Etalon
Energy & communication

Energy Harvesting, Power Supply Design and Energy Storage

Perpetuum

Shift2Rail

Grant Agreement Number: 777576

Energy Harvester Development Objectives

Trackside and on-board developments:

- Investigate opportunities for energy harvesting in the environment.
- Investigate and Demonstrate a level of communication that can be powered with each type of harvester.
- Couple the energy harvester with an appropriate power supply and energy storage device.

On-board solution – high TRL

Demonstrate an energy harvester powered communication system on rolling stock.

Trackside solution – low TRL

Demonstrate functional prototypes exploiting different energy harvesting/generating mechanisms

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SIL-4 Compatibility of Energy Harvester Systems

SIL-4 requires fewer than 1 in 10^9 unsafe operational failures per device.

This can be achieved by having a failsafe state if any fault condition exists.

Energy harvesters use opportunistically available energy sources that can not be guaranteed

- This leads to poor reliability per device.
- Power storage (batteries, capacitors) are used to even out the times when power is available.
- Multiple redundancy (energy source/harvester type and number of harvesters) is applied to achieve the reliability required.

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Energy Harvester Types

Rolling stock and the rail environment provide three significant opportunities for energy harvesting:

- Vibration generated from wheel-rail rolling contact (propagates up and down)
- External installations have solar PV (or wind) available.
- Relative movement of train components can drive energy conversion mechanisms

Examples of these for on-train and trackside were discussed, with only some solutions being investigated or developed further.

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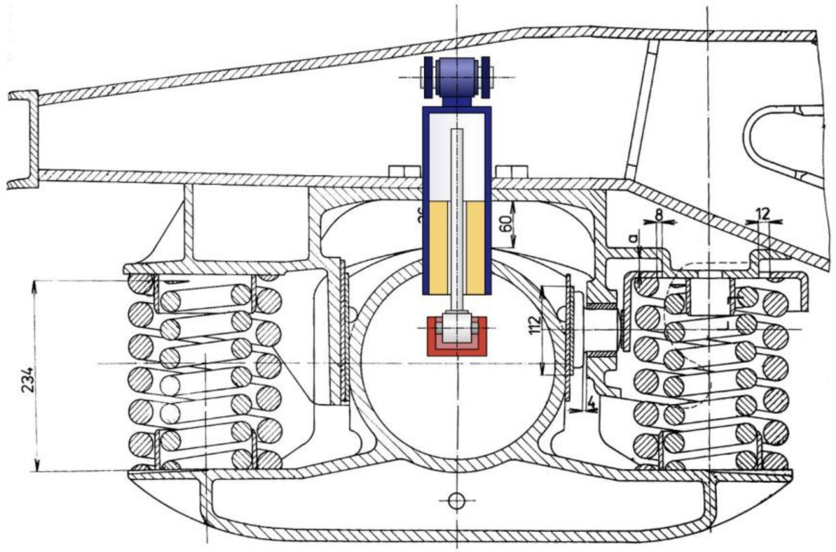
On-Board Energy Harvester Types

Vibration (developed and deployed)



Linear displacement (concept only)

Solar PV (commercial tracking product)

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On-board Energy Harvester Selection

Only the vibration harvester was developed and considered further for on-board for the following reasons:

- ETALON scope calls for adaptation of available technologies if possible.
- The opportunity to monitor wheel and bearing health is also required (mitigates implementation cost)

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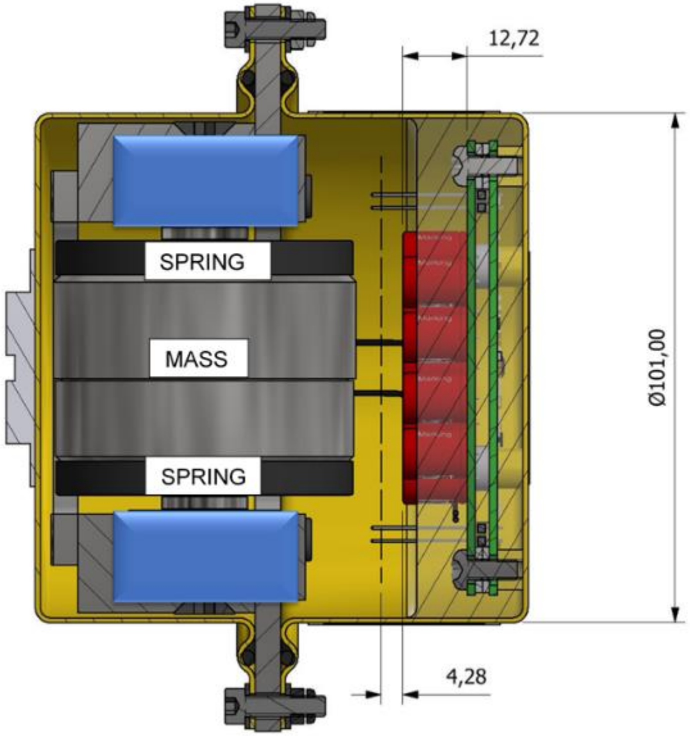
Energy harvester for adaptation

Design changes:

- New spring design
  - more robust, lower cost.
- Balanced mechanical arrangement of the harvester on the bracket (better resilience to shock).
- Increased energy storage.



Existing design ~25000 devices in Operation worldwide.

