Energy Harvesting

Author: Miha Čančula
Advisor: doc. dr. Dušan Ponikvar

Faculty of Mathematics and Physics
University of Ljubljana

January 4, 2012

Energy Harvesting

Definition

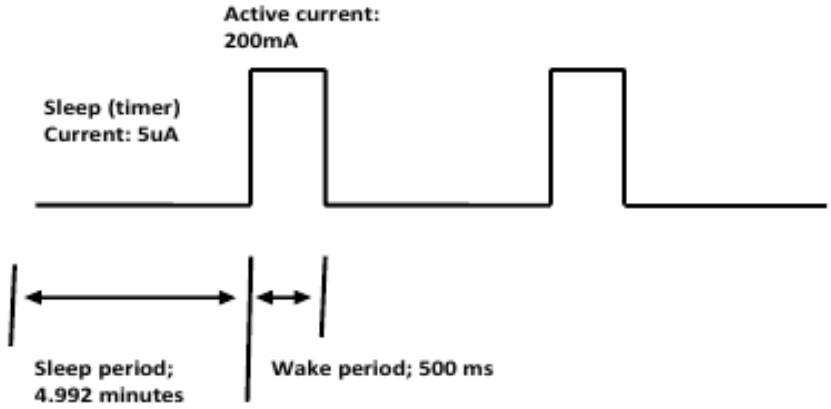
- Self-powered devices
- Small amount of power
  from the immediate environment
- Grid independence

