

Energy Harvesting

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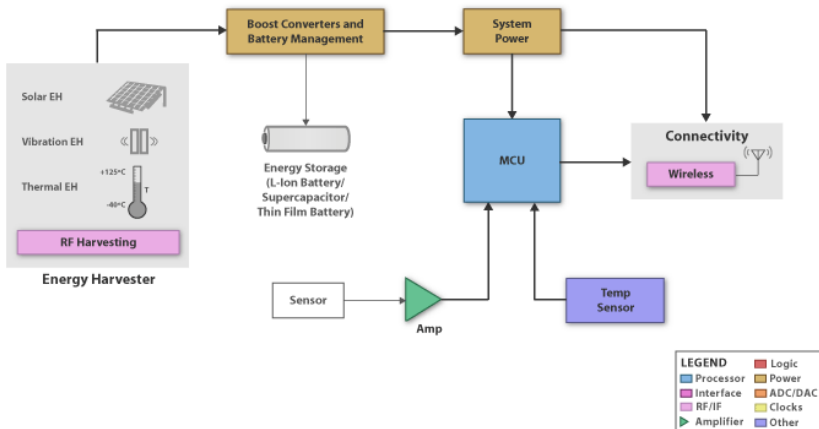
Definition

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

Use-cases

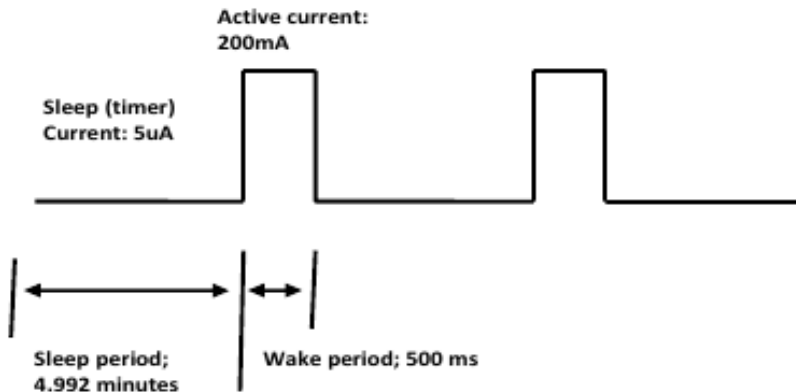
- ▶ Wireless sensors
 - ▶ Intelligent buildings
 - ▶ Fire detection
 - ▶ Pollution monitoring
- ▶ Consumer electronics

Wireless sensor networks



Wireless sensor networks

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



Important characteristics

Electric

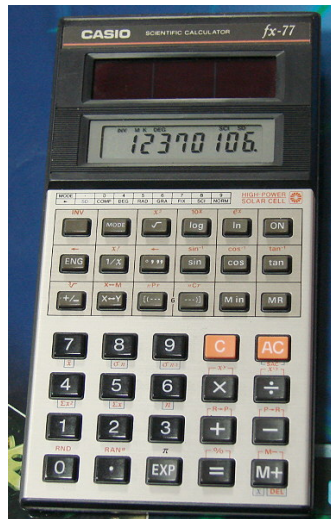
- ▶ Source resistance
- ▶ Open-circuit voltage V_{oc}
- ▶ Short-circuit current I_{sc}
- ▶ $I(V)$ curve and power curve

Physical

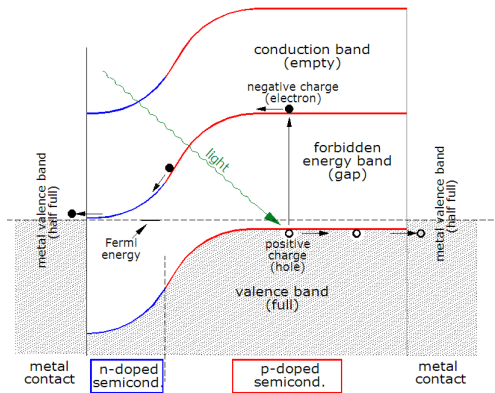
- ▶ Efficiency
- ▶ Size and weight
- ▶ Cost

Photovoltaic cells

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



Theory

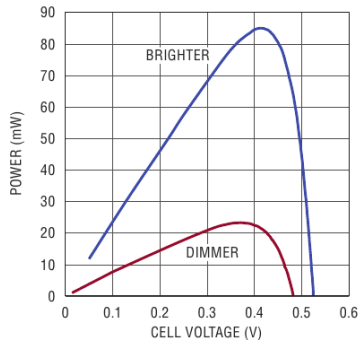
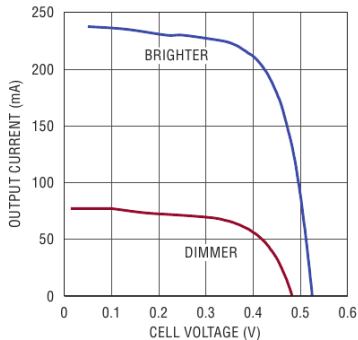


