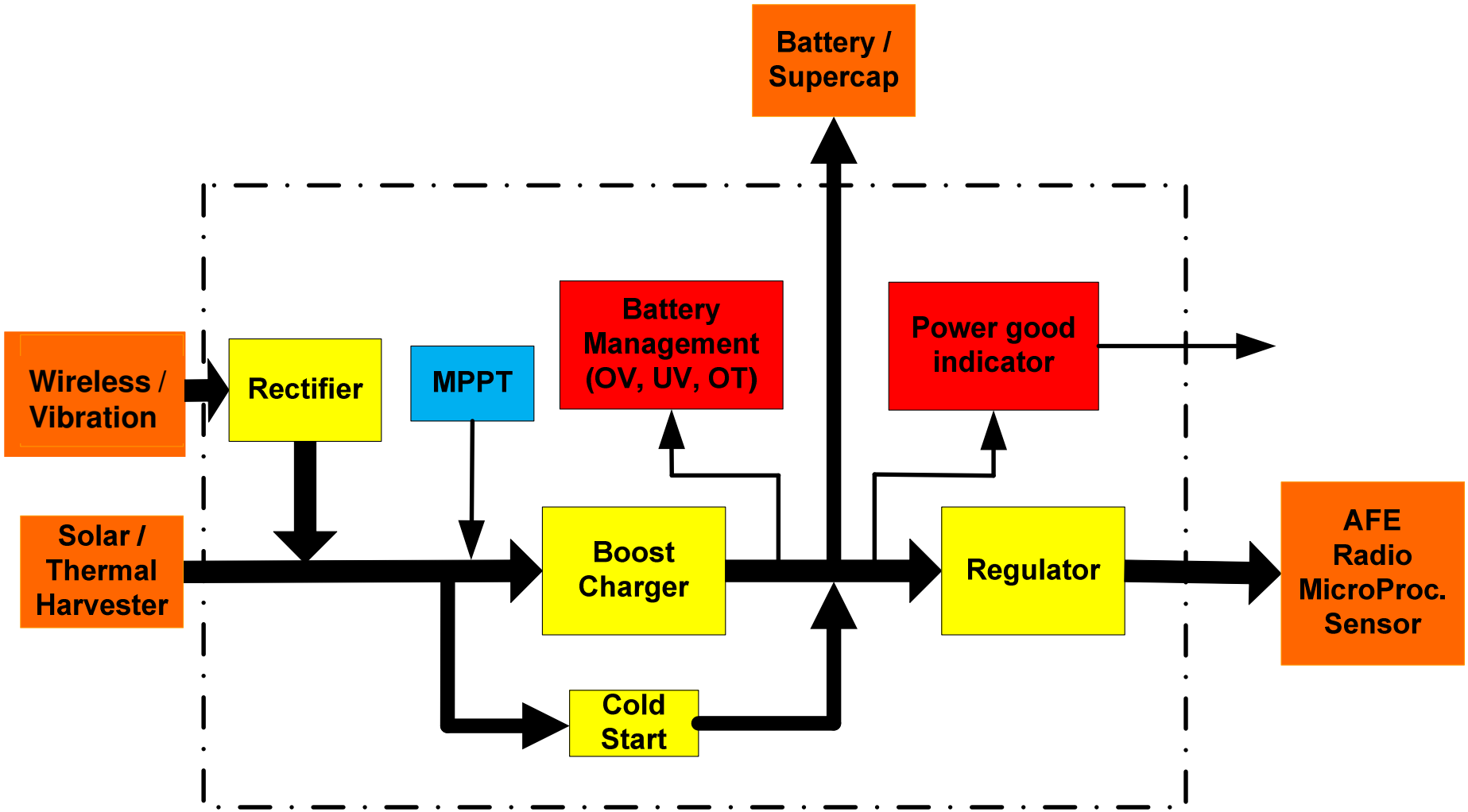


Pulse Width = 50ms

$$D = \frac{\textit{ılse}\quad \textit{'idth}}{\textit{Activity Interval}}$$

$$I(avg) = Iactive * D + Isleep * (1 - D)$$