Installation Mass	Speed (km/h)	Power output/mW
>2.5kg (bracket included)	145	90
	80	30
>1kg (bracket included)	145	30
	80	10
Power required for minimum sensor functions ~3mW average.		

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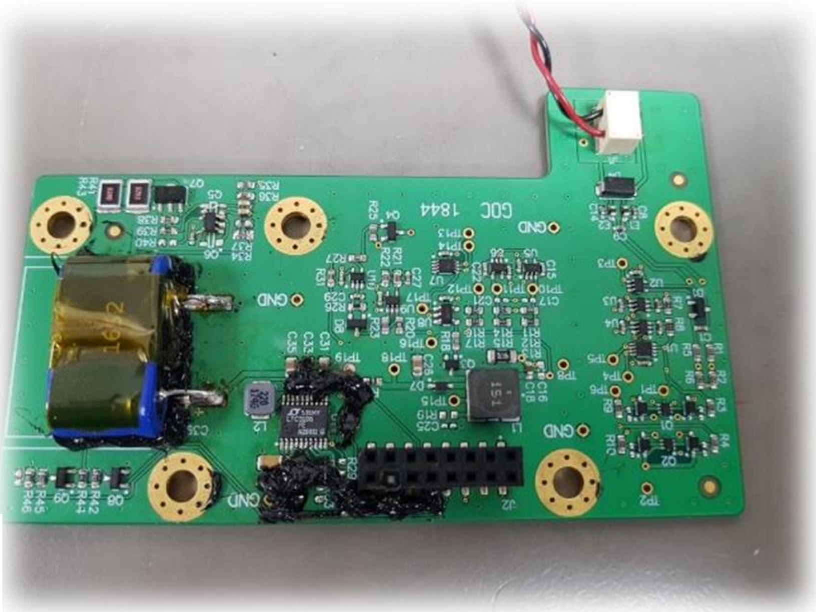
Power Management improvements



Design changes:

- Improved Boost convertor
- Improved Buck/Boost convertor
- Lower power logic families
- Improved capacitor protection

Speed equivalent to vibration applied (km/h [mph])	Current/power @ 3.3VDC nominal for Equilibrium (mA / mW) (Athens version)	VEH Start-up time Initial condition: Fully discharged (seconds)	Time to VEH suspension from zero movement 1.5mA draw @ 3.3VDC (minutes)
		1F Supercap	1F Supercap
32 [20]	1.67 / 5.48 (1.5 / 4.5)	165 (170)	17 min 40s (10mins 26s)
64 [40]	6.42 / 21.04 (4.4 / 13.4)	46 (50)	
128 [80]	19.17 / 62.51 (11.9 / 36.6)	18 (17)	

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Energy Harvester Powered Prototype OTI Platform

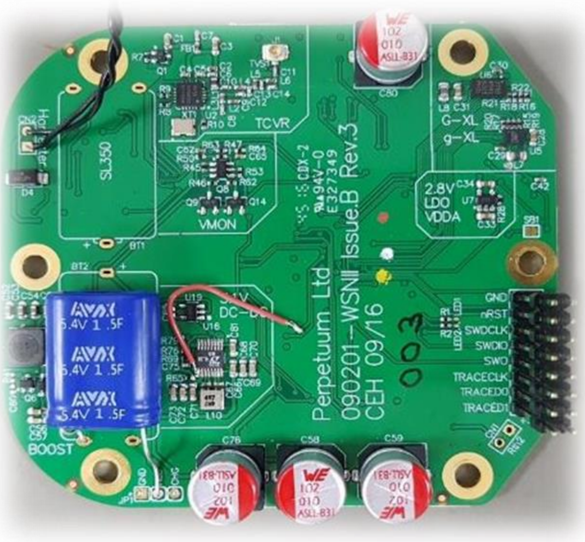
Vibration Energy Harvester, robust design for rail applications.

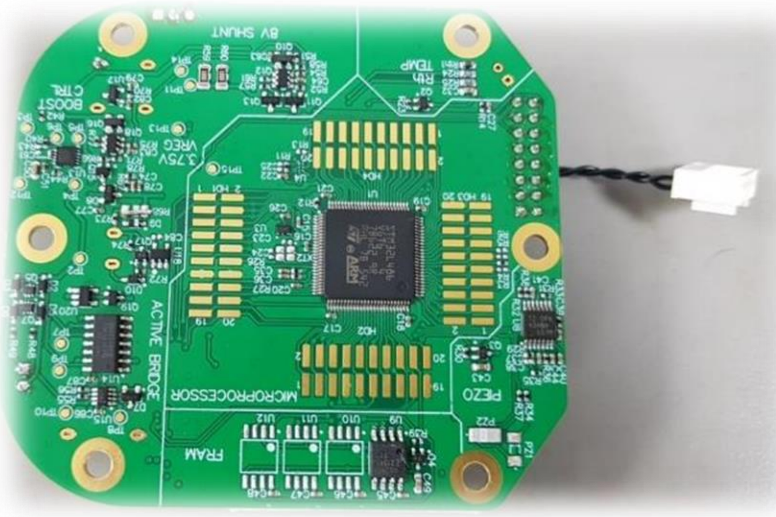
Power management system with extended energy storage and high efficiency harvester interface circuit.

Prototype platform – low power microprocessor with radio. Capable of running the ETALON OTI communications design.

