Power Management in Energy Harvesting Applications at Fraunhofer IIS

Energy Harvesting 2014

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Fraunhofer Institute for Integrated Circuits IIS

Established: 1985

Locations: Erlangen, Fuerth, Nuremberg, Dresden

Employees: ca. 700

Budget: ca. € 80 Mio

Revenue Sources
- 75% Projects
- 25% Basic Funding

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- Power Management
- Battery Management
- Battery Monitoring
- Energy Transmission
- Energy Harvesting

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Integrated Energy Supplies – Ways of Cooperation

- *Technical Consulting:* We investigate your **problem** and propose **solutions**.
- *Study and Concept:* We develop an individual **concept** in close **cooperation** with the customer.
- *Project:* The contract specifies objectives, milestones and deadlines for **component** and **prototype** design.
- *Licensing:* Available **components** and devices can be used via licensing agreements.
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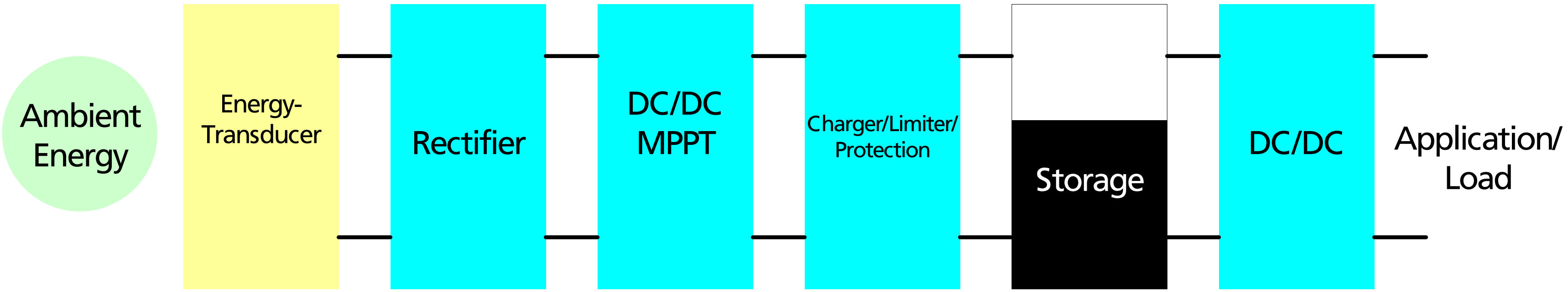
- Ambient Energy – Data Logger
- Power Management for Thermogenerators and Solar Cells
- Power Management for Piezoelectric Generators
- Battery Management for Thin-film Micro-batteries
- Summary

Introduction



- Environment is not constant - ambient energy changes
- AC signal with variable frequencies and amplitudes
- Low voltage or current (mV or µA)
- Self-starting power management
- Focus on rectifier, dc-dc converter, MPPT
- Not all are required in any application and with any transducer
- Charger/limiter/protection are often redundant, because of small currents

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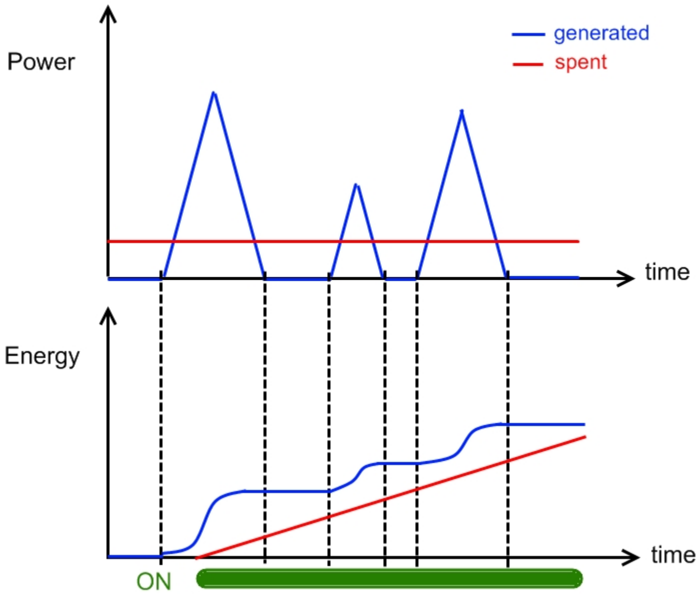
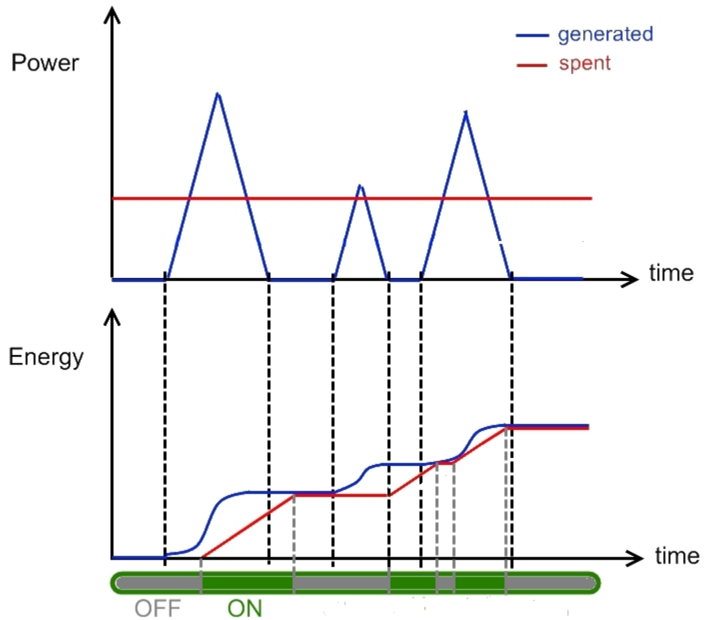
Introduction

- The energy harvested must be equal or greater than the energy consumed by the load (load powered continuously or intermittently)
- Choose the sensor depending on voltage supply, active current consumption, stand-by current consumption and start-up time (stand-by and active time).