Photovoltaic effect

- ▶ 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



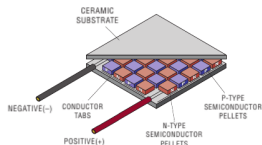
Thermoelectric generators

Operation

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

Heat sources

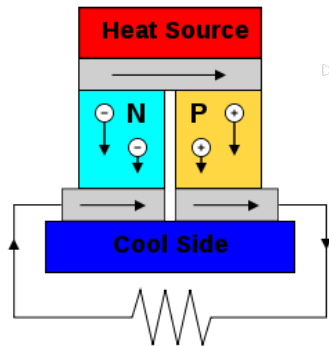
- ▶ Waste heat from machines
- ▶ Buildings
- ▶ Body heat



Theory

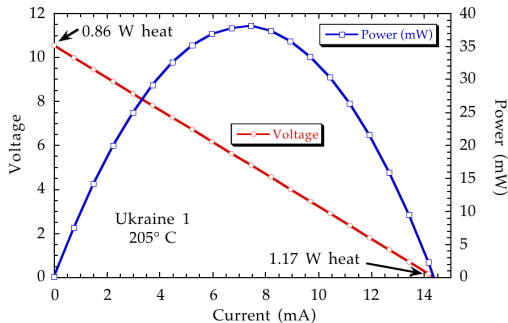
Seebeck effect

- ▶ 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

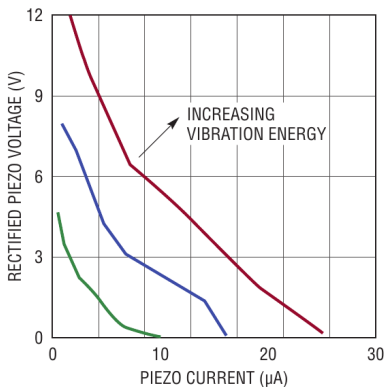
$$\mathbf{S} = s\mathbf{T} + d^t\mathbf{E}$$

$$\mathbf{D} = d\mathbf{T} + \varepsilon\mathbf{E}$$

- ▶ Piezoelectric matrix d is generally sparse
- ▶ Reversible

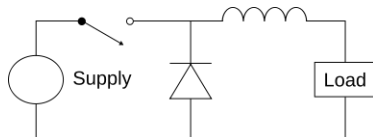
Characteristics

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

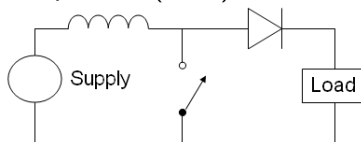


Voltage convertes

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



Step-down (buck) converter



Step-up (boost) converter

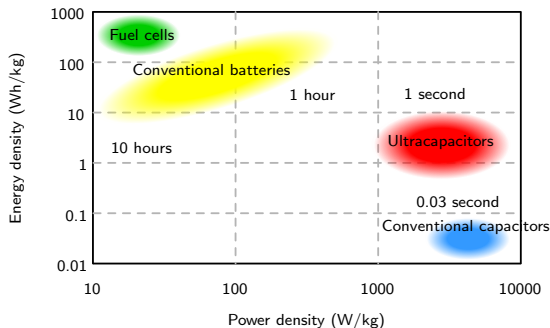
Energy storage

Storage elements

- ▶ Batteries
- ▶ Electric double-layer capacitors

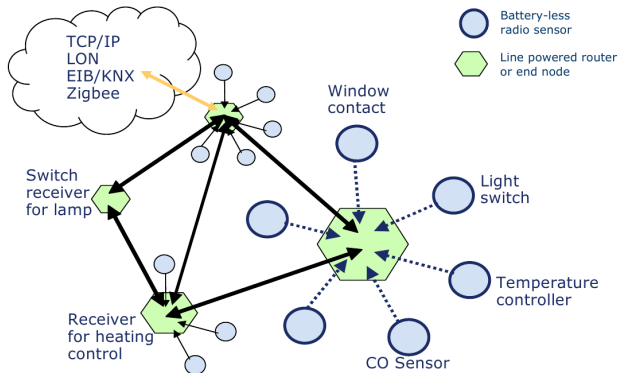
Chargers

- ▶ 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