# Adaptive Power Management Circuits for Selfpowered Systems

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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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# Integrated Energy Supplies

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

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# Adaptive Power Management Circuits for Selfpowered Systems

1. Challenges of Adaptive Power Management
2. Generic Approach
3. Circuit Examples
4. Summary

# Adaptive Power Management
## Challenges

- **Energy Harvesting** shrinks or replaces batteries or extents recharge periods
- **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**
- Most applications are **power-limited**: power output, related to a certain price decides “go-no go”

# Adaptive Power Management
## Challenges

- **Environment** is not constant - ambient energy **changes** due to
  - Day-night, indoor-outdoor, summer-winter, slow-fast,…
- Applications **differ** significantly
- **Energy storage** is always required for peak currents and "no energy" periods

>>Energy Harvesting must **adapt** to the different sources and applications to harvest always "what is possible"

>>**Power management** to cope with different thermal gradients, amplitudes, frequencies, etc.

| 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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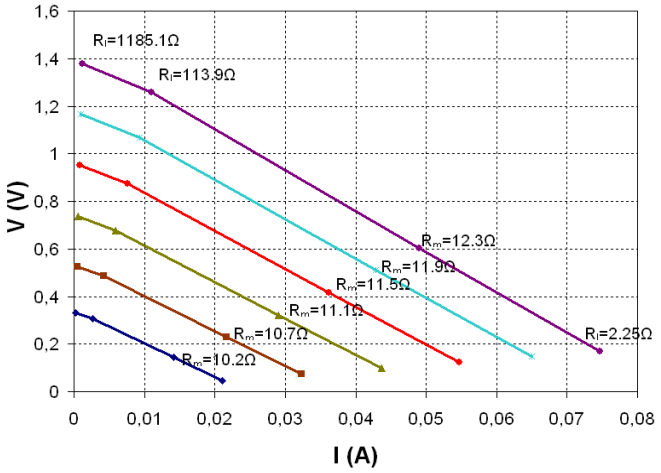
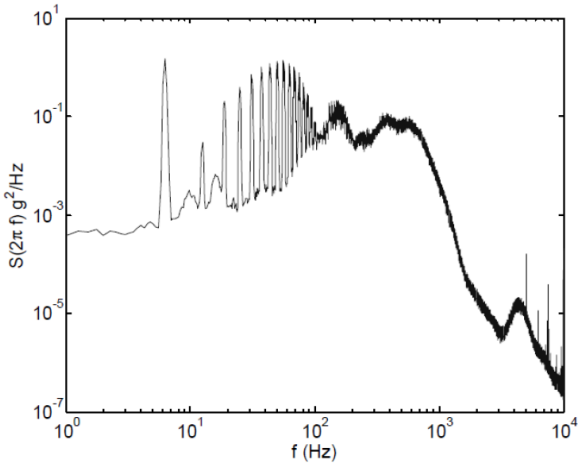
# Adaptive Power Management
## Challenges

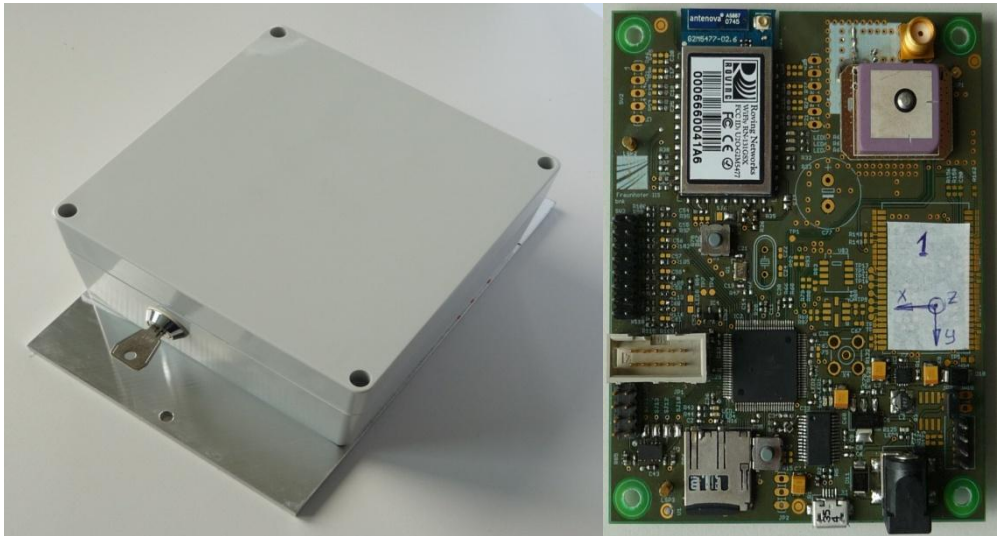
- **Low** input voltage (e.g some mVs)
- Sources with **variable resistance** (depending on temperature and aging)
- AC input with **variable frequencies**
- **Several** discrete AC inputs (spectrum)
- **High dynamic range** of input voltage