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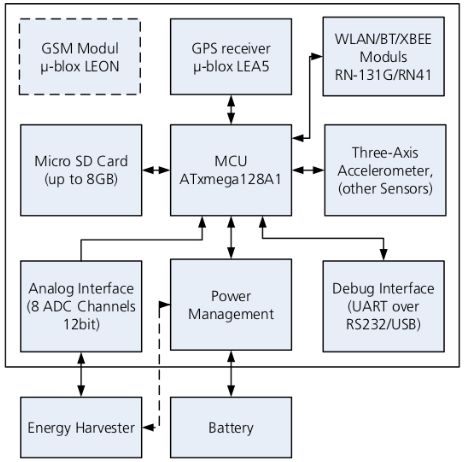
Ambient Energy – Data Logger

- Characterization of Energy Harvesting sources. Environment is not constant - ambient energy changes
- Characterization of Energy Harvesting transducers
- Data logger with GPS
- Accuracy 2.5 m
- Sensors
  - Acceleration (bandwidth up to 1.6 kHz, 13bit resolution at +/-16g)
  - Versatile interface for additional sensors
- SD-Card (8Gbyte)

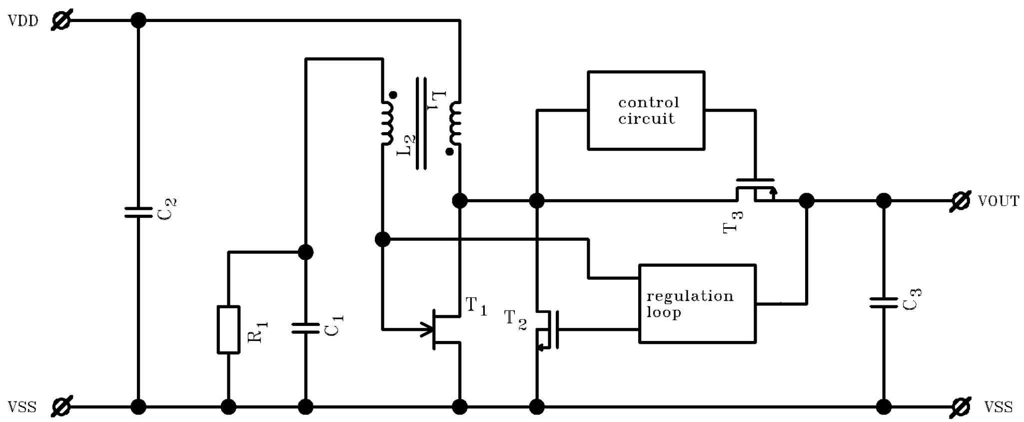


Power Management for Thermogenerators and Solar Cells

- threshold voltages of semiconductor technologies are scaled down
- thermo-generators: about 50 mV per Kelvin
- solar/fuel cells: about 0.5 V
- The main differences compared to state of the art step-up converters:
    - Transformer instead of single coil
    - Power converted only in primary winding
    - Parallel connection of low threshold transistor (JFET) and low on-resistance transistor (MOSFET)

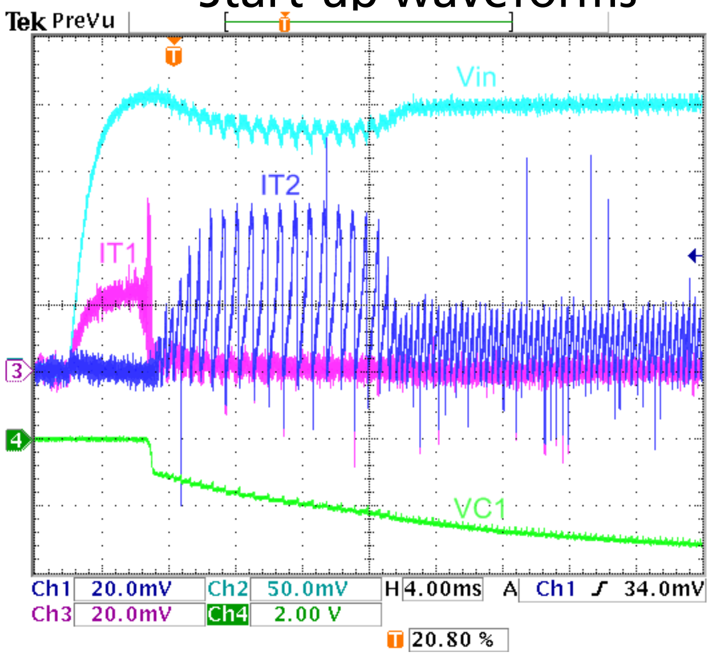
Power Management for Thermogenerators and Solar Cells

Step-up converter



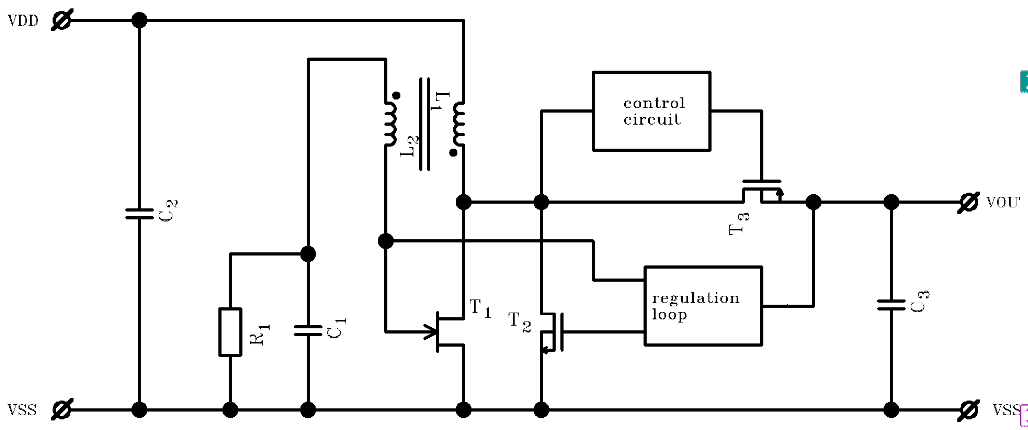
[Pollak]

