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« A fully energy-driven Power Management Unit in the scope of future energy harvesting complex systems »

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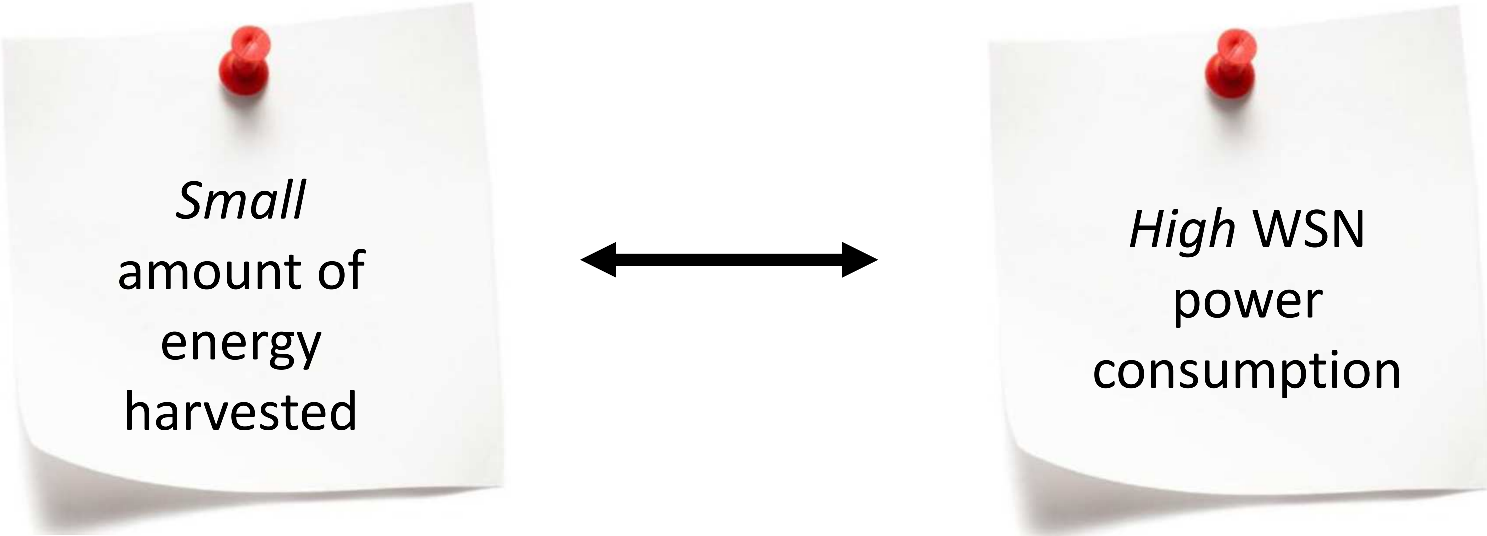
Context of Autonomous Sensor Nodes

- Systems free of any human maintenance
  over their all lifetime

- Self powered by extracting their energy in the environment
  - Energy Harvesting

- Many possible application fields :
  - Building automation
  - Sport and Entertainment
  - Structural health monitoring