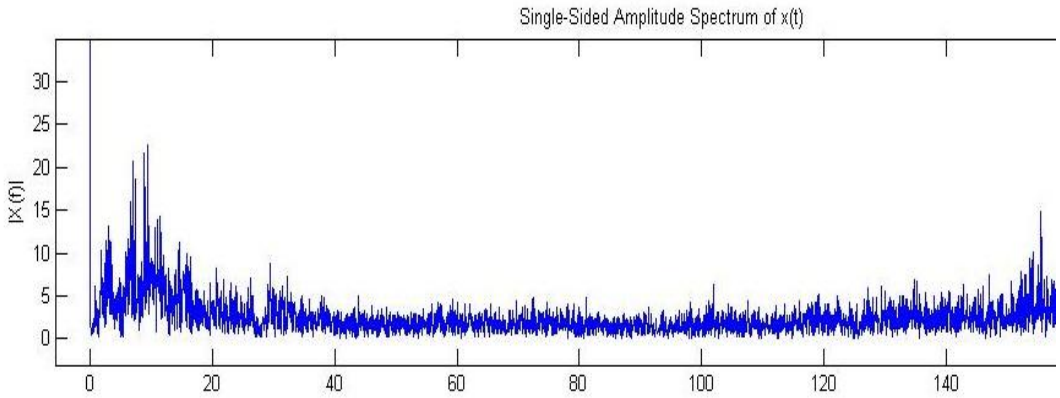


# Adaptive Power Management
## Challenges

- 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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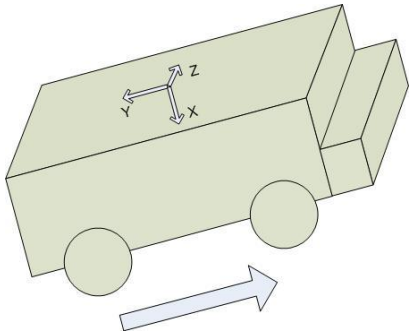
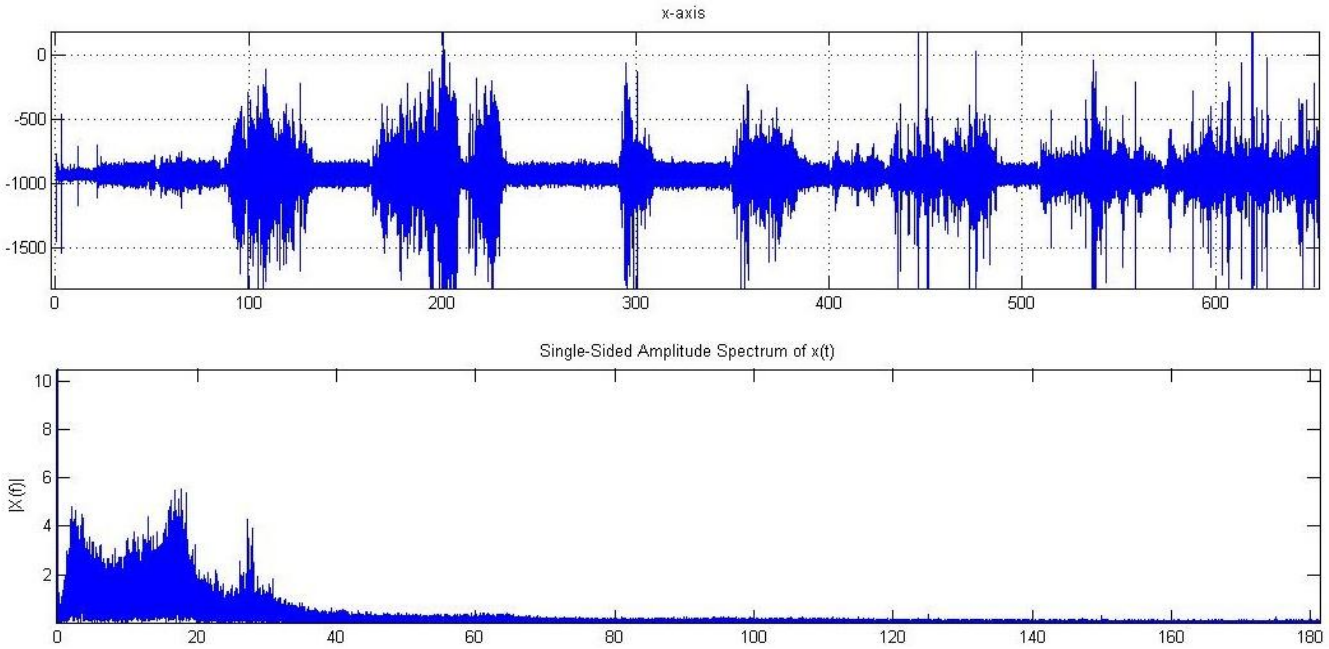
# Adaptive Power Management
## Challenges

- **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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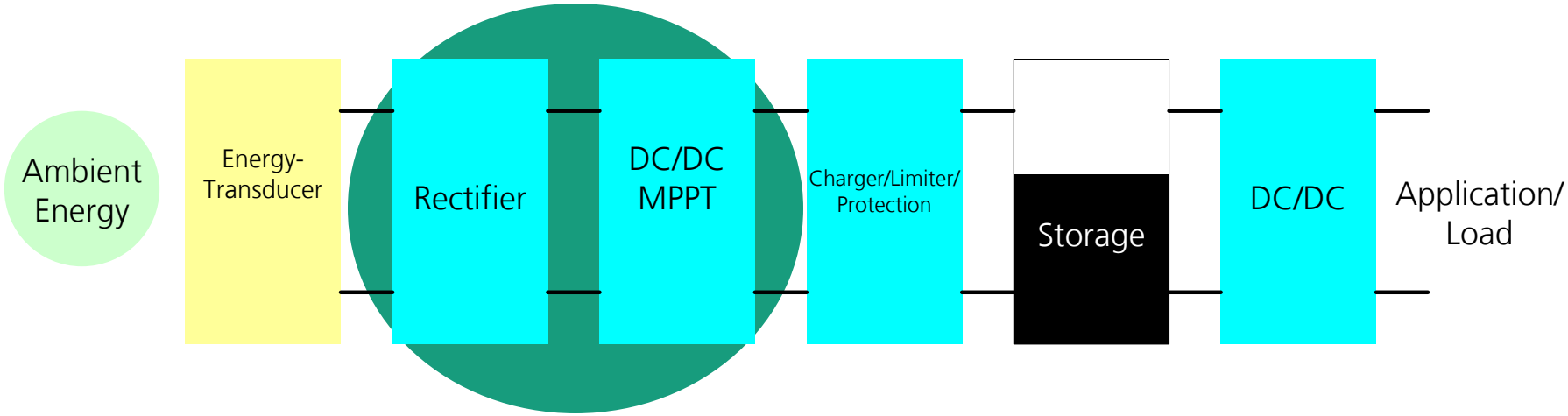
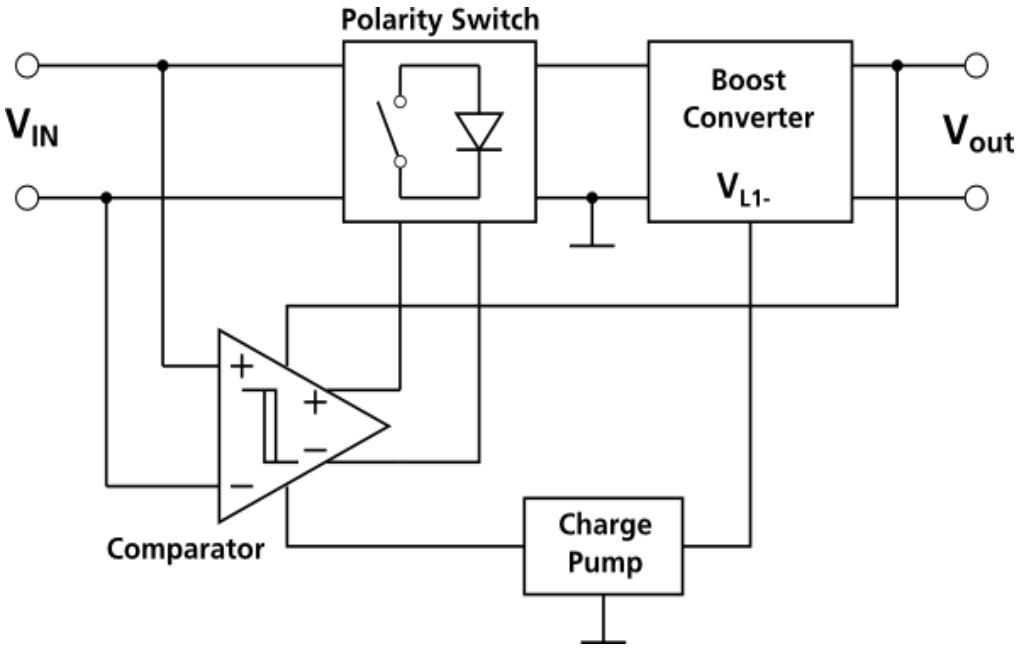
# Adaptive Power Management
## Generic Approach