Start-up waveforms

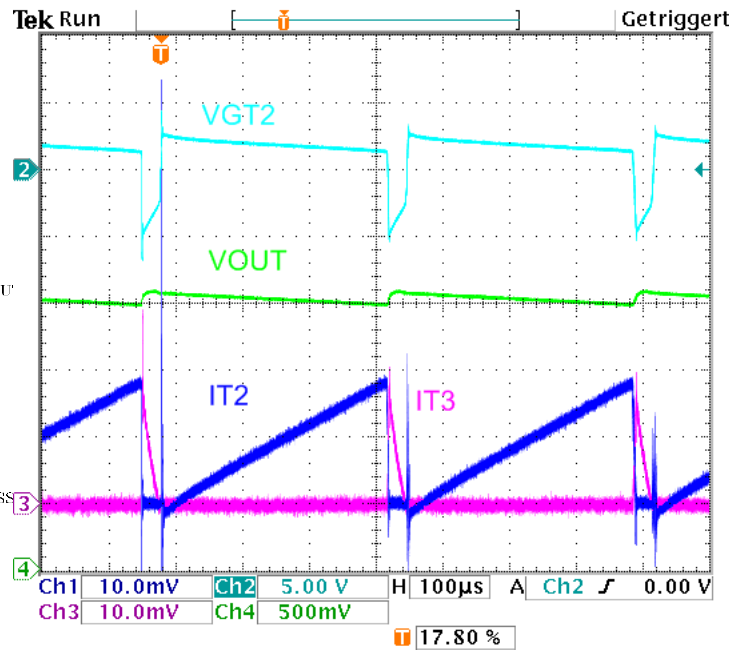


Power Management for Thermogenerators and Solar Cells

Step-up converter



Steady-state waveforms



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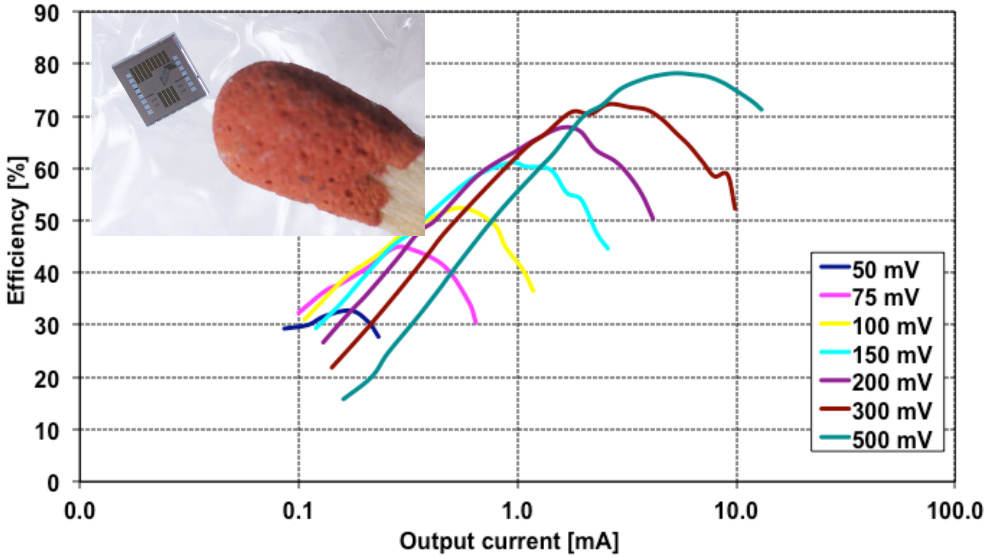
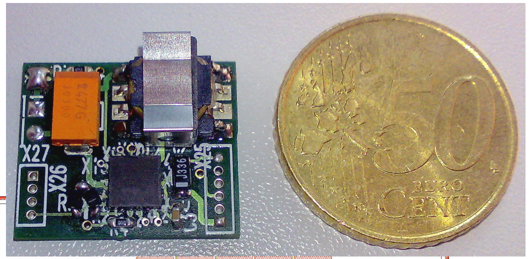
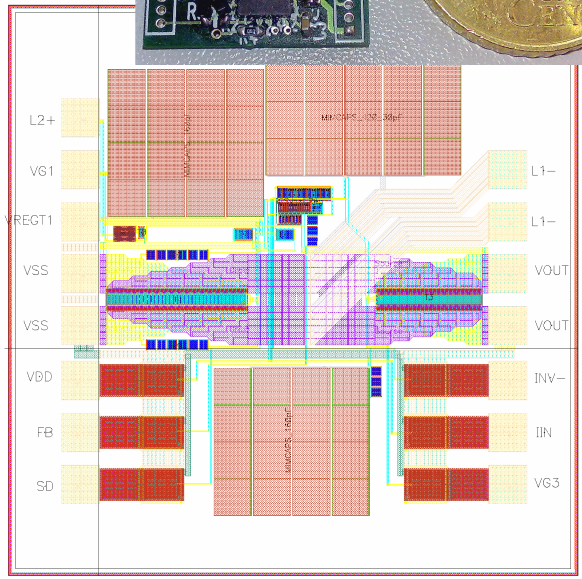
Power Management for Thermogenerators and Solar Cells

- ASIC design reduces volume and costs (CMOS 180 nm, 1.5*1.5mm)
- all components on-chip except transformer (L1=500µH, L2=12mH) and output capacitor
- start-up voltage of **20 mV**, output voltage: 1.5 V to 5 V
- Looking for companies to **commercialize IC**

