Energy harvesting---As an efficient IoT solution

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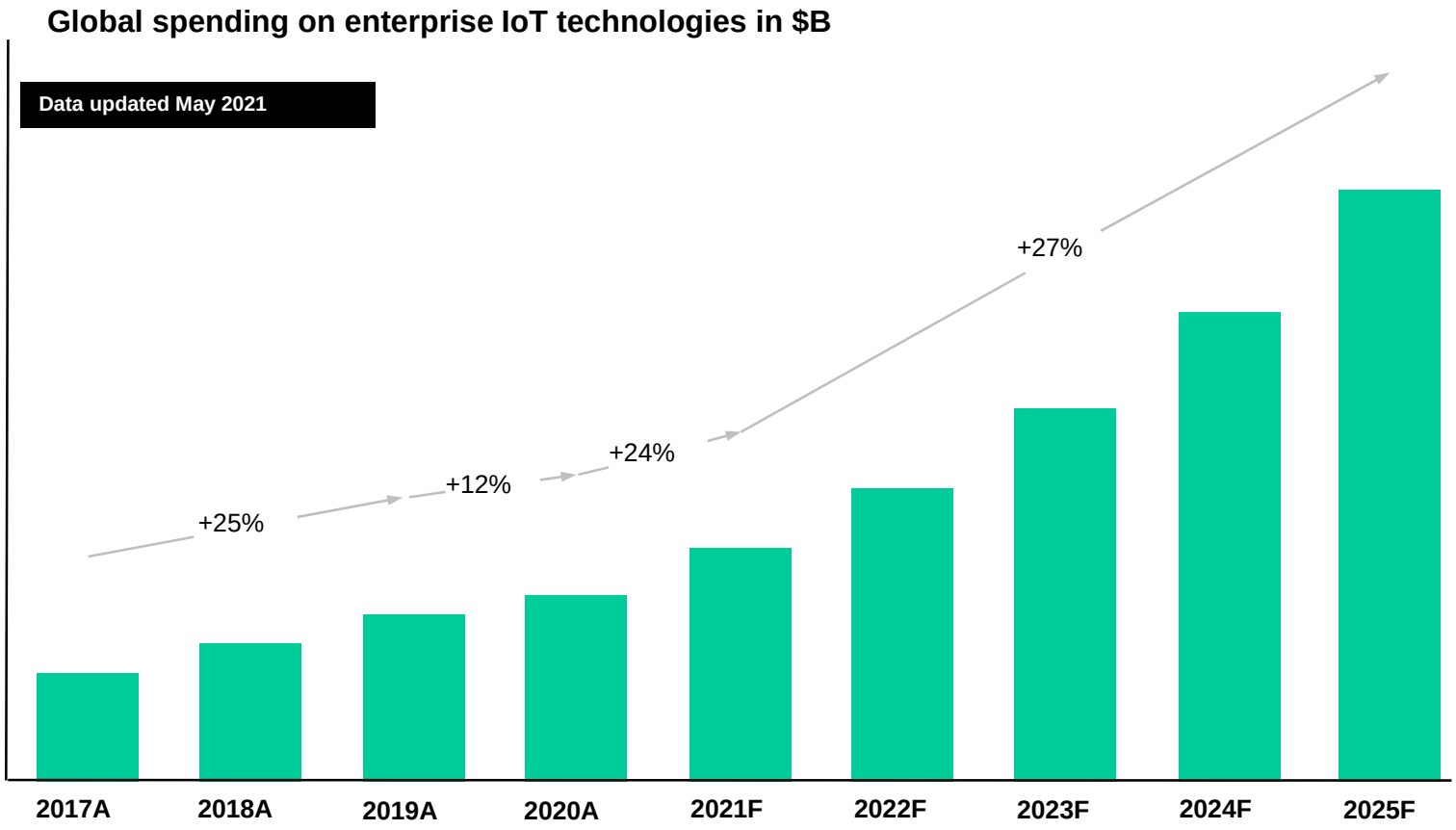
Outline

- Background of Energy Harvesting (EH) for IoT
- Principal of a EH-IoT system
- Real World Applications
- Summary

