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Flying with Liquids:

Aircraft Thermoelectric Energy Harvesting using Phase Change Materials

Tzern Toh

Energy Harvesting Network, 12 March 2014, Hamilton House, London

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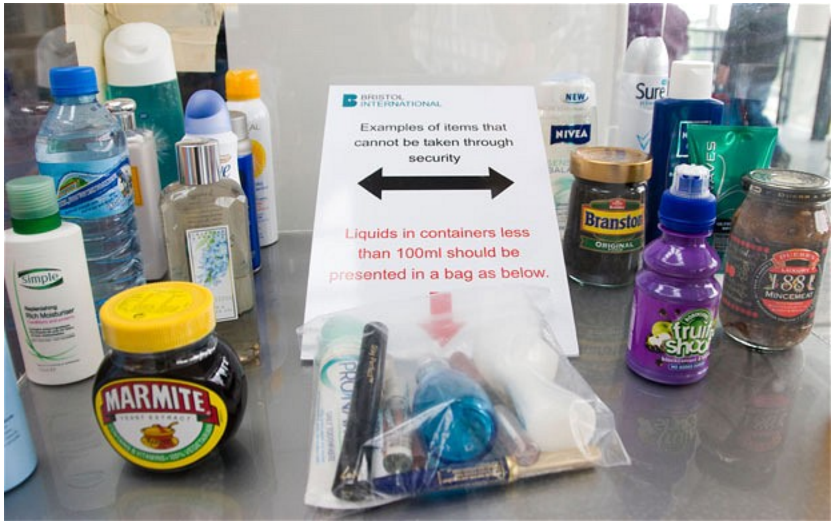
Flying with Liquids



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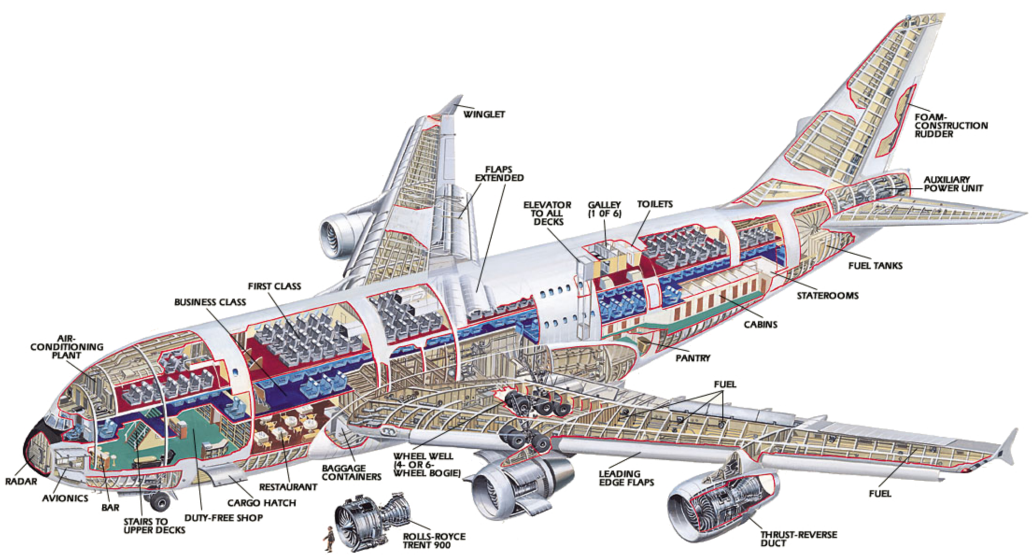
Target Application

- Wireless strain gauge for an aircraft flight test
- 28.5 J per flight is required
- Peak power consumption: 100 mW at 3.3 V
- Dimensions: 9 x 6 x 5 cm

csem

SERMA INGENIERIE
Serma Group

AIRBUS



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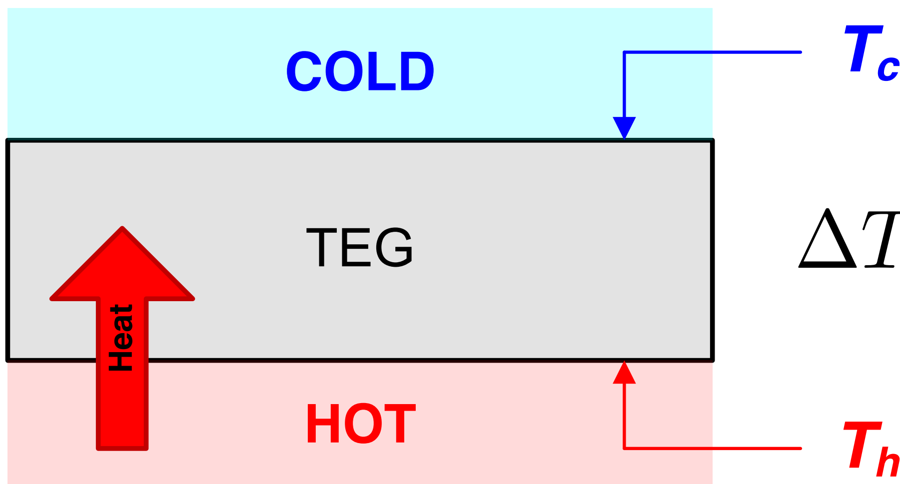
Aircraft Energy Harvesting