Can measure and report vibration for condition based maintenance of the vehicle

Deliverable D4.3 characterisation.





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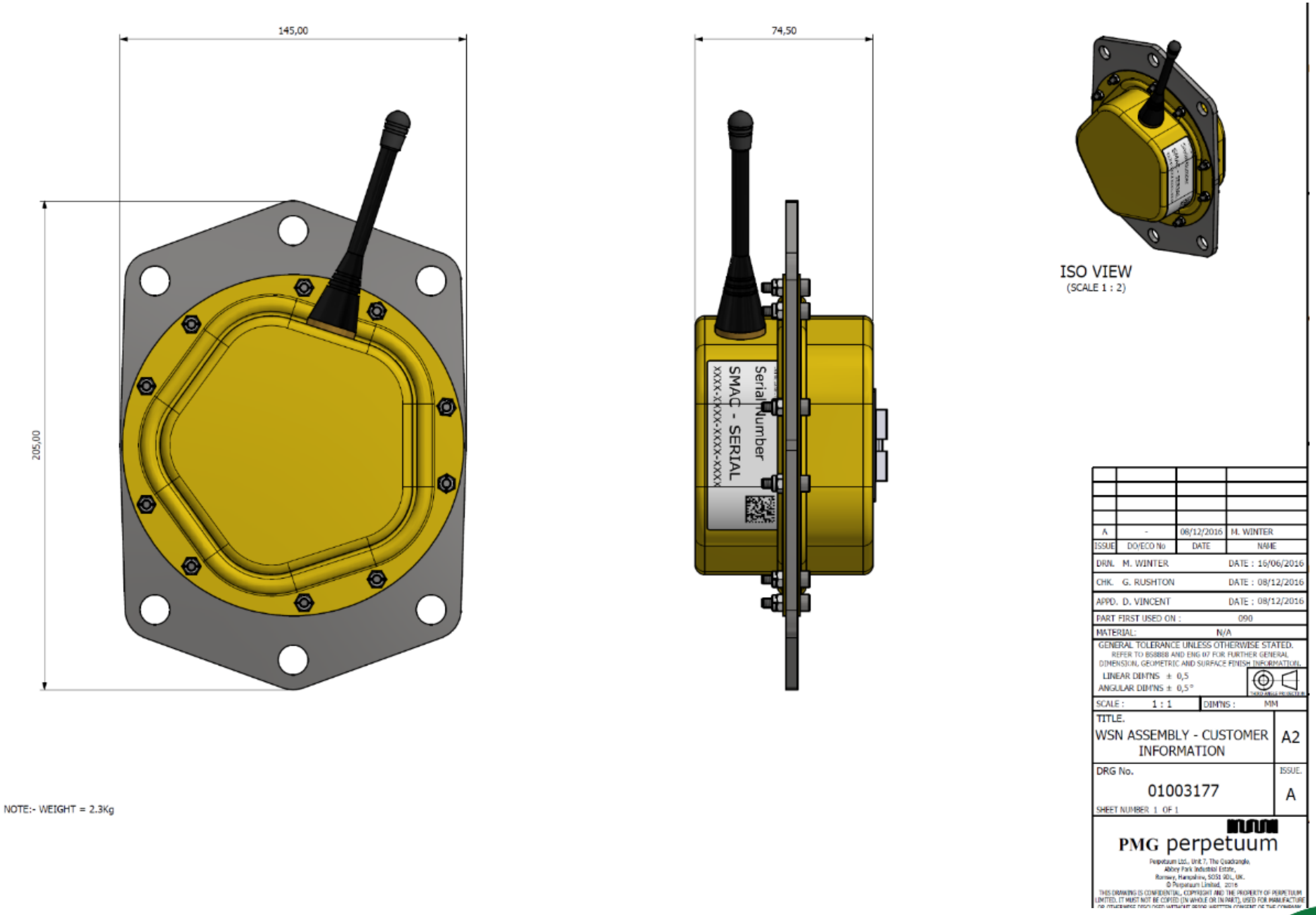
ETALON node for testing in Athens

Improvements from current design:

- Thinner construction
- Lighter
- More power
- Improved data processing
- Improved radio