- **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



# Adaptive Power Management
## Input Polarity Detector

- Output polarity of TEG is dependent on the **direction** of the temperature gradient
- Applications: heaters, HVACs, water pipes
- Capability to work with **positive** and **negative** input voltages
- Rectifier structure: Polarity switch
- Controlled by a comparator
- Dual voltage supply





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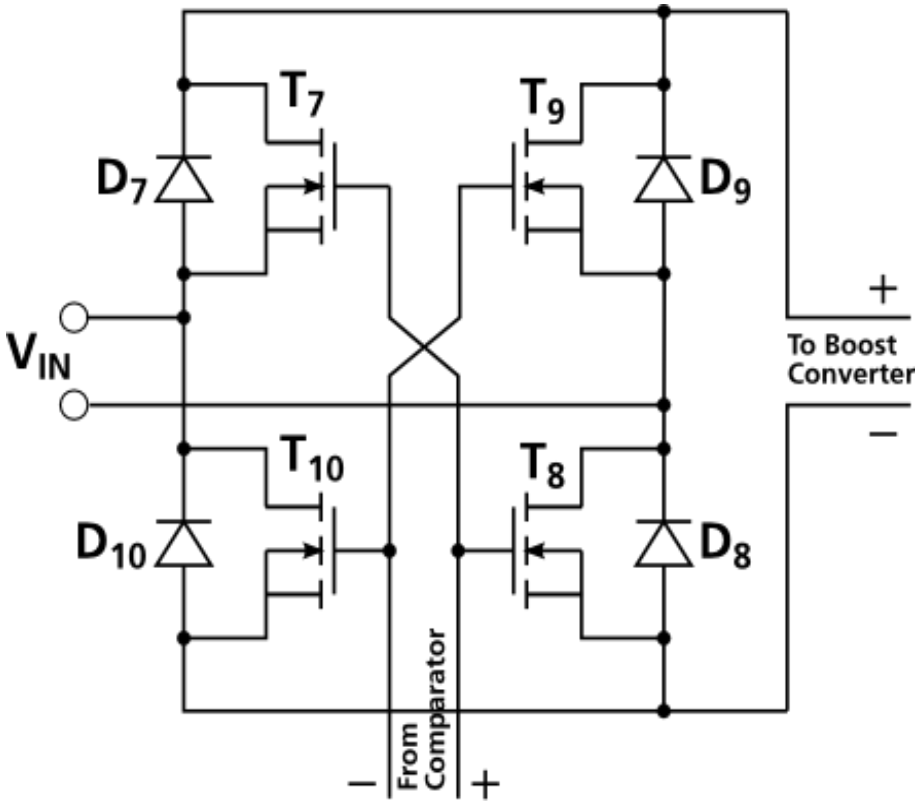
# Adaptive Power Management
## Input Polarity Detector

- Diodes can be short-circuited by switches to **prevent degrading efficiency** from the forward voltage drop
- Diodes are **only active during start-up** where still no supply voltage for the comparator is present
- Prototype: Start-up 150 mV, drop 40 mV, later on 5 mV





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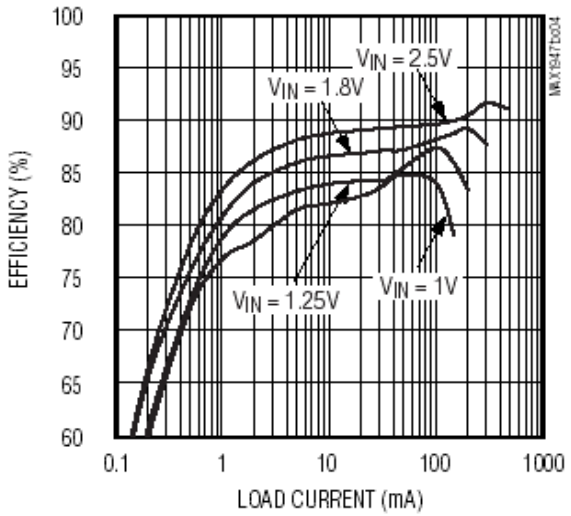
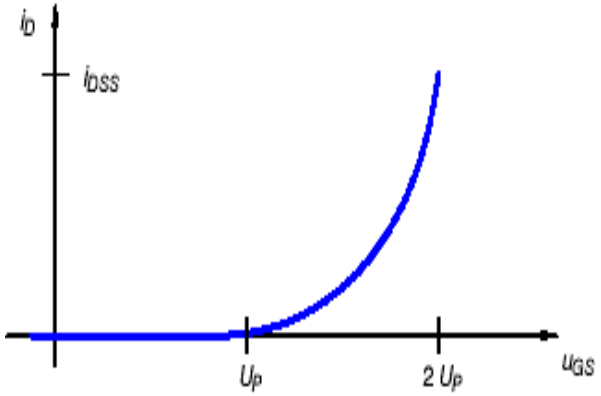
# Adaptive Power Management
## DC-DC Converter for Thermogenerators (TEGs)

- **Threshold voltages** of semiconductor technologies are **scaled down**
- Nevertheless: gap between output of energy transducers and **minimum input of voltage converters** (e.g. 0.5 V)
- Thermo-generators: about **50 mV** per Kelvin
- Solar/fuel cells: about **0.5 V (OCV)**
- To use minimum amounts of energy (small temperature gradients, little illumination) **low-voltage DC-DC up converters** are required



