Low Power Converter Technology for Energy Harvesting

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Low Power Converter Technology for Energy Harvesting

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

Low Power Converter Technology for Energy Harvesting
Introduction

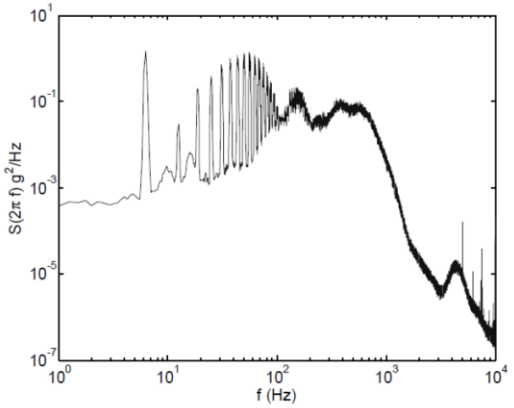
- **Mobile applications** of electronic systems become more and more popular
- Power supply **difficult**, because
  - **wires** are not feasible
  - **batteries** limit mobility or produce costs
- **Power output** of Energy Harvesting transducers is related to their **size** (area, volume) and thus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

Low Power Converter Technology for Energy Harvesting
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

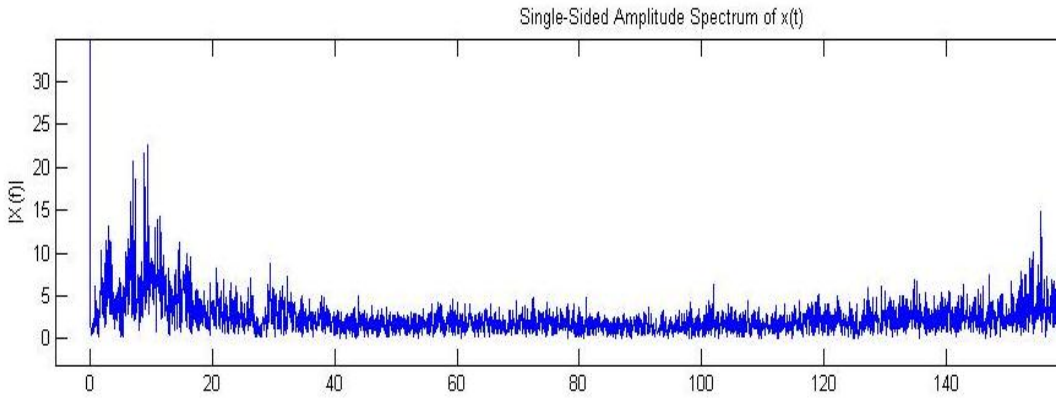
Vibration Source	Peak Acc. (m/s^2)	Frequency of Peak (Hz)
Base of 5 HP 3-axis machine tool with 36" bed	10	70
Kitchen blender casing	6.4	121
Clothes dryer	3.5	121
Door frame just after door closes	3	125
Small microwave oven	2.25	121
HVAC vents in office building	0.2 – 1.5	60
Wooden deck with people walking	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]



Low Power Converter Technology for Energy Harvesting
Challenges

- Small **knowledge about vibration** energy
- Vibration=f(velocity)
- **Datalogger** 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)
- Interface for **EH verification**



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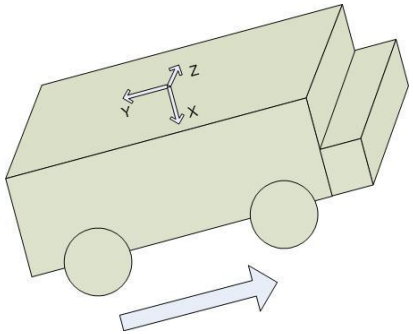
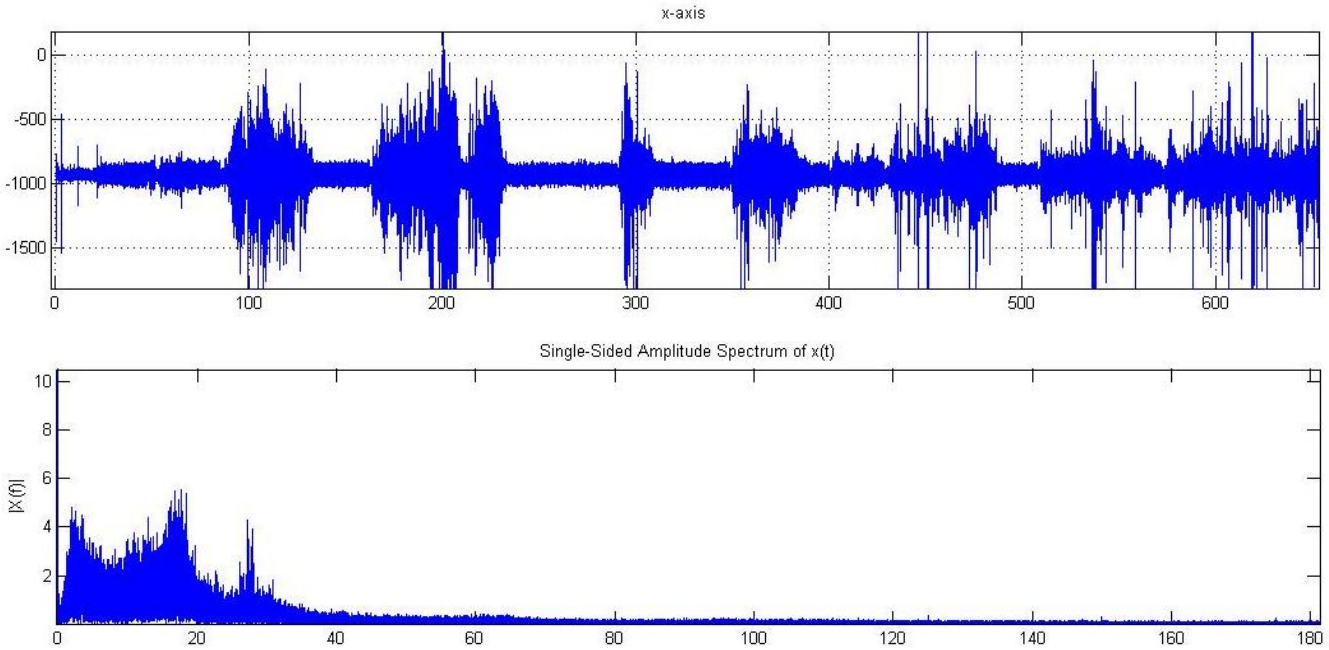
Challenges