IoT Market Background



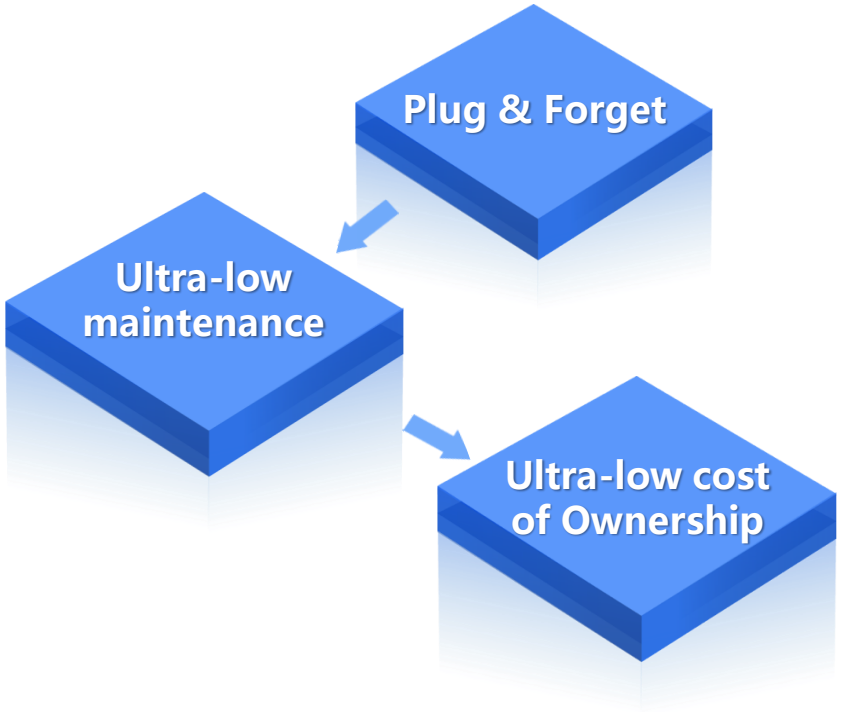
The Bottleneck in the Field of Industrial IoT

- IoT is connecting physical and virtual objects to optimize cooperation;
- Gathering data by sensors, transmitting, processing, controlling actuators;
- Remote controls and no access to the power grid;
- Wires and cables add tremendous efforts;
- Power supply is a bottleneck: Decrease of revenues --- makes applications unfeasible:
  - Battery replacement is impractical with large or remote deployments;
  - Large capacity, long life batteries are band-aid fixes;

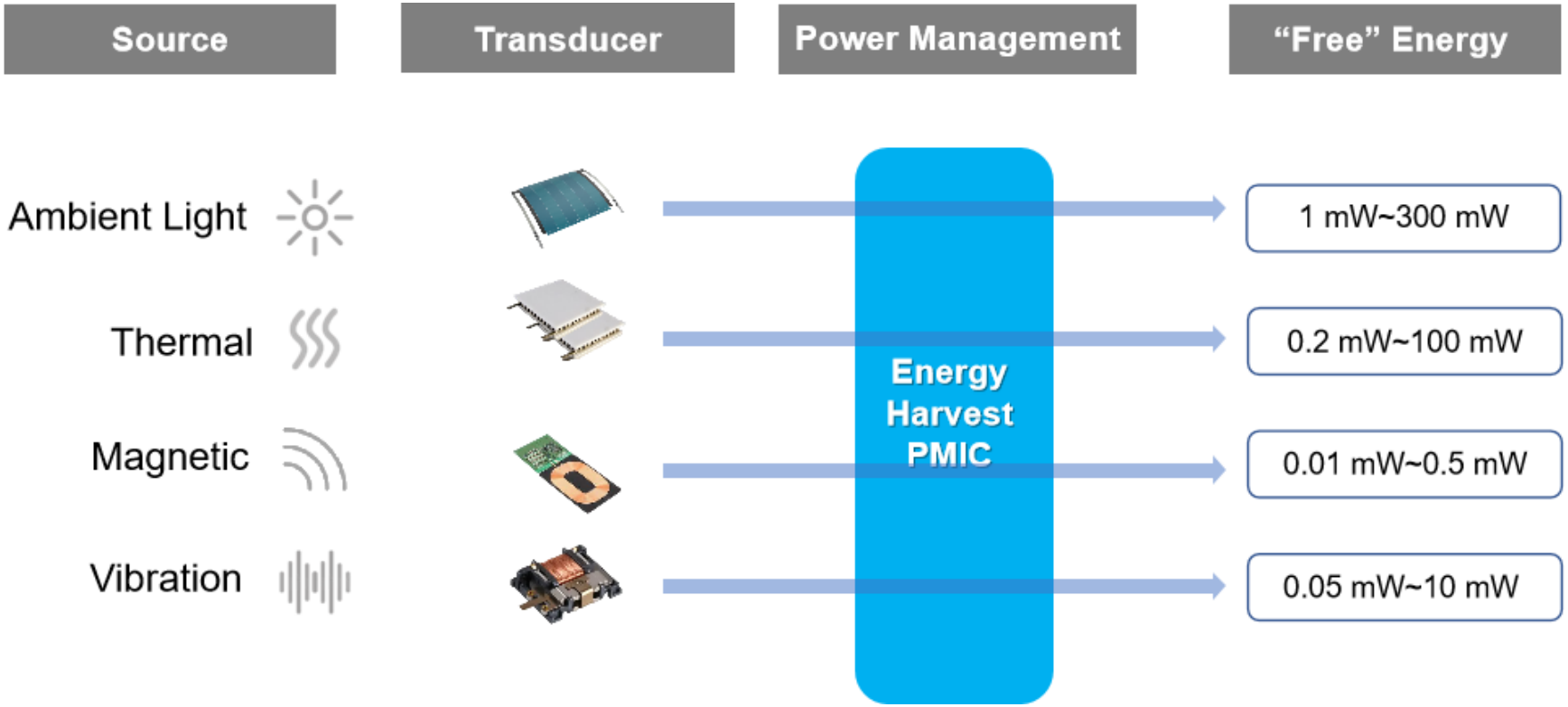
What is the future IoT System?