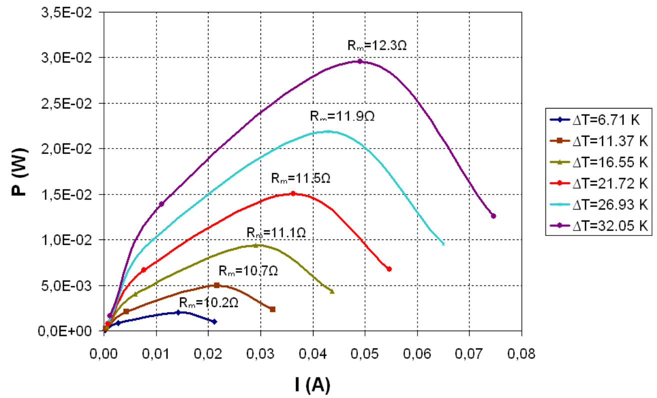


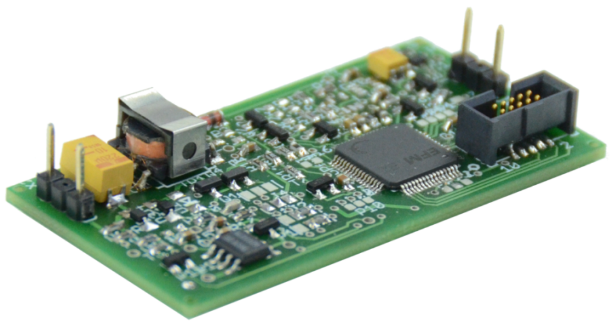




Power Management for Thermogenerators and Solar Cells – MPPT

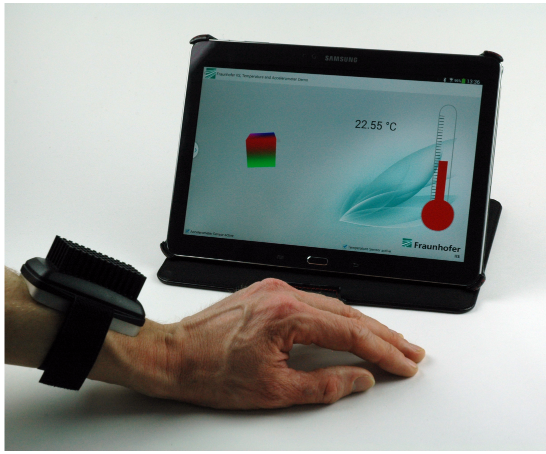
- Maximum Power Point Tracker (MPPT) digitally controlled
- A low-power microcontroller regulates the duty cycle of the DC-DC converter to maximize its output power
- Minimum start-up voltage of 150mV
- Output voltage between 2 V and 5.5 V
- Power consumption of MPPT (µC) is determined by frequency of duty cycle update (very low for ambient energy)
- Algorithmus (Hill Climbing) easily portable to another microcontroller





Power Management for Thermogenerators and Solar Cells – Demonstrators

- Application field: house automation in windows, heatings, etc.
- Thermo-electrical power supply for wireless sensors
- Combination of thermogenerators and solar cells
- Application example: power sensors, RF transmitters and a Bluetooth low energy module.



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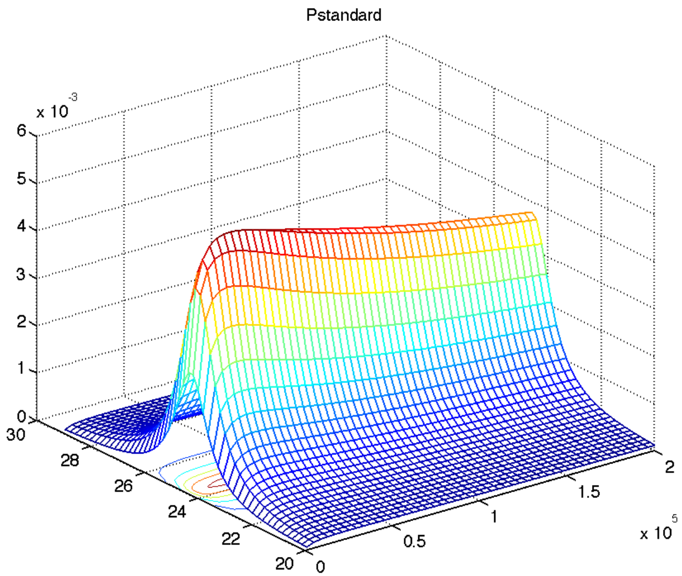
Power Management for Piezoelectric Generators

- BMBF-Project PiezoEN with Wölfel Beratende Ingenieure GmbH + Co. KG and Invent GmbH
- Goal: Self-powered sensor system for structural health monitoring
- Analysis of bridge reveals natural frequency: Tuning of generators
- Test structures for evaluation of power output, substrate materials, piezo-patches, etc.

Test instalation in a bridge (359m long in Bayern)

Power Management for Piezoelectric Generators



- The maximum harvested power if a diode bridge is employed as rectifier is 5.23 mW
- The harvested power if a complex conjugate load is employed is 9.18 mW
- The power ratio is 0.57
- M=0.42

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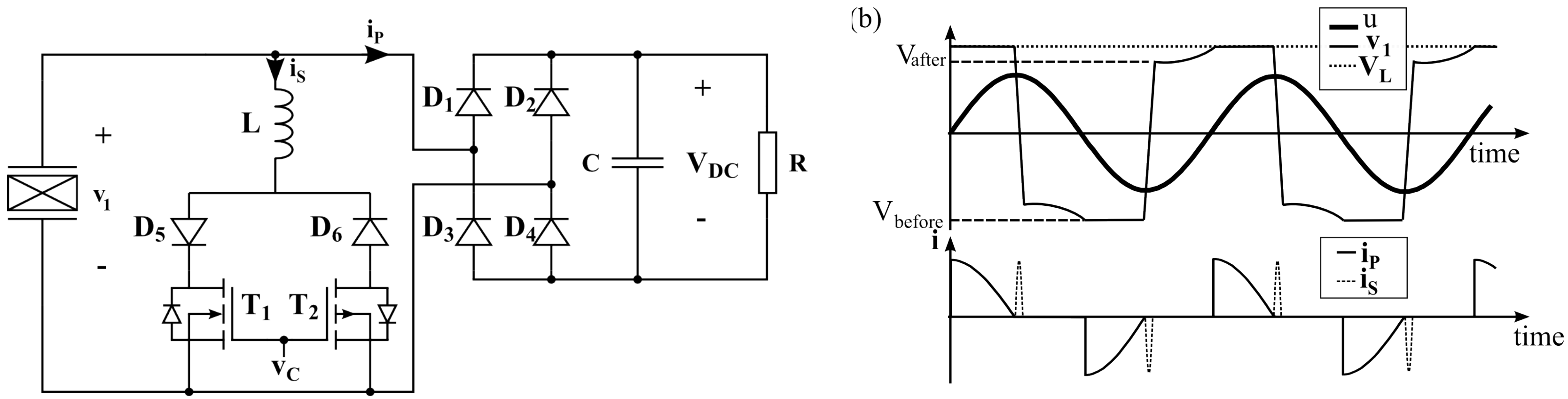
Power Management for Piezoelectric Generators – Parallel SSHI