- **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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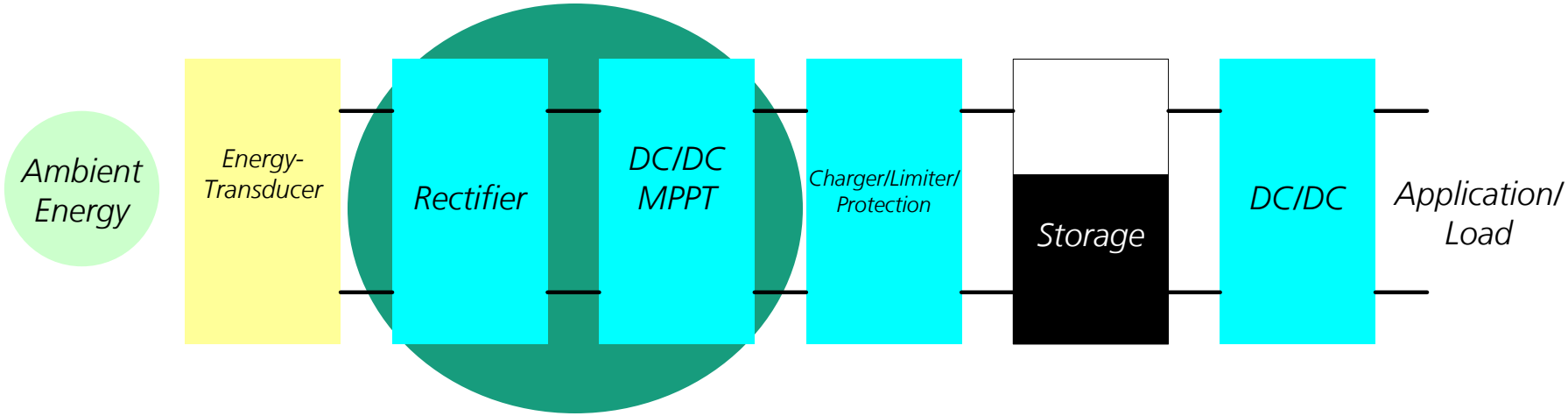
Low Power Converter Technology for Energy Harvesting
Generic Approach

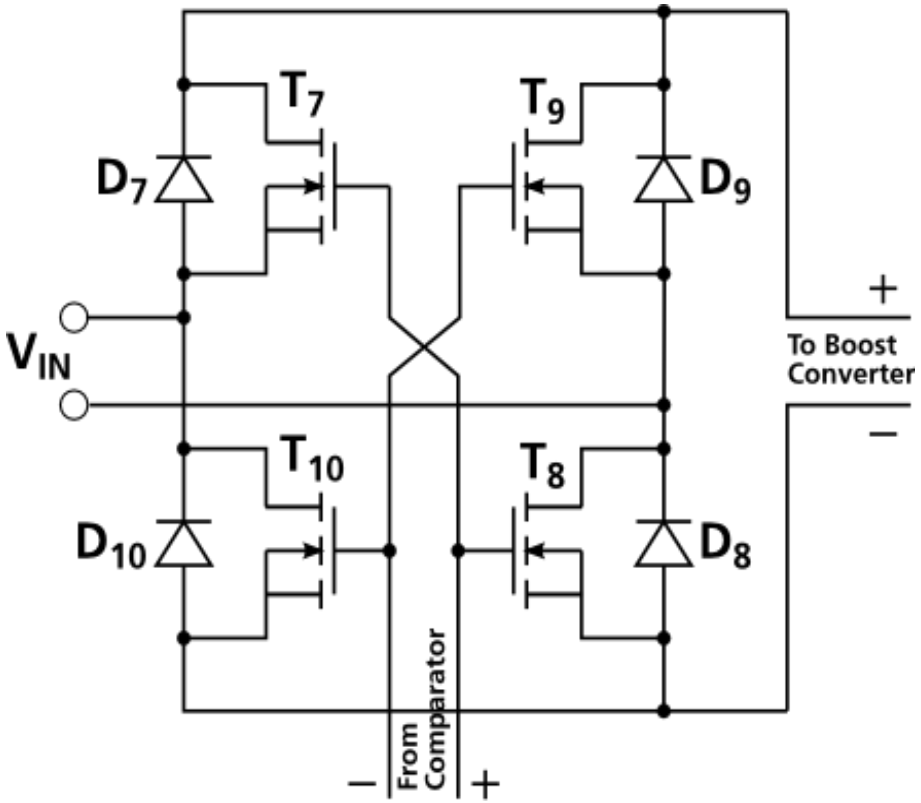
- **Dedicated blocks**, depending on energy source, ambient conditions and application
- **Not all are required** in any application and with any source
- Focus on rectifier, dc-dc converter, MPPT and ac-dc converter
- Charger/limiter/protection often to **some extent redundant**, because of small currents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