A unique inflection point today

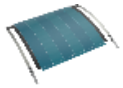
- Compute and sensor power requirements continue to decrease;
- Energy harvesting capabilities continue to improve;
- Multi-modal energy harvesting technology and advanced energy storage technoque continue to develop.



Energy Sourses and their Features



Energy Sourses and their Features (cont'd)



Ambient Light

0 V~5.5 V → at least 50 LUX, need low voltage start and MPPT

Thermal

0 mV~300 mV → Overall efficiency, need ultra low voltage start

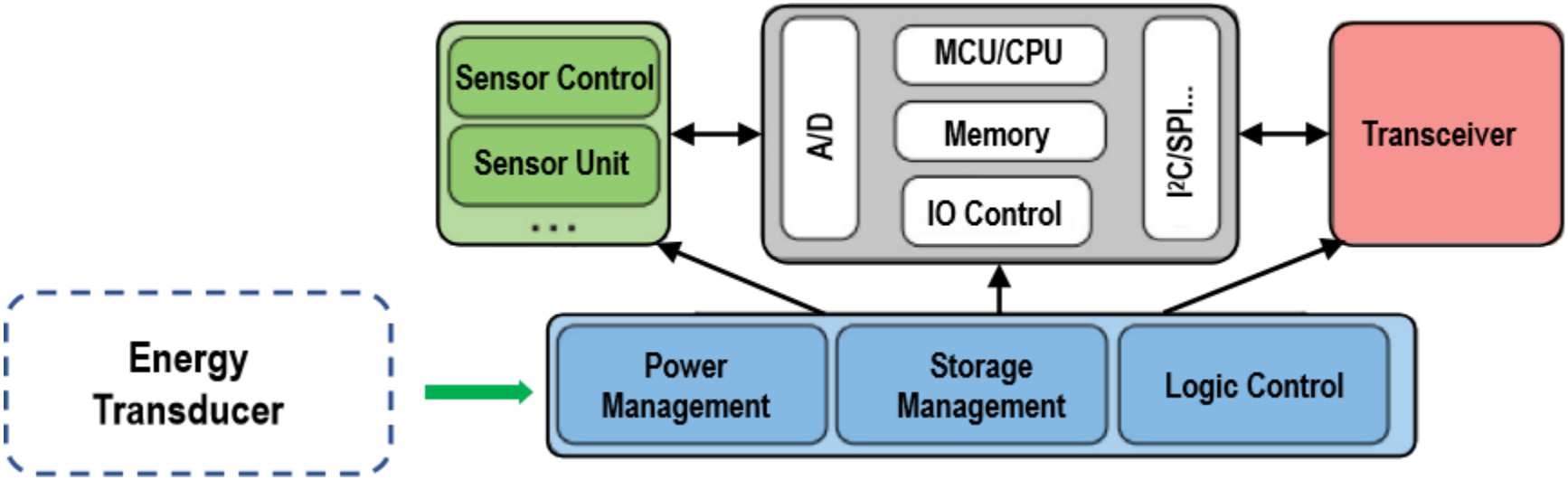
Magnetic

0 mV~50 mV → Frequency dependent, post-rectification efficiency

Vibration

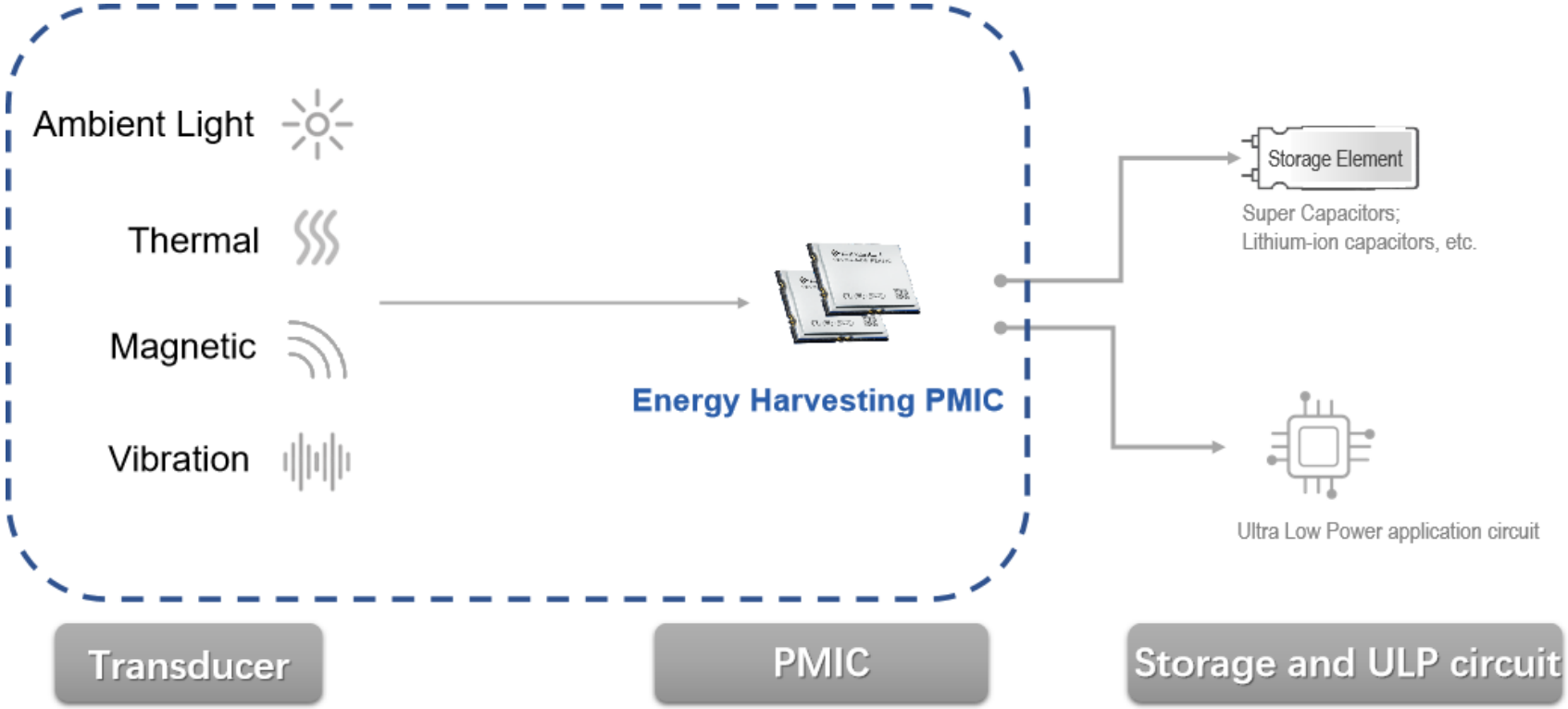
0 mV~40 V → Overall efficiency, high dynamic range

General Architecture of an Energy Harvesting WSN

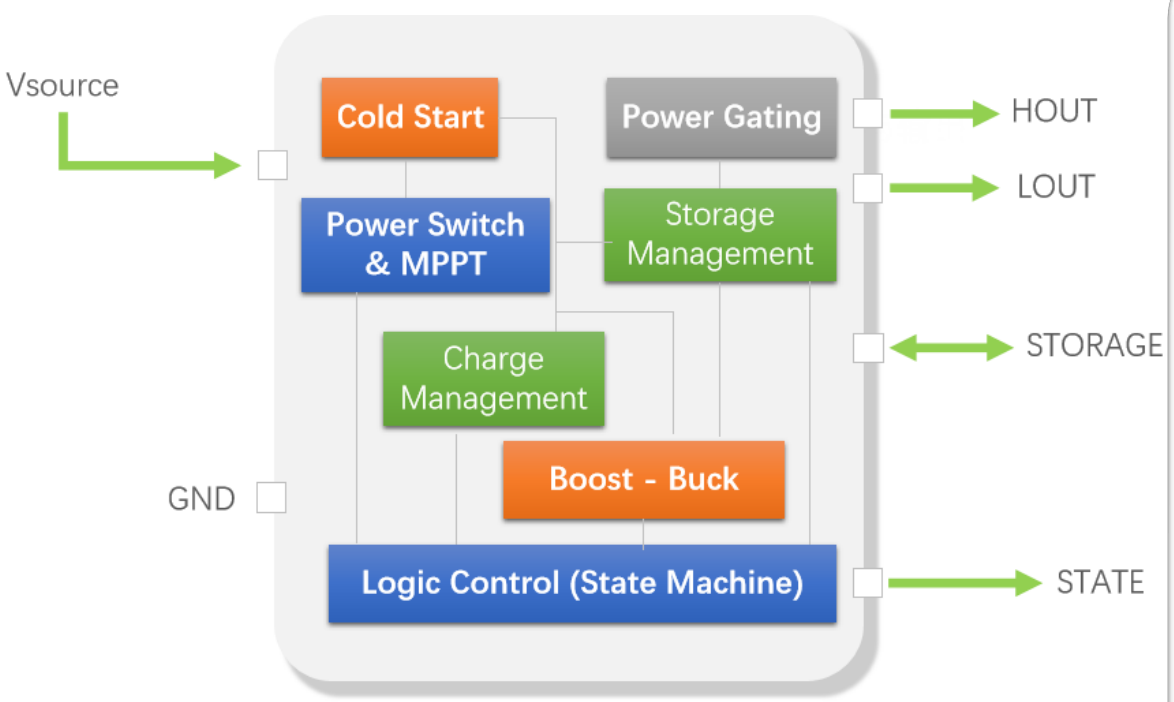


- Energy transducer
- Power management
- Ultra low power data acquisition and transmission