[Priya]

- The current of the piezoelectric element flows through the diode bridge until a voltage peak is reached.
- The current flowing in the switching system is always null, except during the inversion phase.
- During the inversion phase, the piezoelectric voltage changes its polarity in a time given by $t_I = \pi\sqrt{L_{res}C_{piezo}}$

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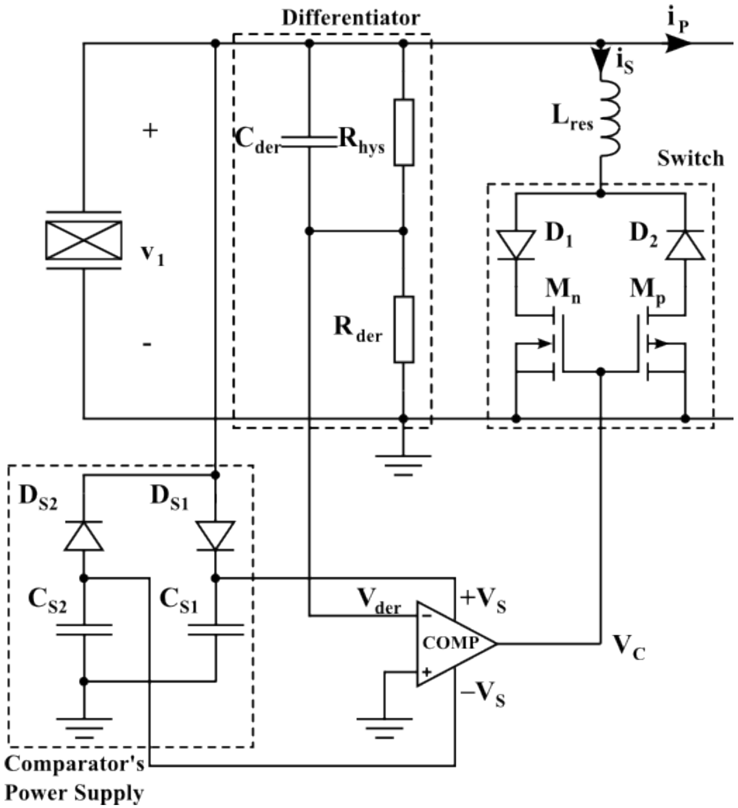
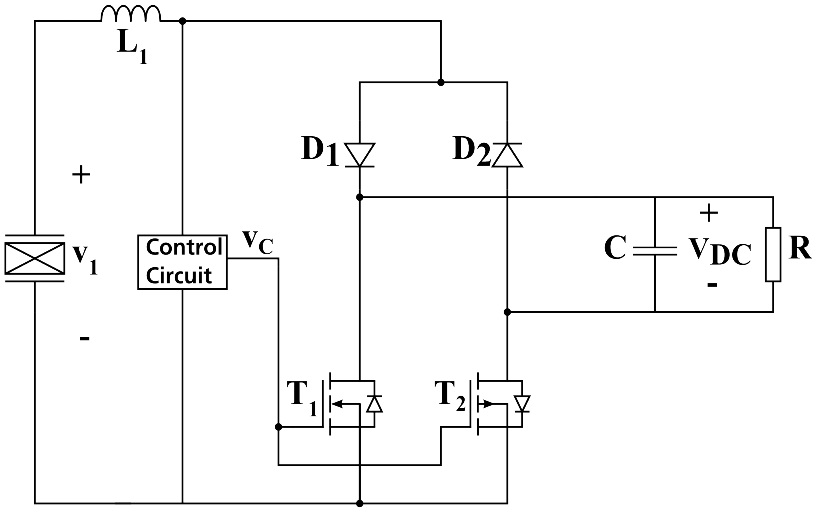
Power Management for Piezoelectric Generators – Parallel SSHI

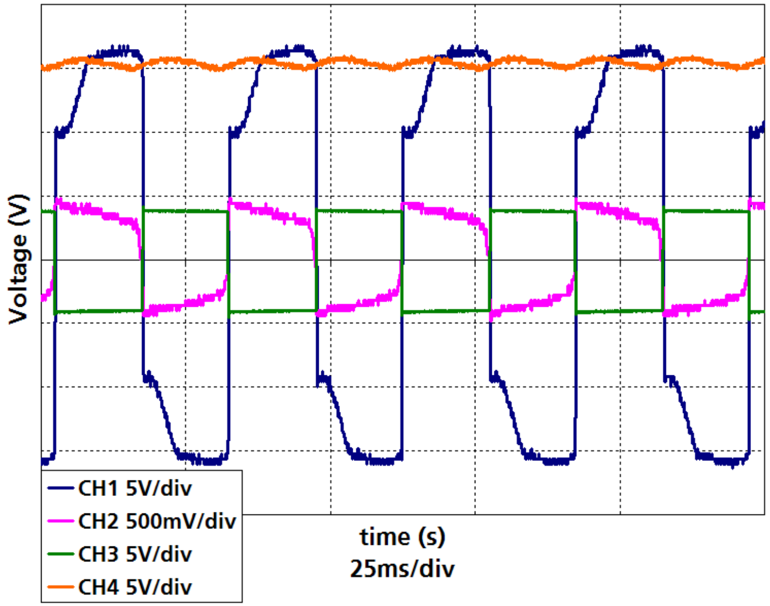


[Ben-Yaakov]

- Control circuit in combination with the Parallel SSHI
- The control circuit is powered by the piezoelectric element
- The differentiator detects the peak voltage
- The output of the differentiator is used as an input in a comparator
- M_n and D_1 conform the switch for the positive to negative voltage inversion
- M_p and D_2 conform the switch for the negative to positive voltage inversion
- The diodes prevent that the current flows through the inductor once the inversion has taken place