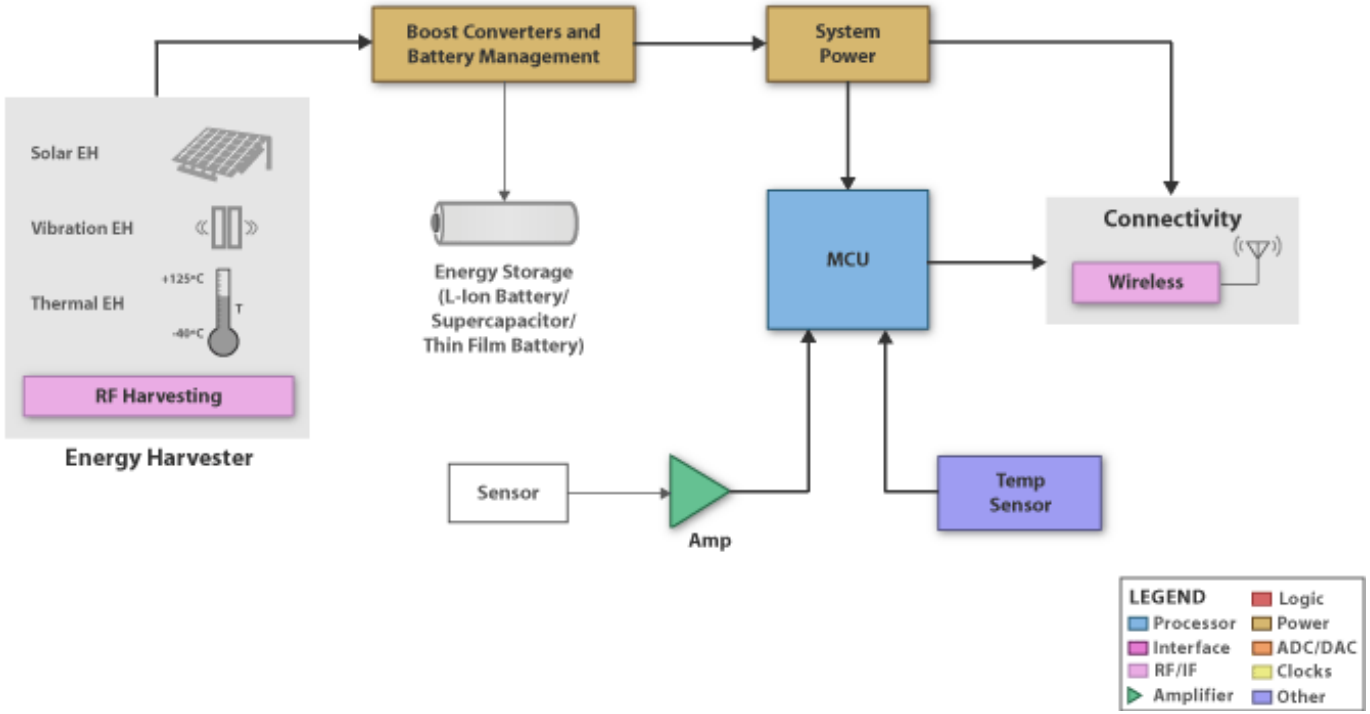
Use-cases

- Wireless sensors
  - Intelligent buildings
  - Fire detection
  - Pollution monitoring
- Consumer electronics

Wireless sensor networks

- Low power consumption
- Most time in “sleep” mode
- Most power needed for transmission





Important characteristics

Electric

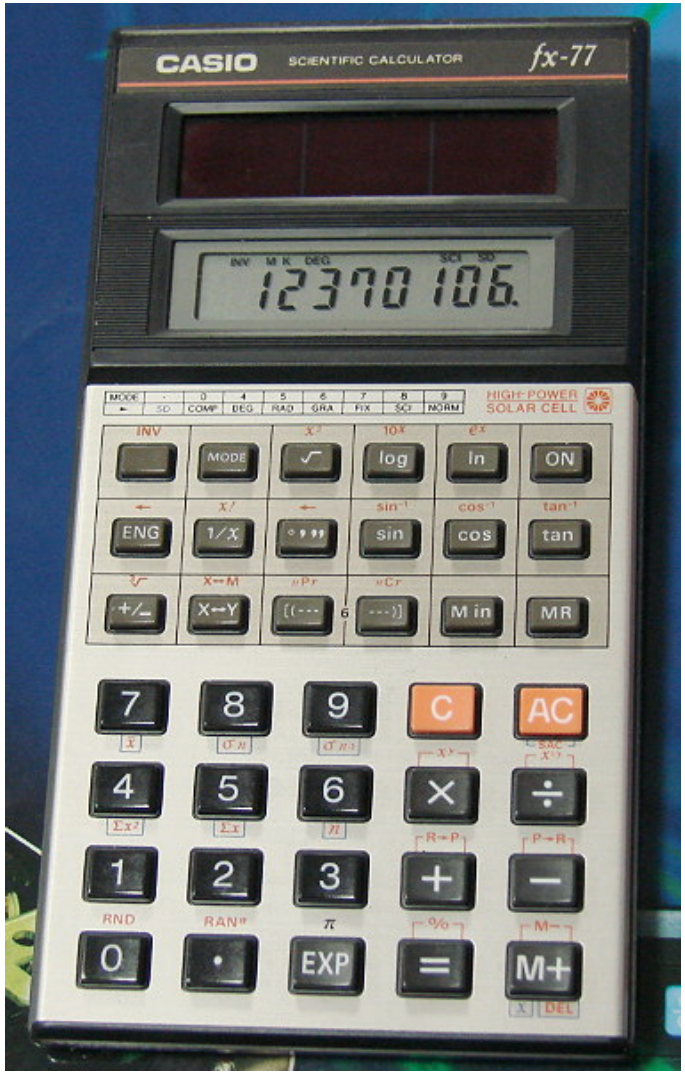
- Source resistance
- Open-circuit voltage V_{oc}
- Short-circuit current I_{sc}
- $I(V)$ curve and power curve

