Integrating Power Management architectures for Energy Harvesting

3rd International Workshop on Power Supply on Chip

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San Francisco, November 16, 2012

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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Integrated Energy Supplies

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

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Integrating Power Management architectures for Energy Harvesting

1. Challenges of Low Power Converters
2. Generic Approach
3. Circuit Examples
4. Application Examples
5. Summary

Integrating Power Management architectures for Energy Harvesting
Introduction

- **Mobile applications** of electronic systems become more and more popular
- Power supply **difficult**, because
  - **wires** are not feasible
  - **batteries** limit mobility or produce costs
- **Power output** of Energy Harvesting transducers is related to their **size** (area, volume) and thus to their **price**
- **Power management** matches load and transducer and cares for **maximum energy output**

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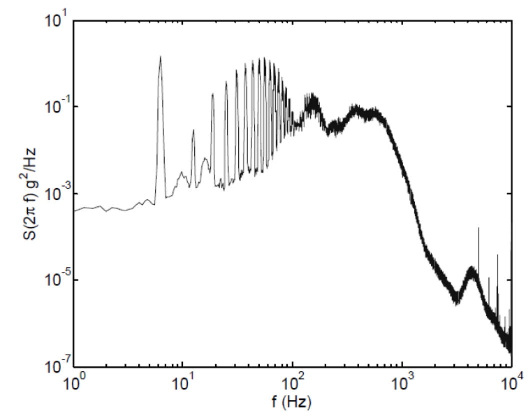
Challenges

- **Environment** is not constant - ambient energy **changes**

  Energy Harvesting must **adapt** to the different sources to harvest "what is possible"
- **Low** voltage or current (e.g some mVs or µAs)
- Sources with **variable resistance** (depending on temperature and aging)
- AC signal with **variable frequencies**
- **High dynamic range** of amplitudes

Vibration Source	Peak Acc. (m/s^2)	Frequency of Peak (Hz)
Base of 5 HP 3-axis machine tool with 36" bed	10	70
Kitchen blender casing	6.4	121
Clothes dryer	3.5	121
Door frame just after door closes	3	125
Small microwave oven	2.25	121
HVAC vents in office building	0.2 – 1.5	60
Wooden deck with people walking	1.3	385
Breadmaker	1.03	121
External windows (size 2 ft X 3 ft) next to a busy street	0.7	100
Notebook computer while CD is being read	0.6	75
Washing Machine	0.5	109
Second story floor of a wood frame office building	0.2	100
Refrigerator	0.1	240

[rou1]



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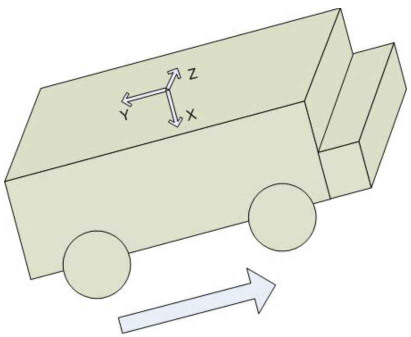
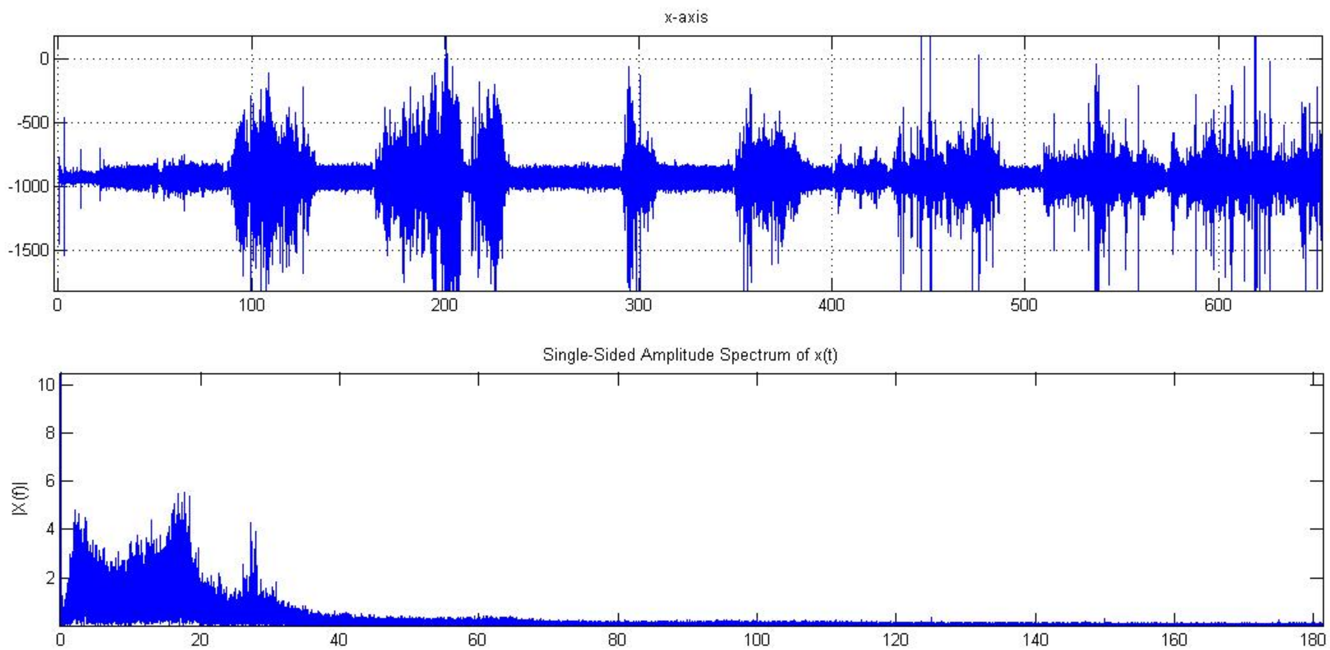
Challenges