- Motivation:
  - Reduce internal wiring
  - Recharge batteries of wireless sensor nodes

- Available power sources in an aircraft:
  - Vibration
  - Solar
  - Radio frequency radiation
  - Thermal

Thermoelectric Generators (TEG)

- Conventional approach:
  - In direct contact with a hot and a cold surface



$$\Delta T = T_h - T_c$$

  - Heat availability is unlimited

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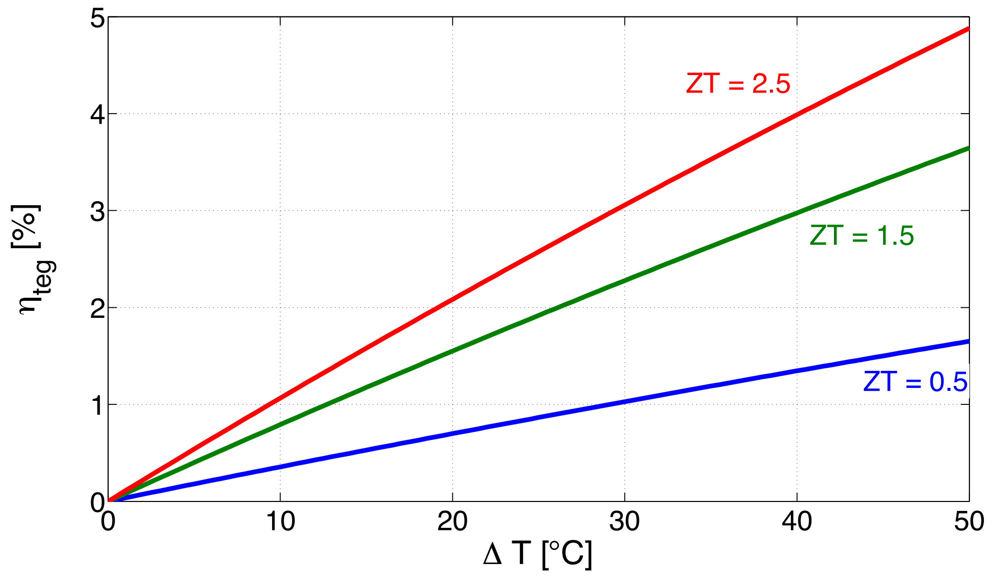
Thermoelectric Generators (TEG)

- Efficiency:

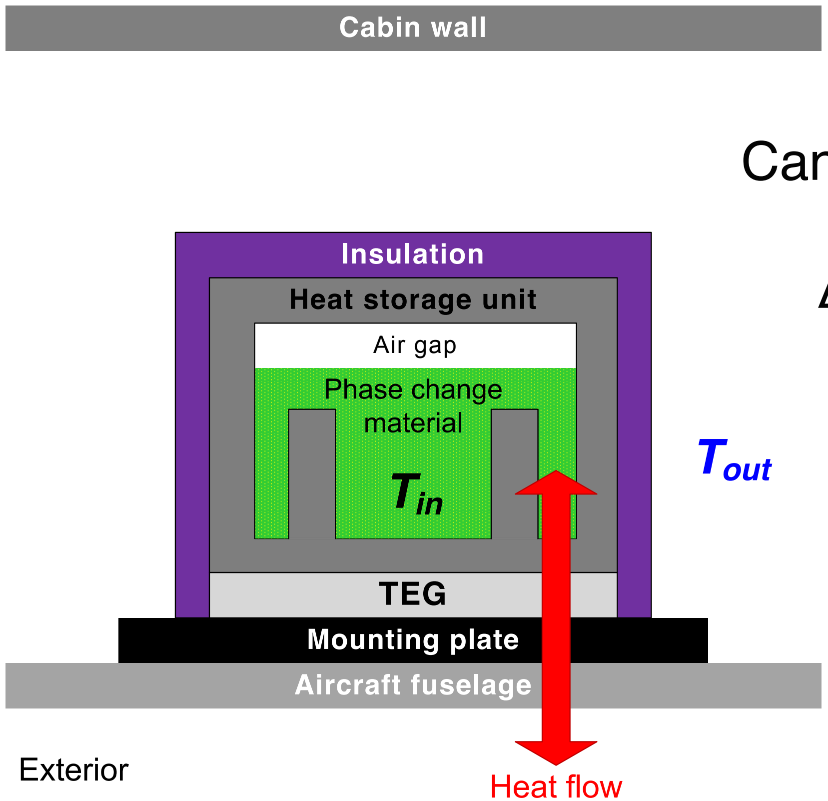
$$\eta_{teg} = \frac{\Delta T}{T_h} \cdot \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_c}{T_h}}$$



- Electrical output power: $P_{out} = \eta_{teg} \cdot \dot{Q}$

New Approach: Aircraft Application

- Exterior temperature: +20°C to -25°C and back



Can we store the thermal energy and delay ΔT changing sign?