Physical

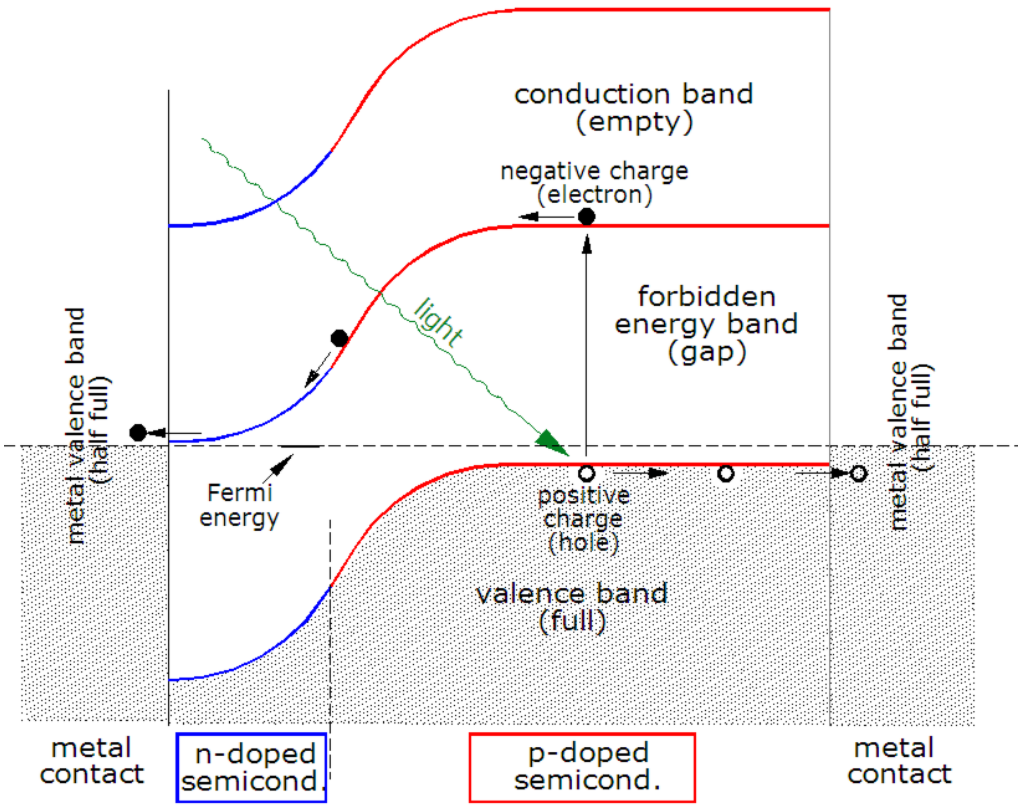
- Efficiency
- Size and weight
- Cost

Photovoltaic cells

- Most used today
- Produce the most power
- Variable output



Theory

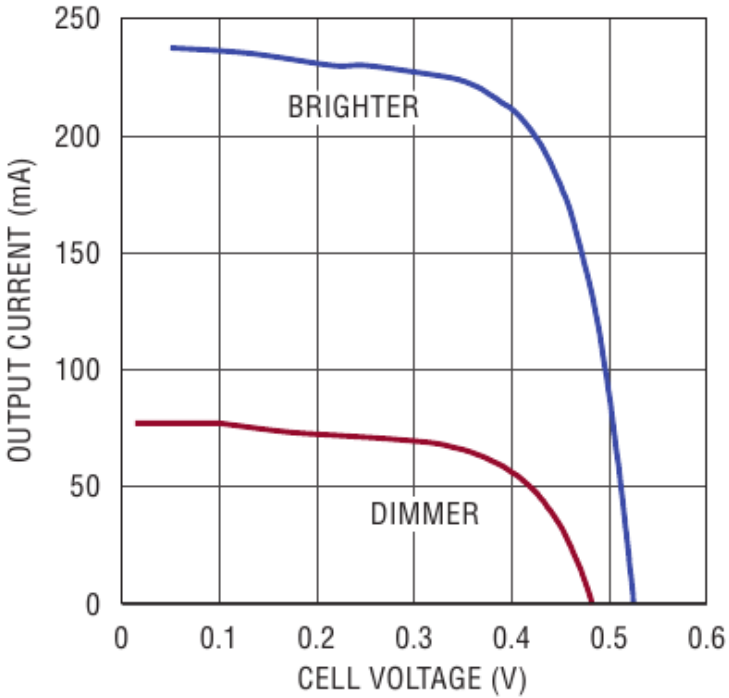


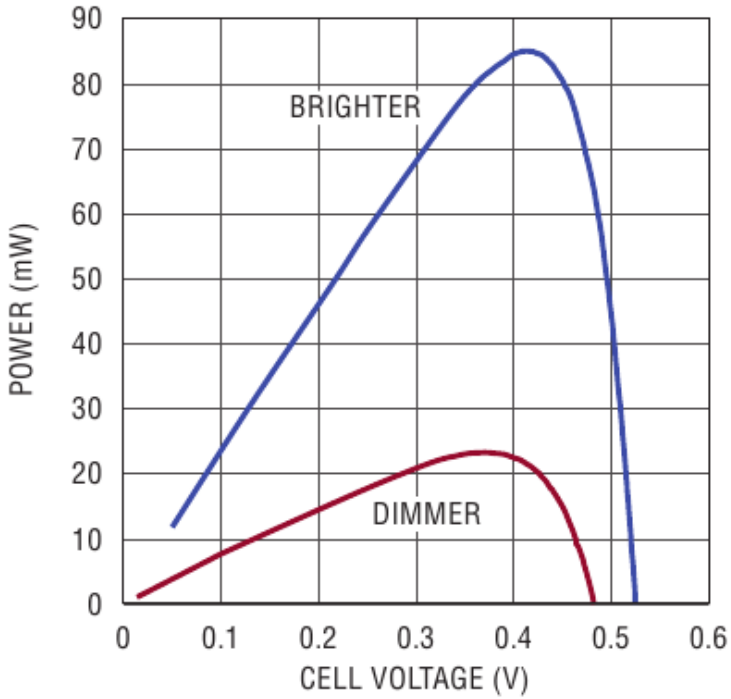
Photovoltaic effect

- Photon excites electron, creates electron-hole pair
- Electron moves to n-doped side