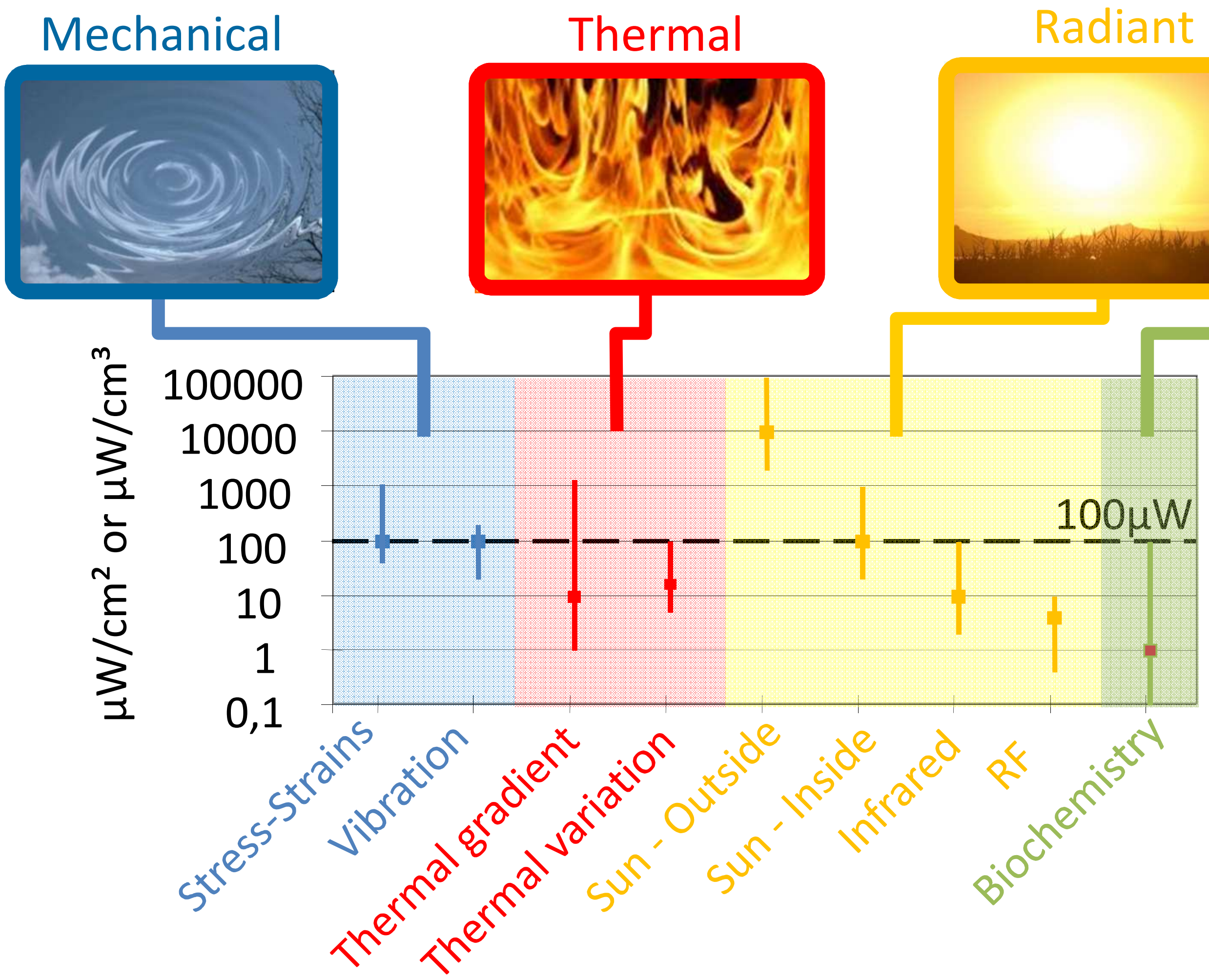
Energy harvesting and autonomy paradox



- (Re)Design the entire wireless autonomous sensor node
  - Not only replace the battery with an energy harvester
- New partitioning between scheduling, communication and power management
  - Ultra low power consumption
- Take into account environmental variations and node specific needs