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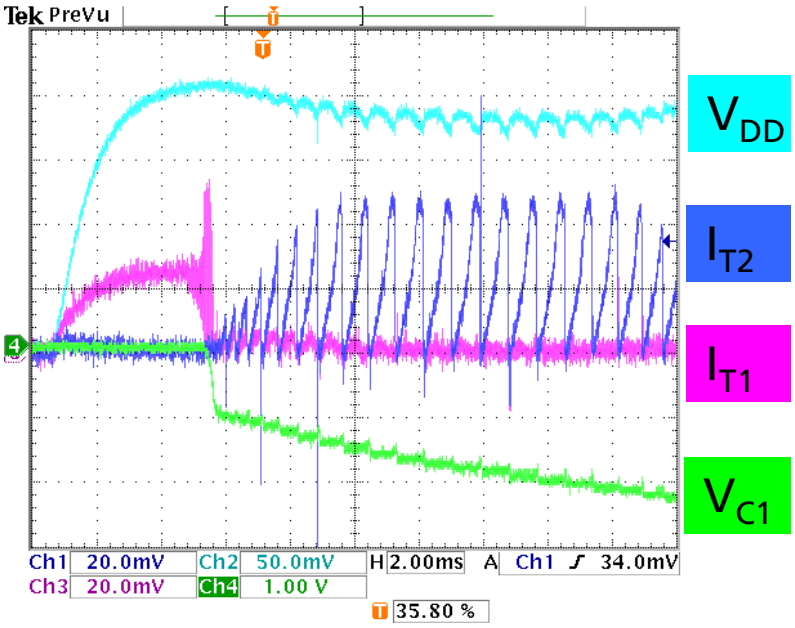
# Adaptive Power Management
## DC-DC Converter for Thermogenerators (TEGs)

- 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

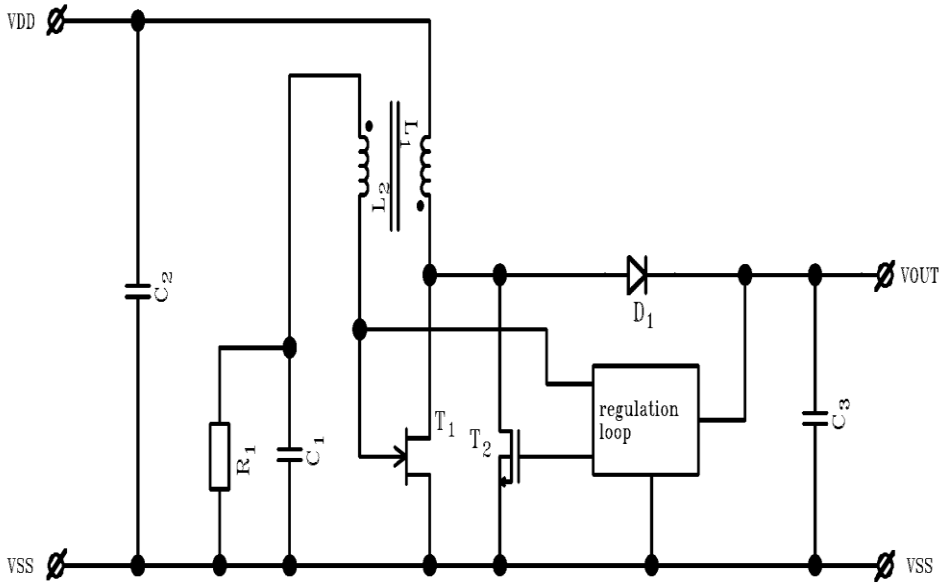



$V_{DD}$

$I_{T2}$

$I_{T1}$

$V_{C1}$



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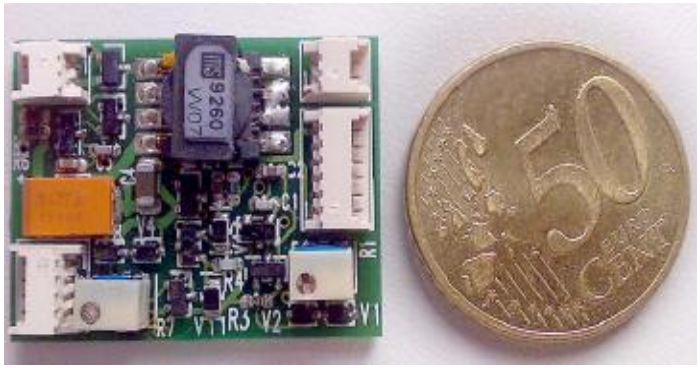
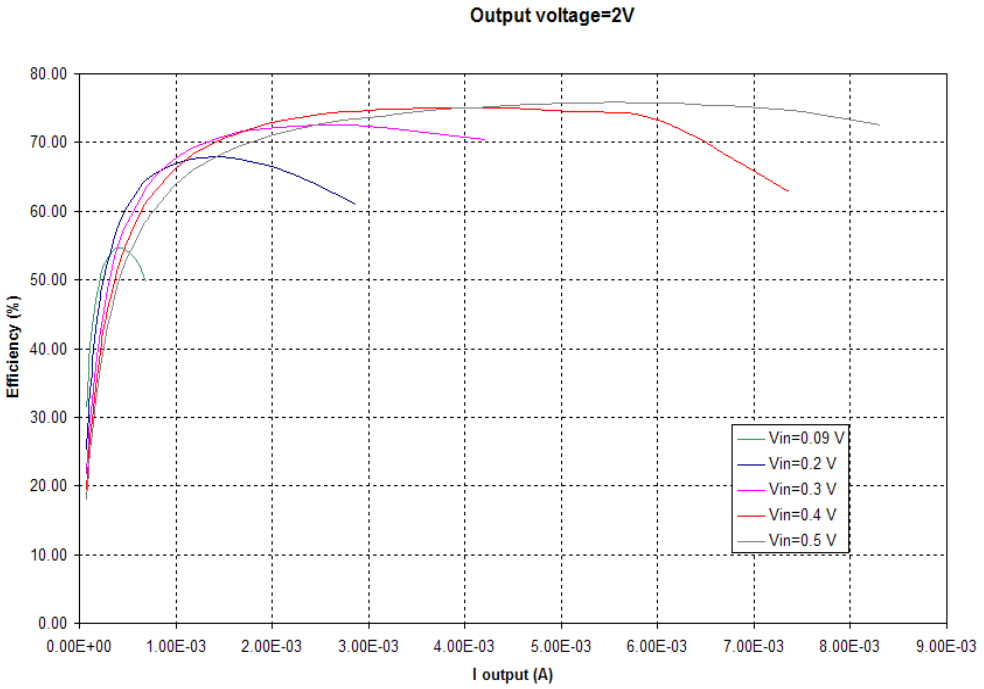
# Adaptive Power Management
## DC-DC Converter for Thermogenerators (TEGs)