Characteristics

- Efficiency $\sim$ 30%
- Low $V_{oc} \Rightarrow$ connected in series
- Close to ideal current source

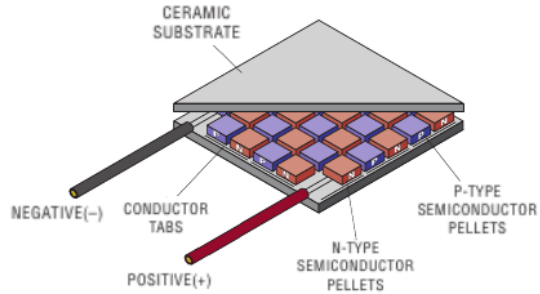


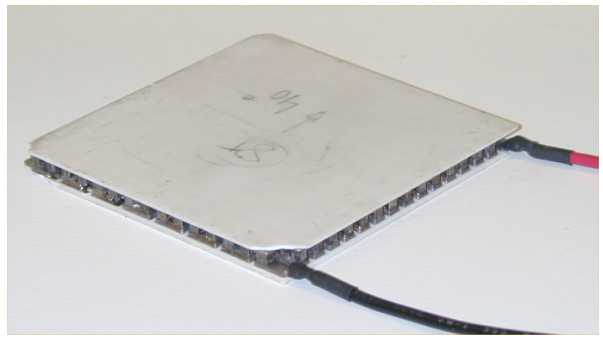


Thermoelectric generators

Operation

- Electricity from tempareture gradient
- Cheap, simple and reliable
- Also used as coolers