➲ **Energy-driven and Data-driven behavior**

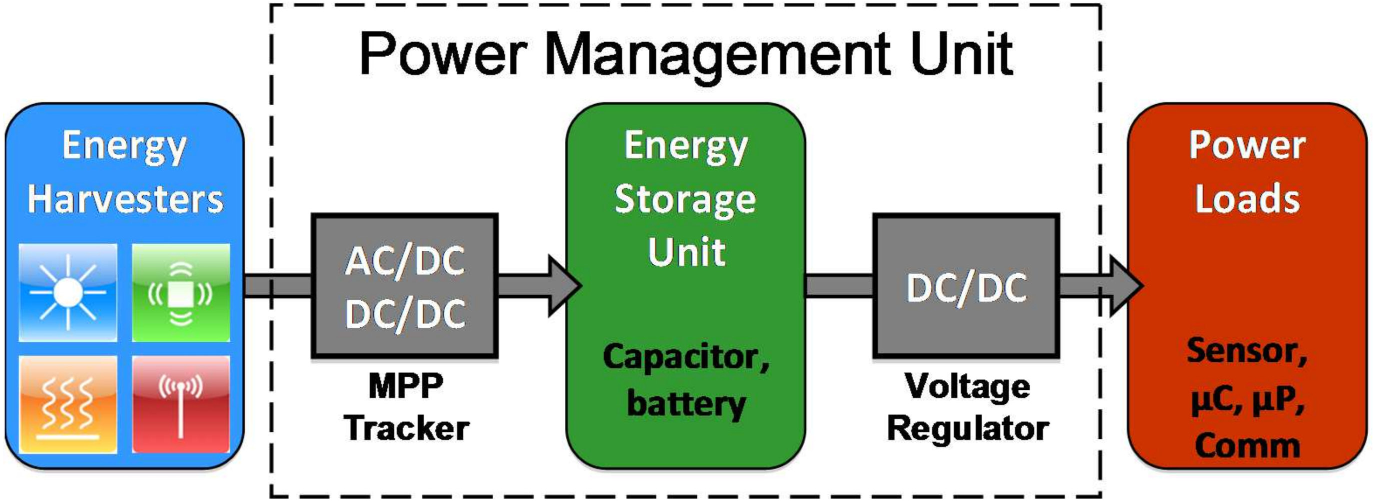
Main Ambient Energy Sources



- Multiple energy sources
- Best source choice according to environmental conditions
  - Outdoor sun
  - Thermal gradients
  - Vibrations

Autonomous Sensor Nodes Architectures

- Simplest architectures : one source, one load, a storage system

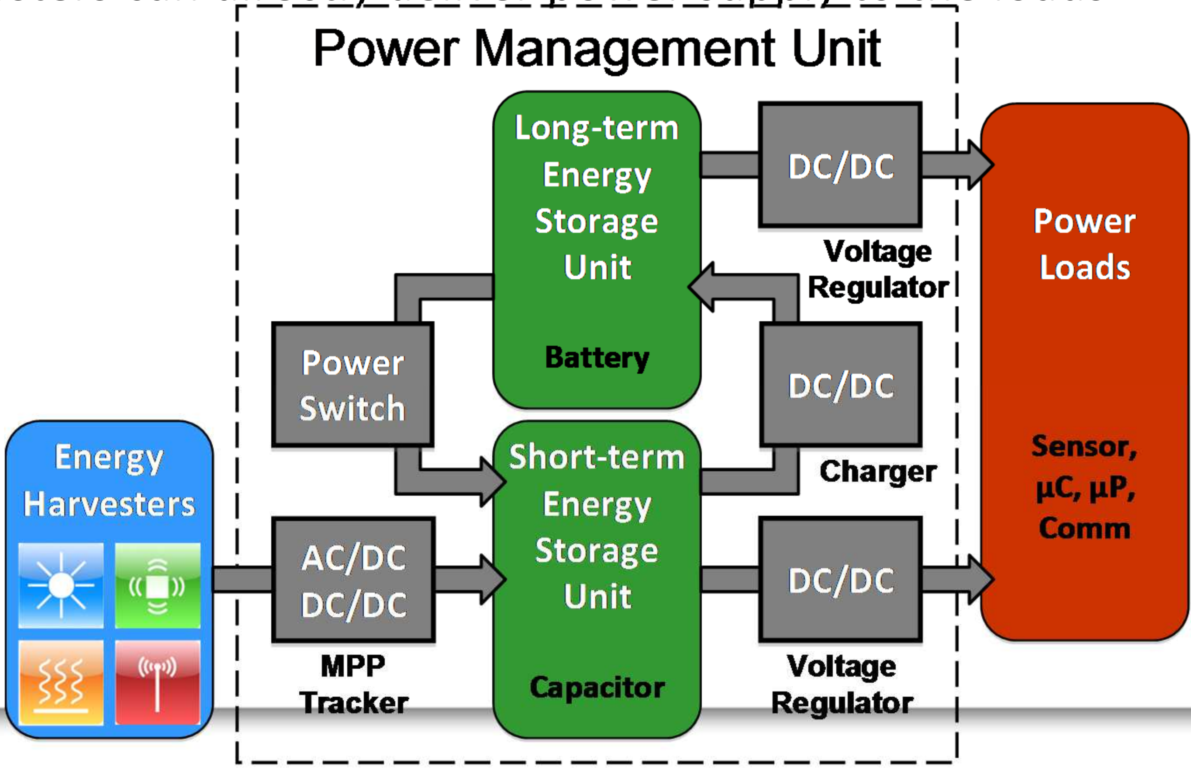


- Towards high energy efficiency power management:
  - Multiple energy sources
  - Multiple loads

➲ Energy Efficiency Enhancement

Autonomous Sensor Nodes Architectures

- Multiple-input Multiple-output architectures
- High efficiency power management :
  - Dual power path architectures
  - Avoid a systematic battery charging
  - Harvesters can directly deliver power supply to the loads