- **Field tests** in the trunk of a car, inner-city
- Spectrum of acceleration as a **measure for energy**
- Important details for **design of vibration transducer** and power management





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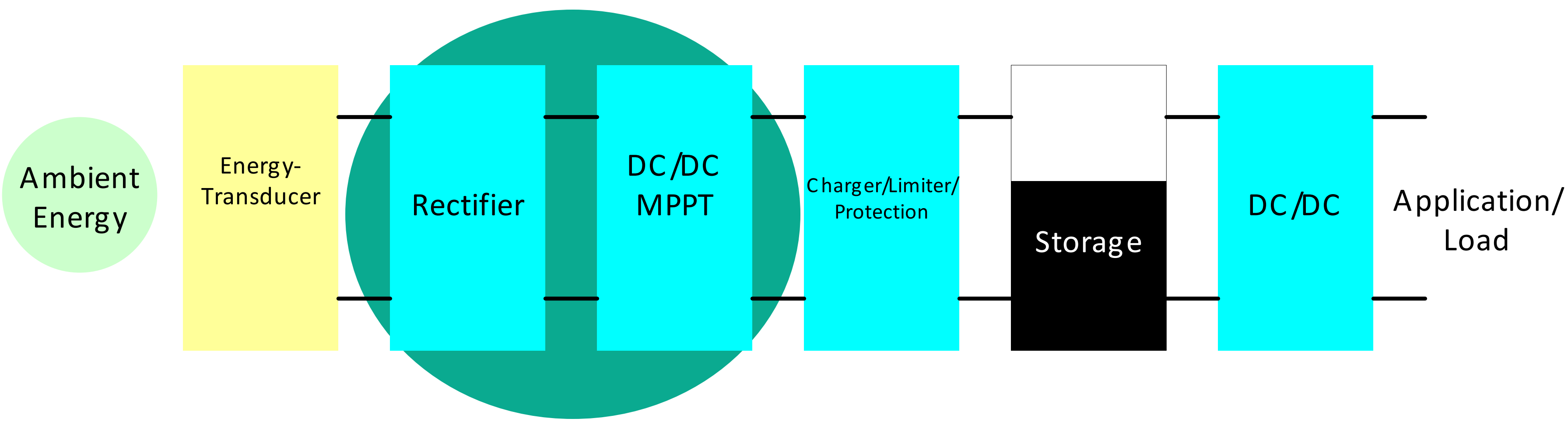
Generic Approach

- **Dedicated blocks**, depending on energy source, ambient conditions and application
- **Not all are required** in any application and with any source
- Focus on rectifier, dc-dc converter, MPPT and ac-dc converter
- Charger/limiter/protection often to **some extent redundant**, because of small currents
- DC-DC between storage and load **state-of-the-art** component