Energy Harvesting System

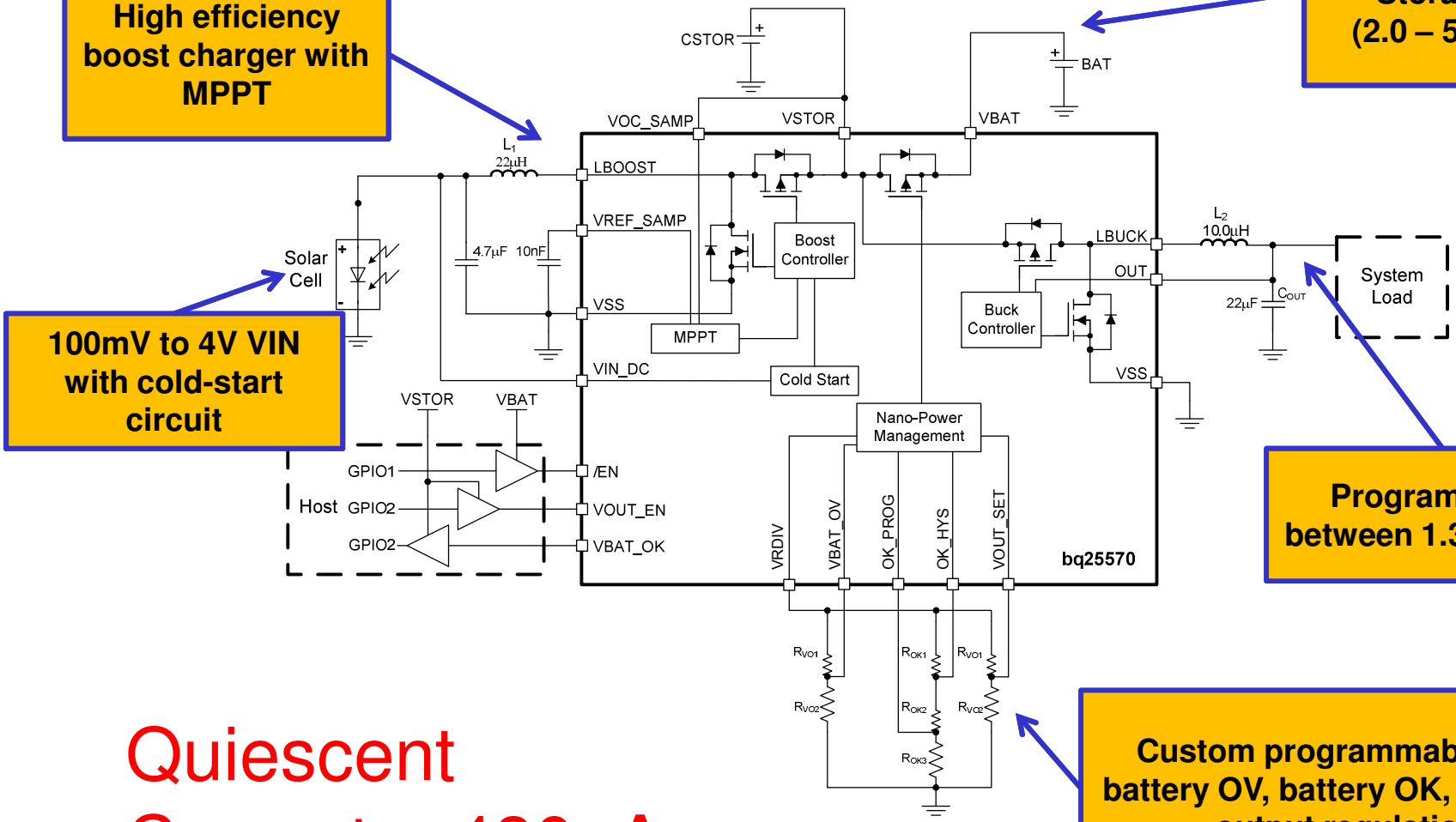


Energy harvesters are power sources

Energy Mgmt. IC -BQ25570

High efficiency boost charger with MPPT

Harvester Storage (2.0 – 5.5V)