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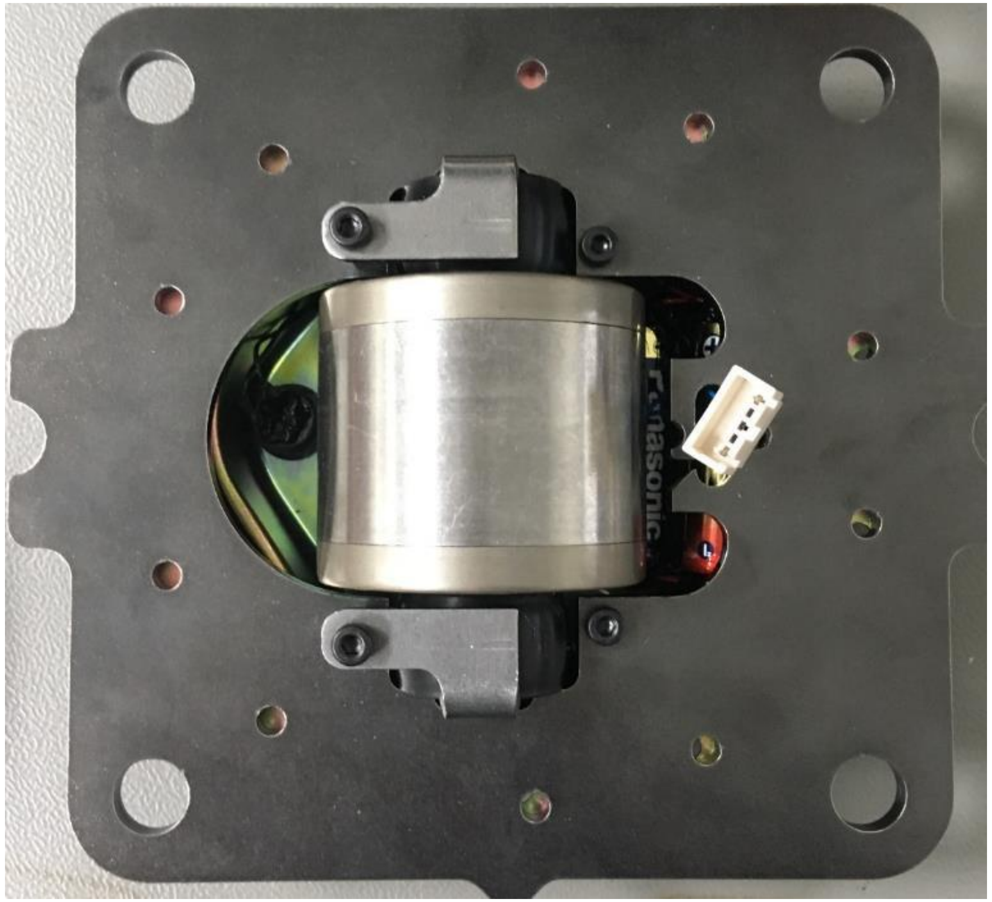
ETALON node for testing in Athens



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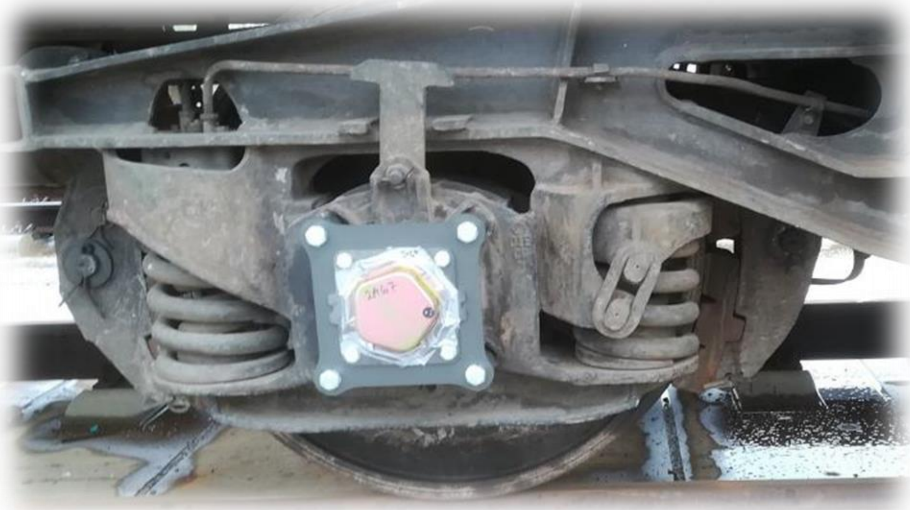
ETALON node testing in Athens



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Trackside Energy Harvesting

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Trackside Energy Harvesting Objectives

<u>Low</u> TRL investigation into available trackside harvesting:

Exploit energy available from passing trains.

Harvester mechanism must not damage the track or train.

Compatibility with track maintenance procedures

SIL-4 compatible

Sufficient power for a **<u>future generation</u>** of ultra-low power object controllers

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Energy requirements and opportunities in the trackside environment

Demand	Supply
S&C: 1 – 5kW	Power grid, solar panels (500W/m^2), wind generator with >>kWhr of energy storage. SIL-4 requirement dictates significant margin for energy generation and storage. Trackside generator equipment may be more valuable than the equivalent cables.
Current generation object controllers: >15W	Smaller solar panels, wind generator, >>100WHr energy storage
Next generation object controllers <50mW	Wheel-rail interaction, wheel-harvester interaction, >Whr storage
RCM for trackside elements (for example) <1mW	Wheel-rail interaction, wheel-harvester interaction, small solar PV, <<Whr storage. No SIL-4 constraints.

Environmental energy generation output is not related to demand from rail traffic, therefore energy storage must be used to maintain reliability in the worst case scenario. Energy storage must be disproportionately larger, compared to energy harvesters with an output that increases with traffic.

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Solutions developed:

Three different mechanisms exploited:

1) Vibration – energy that normally dissipates into the ground can be used to move a coil in a magnetic field (electromagnetic system).

2) The movement of the wheel through a magnetic circuit can trigger a rapid switching of magnetic flux through a coil. The reluctance of the magnetic circuit is changed. Non-contact magnetic drag on the wheel draws energy from the train movement.

3) Direct mechanical contact between a wheel and a linear electromagnetic generator. Contact with the wheel draws energy from train movement.

A study of solar PV opportunities and limitations is developed, no hardware was procured (very mature solutions available).