Low Power Converter Technology for Energy Harvesting

Input Polarity Detector

- Output polarity of TEG is dependent on the **direction** of the temperature gradient
- Capability to work with **positive** and **negative** input voltages
- Rectifier structure: Polarity switch
- Diodes can be short-circuited by switches to **prevent degrading efficiency** from the forward voltage drop
- Prototype: Start-up 150 mV, drop 40 mV, later on 5 mV



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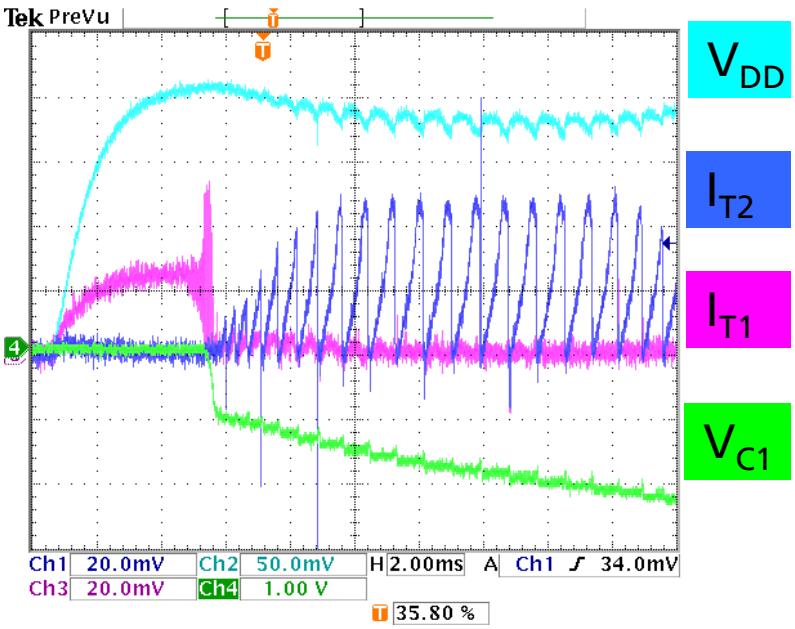
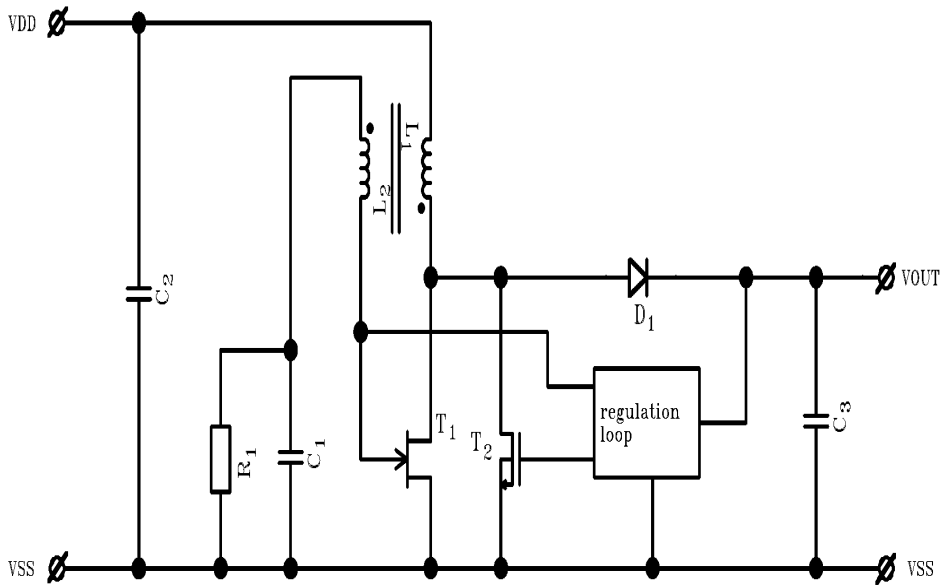
Low Power Converter Technology for Energy Harvesting
DC-DC Converter for Thermogenerators (TEGs)