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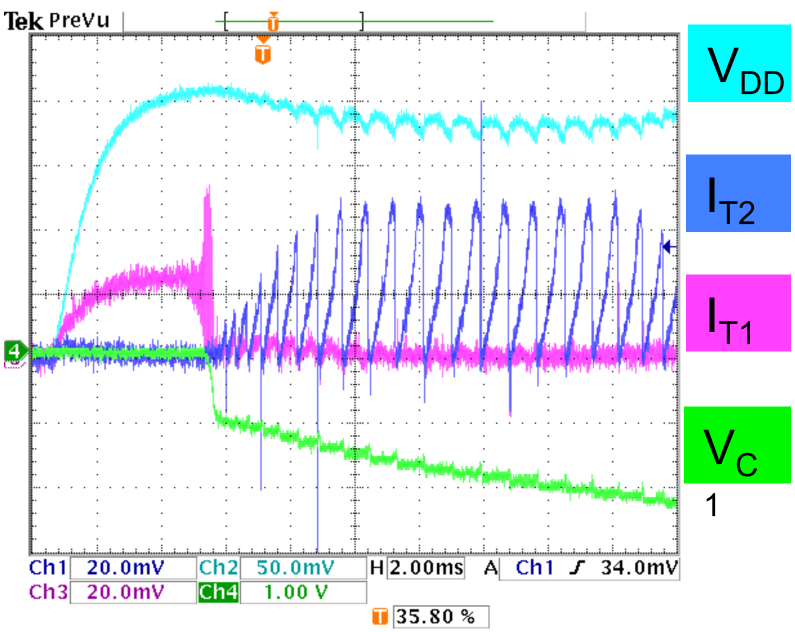
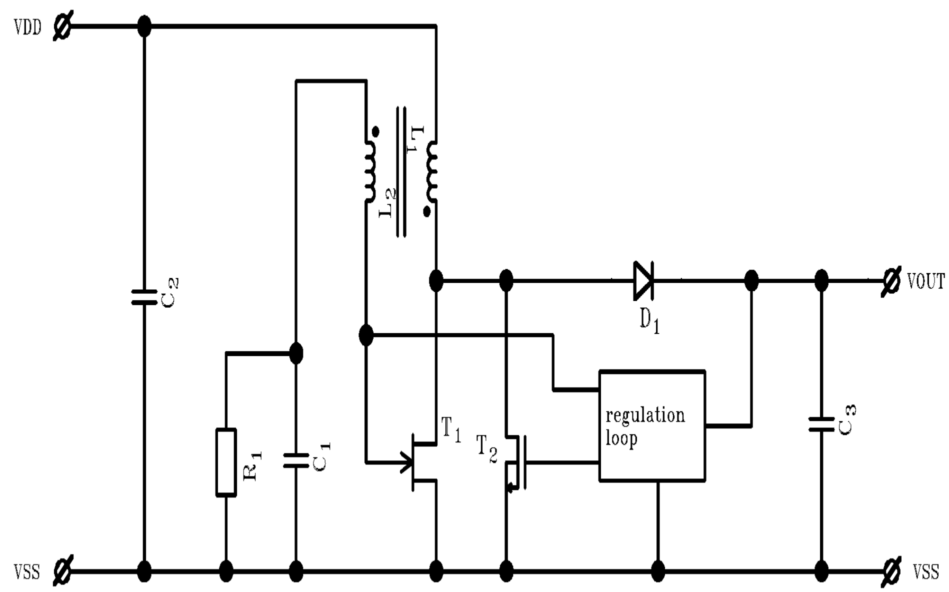
DC-DC Converter for Thermogenerators (TEGs)

- Coupled inductor DC-DC converter **starts with 20 mV** due to JFET (Junction Field Effect Transistor) and transformer
- Works with **minimum thermal gradient** (2-3K), depending on TEG
- **Efficiency** between 30 and 75 %, improves with input voltage