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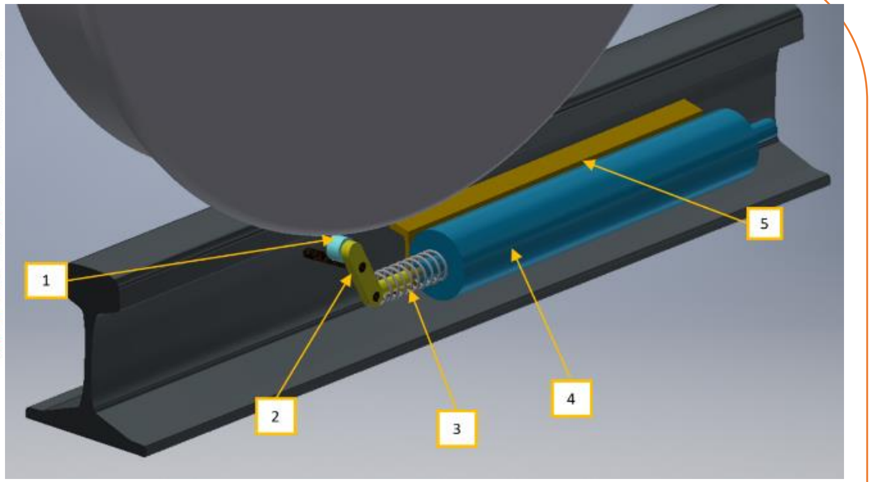
Trackside Energy Harvester Solutions

Passive – harvests waste energy through vibration

Magnetic interaction



Mechanical contact

Active – convert train movement into energy

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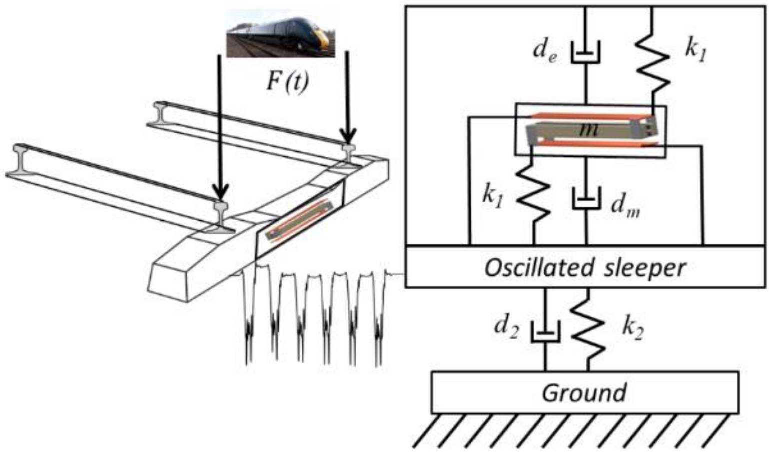
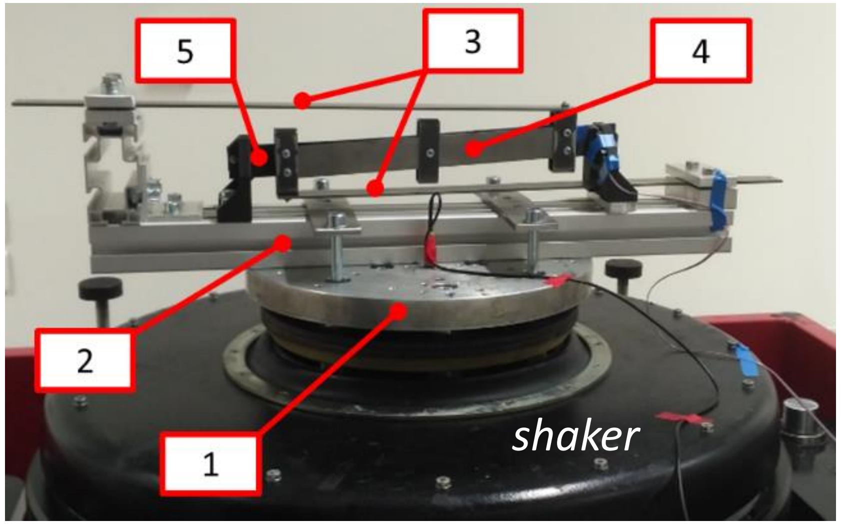
Vibration Trackside Energy Harvester

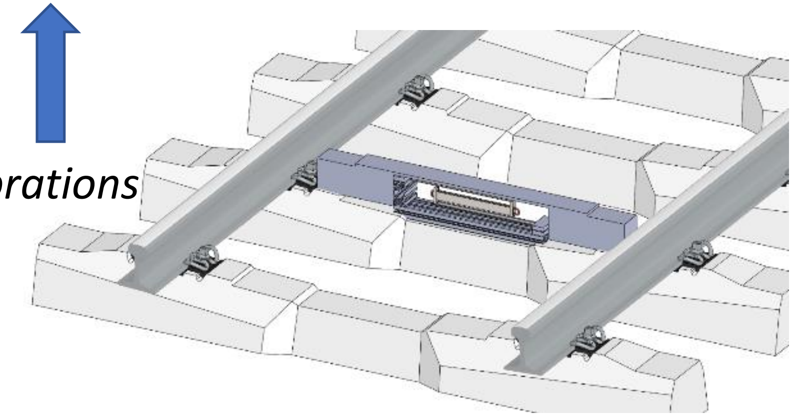




- Base (2) fixed on vibrating structure (1)
- Flexible suspension of resonator (3)
- Resonator mass – mag. circuit (4)
- Self-bonded air coil with plastic coil holder (5)
- Power management electronics

