

Mixing-Sourcing Technologies to Extend the Operational Life of Ultra-Portable Micro-Scale Electronics

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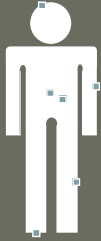
Outline

Advocating Hybrid Supplies

- **Motivation**
Wireless Micro-Sensors...
- **Requirements**
System Power Profile
- **State of the Art**
Energy/Power Sources
- **Approach**
Hybrid Power Supplies
Electrostatic Harvestors
Low Power Telemetry
System Integration

Motivation: Wireless Micro-Sensors...

Autonomous, Long-lasting, and Non-invasive



Biological

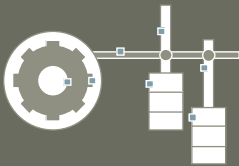
Non-invasive Alternative to Diagnostic Surgery
Permanent Sense Restoration and Enhancement



Military and Scientific

Monitoring Battlefield and Equipment

Collecting Many Distributed Samples of a Large Area over a Long Time
Recording Variables that Change Slowly Like Temperature and Pressure



Industrial

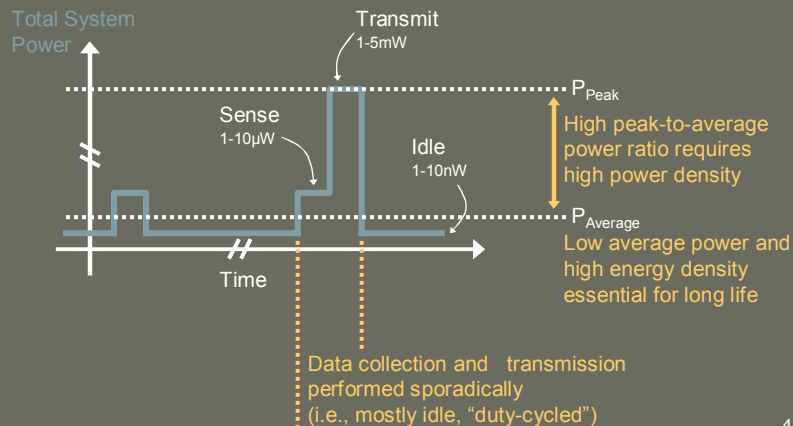
Retrofitting Old Equipment to Manage Energy and Improve Efficiency
Adding Real-time Feedback and Control

[1] D. Puccinelli and M. Haenggi, "Wireless sensor networks: applications and challenges of ubiquitous sensing," *IEEE Circuits and Systems Magazine*, vol. 3, no. 4, pp. 19-29, 2005.

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Requirements: System Power Profile

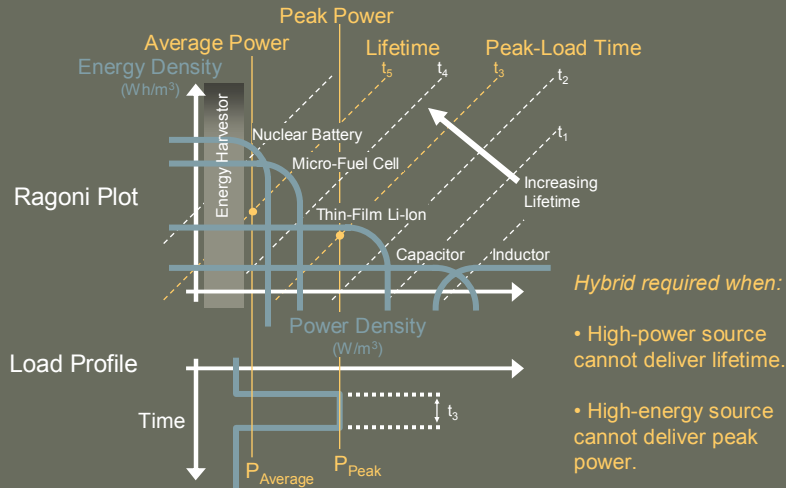
Periodic or Asynchronous Operation



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State of the Art: Energy Sources