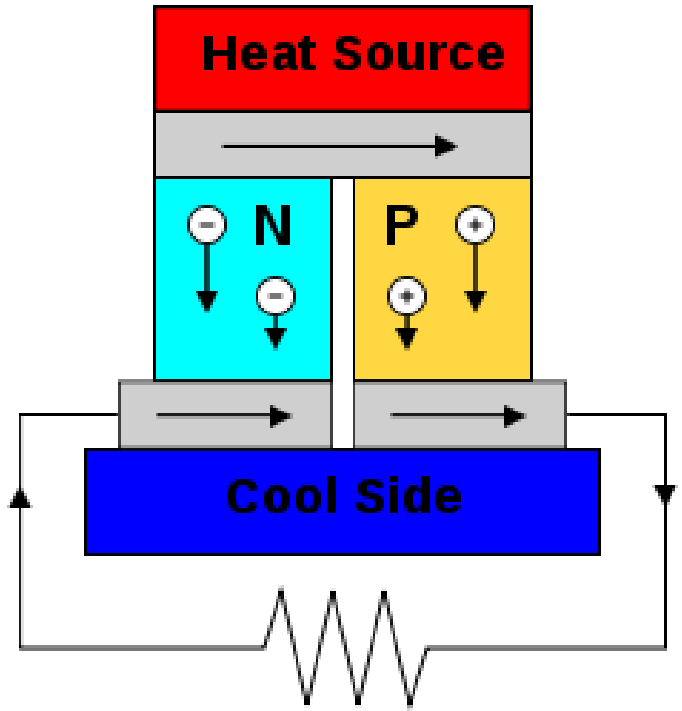
Heat sources

- Waste heat from machines
- Buildings
- Body heat

Theory

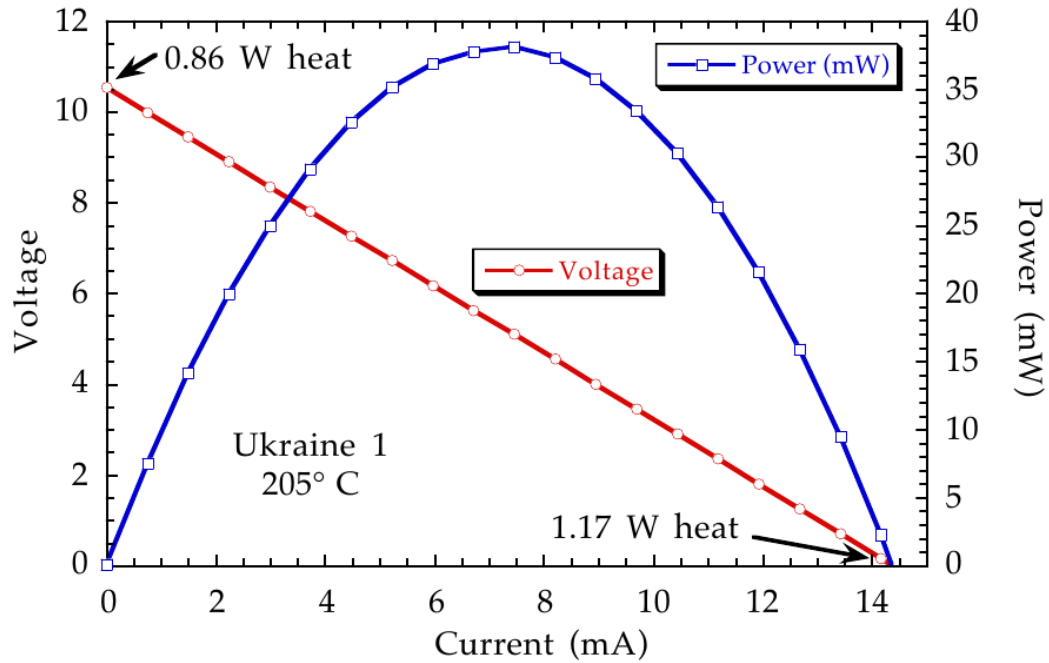
Seebeck effect

- Thermocouples
- Directed diffusion of charge carriers
- Reversible
- Strongest in semiconductors



Characteristics

- V_{oc} and R grow linearly with number of couples
- Linear $I(V)$ curve
- Heat engines – limited by Carnot efficiency $\eta = \Delta T / T_{max}$.