Physical principle of V TEH is based on a response of kinetic resonator.

vibrations



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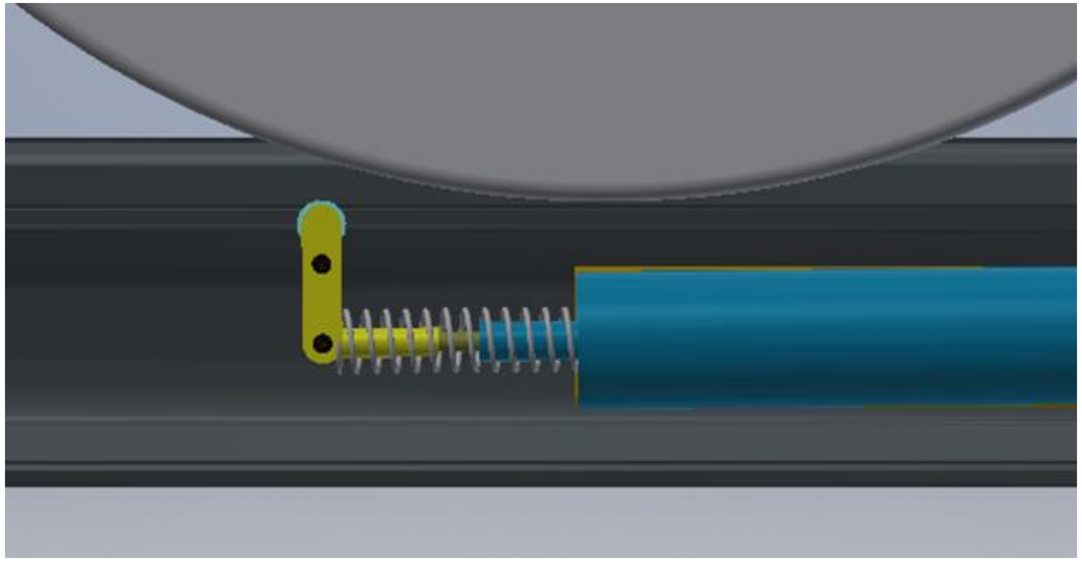
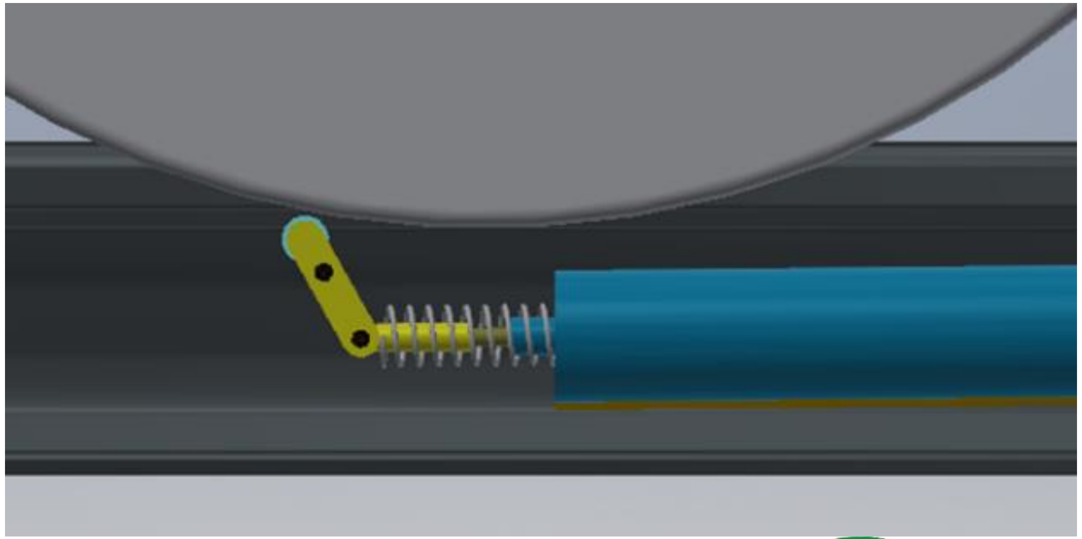
Linear Generator Trackside Energy Harvester

Outline LG TEH

- Used to calculate representative actuation profile
    - Average velocity of shaft when actuated by the wheel of a passing train
    - 5m/s for train speed of 100km/h
- Actuation profile used to determine representative actuation profile for testing linear generator
    - Cam with 2 lobes separated by base radius
    - Intermittent actuation with pause after return stoke
        - Representing pause between wheels of passing train