Power Management for Piezoelectric Generators – Modified Parallel SSHI



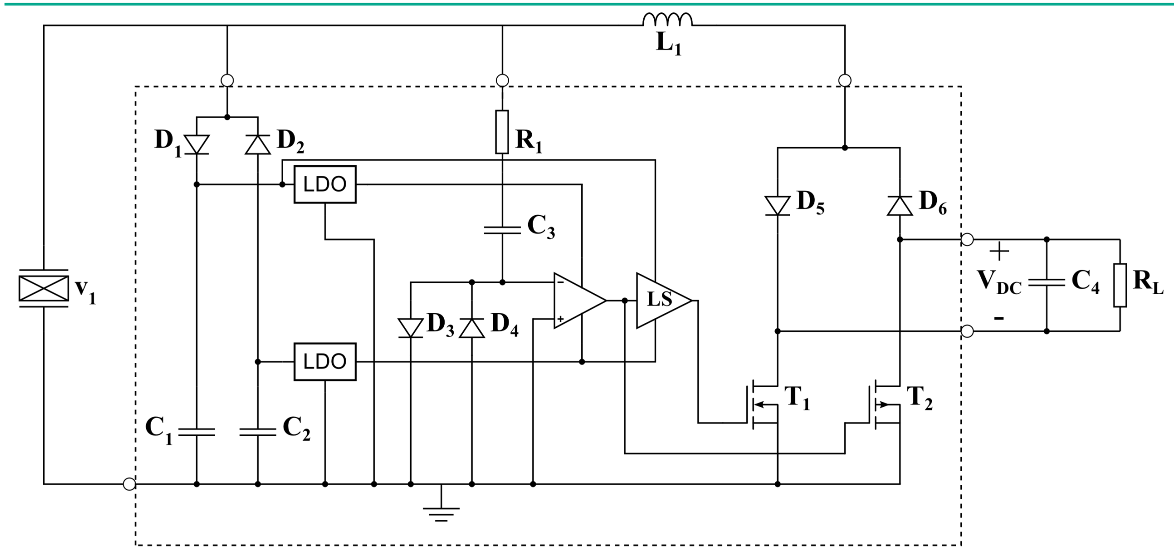


- The number of diodes has been reduced from six to just two and the number of MOSFETs remains two

- CH1, piezoelectric voltage v_1
- CH2, output signal of the differentiator
- CH3 is the control signal of the MOSFETs v_C
- CH4 is the unregulated DC output voltage V_{DC}

[Mateu]

Power Management for Piezoelectric Generators – Control Circuit



- Challenge is the control circuit
- Peak detection with differentiator for a narrow bandwidth
- R_1, C_3, D_3, D_4 act as differentiator for low frequencies with higher bandwidth
- Broadband control circuit can enable broadband or self-adjusting AC-DC converter

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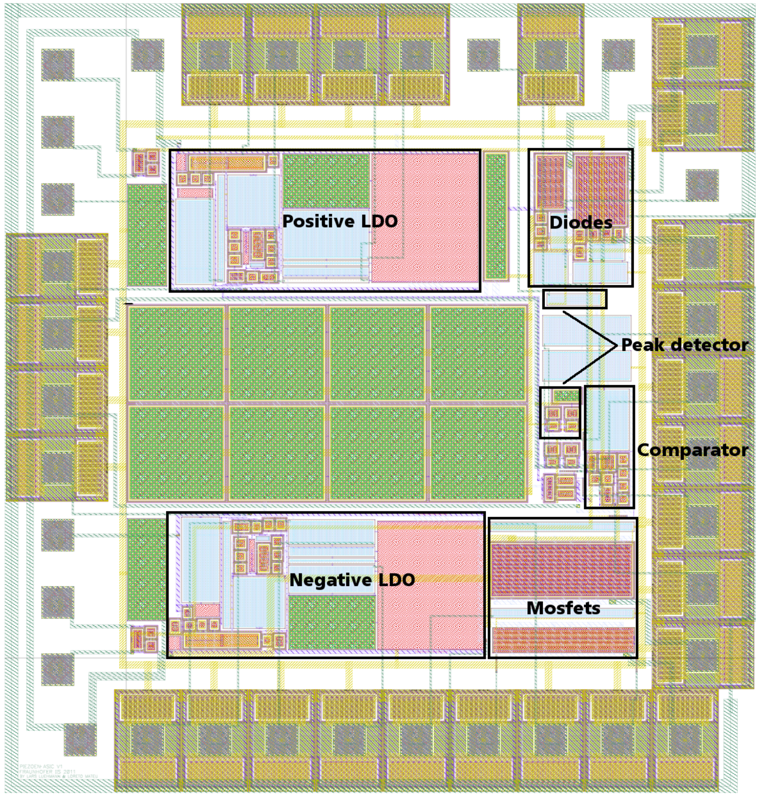
Power Management for Piezoelectric Generators – ASIC Design

- The input voltage range is ±20 V.
- All components on-chip except inductor
- Diodes D5 and D6 are synchronous diodes.
- Ultra-low power consumption of LDOs, comparator and level shifters
- Power consumption:
  ca. 35 µW at 20 Hz
- Technology: AMS H35B4
- Chip-Size 2.2x2.3 mm
- Currently: Test and evaluation