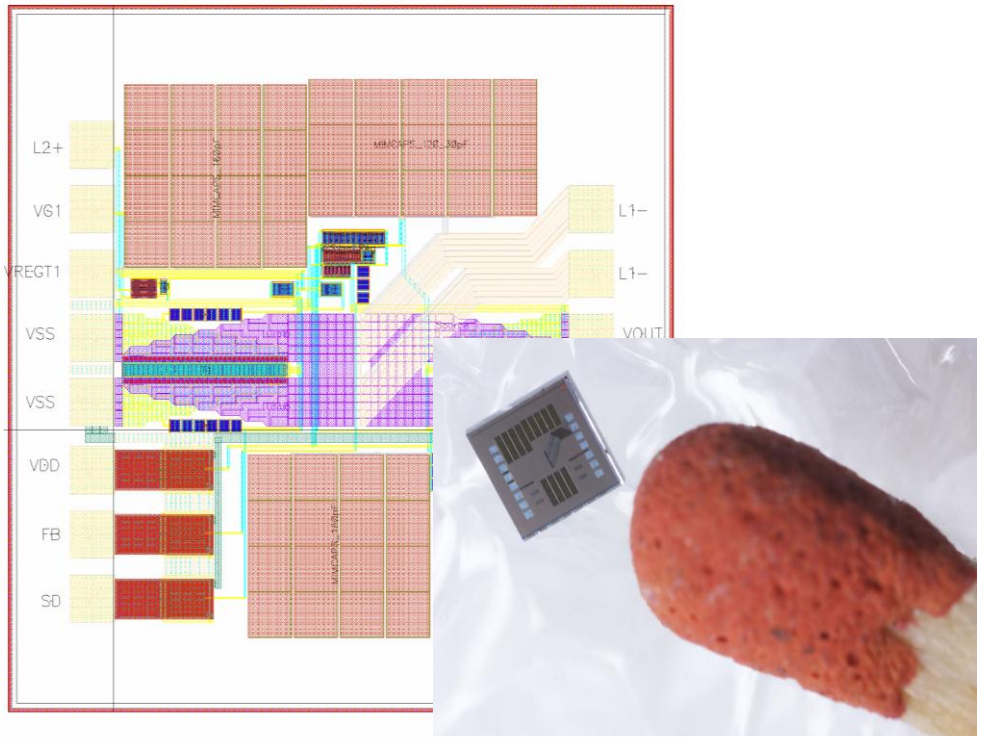
- Coupled inductor DC-DC converter **starts with 20 mV** due to JFET (Junction Field Effect Transistor) and transformer
- Works with **minimum thermal gradient** (2-3K), depending on TEG
- **Efficiency** between 30 and 75 %, improves with input voltage





Low Power Converter Technology for Energy Harvesting
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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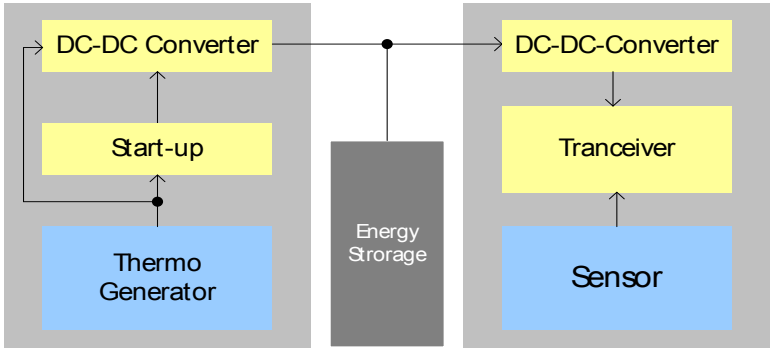
Low Power Converter Technology for Energy Harvesting
DC-DC Converter for Thermogenerators (TEGs)

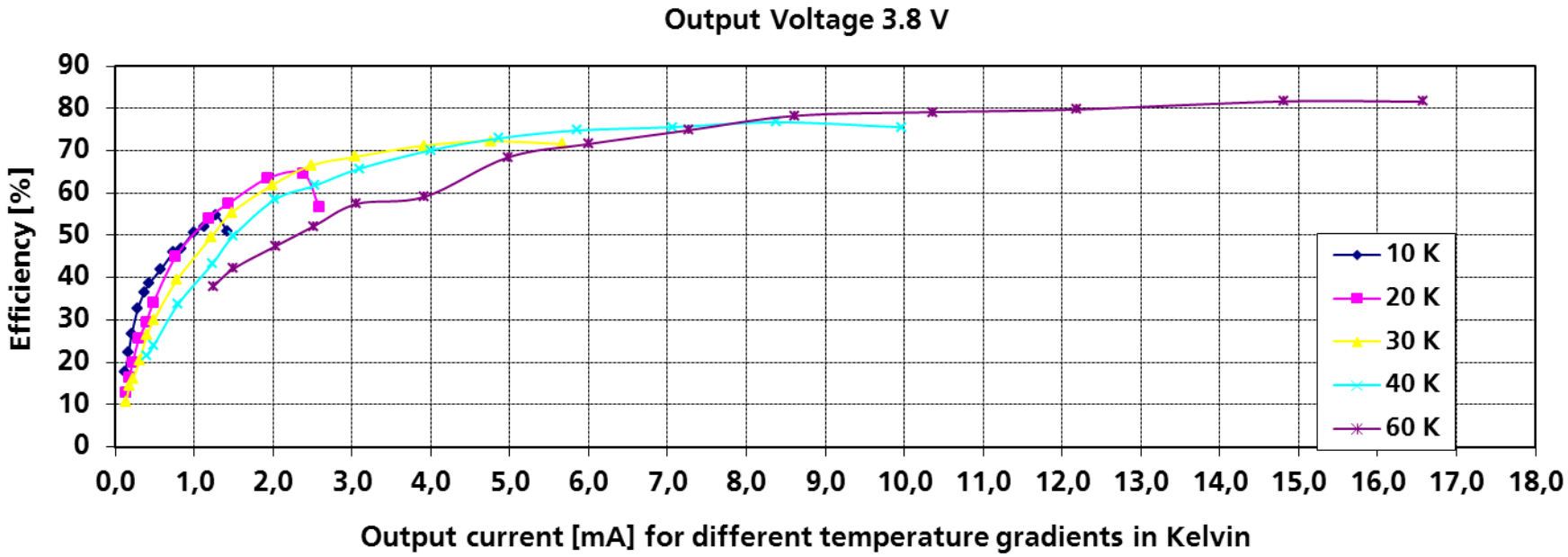
- Low-voltage dc-dc converter enables operation with **low thermal gradient**
- Thermo-electrical power supply for **wireless sensors**
- T-sensor and transceiver supplied with **2 K delta T** (2 mW)
- **Application example:** human body