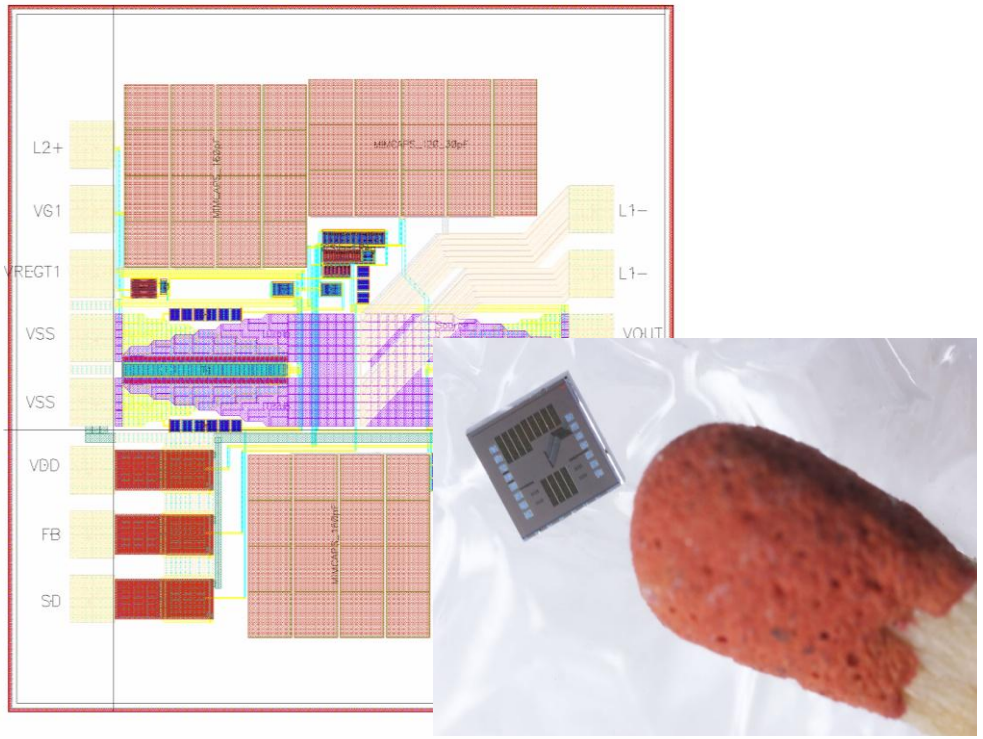
- **Efficiency** between 30 and 75 %, improves with input voltage
- Depending on **input voltage** and **load current**





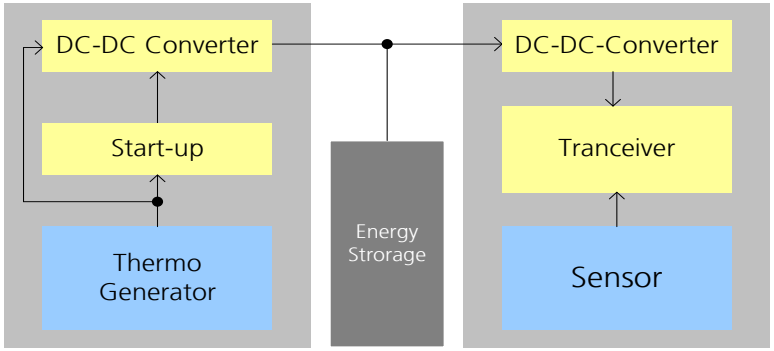
# Adaptive Power Management
## DC-DC Converter for Thermogenerators (TEGs)

- **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**



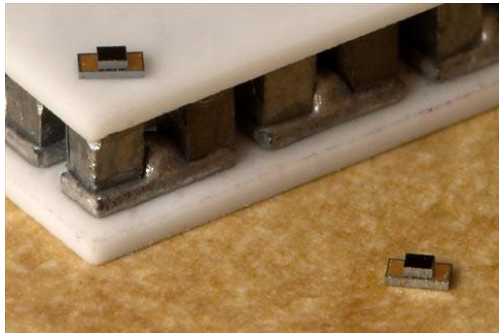
# Adaptive Power Management
## DC-DC Converter for Thermogenerators (TEGs)

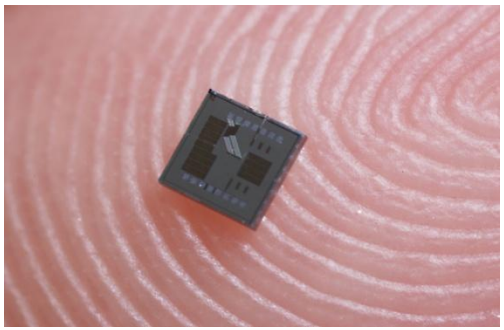
- Low-voltage dc-dc converter enables operation with **low thermal gradient**
- Thermo-electrical power supply for **wireless sensors**
- T-sensor and transceiver supplied with **2 K delta T** (2 mW)
- **Application example:** human body