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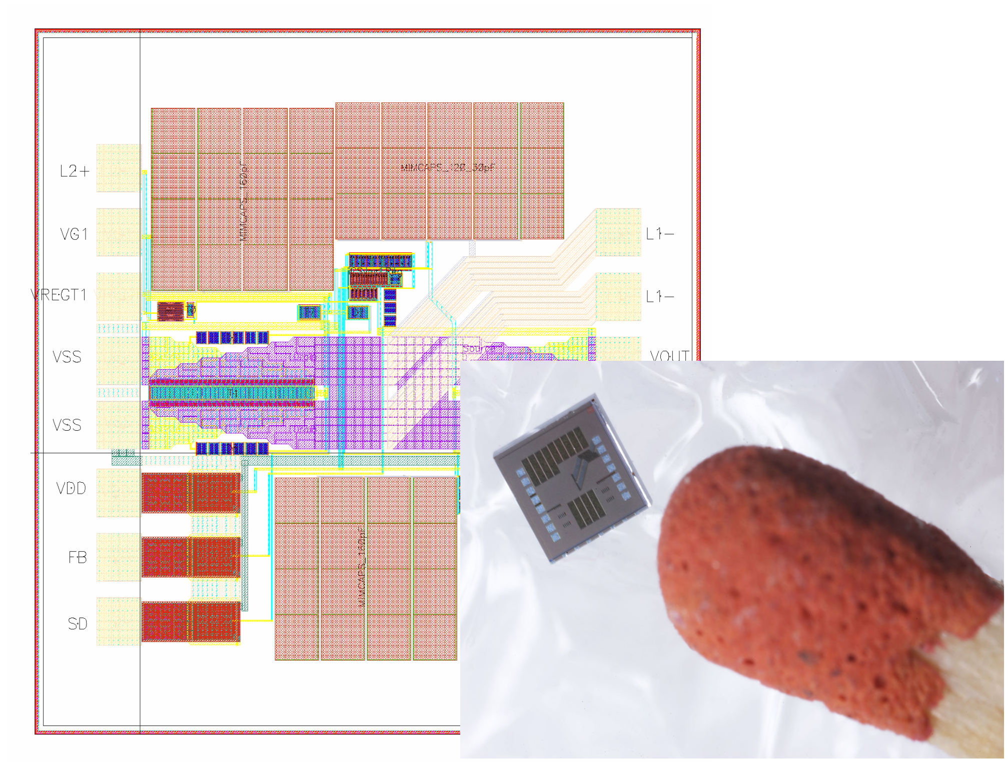
DC-DC Converter for Thermogenerators (TEGs)

- **Broad input range** with reasonable efficiency
- **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-C
- ASIC works with **V_{In}=20 mV**
- **Better performance** as discrete circuit
- Looking for companies to **commercialize IC**



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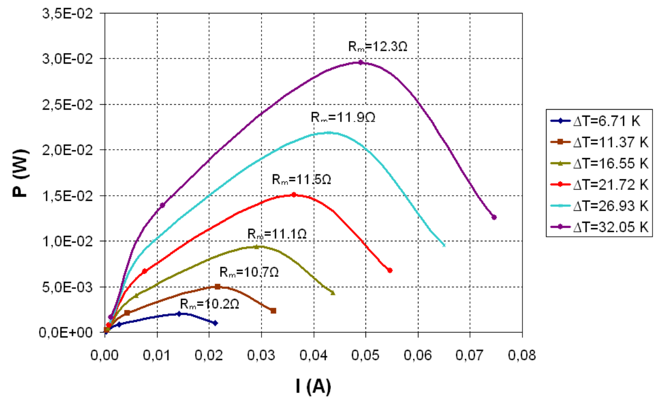
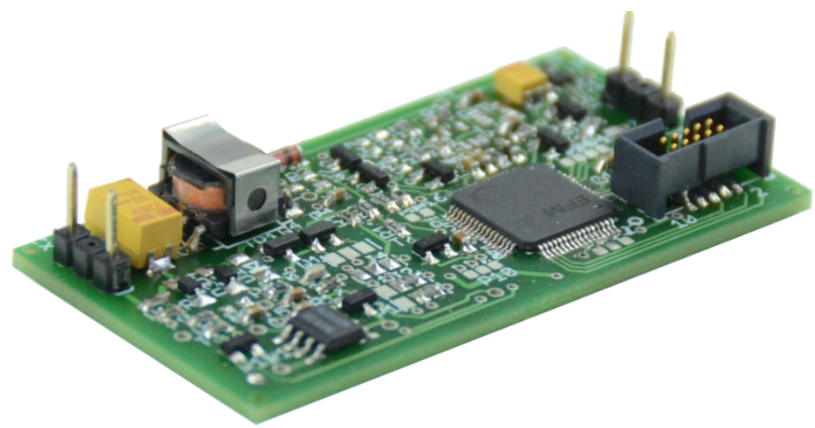
DC-DC Converter for Thermogenerators (TEGs)