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New Approach: Phase Change Material (PCM)

- Phase change material:

Characteristic	Water	Radiator oil
Heat capacity [kJ/kg/°C]	4.2	~2
Latent heat (melting) [kJ/kg]	334	~100
Melting temperature	0°C	< 0°C

- Heat storage unit (HSU)

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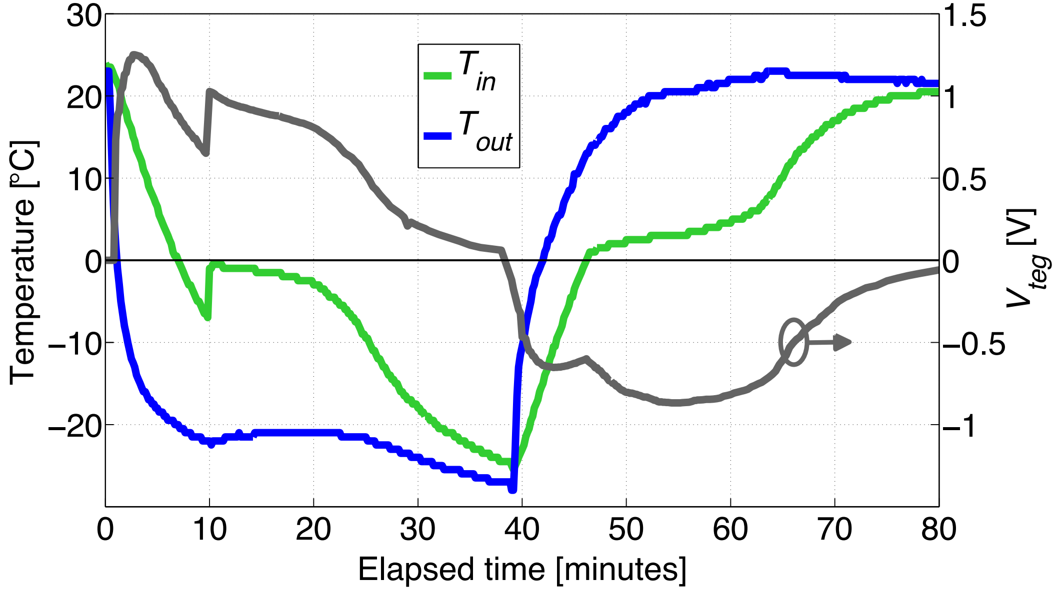
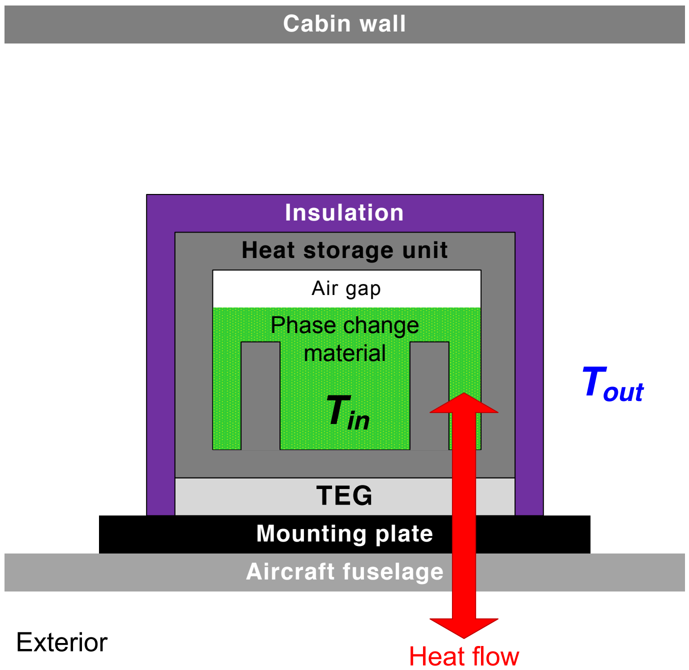
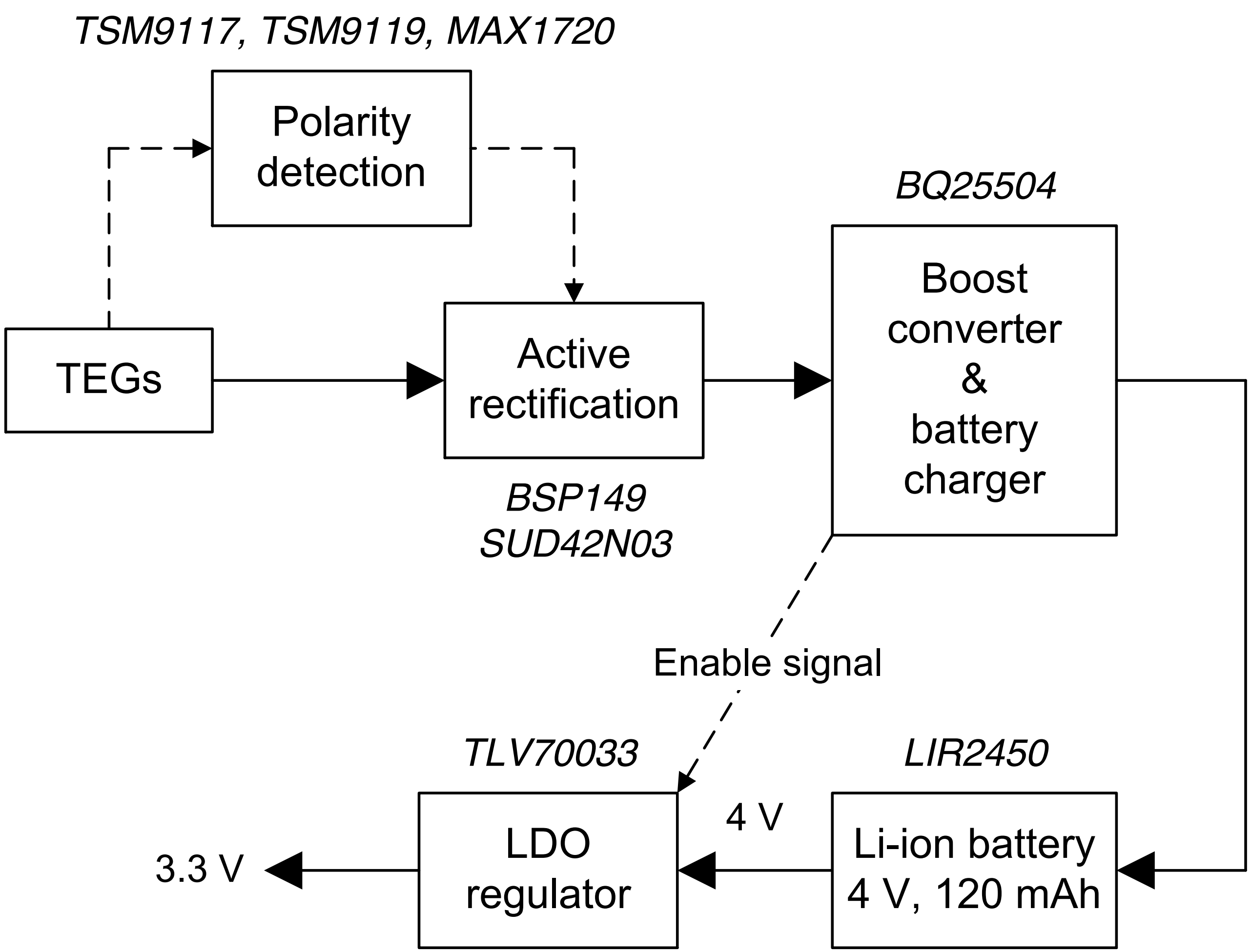
Device Characteristics