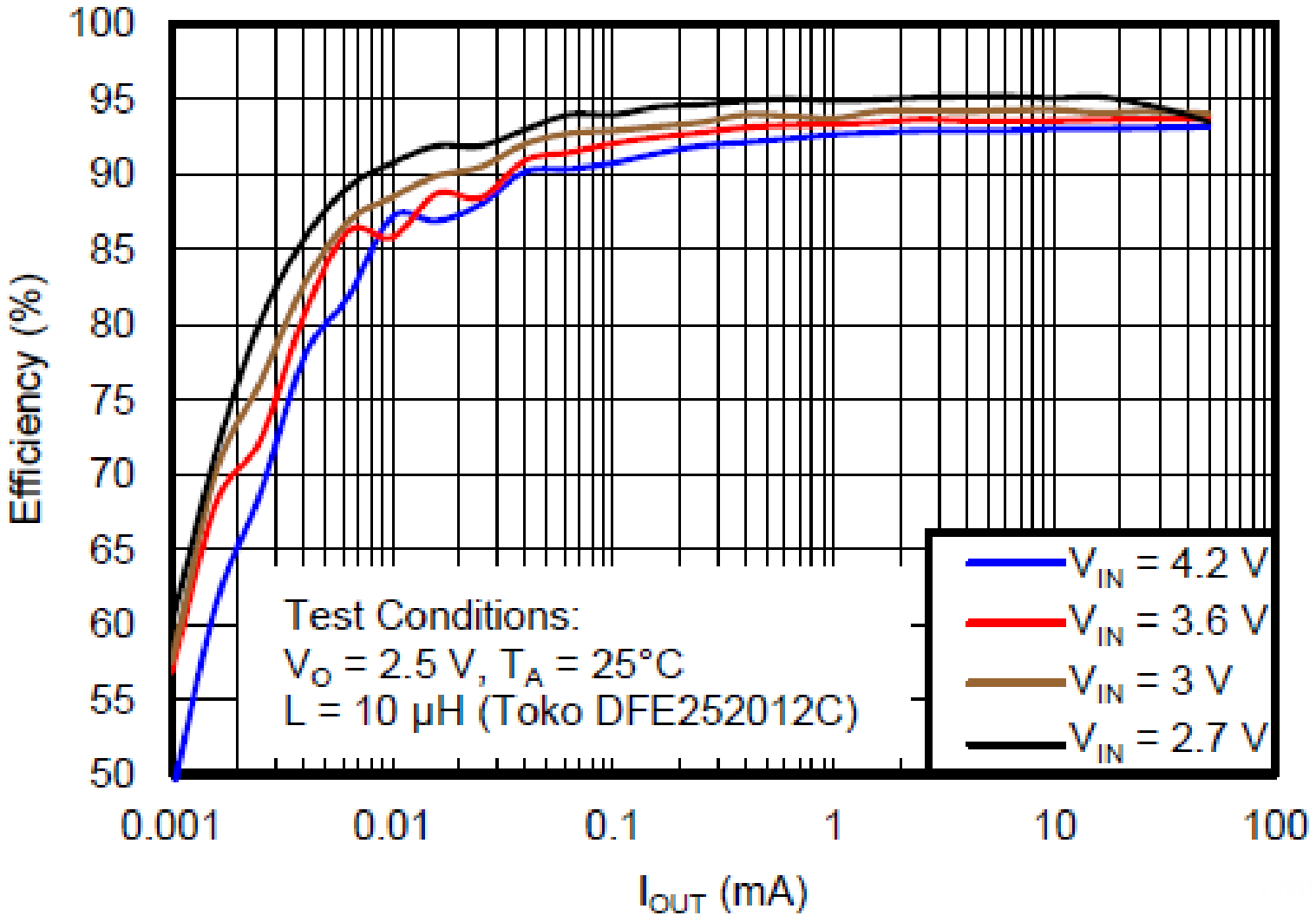
100mV to 4V VIN with cold-start circuit

Programmable between 1.3V and 5V

Quiescent Current = 480nA

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

Buck Converter Efficiency



- Efficiency vs. I_{OUT}, V_{OUT} = 2.5V

Summary

- Advances in circuit design techniques and architectures have made it possible for electronic systems to be completely self-powered
- Energy harvesting sources differ in characteristics from conventional batteries requiring specialized interface circuits
- Optimized energy processing circuits are crucial to manage the ultra-low power levels output by energy harvesters