- **DC/DC converter** controlled by microcontroller
- Start up circuit starts at **70mV**
- **Digitally controlled** maximum power point tracker
- Integrate your own **application**
- Algorithm is **portable**
- Regulation of **input** or **output** power





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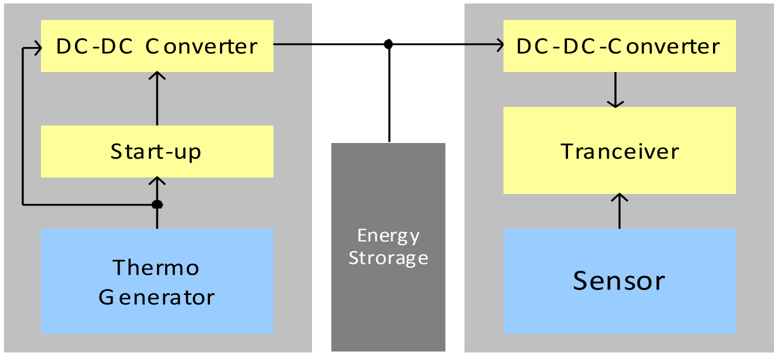
DC-DC Converter for Thermogenerators (TEGs)

- Low-voltage dc-dc converter enables operation with **low thermal gradient**
- Thermo-electrical power supply for **wireless sensors**
- T-sensor and transceiver supplied with **2 K delta T** (2 mW)
- **Application example:** human body



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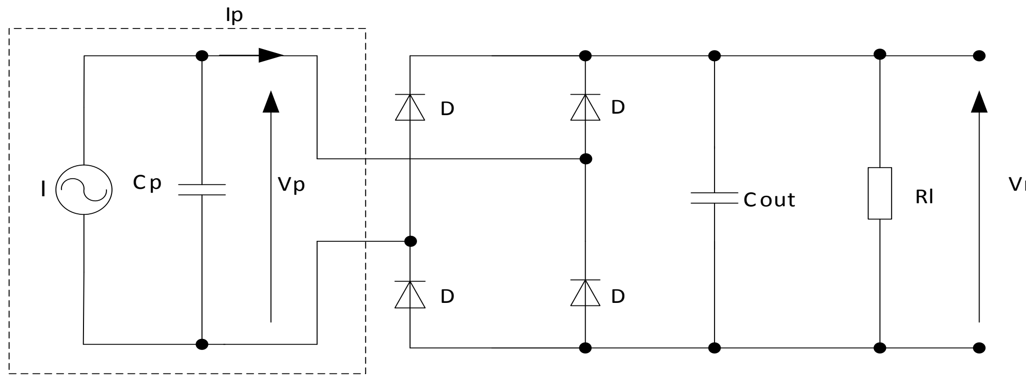
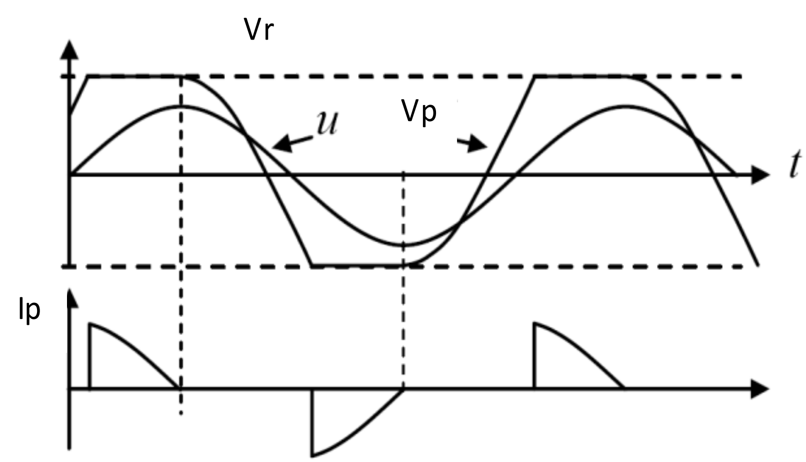
AC-DC Converter for Piezo-Generators (PEGs)