Piezoelectric generators

Operation

- Converts mechanical stress to electricity
- Harvest energy of vibration

Vibration sources

- Machines
- Human movement
- Buttons in remote controls

Theory

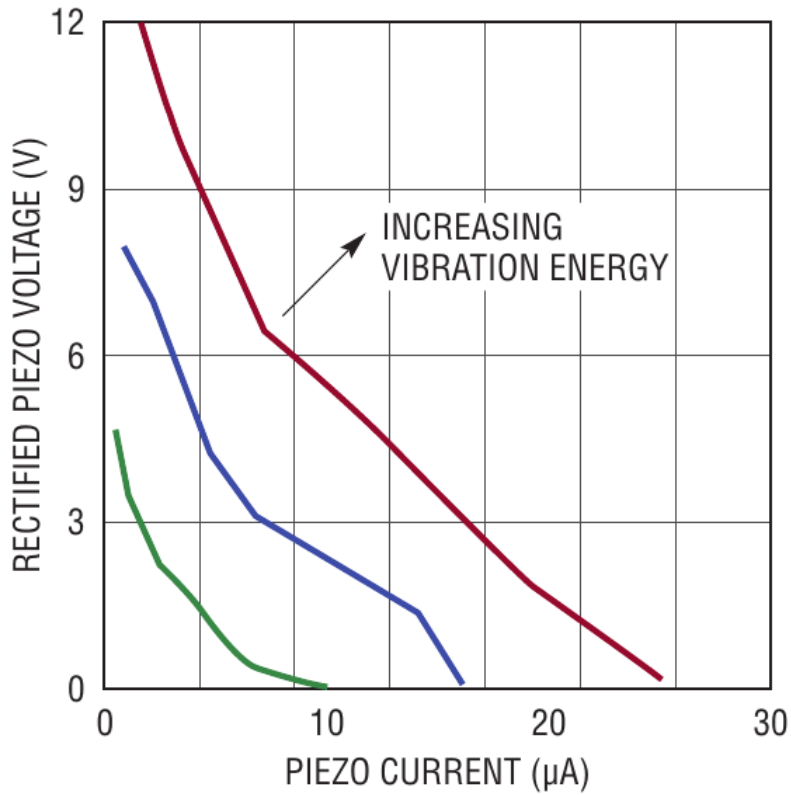
- Crystalline materials
- Asymmetric unit cells
- Coupled Hooke's law and dielectric response

$$\mathbf{S} = s\mathbf{T} + d^t\mathbf{E}$$
$$\mathbf{D} = d\mathbf{T} + \varepsilon\mathbf{E}$$