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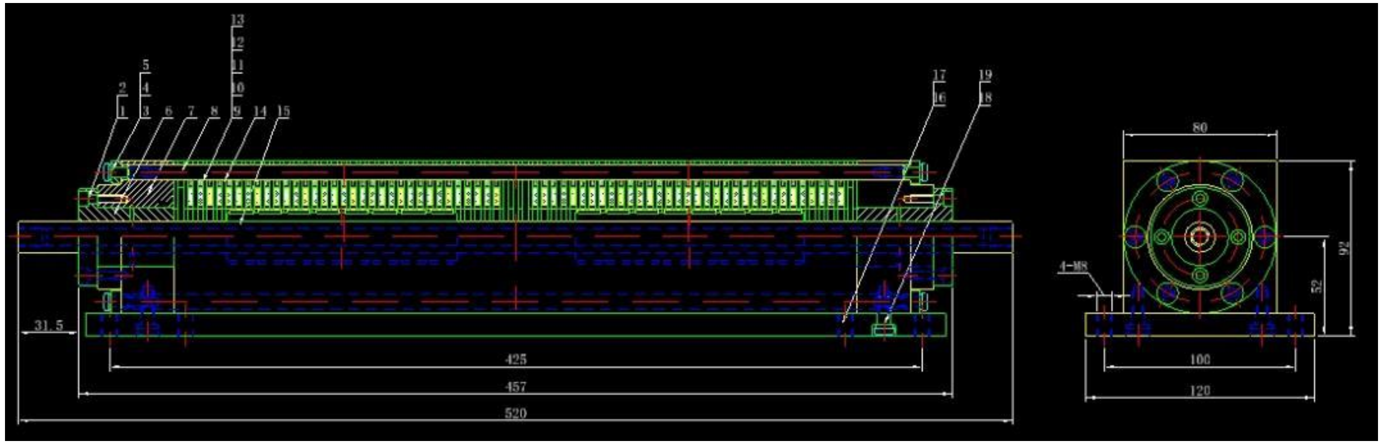
Trackside Linear Generator Energy Harvester

- Detailed design developed
  - Designed to maximise energy harvesting from form, stroke and actuation profile
- Prototype constructed
  - 460mm x 80mm x 80mm form
  - 60 coil stator wired in 3 series phases
    - 20 poles, with a pole pitch 15mm
  - Shaft 30mm stroke 16 magnets
    - 16 poles, with a pole pitch 15mm



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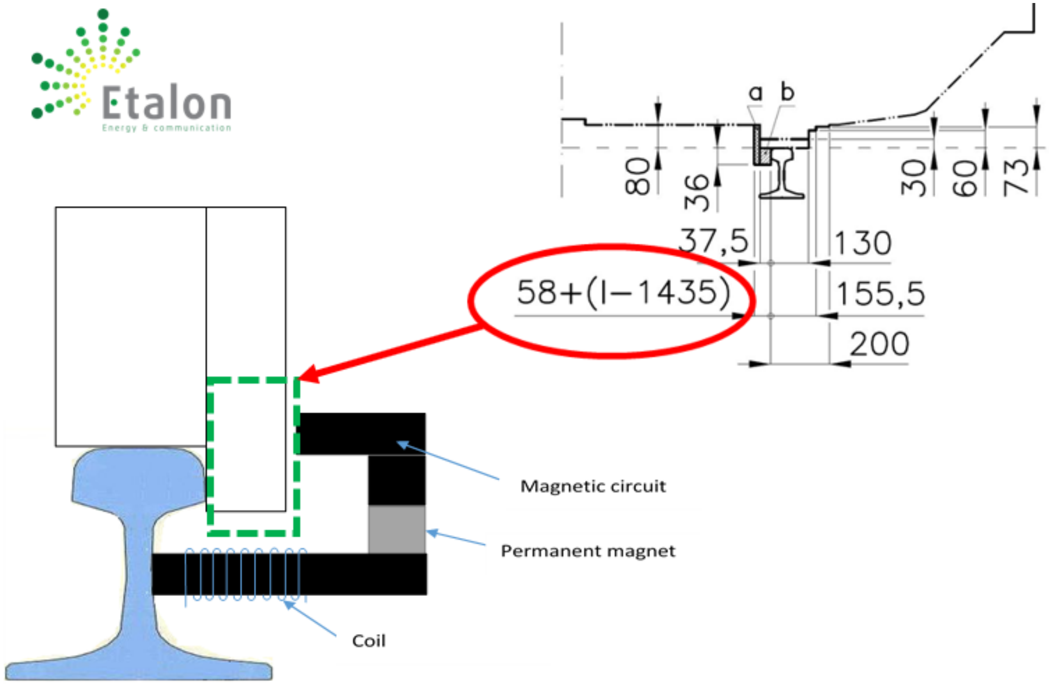
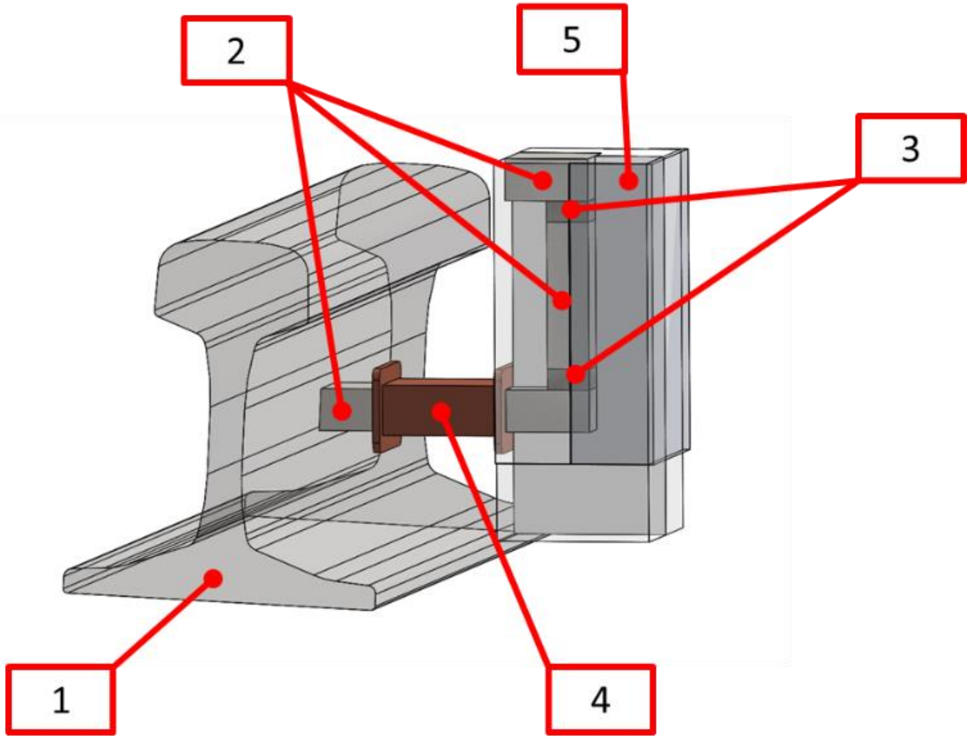
Variable Reluctance TEH