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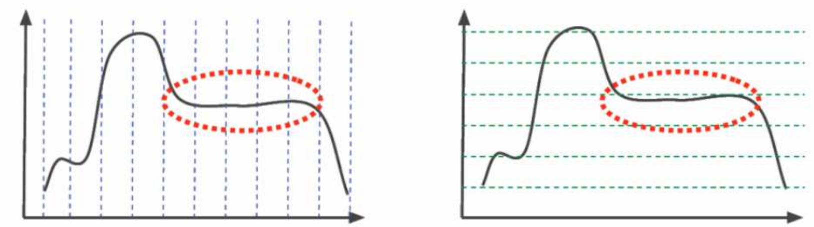
Energy/Event-driven architecture (1)

- Energy-driven and Event-driven scheme: naturally reacts on *environmental resources* and/or *node's functional requirements*
- Two main goals
  - Optimize the system power efficiency
  - Reduce the overall system power consumption
- A dual architecture
  - Energy-aware configuration
  - Data-driven reconfiguration
- An Energy/Event-driven behavior
  - Voltage thresholds → Energy events
  - Wake-up sensors → data (physical) events

Energy/Event-driven architecture (2)

- Avoiding a continuous clock sampling within the architecture
- Allowing a tracking on energy/voltage levels and not on timings



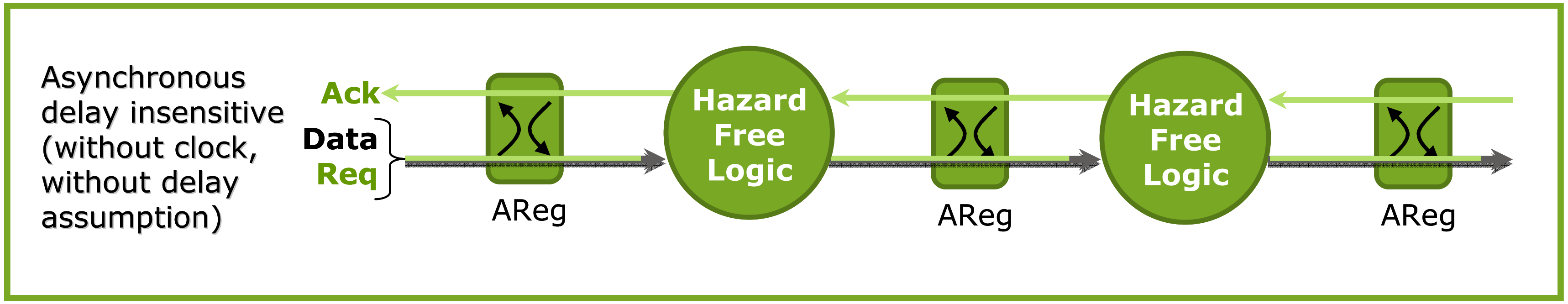
Conventional uniform Nyquist sampling | *Non-uniform level-crossing sampling*

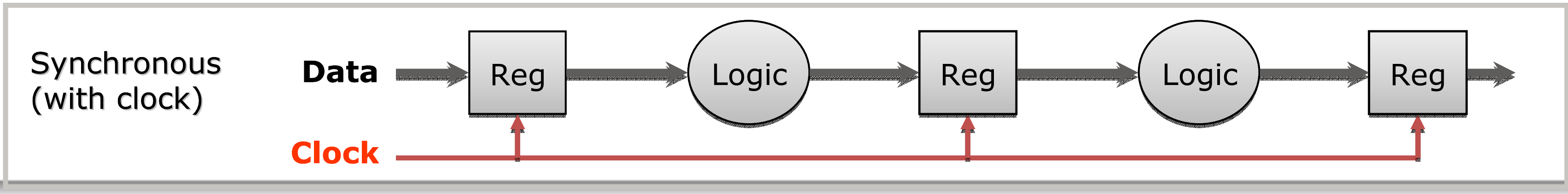
- Automatic sleeping/wake-up mode :
  - As soon as energy is available : energy-events
  - A soon as a measurement request is sent : data-event

➲ **Fitting energy harvesting platforms**
  - **Few available energy levels**
  - **Low frequency applications**
  - **Quality-of-service or best-effort application request**
  - **Ultra low power consumption during inactivity phases**