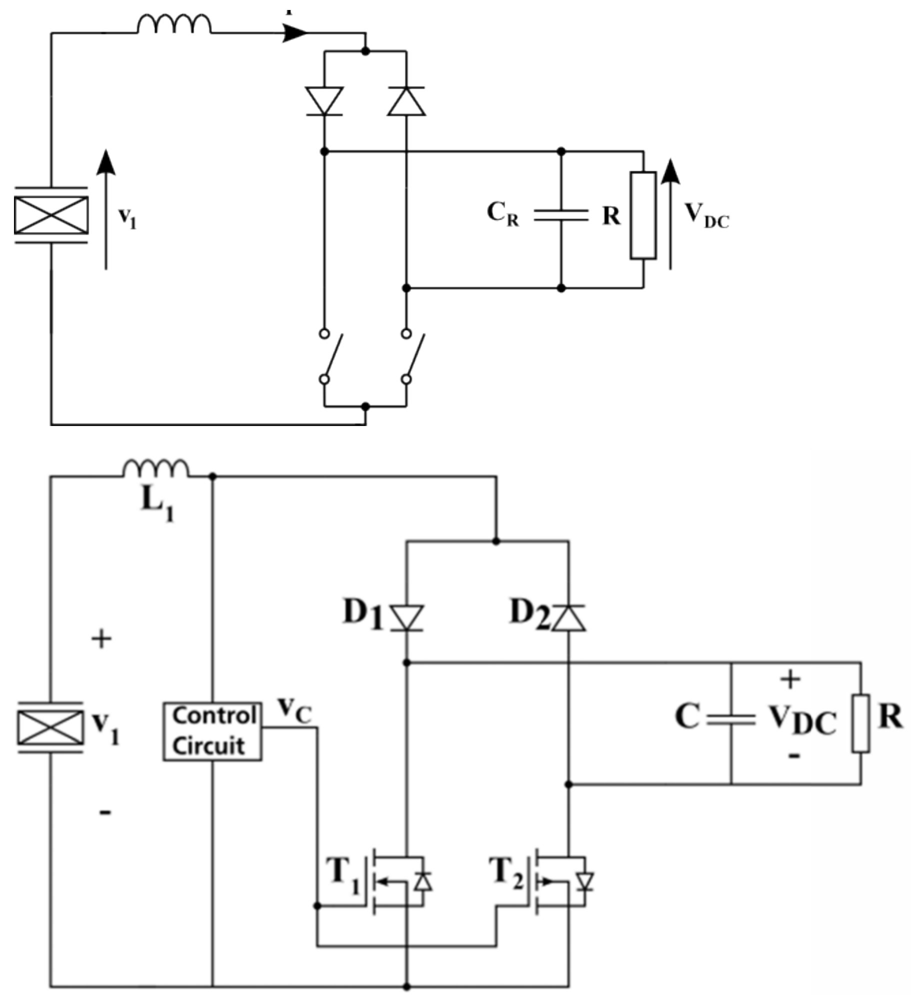
- Piezo-transducers provide **minimum amounts of charge/current**
- **State-of-the-art:** rectification and filtering
- Problem: **capacitive nature of piezo** >> voltage and current phase-shifted (capacitor)





AC-DC Converter for Piezo-Generators (PEGs)

- **Modified** parallel SSHI converter: Synchronized switch harvesting on inductor
- Switched inductor **shifts V and I in-phase >> Power maximum**
- **Reduces** number of diodes to two
- **Challenge:** Low-power control circuitry
- **Optimization:** Avoid voltage drop and ohmic losses