- PCM: 23 ml water
- Marlow TEGs: TG12-2.5, $ZT = 0.72$, $R_{teg} = 5\ \Omega$



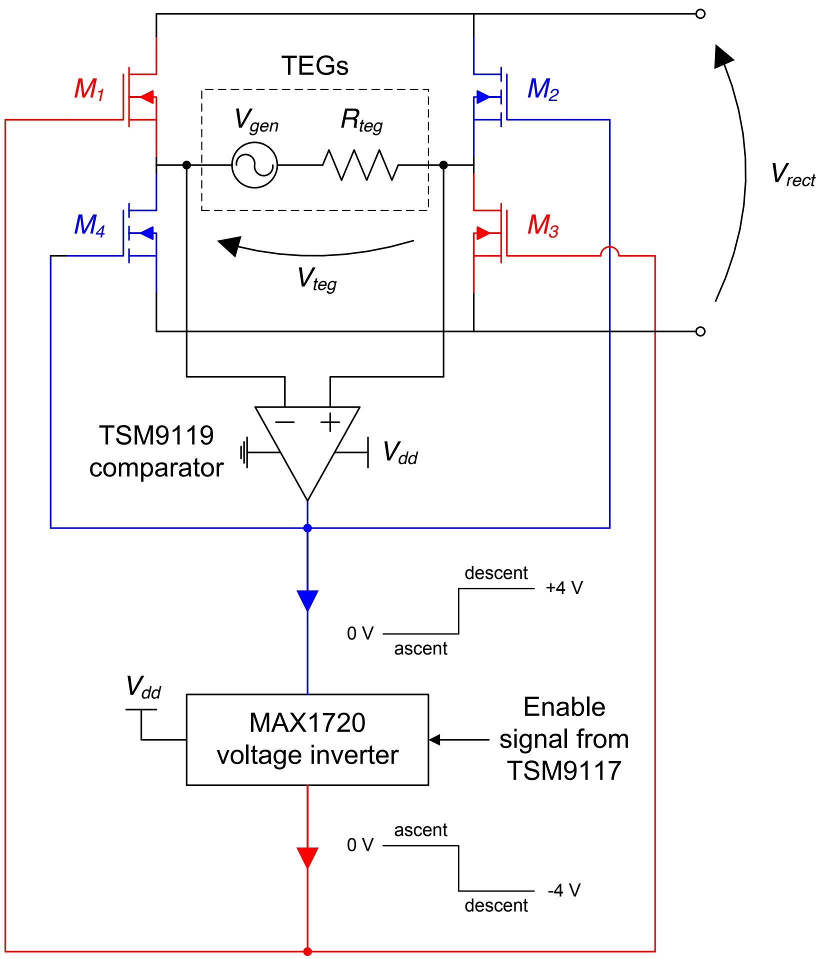


Harvester Interface Electronics



New Rectifier Topology

- Polarity of V_{teg} is known beforehand
- Depletion:
  - $V_{gs(th)}$ = -1.4 V, $R_{ds(on)}$ = 1.7 Ω
- Enhancement:
  - $V_{gs(th)}$ = 1.6 V, $R_{ds(on)}$ = 3.7 mΩ



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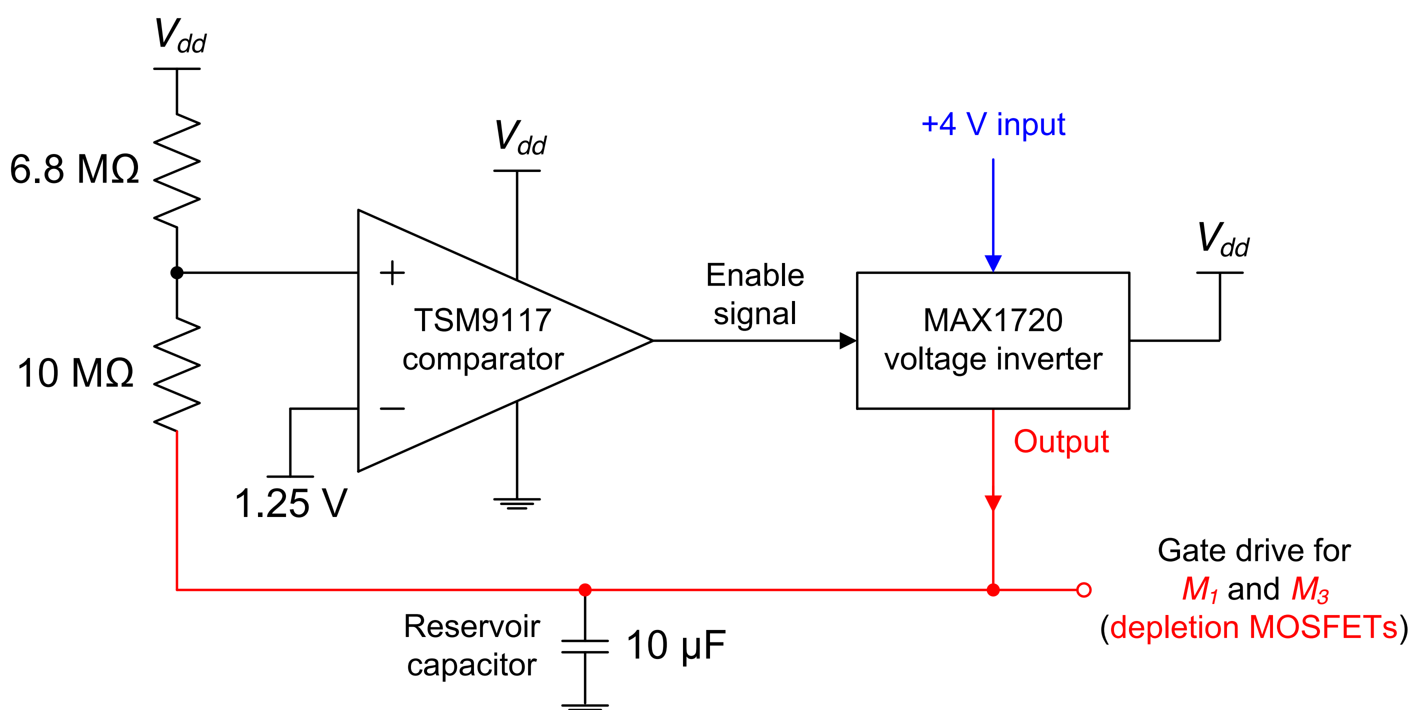
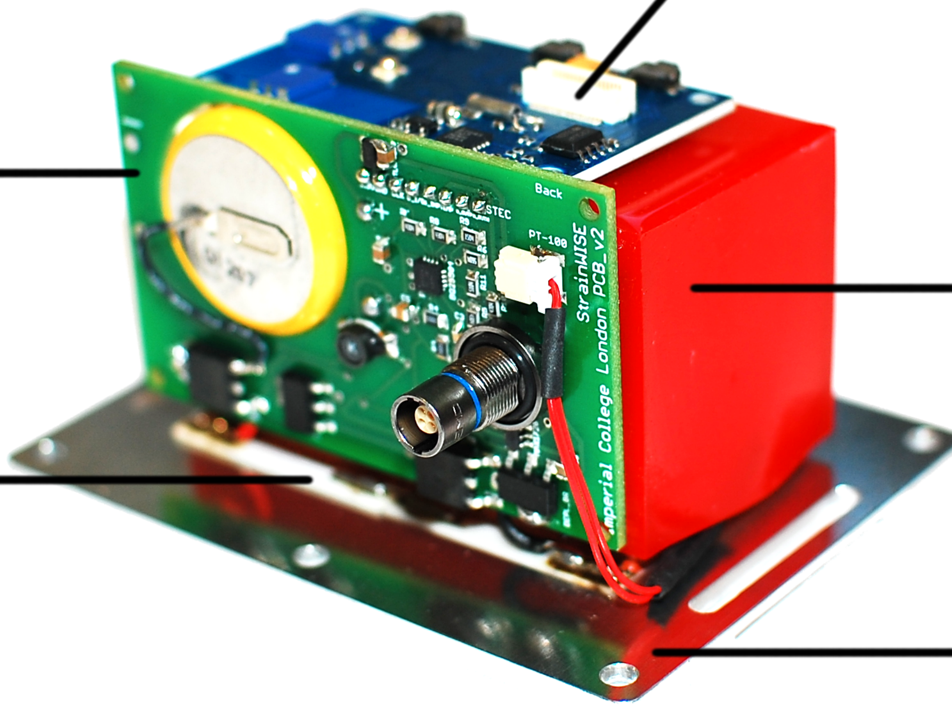
Duty Cycling the Voltage Inverter