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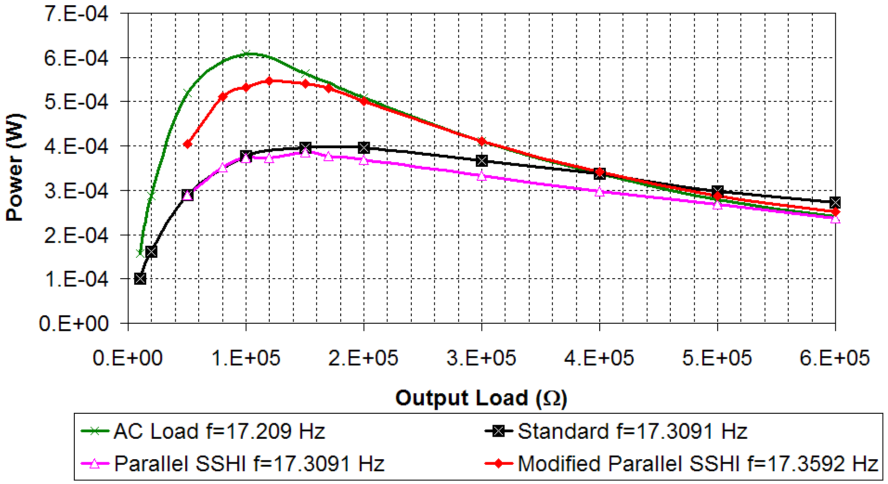
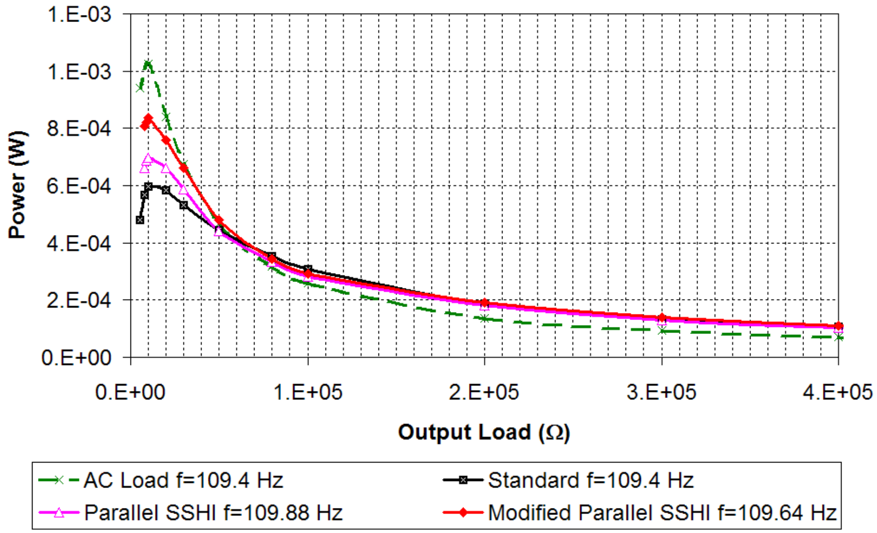
Power Management for Piezoelectric Generators – Modified Parallel SSHI



DuraAct P-876.A12 piezoelectric element excited at 0.1 g



Midé QP20W piezoelectric element excited at 1 g

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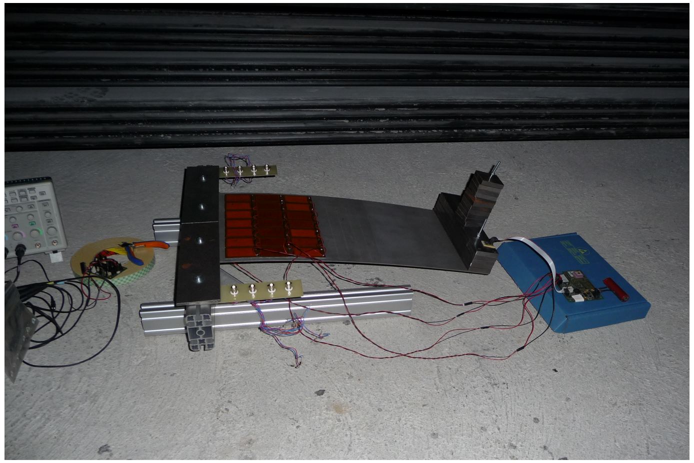
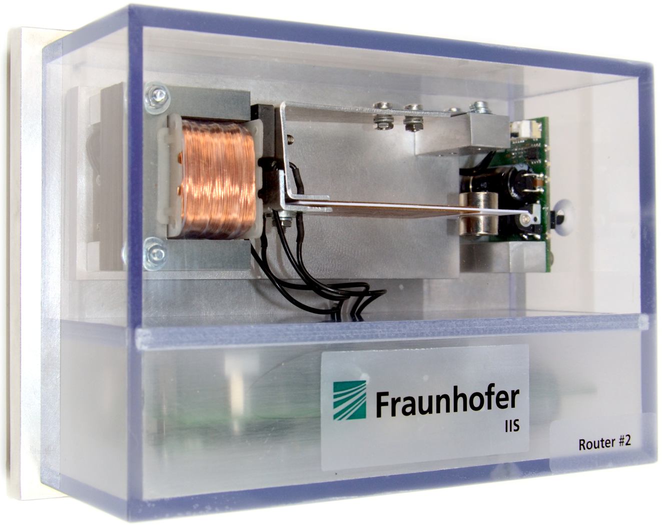
Power Management for Piezoelectric Generators – Bridge Monitoring

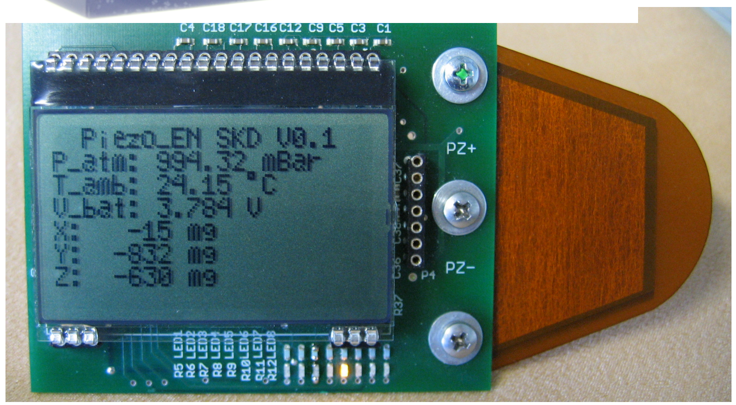
- Power output: max. 0.8 mW, mean 0.1 mW per piezo patch
- f=2.25 Hz
- Bridge is not space-limited