Divergence of Energy and Power



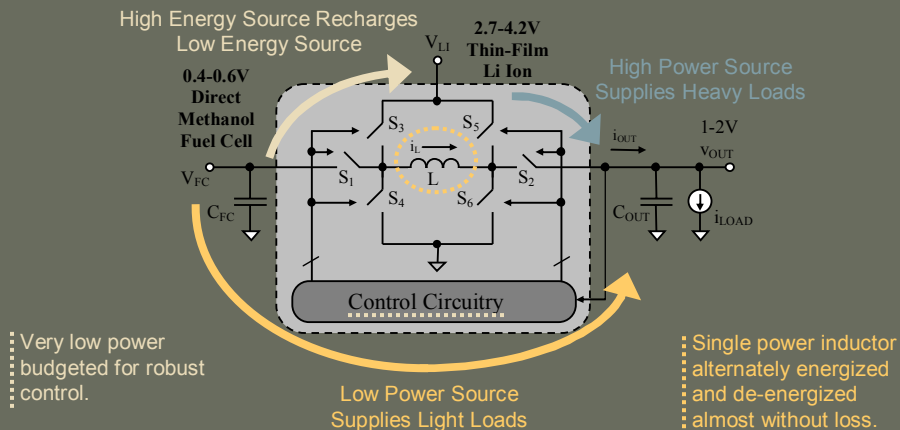
[2] J.B. Bates et al., "Thin-film lithium and lithium-ion batteries," *Solid State Ionics*, vol. 135, no. 1-4, pp. 33-45, Nov. 2000.

[3] C.W. Moore et al., "Microfabricated fuel cells with thin-film silicon dioxide proton exchange membranes," *Journal of the Electrochemical Society*, vol. 51, no. 8, pp. A1606-12, Aug. 2005.

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Approach: Hybrid Supplies

High-Energy Source Recharges High-Power Source

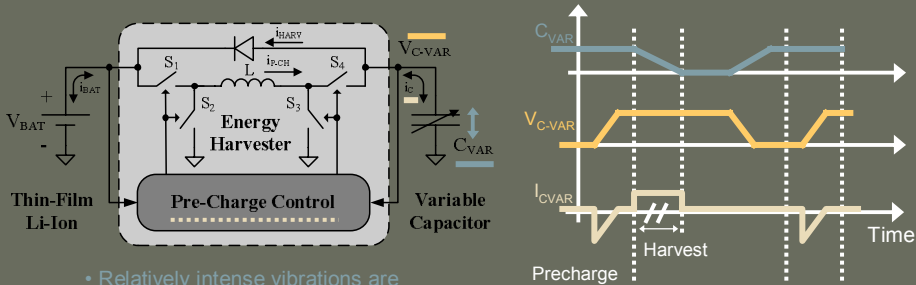


[4] M. Chen, J. Vogt, and G.A. Rincón-Mora, "Design Methodology of a Hybrid Micro-Scale Fuel Cell-Thin-Film Lithium Ion Source," *International Midwest Symposium on Circuits and Systems*, 2007.

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Approach: Electrostatic Harvesters