General consideration of a real EH-based sensor node

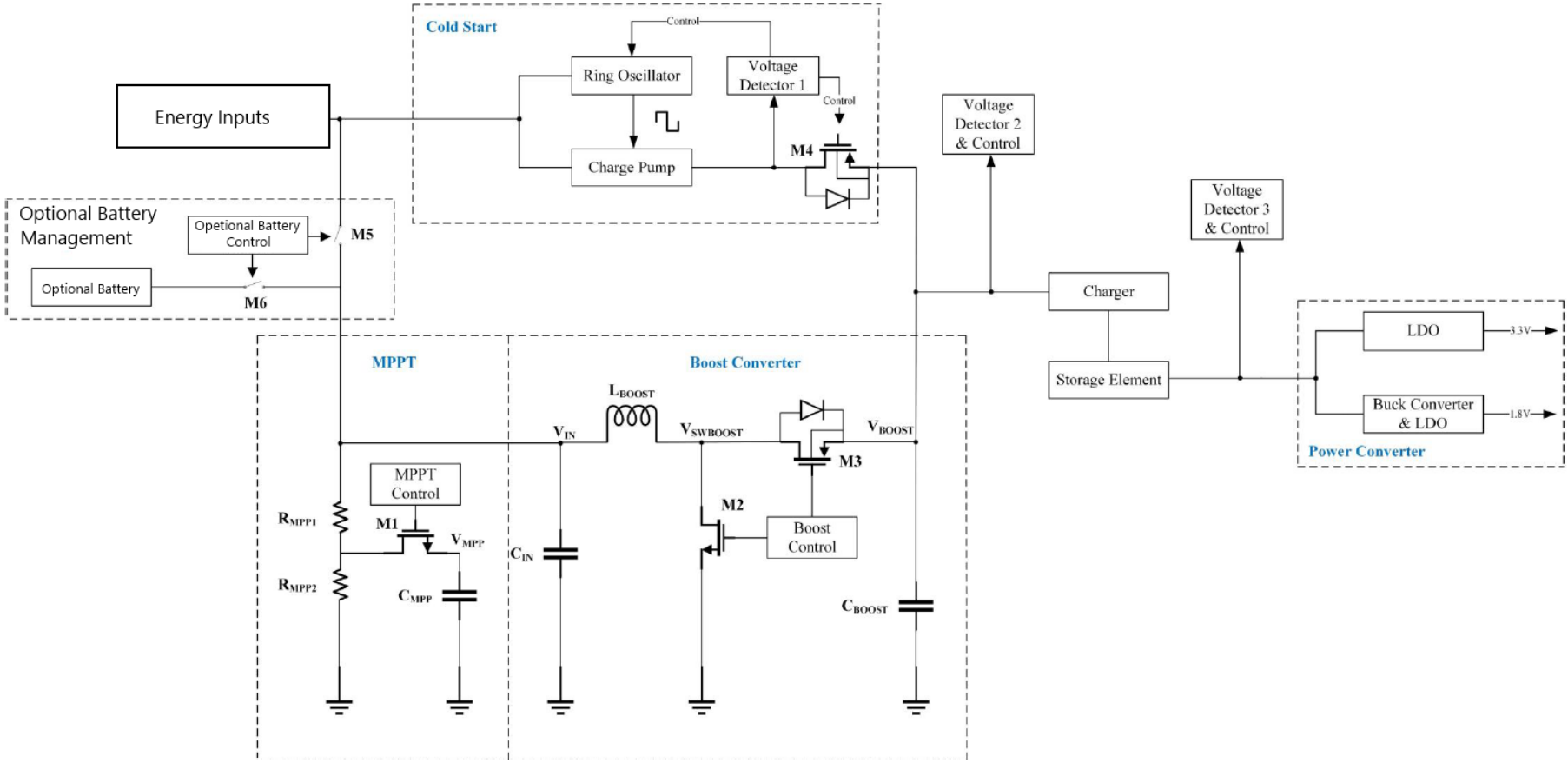


Basic structure of one example EH-PMIC



- Capable of capturing multi-modal ambient energy sources;
- Dynamic storage and power gating management;
- High efficiency over a wide range of energy input levels.
- Replace batteries or prolong battery life in IoT devices;