Event-driven (Asynchronous) digital circuits

- Synchronous circuits: global clock
  - Critical path : “worst case” approach
  - Timing assumptions : setup / hold, tpd, skew
- Asynchronous circuits: no global clock
  - Sender-Receiver, communicating with handshake
  - Local and distributed control
  - Event-based logic





Motivations for Asynchronous logic

- Autonomous microsystems main constraints
  - Unpredictable environmental changes → Event-driven behavior
  - Small amounts of energy → Reduced power consumption
- Asynchronous Quasi Delay Insensitive (QDI) Logic
  - Automatic sleep mode

No additional circuitry	Time independant

  - Distributed activity

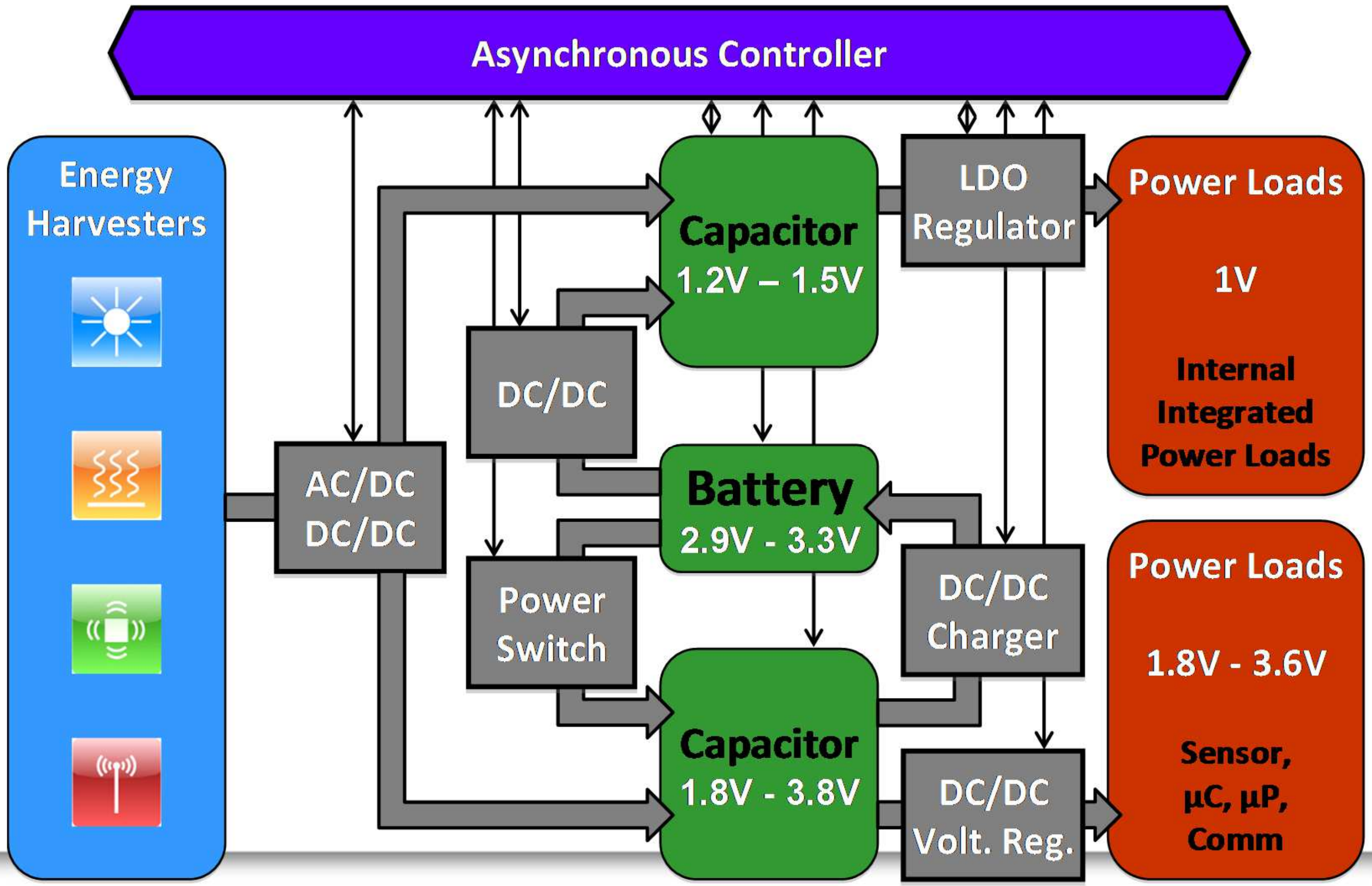
Smooth current profile	Low EMI

  - Robust to variable supply voltage level

Low power supply voltage	Reduced power supply constraints

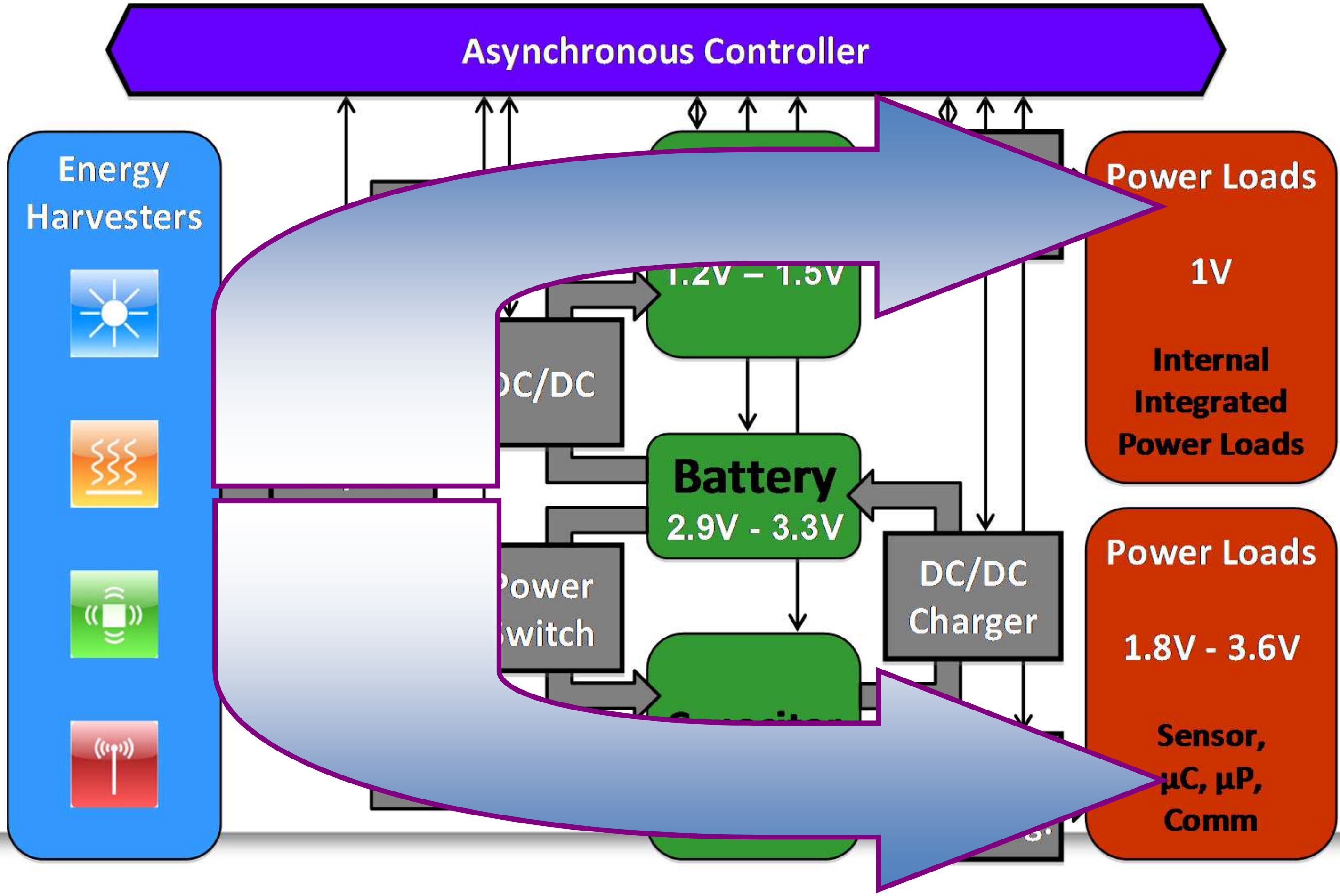
Proposed Event and Energy-driven architecture

- A fully asynchronous platform is proposed either for digital control or analog tracking blocks