- Use reservoir capacitor to maintain the negative gate voltage
- Negative gate voltage is kept between -4 V and -2.5 V

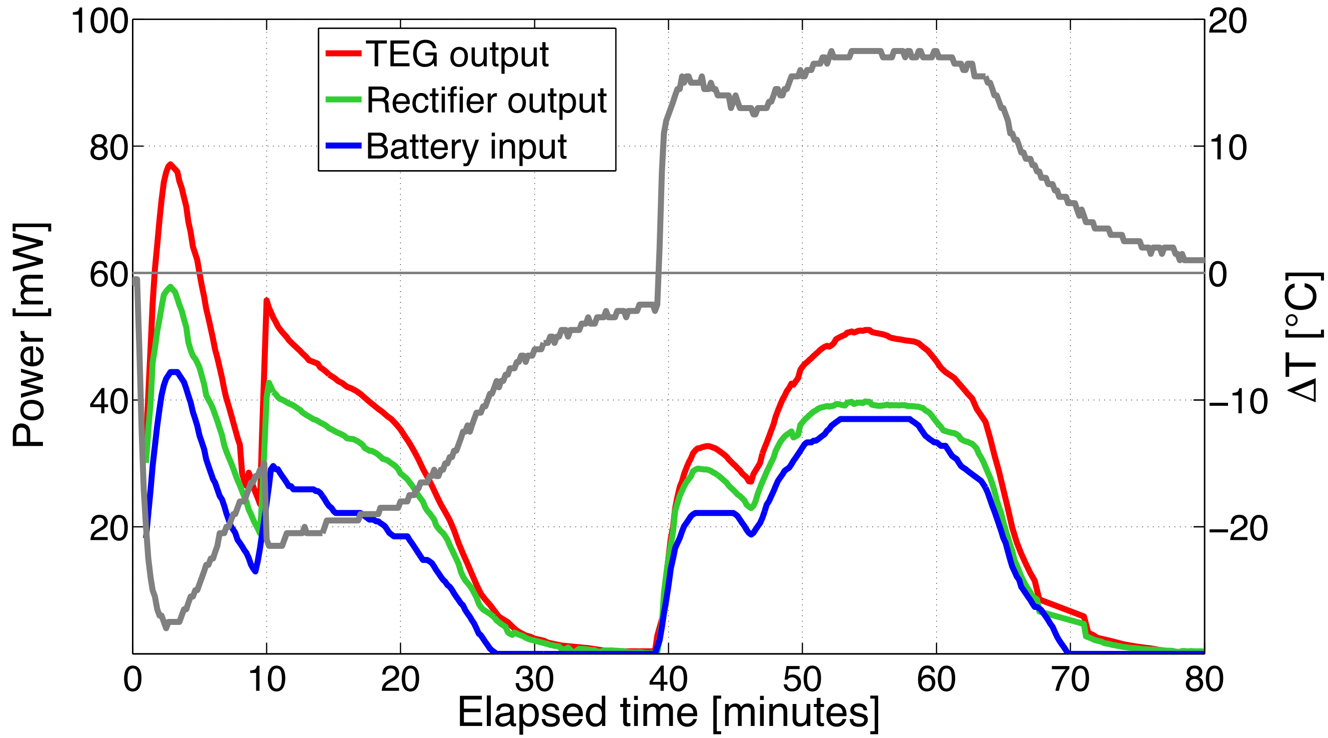


Prototype


Wireless
sensor node
Power
management
electronics
Heat
storage unit
Thermoelectric
generators
Aluminium
base plate

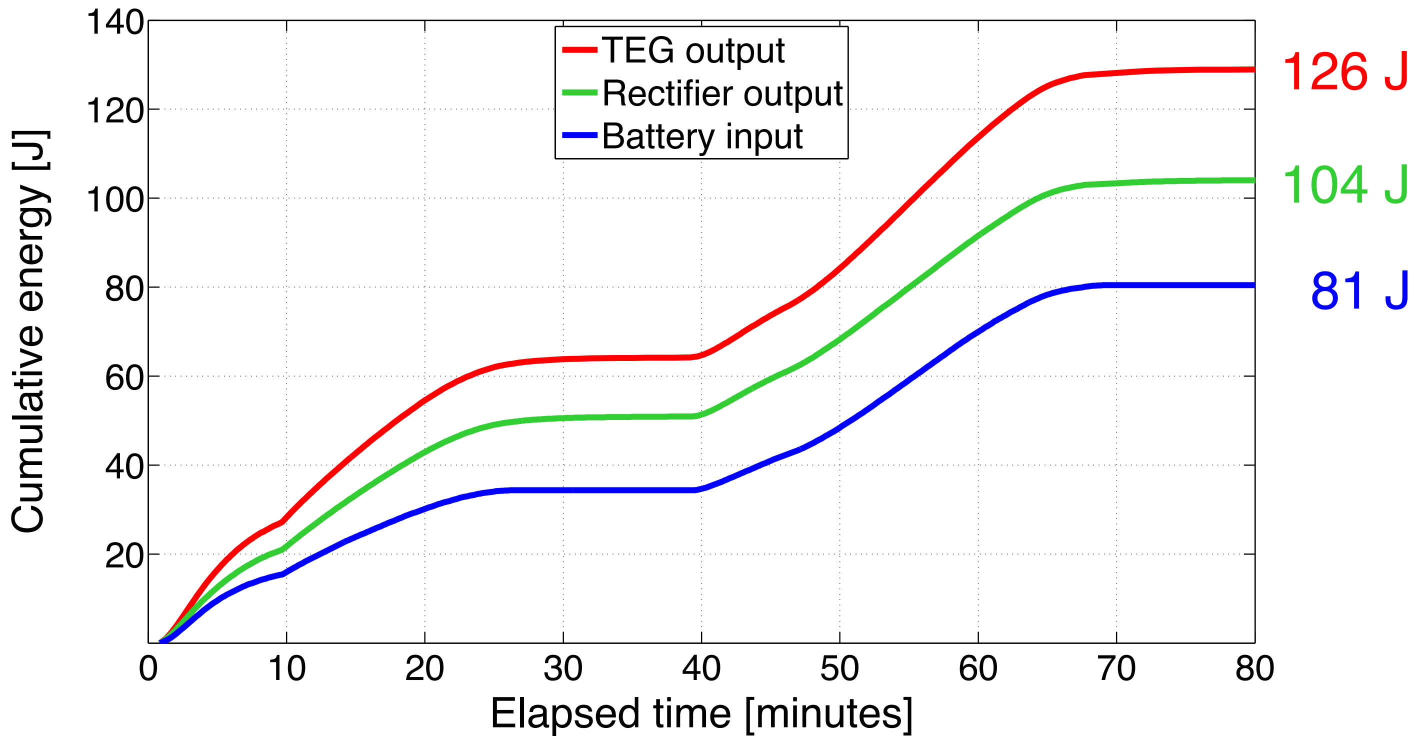
Experimental Results

- Instantaneous power at the TEG output, rectifier output and battery input



Experimental Results

- Cumulative energy: TEG output, rectifier output, battery input
- Thermal energy = 2*(c•ΔT + L) ≈ 21 kJ