- Piezoelectric matrix d is generally sparse
- Reversible

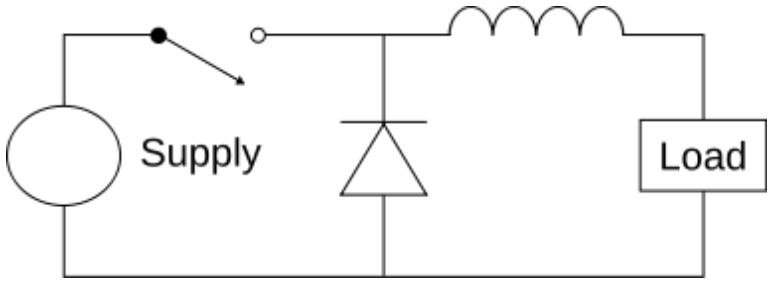
Characteristics

- Low power output $\sim$ 1mW
- High voltage V_{oc}
- Constant power curve

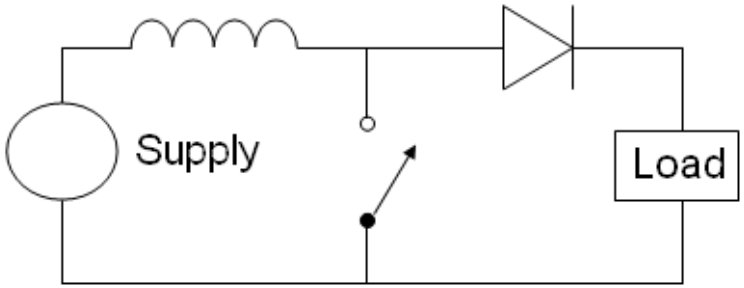


Voltage convertes

- Switched-mode
- Step-up or step-down
- Store energy in an inductor
- Switch frequency $\sim$ 1MHz
- Voltage gain depends only on duty cycle
- Efficiency over 90%
- Dynamically adjustable