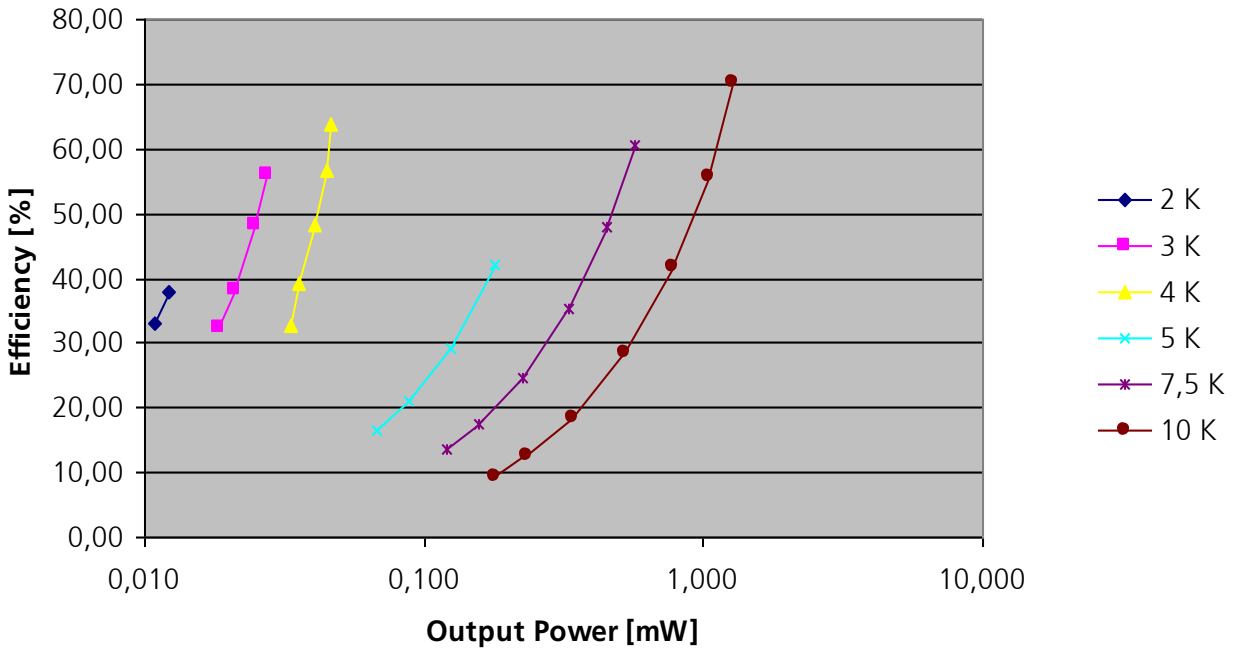


# Adaptive Power Management
## DC-DC Converter for Thermogenerators (TEGs)

- Vision: **Micro-electronic** power source with micro-TEGs and DC-DC ASIC







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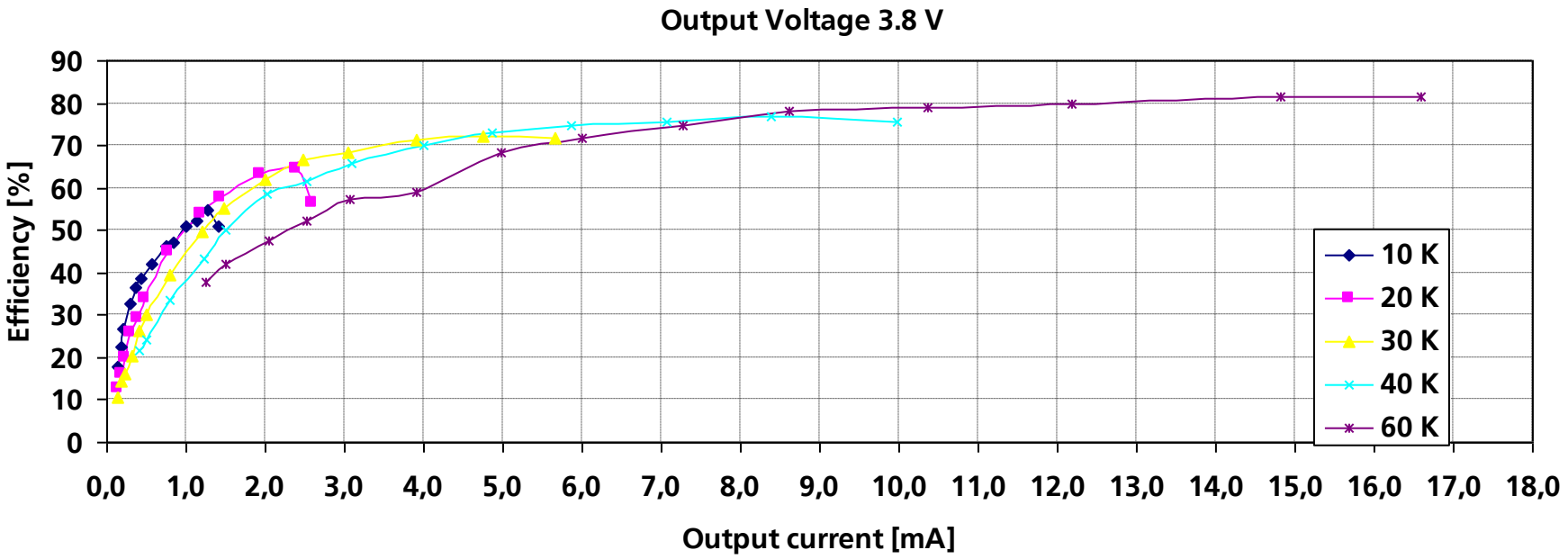
# Adaptive Power Management
## DC-DC Converter for Thermogenerators (TEGs)

- 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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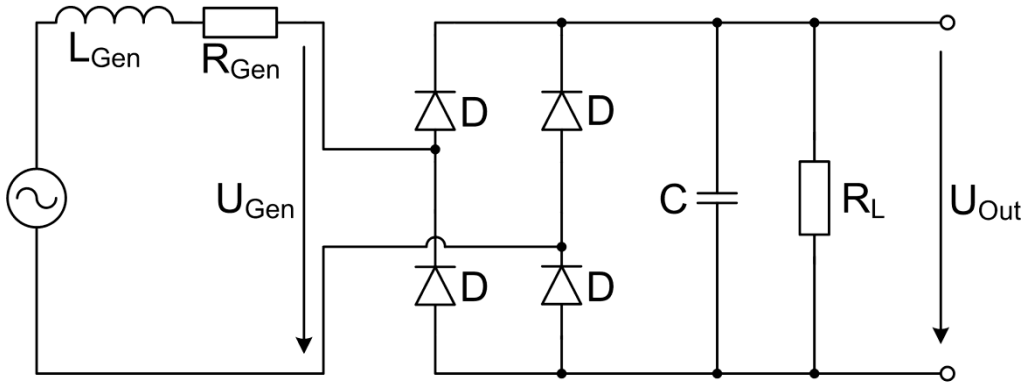
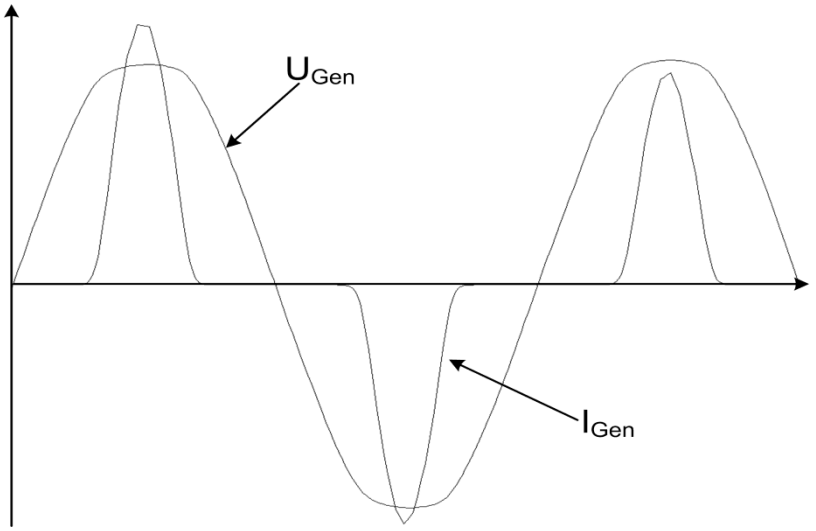
# Adaptive Power Management