Low Power Converter Technology for Energy Harvesting
DC-DC Converter for Thermogenerators (TEGs)

- Large input range with **reasonable efficiency**
- Idea of Energy Harvesting: **“Collect as much as possible”**

→ **Shrink size of TEG** to save money and space



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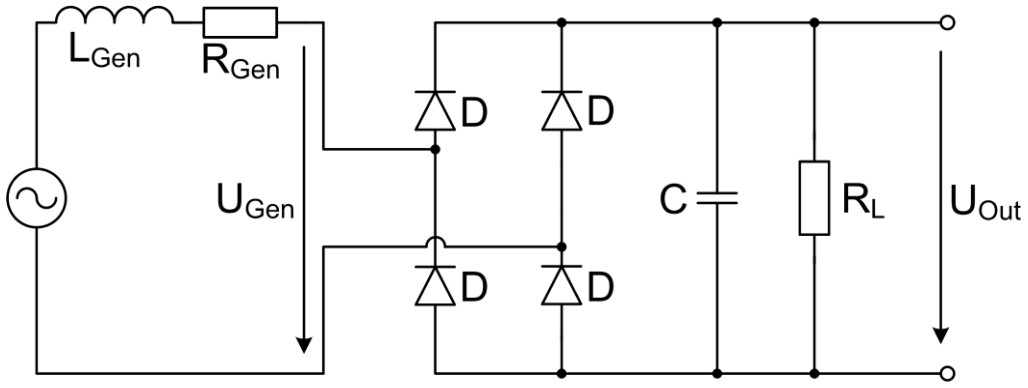
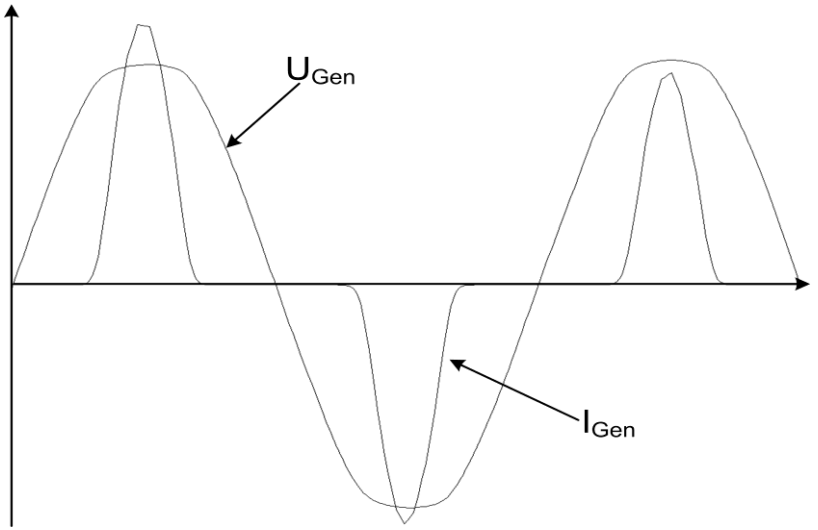
Low Power Converter Technology for Energy Harvesting

AC-DC Converter for Electrodynamic-Generators (EDGs)

- Electrodynamic transducers provide **low voltages**
- **State-of-the-art:** rectification and filtering
- **Drawbacks**: forward losses of diodes, no optimum load





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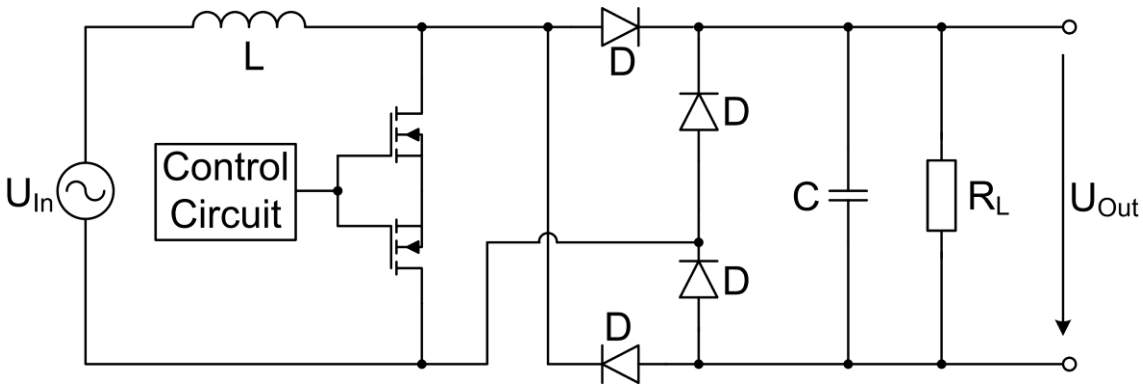
Low Power Converter Technology for Energy Harvesting