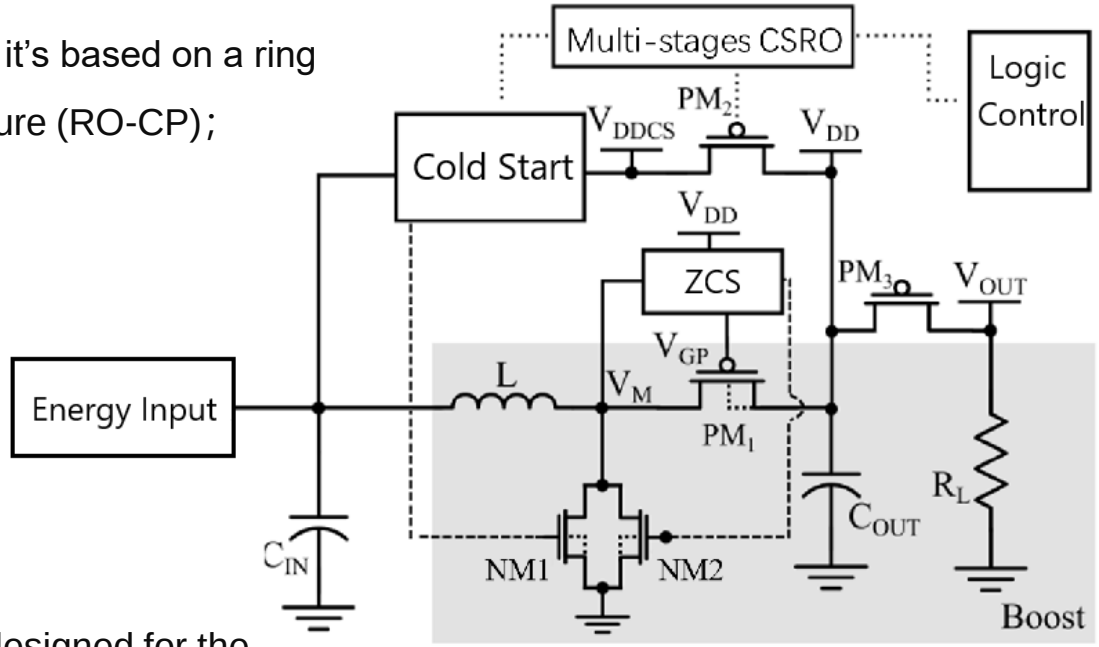
Basic structure of one example EH-PMIC



Key Feature of a EH-PMIC --- Low Voltage Start

Ultra low power start beased on RO-CP architecture

- Cold Start is one of the key parts; it's based on a ring oscillator and charge pump structure (RO-CP);
- Multi stages current starved ring oscillator (CSRO) is responsible for generating the clock signal, and part of the control block, giving rise to the building up of node VDD.
- ZCS (Zero Current Switching) is designed for the efficient steady-state operation under ultra-low input voltages.