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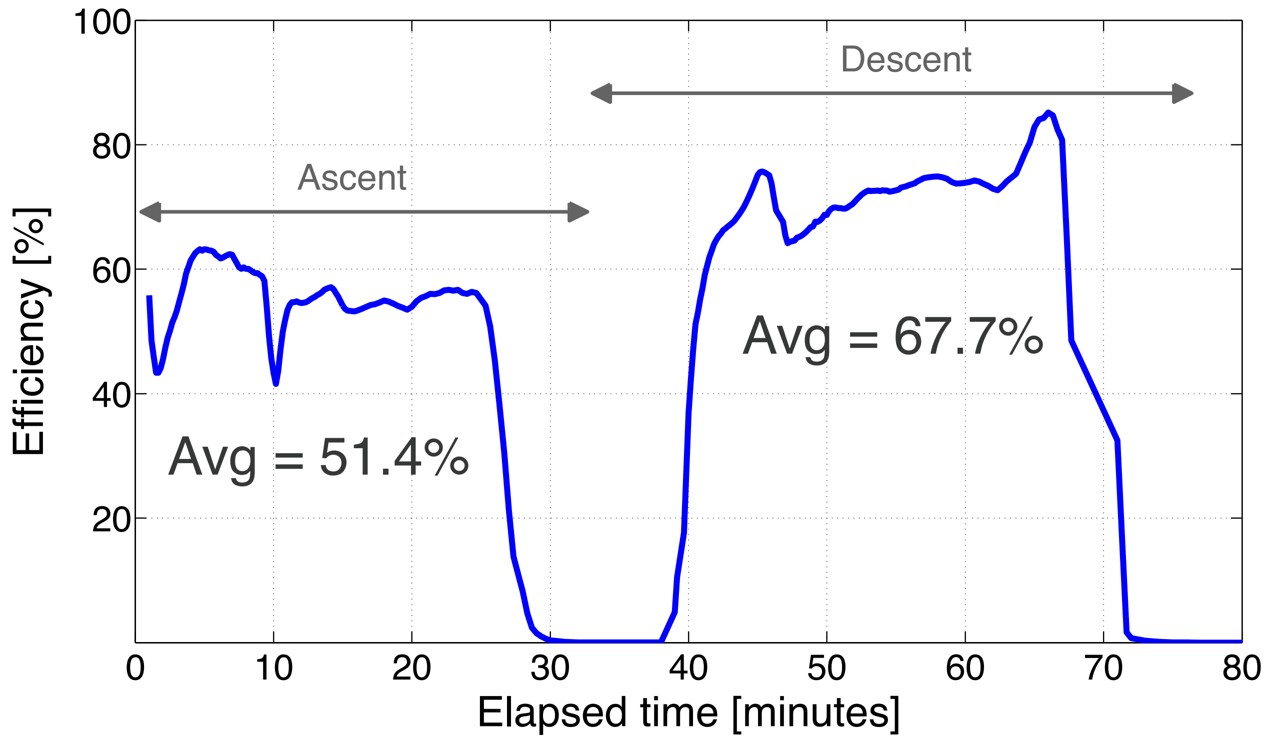
Experimental Results

- Instantaneous efficiency of the interface electronics



Conclusions

- Heat storage thermoelectric energy harvesting is a promising energy solution for aircraft wireless sensor nodes
- Rectifier topology does not require bias voltages to start and potentially less $R_{ds(on)}$ losses in the depletion devices
- TEG generated 126 J and 81 J delivered to battery: ~3x the 28.5 J required by the sensor node
- Overall TEG-to-battery efficiency of 64.3%

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Acknowledgements

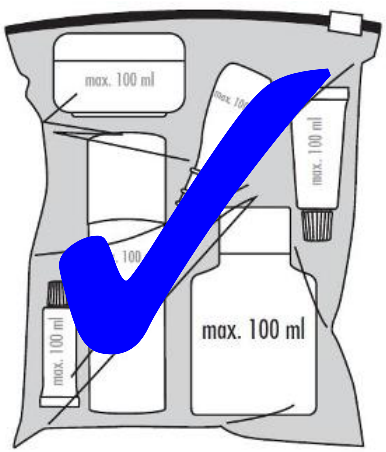
- Imperial College London, UK:
  - Steve Wright, Michail Kiziroglou, Paul Mitcheson and Eric Yeatman
- Centre Suisse d'Electronique et Microtechnique, Neuchâtel, Switzerland:
  - Damien Piguet, Laurent von Allmen and Jean-Dominique Decotignie
- Serma Ingeniere, Toulouse, France:
  - Christophe Leroux and Georges Bailleul
- Airbus, Hamburg, Germany:
  - Alexander Weisser and Jan Müller
- Clean Sky Joint Technology Initiative: JTI-CS-2010-1-SFWA-01-016

Thank you

Tzern Toh

Imperial College London

tzern.toh@imperial.ac.uk



23 ml PCM → 126 J