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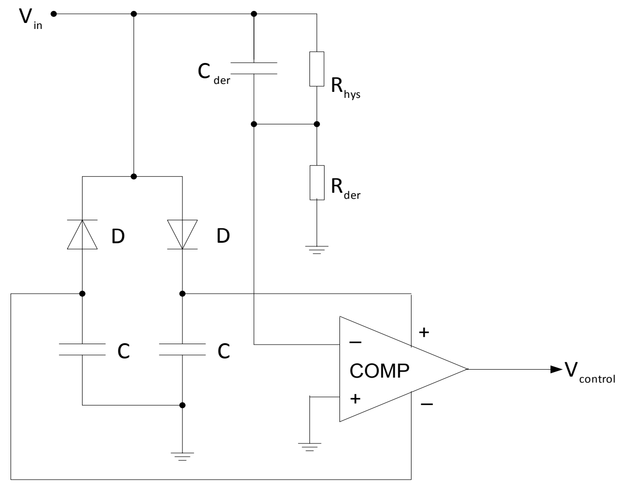
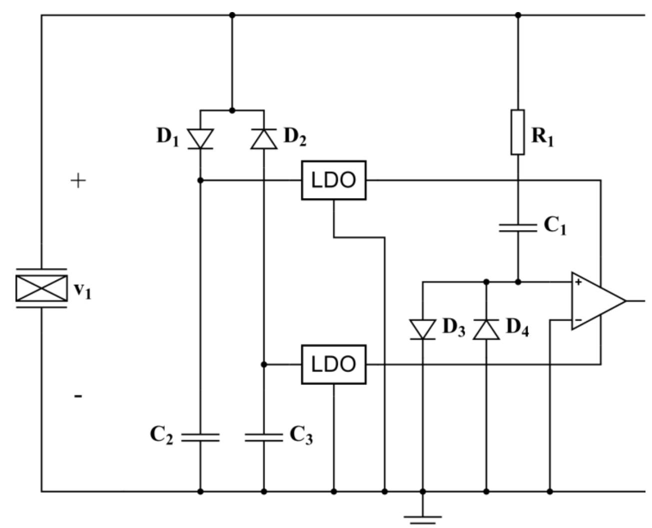
AC-DC Converter for Piezo-Generators (PEGs)

- Challenge is the **control circuit**
- Power supply **directly from input V_{in}**
- **Peak detection** with differentiator for **certain bandwidth** [ben1]



- **R_1, C_1, D_3, D_4** act as **differentiator** for low frequencies [mat1]
- **Broadband control circuit** can enable broadband or self-adjusting AC-DC converter



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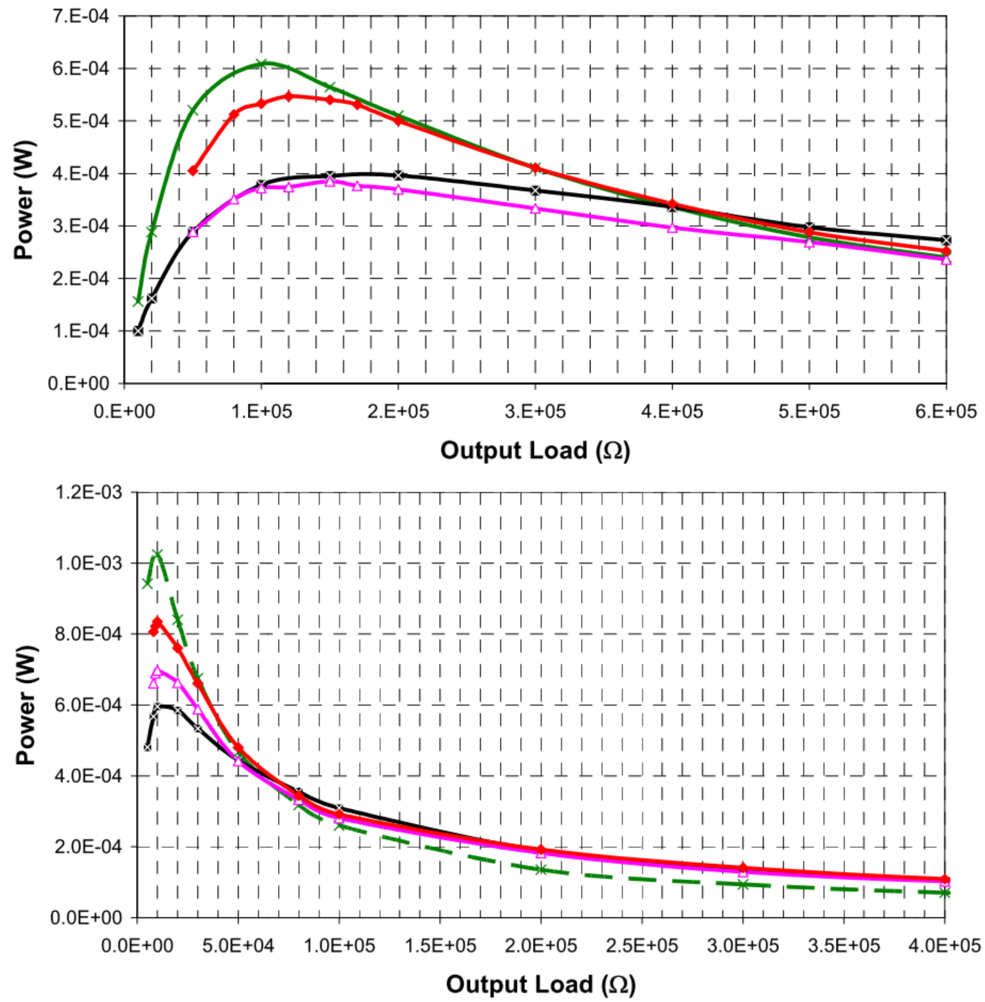
AC-DC Converter for Piezo-Generators (PEGs)