Vibrations Working Against the Force of an Electric Field



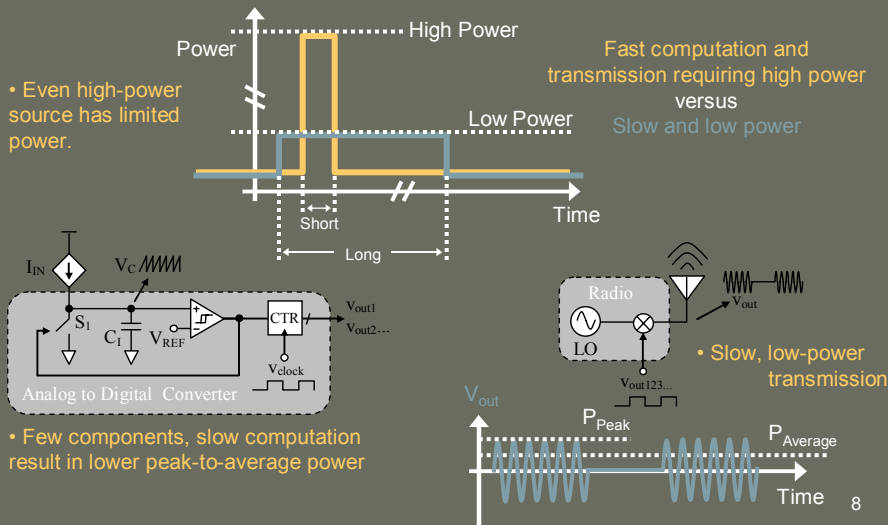
- Relatively intense vibrations are abundant (i.e., energy density is infinite)
- Asynchronous precharge maximizes harvested energy from every vibration cycle big or small, fast or short.

• Converter precharges capacitor with energy later recovered as part of the harvested energy.

[5] E.O. Torres and G.A. Rincón-Mora, "Long-lasting, self-sustaining, and energy-harvesting system-in-package (SIP) wireless micro-sensor solution," *Proc. International Conference on Energy, Environment, and Disasters (INCEED)*, July 2005.

Approach: Low Power Telemetry

Slow and Efficient Data Converters and Radios



- Even high-power source has limited power.

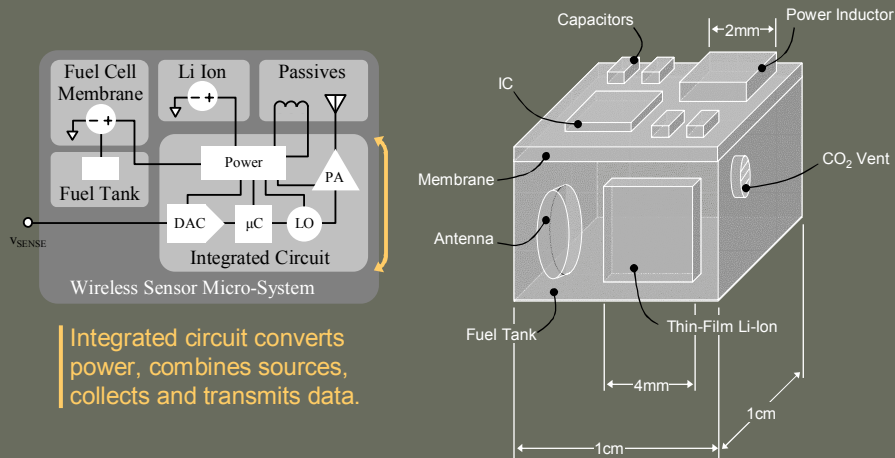
Fast computation and transmission requiring high power versus Slow and low power

- Few components, slow computation result in lower peak-to-average power

• Slow, low-power transmission

Approach: System Integration

Maximizing Energy Storage

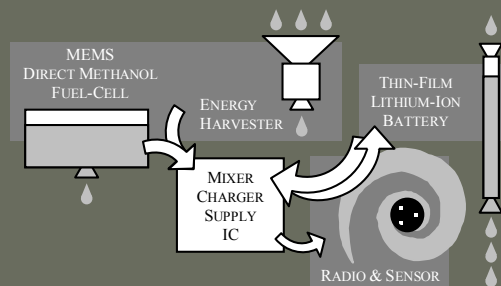


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Conclusions

Hybrid Supplies Surpass Limits of Individual Sources

- Autonomy requires high energy density and high power density.
- Hybrid supplies required when peak power exceeds limits of high energy sources or lifetime energy exceeds capacity of high power sources.
- Energy harvesters extend energy density to infinity.
- Low power telemetry reduces peak to average power ratio and average power making power solutions easier.



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