## 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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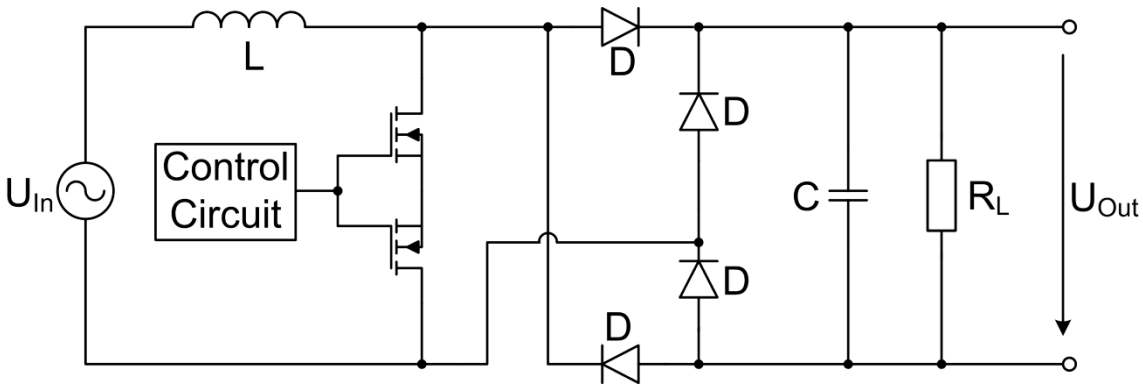
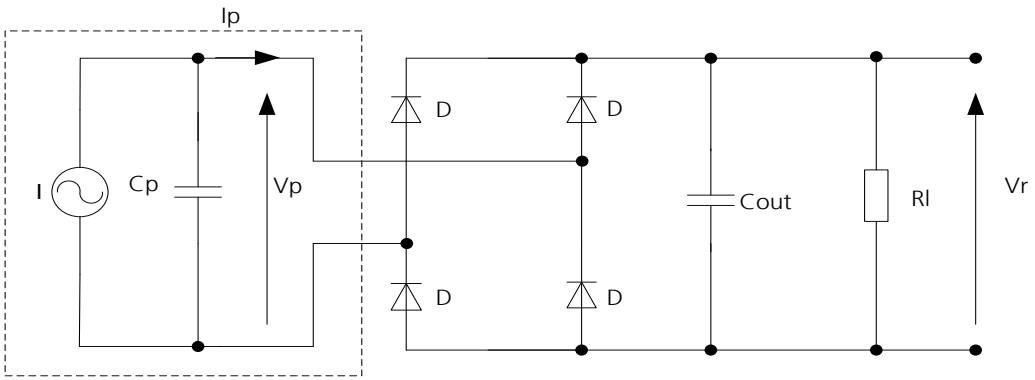
# Adaptive Power Management
## AC-DC Converter for Electrodynamic-Generators (EDGs)

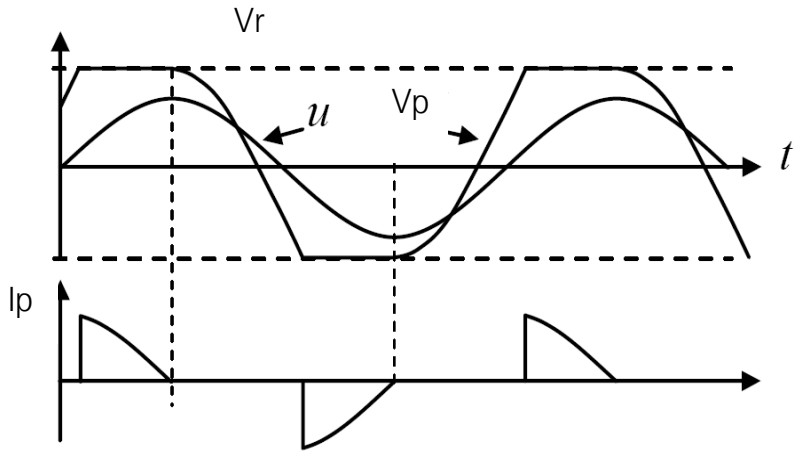
- **Direct** ac-to-dc conversion [dwa1]
- Boost-converter with **bipolar switch**
- Switches on **positive** and **negative** half-wave
- Represents **optimum load** as seen by generator
- Diodes on secondary side with **lower currents**
- Challenge: low-power control circuit



# Adaptive Power Management
## AC-DC Converter for Piezo-Generators (PEGs)

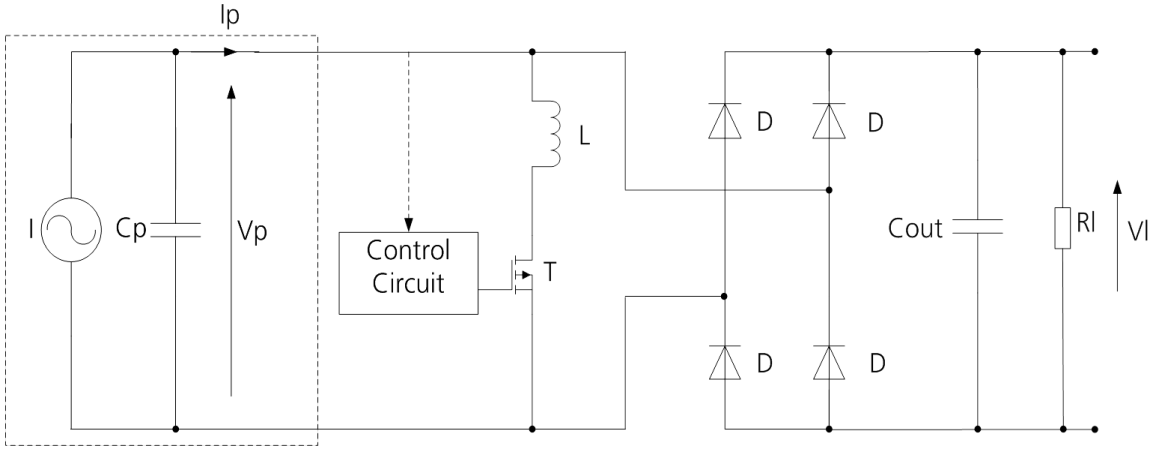
- Piezo-transducers provide **minimum amounts of charge/current**
- **State-of-the-art:** rectification and filtering
- Problem: **capacitive nature of piezo** >> voltage and current phase-shifted (capacitor)

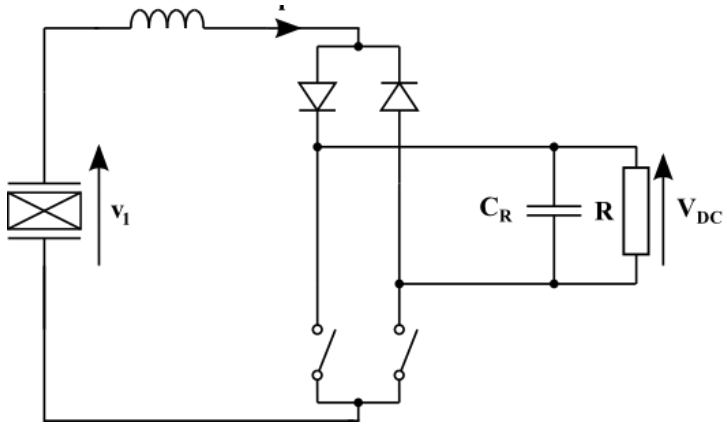


# Adaptive Power Management
## AC-DC Converter for Piezo-Generators (PEGs)

- **SSHI**: Synchronized switch harvesting on inductor [bad1]
- Switched inductor **shifts V and I in-phase >> Power maximum**
- L in parallel or serial to piezo
- **Challenge:** Low-power control circuitry
- **Optimization:** Avoid voltage drop and ohmic losses