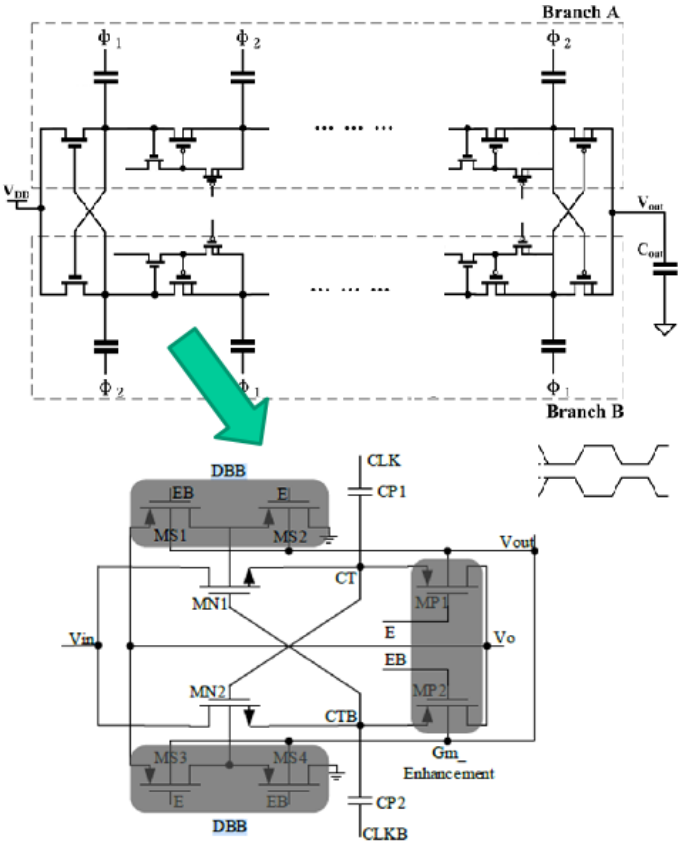


Key Feature of a EH-PMIC --- Ultra Low Power Comsuption

Ultra low power based on subthreshold electronics and DBB technique

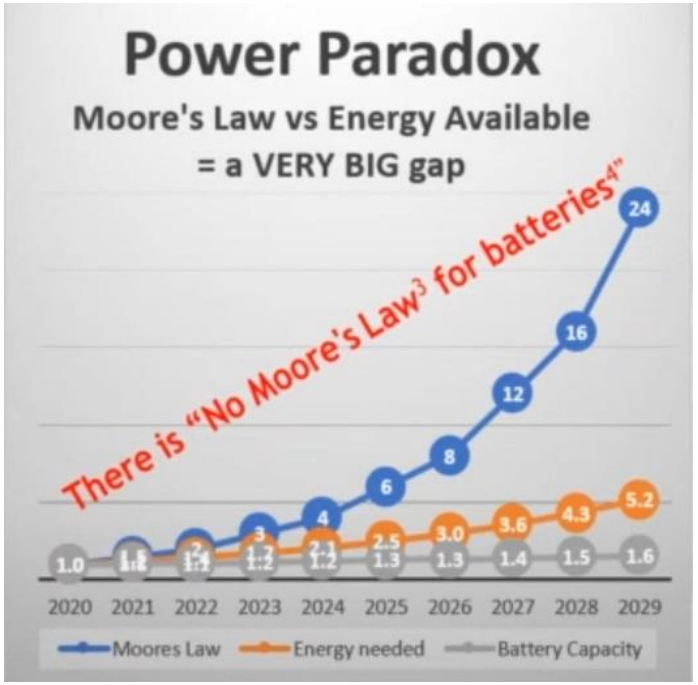
- The design for the parts that handle very low energy in this EHPMIC has considered the subthreshold feature ---the subthreshold current of element can be controlled by the gate voltage.

- By adding a specially designed DBB (Dynamic Body Bias) bias generation circuit to some specific low-power modules (such as the Cross Coupled Charge Pump), and applying bias voltage to the NMOS or PMOS substrate, PMOS can be turned off or turned on as much as possible to reduce leakage current.



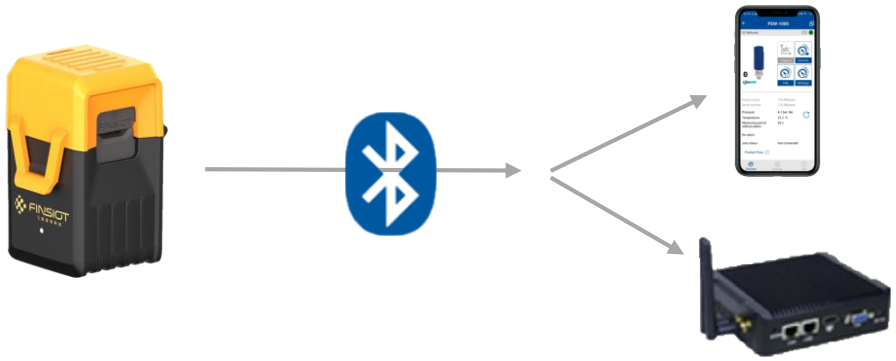
Obstacles in IIoT

- Industrial applications need more data than ever, but thus needs more power for longer
- Industrial users resist to put extra efforts on data aqusicion systems
- Cost-effective is always the high priority consideration.
- Either batteries or wired power
- Koomey's law slowed in 2010
  - Computing load per joule halves every 2.6 years instead of 1.5 year
- More or bigger batteries won't solve the problem



ESA with Magnetic Energy Harvesting

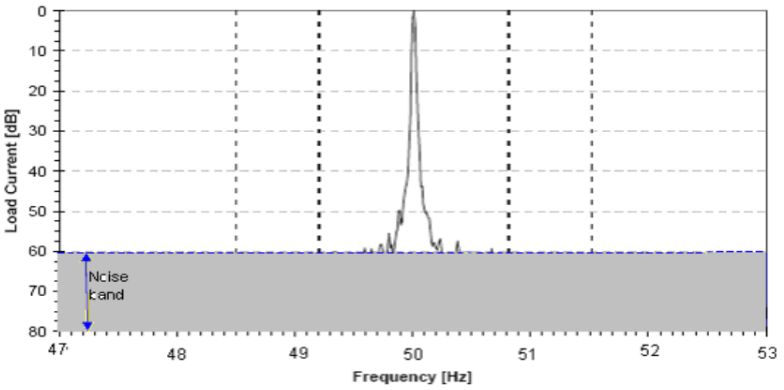
- ESA (Electrical Signature Analysis) is fundamental for industrial machine state monitoring and PHM;
- Introduction of a EH-PMIC, that extends CT (current transformer) energy harvesting's capability;
  - Minimum primary side current for stable sensing is as low as 0.3 A
- Capable capture actual full current waveform for harmonic analysis;