Step-down (buck) converter



Step-up (boost) converter

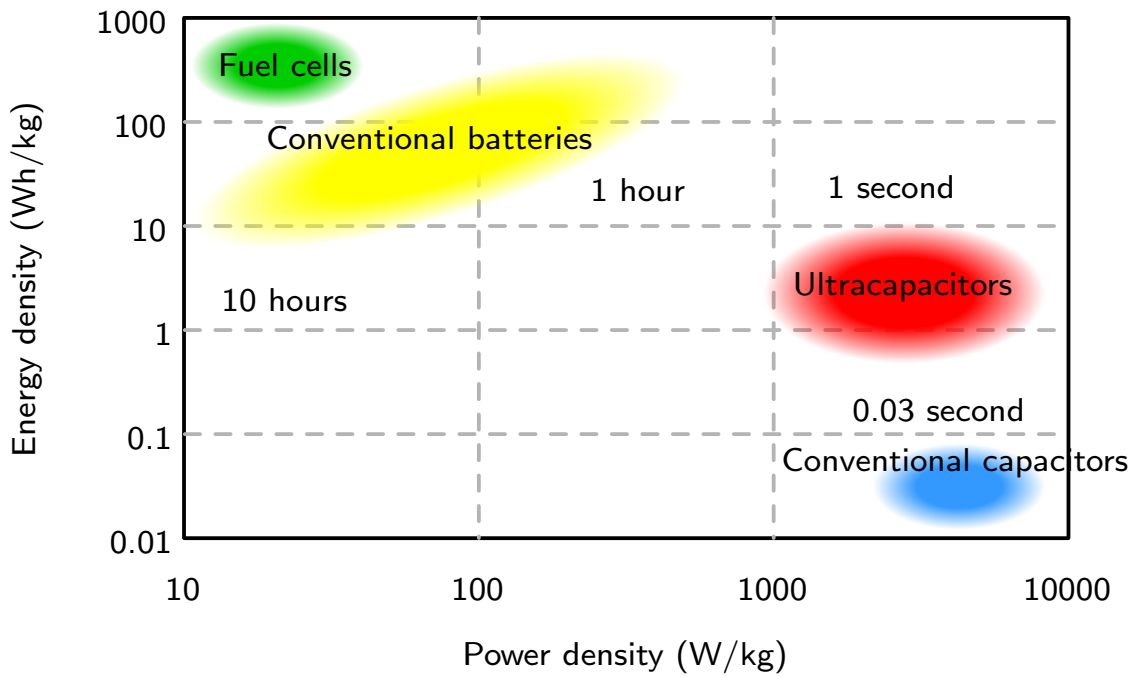
Energy storage

Storage elements

- Batteries
- Electric double-layer capacitors

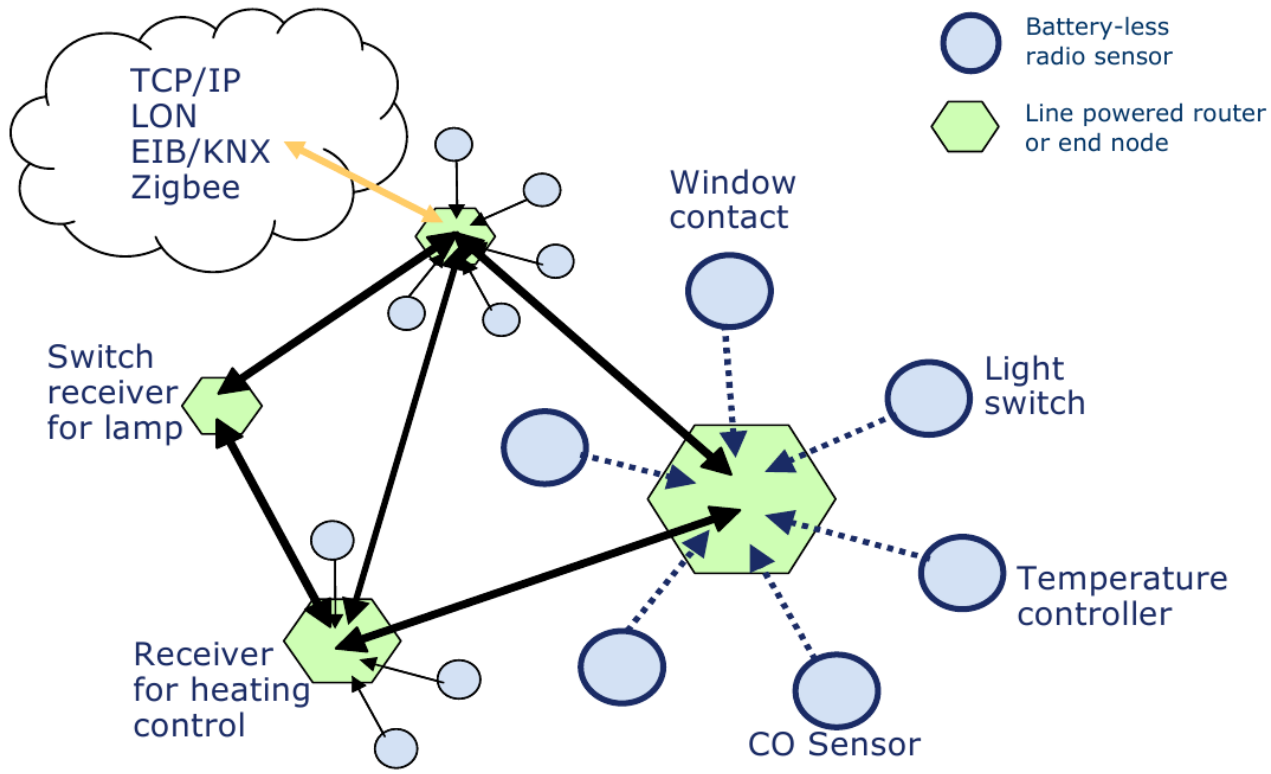
Chargers

- Prevent overcharging and over-discharging
- Limit input and output current



Building automation

- Wireless sensors and switches, grid-powered central nodes
- Various energy sources
- Standards: EnOcean, ZigBee



Phone chargers

- Extend battery life
- Photovoltaic cells
- $30 for phone charger, $500 for laptop charger

Conclusion

Uses

- Wireless sensors
- Batteryless electronics
- Remote locations

Benefits

- Low maintenance
- Grid independence
- Convenience

Conversion methods

- Photovoltaic cells
- Thermoelectric generators
- Piezoelectrics

Power management

- DC-DC converter
- Storage element and charger
- Batteries or ultracapacitors