- **AC Load** (green): Matched resistor
- **Standard** (black): Simple rectifier and filter
- **Parallel SSHI** (pink)
- **Modified parallel SSHI** (red)

- Top: **DuraAct** piezo, 0,1g, 17,2 Hz
- Bottom: **Midé** piezo, 1g, 110 Hz



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AC-DC Converter for Piezo-Generators (PEGs)

- ASIC-Layout
- All components **on-chip** except inductor
- Power consumption:
  ca. **35 µW at 20 Hz**
- Technology: **AMS H35B4**
- Max. Voltage **ca. 40 V**
- Chip-Size **2.2*2.3 mm**
- **Currently:** Test and evaluation

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Bridge Monitoring

- 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.

Pilotinstallation an einer Brücke (Länge 359m) der BAB 3 – Mainquerung bei Dettelbach (Bayern)

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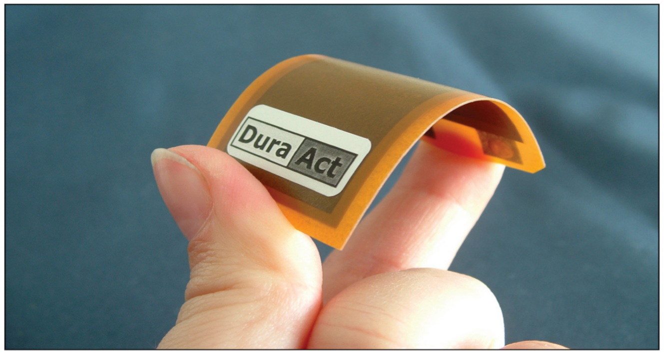
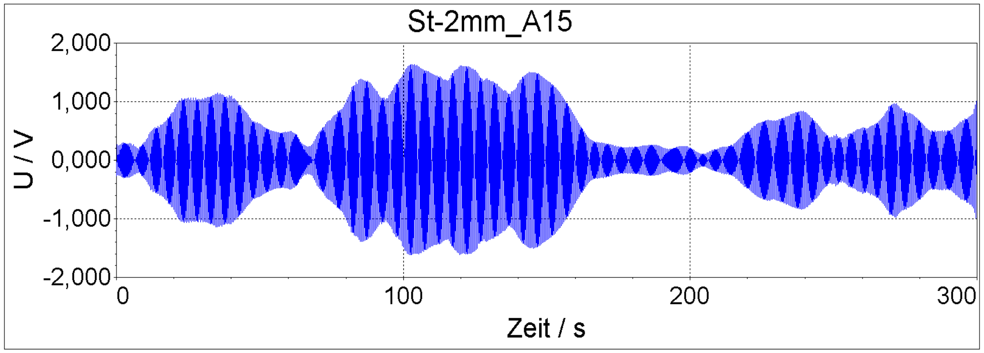
Bridge Monitoring

- Power output: max. 0.8 mW, mean **0.1 mW per piezo patch**
- f=2.25 Hz
- Bridge is **not space-limited**: 10 patches produce 1 mW





Electrical Voltage

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Self-powered Tracking System

- Customer survey reveals
  - **Transmission once per day** is OK
  - **Accuracy** should be 100 m
  - Position **update** every 5 min (350 mW*5 s*288=504 Ws)
- Power consumption depends significantly on **duty cycle of data transmission**

>>15 mW for 15 h (810 Ws) is presently **calculated** for a positive power budget

- **Target applications:** Railway trains, trailers, …

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Summary

- Ambient energy sources are **not constant**
- **Power output** is critical
- Most power available if **load matches source**
- **Power management** ensures maximum power output
- **Adapt** as much as possible to the energy transducer (MPPT, SSHI)
- **Transducers can be shrunken** due to more efficient power management

Thank you for listening!

Any questions…..?

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