AC-DC Converter for Electrodynamic-Generators (EDGs)

- **Direct** ac-to-dc conversion [dwa1]
- Boost-converter with **bipolar switch**
- Switches on **positive** and **negative** half-wave
- Represents **optimum load** as seen by generator
- Diodes on secondary side with **lower currents**
- Challenge: low-power control circuit
- MPPT



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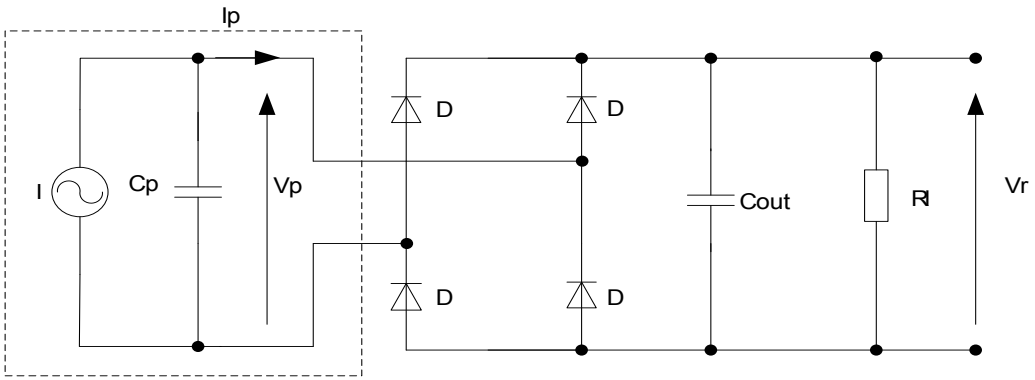
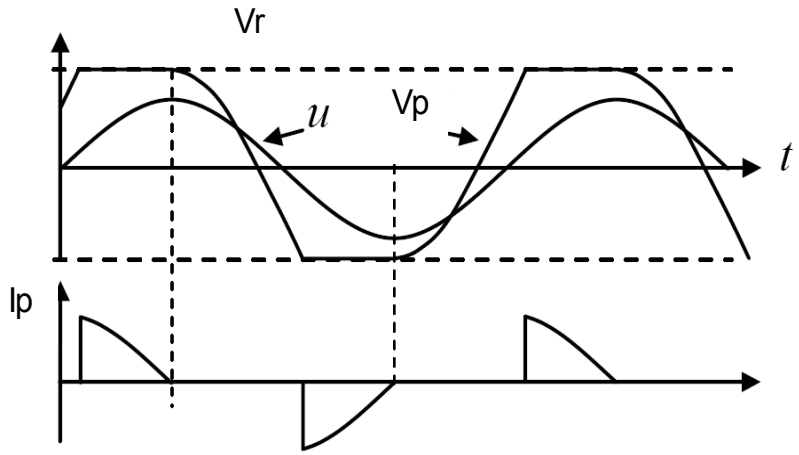
AC-DC Converter for Piezo-Generators (PEGs)

- 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)





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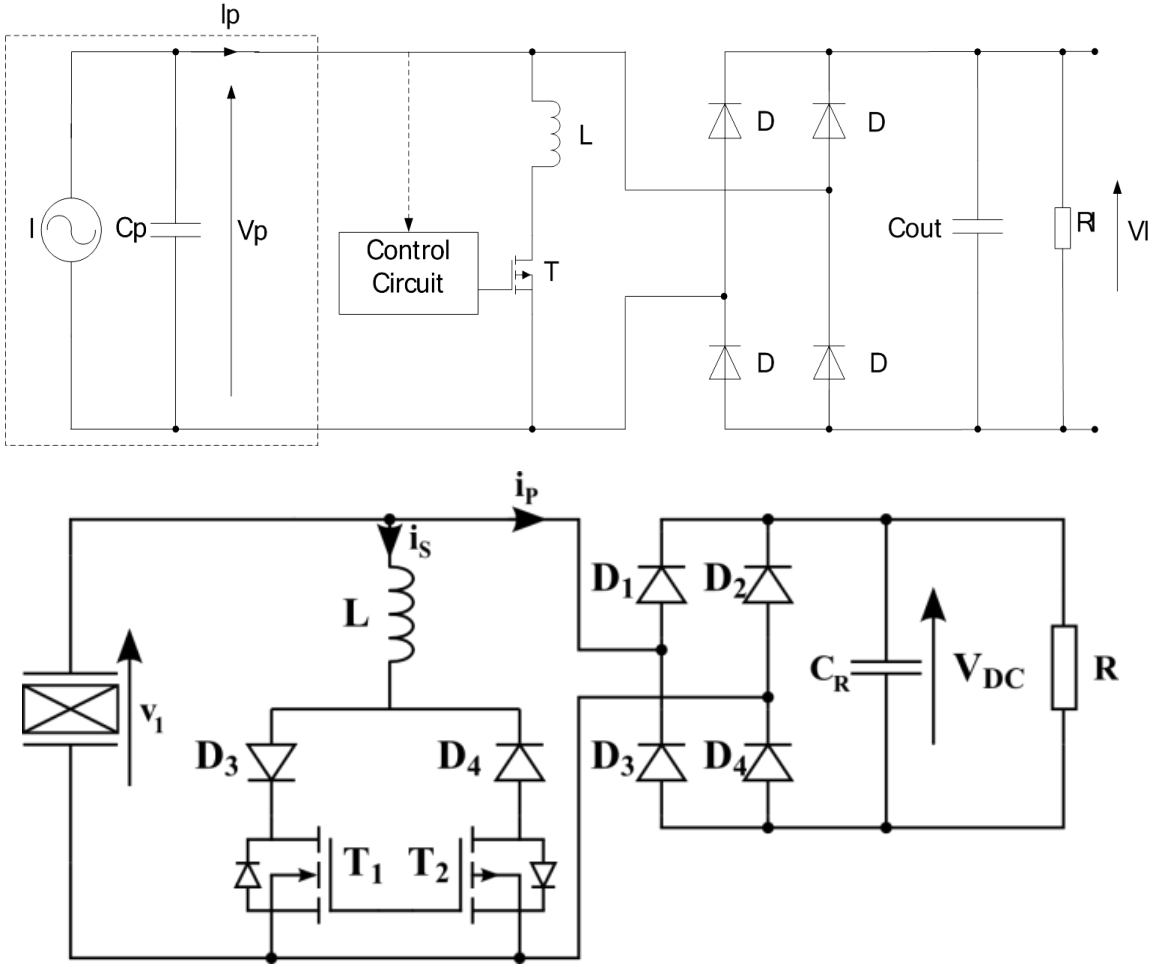
AC-DC Converter for Piezo-Generators (PEGs)