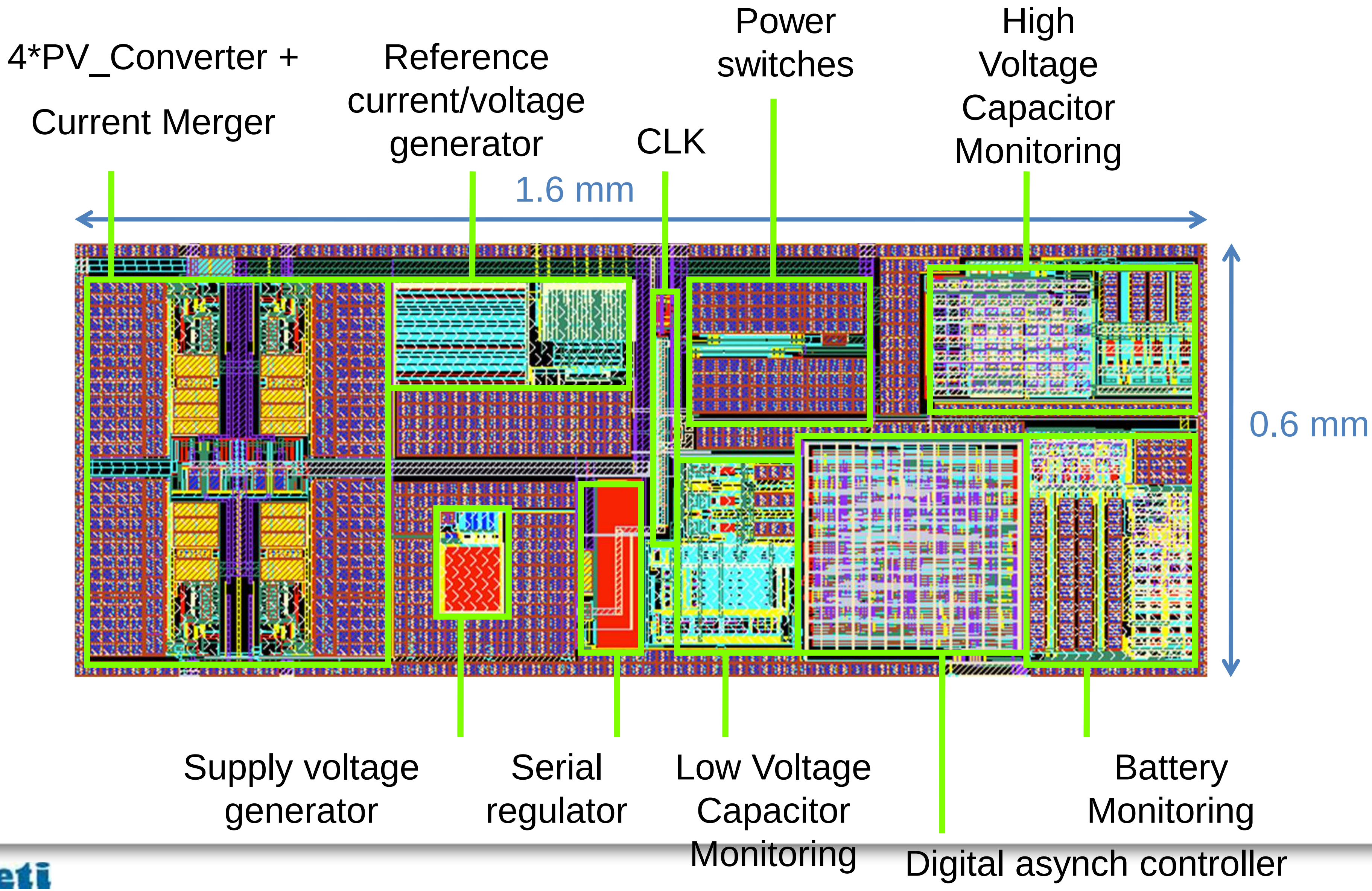


Proposed Event and Energy-driven architecture

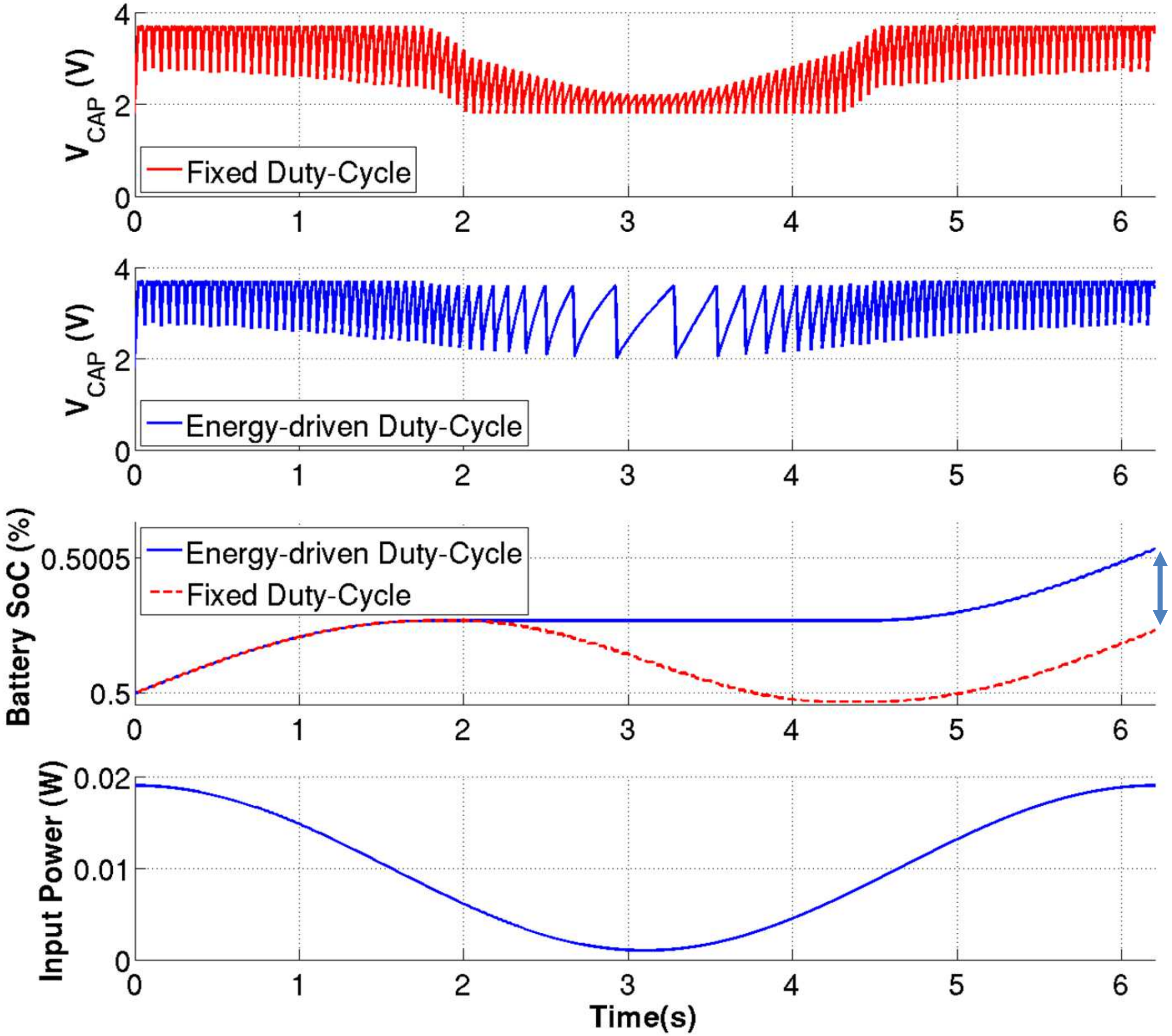
- A fully asynchronous platform is proposed either for digital control or analog tracking blocks
- Allows direct power path at high efficiency



Circuit Implementation (UMC 180 nm)



Energy-driven proposed algorithm



+130,75% energy saved

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Conclusion

- Energy harvesters, power management architectures and scheduling algorithms are all following the same goal:
  - High energy efficiency to maximize sensor node autonomy

- Power path optimization : Low voltage and high voltage management
  - Multiple-input multiple-output nodes
  - Direct power path

- Energy- and Data-driven platforms are fitting energy harvesting requirements (battery SOC, incoming harvesting power, wake-up sensors, digital control)
  - Optimize the system power efficiency
  - Reduce the overall system power consumption

- Automatic sleeping/wake-up mode :
  - As soon as energy is available : energy-events
  - As soon as a measurement request is sent : data-event