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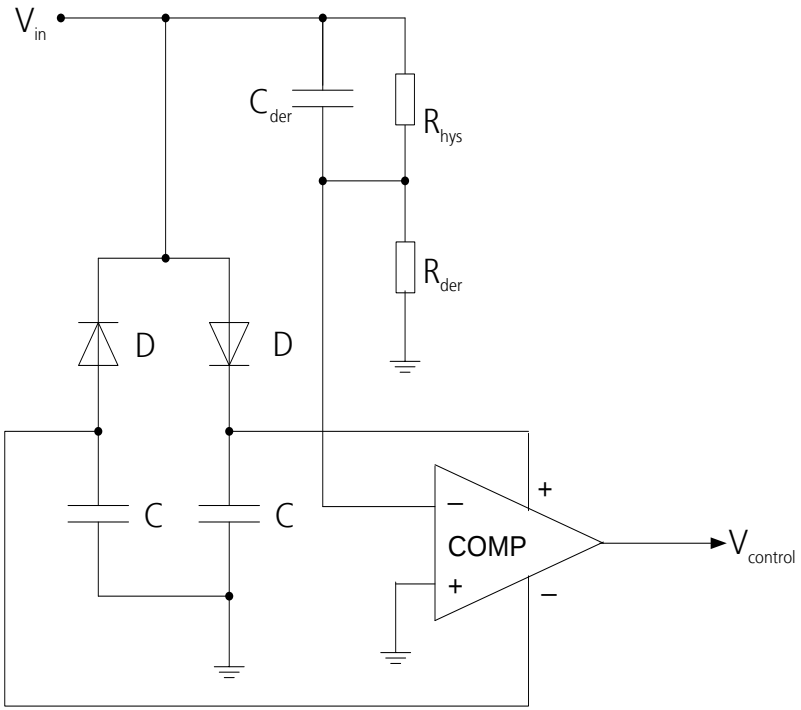
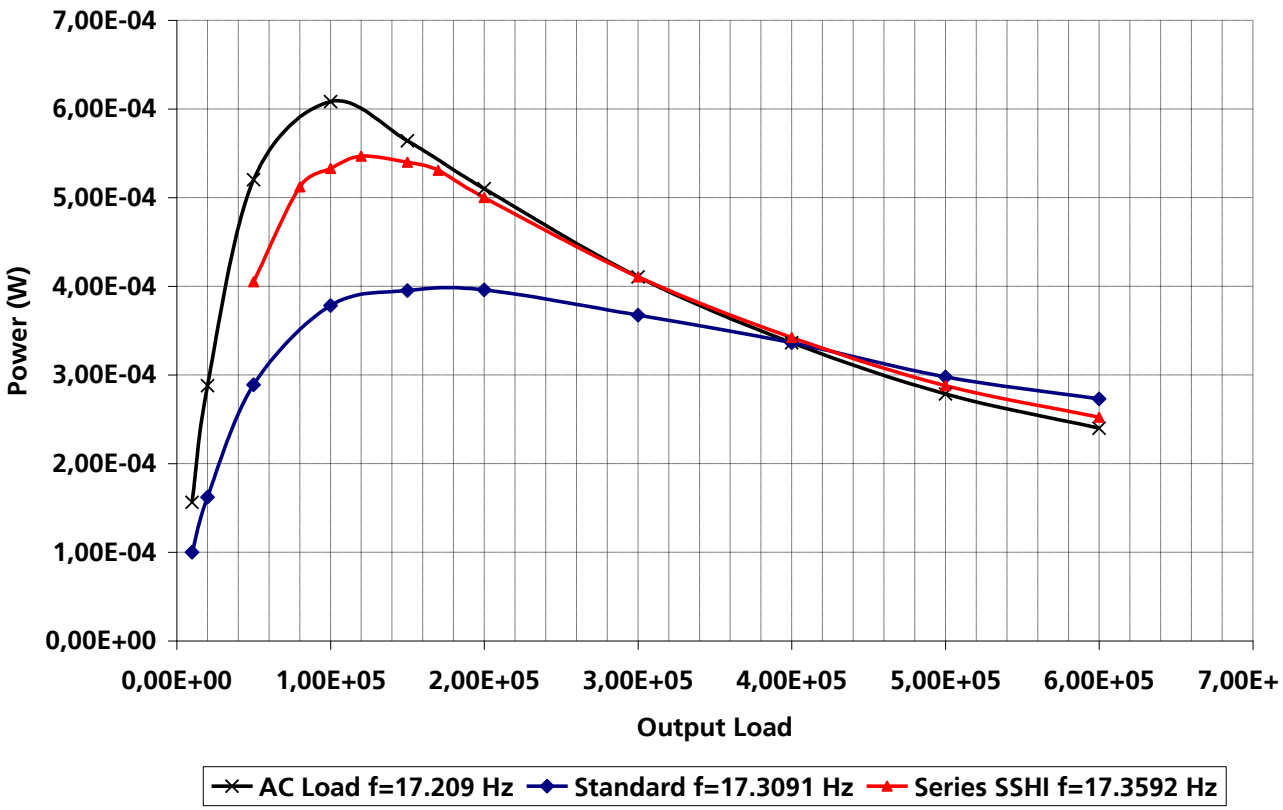
# Adaptive Power Management
## AC-DC Converter for Piezo-Generators (PEGs)

- Challenge is the **control circuit** [ben1]
- Power supply **directly from input $V_{In}$**
- Control of switching transistor with $V_{control}$
- **Broadband control circuit** can enable broadband or self-adjusting AC-DC converter



# Adaptive Power Management
## AC-DC Converter for Piezo-Generators (PEGs)

- Piezo with 0.1 g
- **AC Load** (black): Matched resistor
- **SSHI** (red)
- **Standard** (blue): Simple rectifier and filter



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# Adaptive Power Management Circuits for Selfpowered Systems

## Summary

- Ambient energy sources are **not constant**
- **Power output** is critical
- **Semiconductor development** supports Energy Harvesting
- Most power available if **load matches source**
- **Power management** ensures maximum power output
- **Energy storage** required
- **Transducers can be shrunken** due to more efficient power management

# Thank you for listening!

## Any questions…..?


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