- **SSHI**: Synchronized switch harvesting on inductor [bad1]
- Switched inductor **shifts V and I in-phase >> Power maximum**
- **L** in **parallel** to piezo



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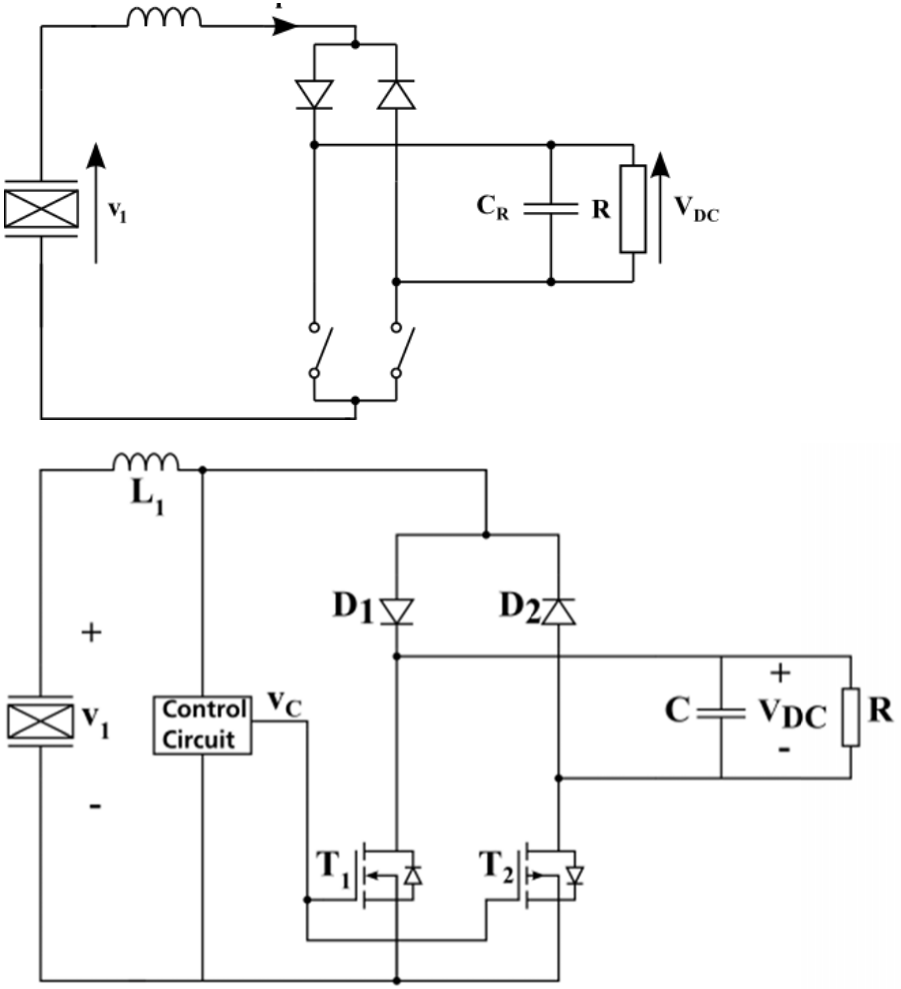
AC-DC Converter for Piezo-Generators (PEGs)

- **Modified** parallel SSHI converter
- **Reduces** number of diodes to two
- **Challenge:** Low-power control circuitry
- **Optimization:** Avoid voltage drop and ohmic losses