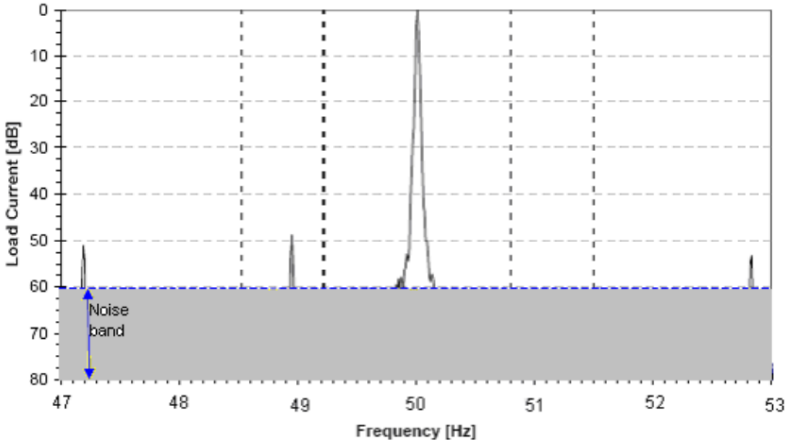
ESA with Magnetic Energy Harvesting

- ESA requires current and voltage measurements in order to the spectrum analysis
- Current signature could be obtained by the wireless current sensor with a high sample rate (5~10 kHz)
- FFT or envelope analysis will be performed on the basis of the acquired time-dependent data
- As shown in the right bottom, extra harmonic components are a sign of initial rotor asymmetry.

A Healthy Motor



Motor with defects of initial rotor asymmetry

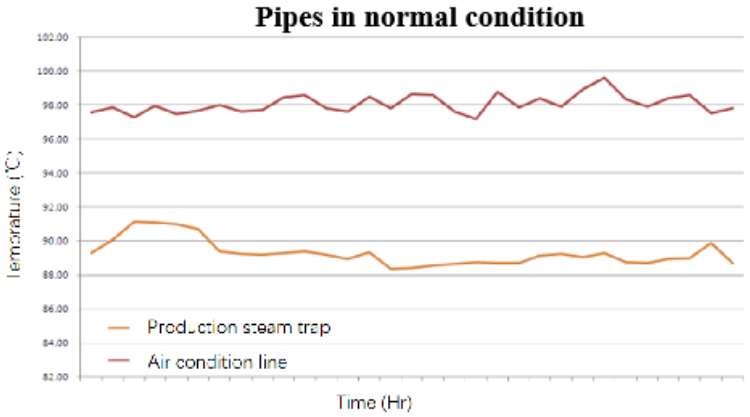


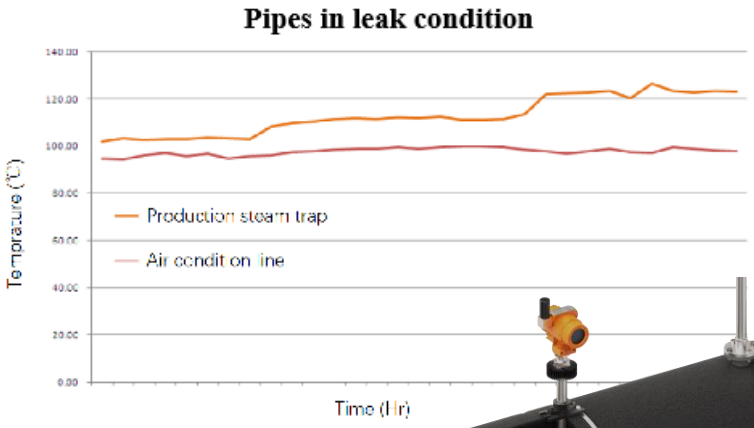
Non-invasive Steam Piping Monitoring with Thermal Energy Harvesting

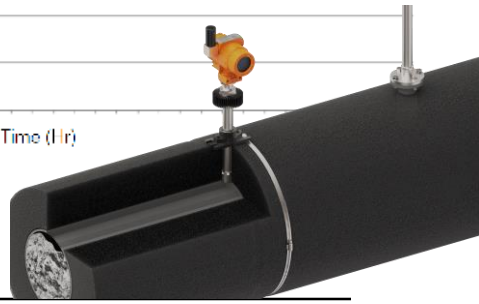
- Wiring and installation can amount to almost 90 percent of the total cost of a device in steam piping systems
- Exchanging batteries is not quite optional for steam piping industry
- Non-invasive temperature monitoring helps to prevent leakage, blockage, and unexpected operations
- Enabling the temperature transmitters autonomous is now a huge step forward.

Non-invasive Steam Piping Monitoring with Thermal Energy Harvesting

- Piping monitoring requires long term none-stop operation, wired or battery-powered scheme is NOT optional
- Temperature profiles can be analyzed as a signature when leak occurs
- As shown in the right, the same pipes are monitored by pipe wall temperature, the data is indicative for leaks, and could be used for further algorithms to detect more defects.







Summary

- Replace batteries or power cords;
- Enabvle unlimited standy-by or operation times;
- New application become possible;
- Installation and maintenance costs are minimized;
- Applications in industrial are very promising, especially considering the life-time costs.

THANKS