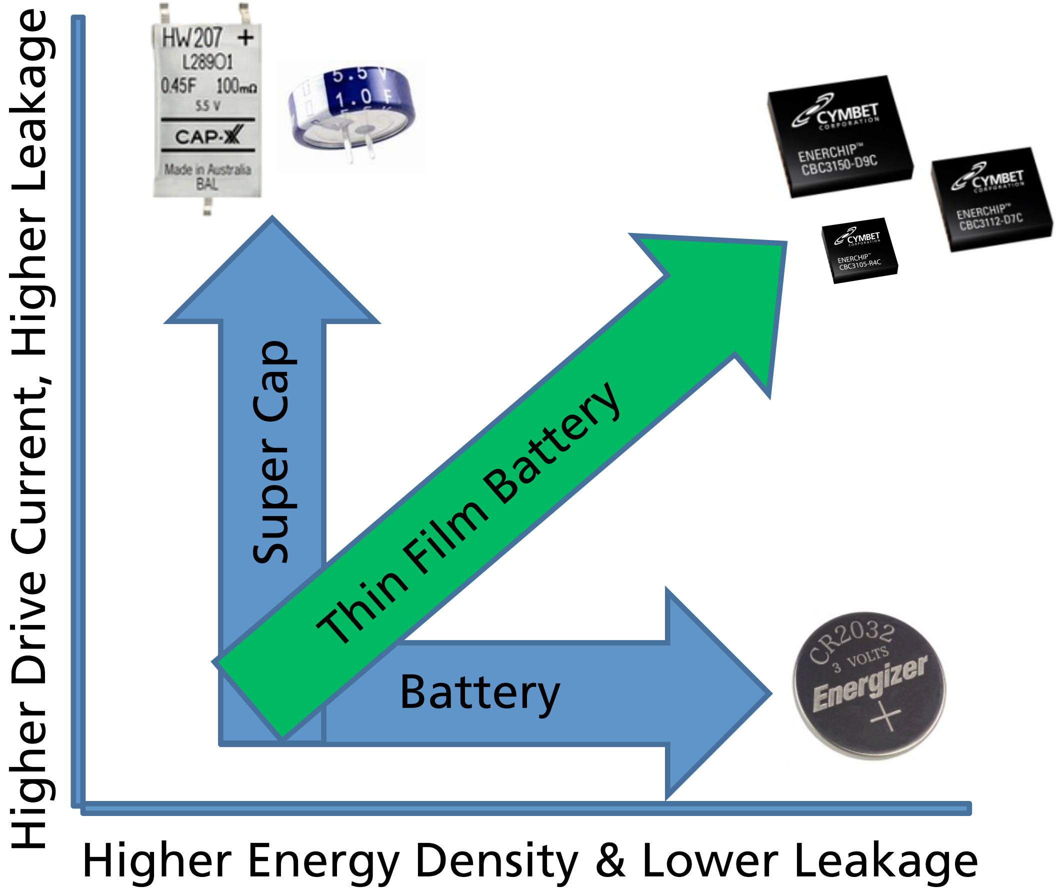
Power Management for Piezoelectric Generators – Demonstrators

- Application fields: structural health monitoring, condition monitoring, GPS tracking for logistics,…
- Voltage converter adapts voltage peaks
- Input source: Hand movement (1 – 2 Hz, 0.5 – 1 mW)
- Application examples: power display, sensors and a RF transmitter





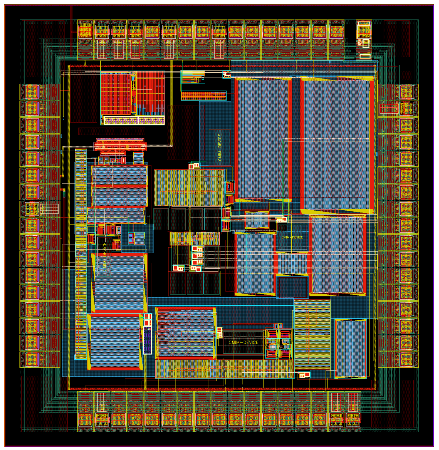
Battery Management and Monitoring for Thin Film Micro Batteries

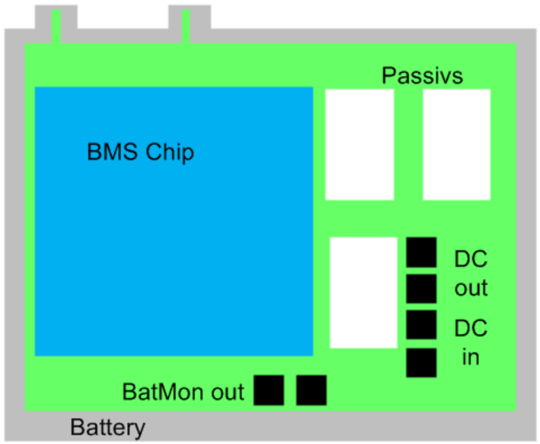


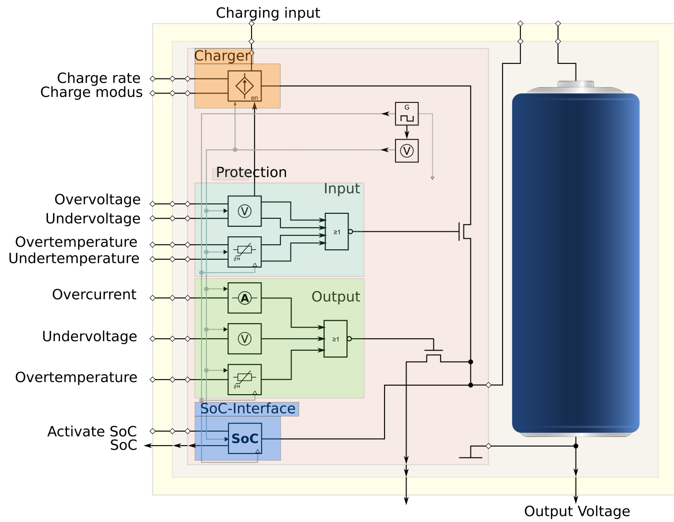
- High Drive Current
- High Energy Density
  - 50 X > SuperCap
- Low Leakage (self-discharge)
  - 4,000 X < SuperCap
- Rechargeable / Long Life (more recharge cycles than either a coin cell or a Li-ion Polymer)

Battery Management and Monitoring for Thin Film Micro Batteries

- Battery management ASIC for micro-batteries (e.g. C =1 mAh)
- Power consumption < 1 µA, sleep < 10 nA
- Charge control and protection
- State-of-charge estimation: State-alone or µC-assisted
- Currently: Test and evaluation of the ASIC







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Summary

- It is necessary to monitorize the ambient energy to be used
- Additional functionality required in the power management unit (detectors, low-voltage dc-dc converters, MPP trackers), which must not degrade efficiency
- State-of-the art power management circuits are not well suited for energy harvesting (impedance matching, real MPPT tracker, ultra low start-up voltage, low start-up time)
- Energy versus power consumption. Energy storage is required.
- Battery management and monitoring of thin film micro batteries.
- There are still a lot of unsolved challenges: leakage / standby currents, efficiency versus load range, reduce start-up voltage, frequency tuning
- Energy Harvesting can supply low power electronic devices

References

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