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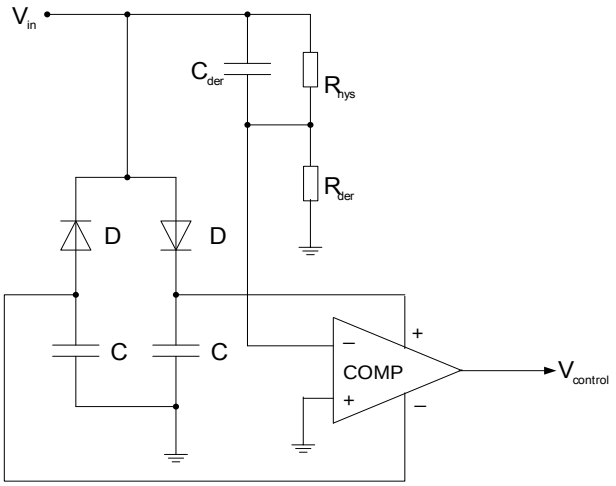
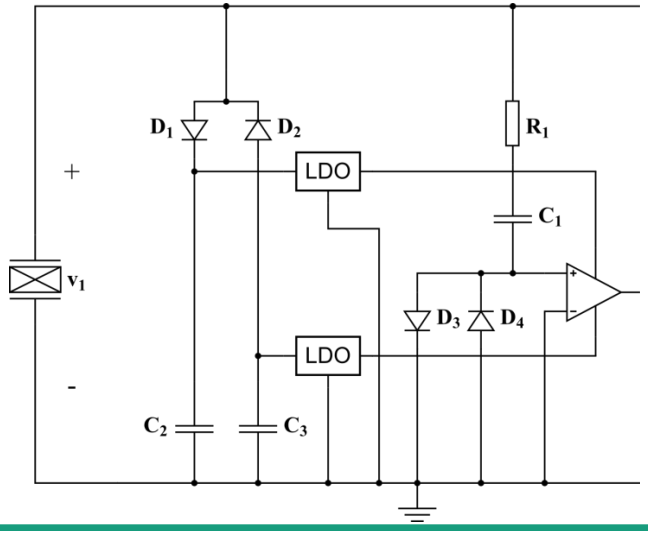
AC-DC Converter for Piezo-Generators (PEGs)

- 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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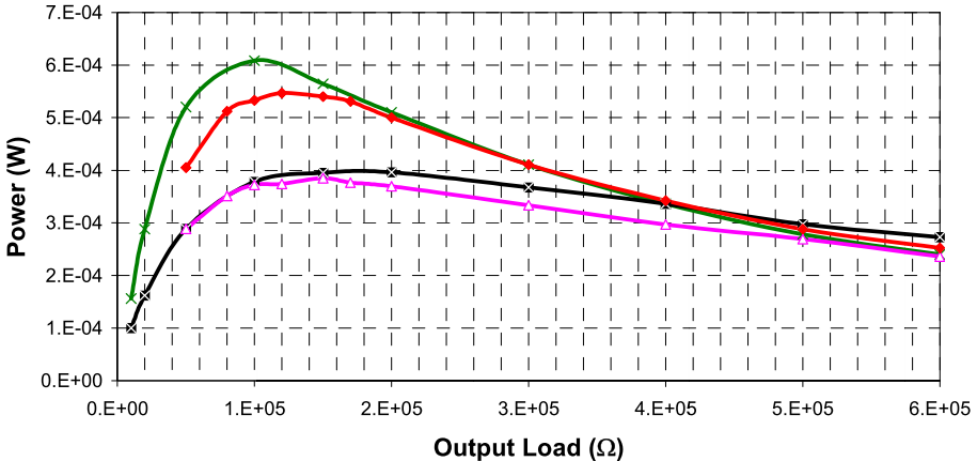
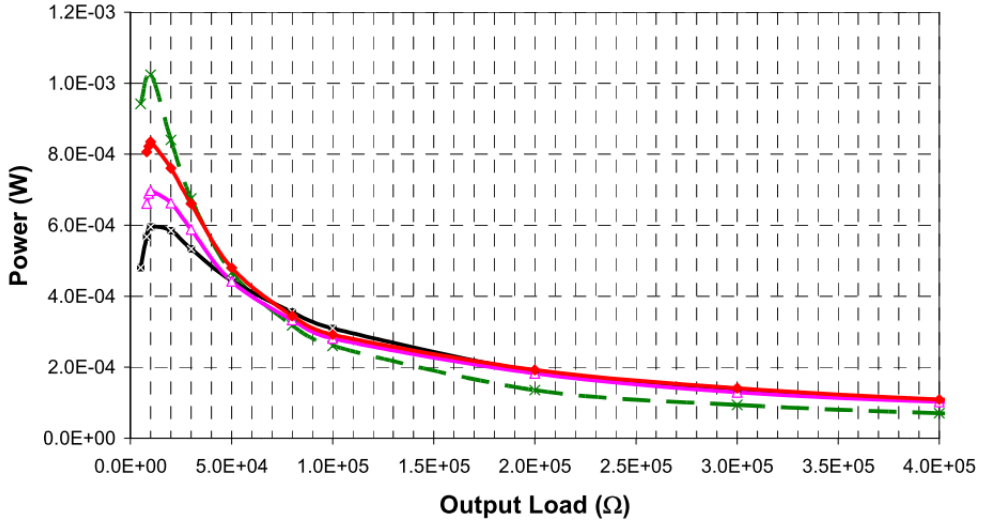
AC-DC Converter for Piezo-Generators (PEGs)

- **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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Low Power Converter Technology for Energy Harvesting

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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- www.smart-power.fraunhofer.de

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