Physical principle of VR TEH is based on a change of magnetic flux through coil in time of passing wheel.





- Rail (1)
- Ferromagnetic parts of magnetic circuit (2)
- Two FeNdB magnets (3)
- Coil - wounded on plastic frame (4)
- Plastic cover of VR TEH (5)

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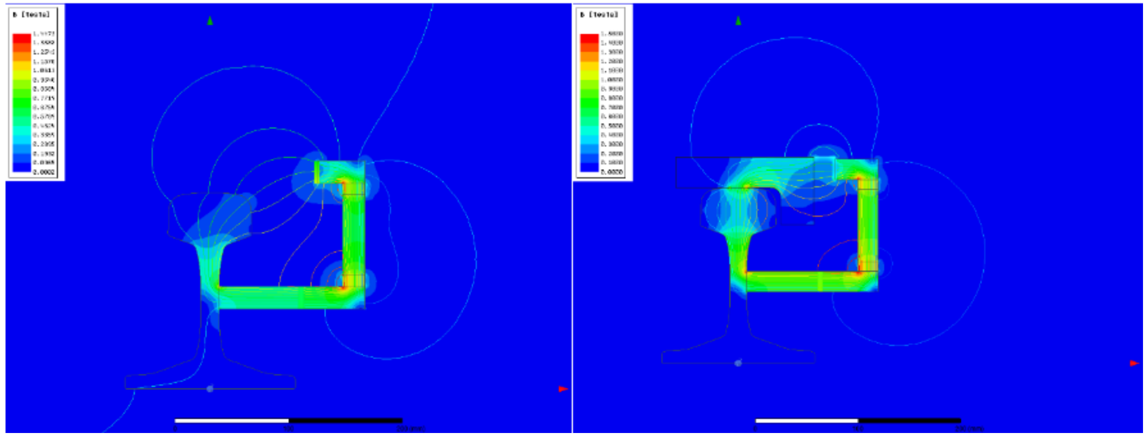
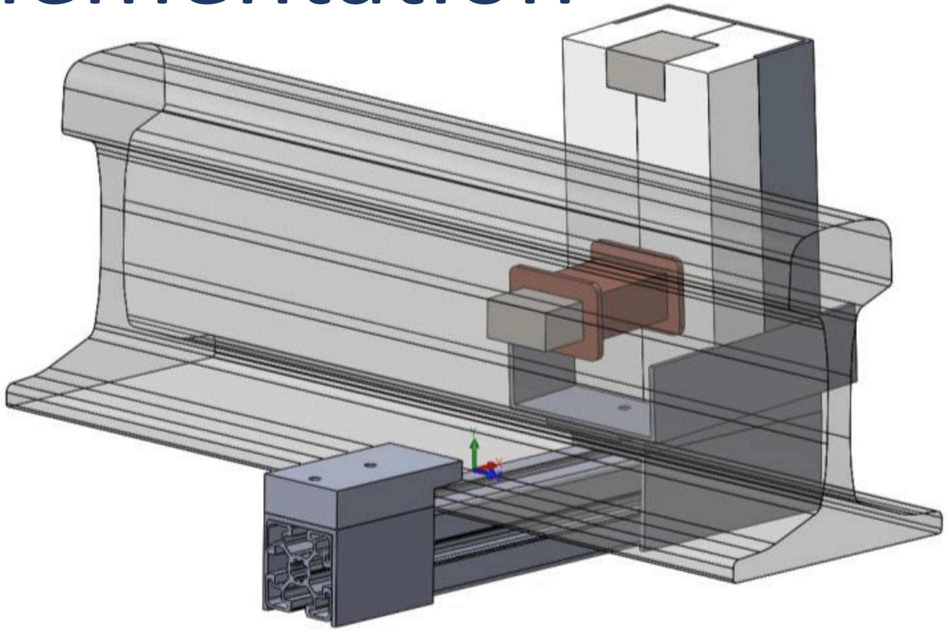
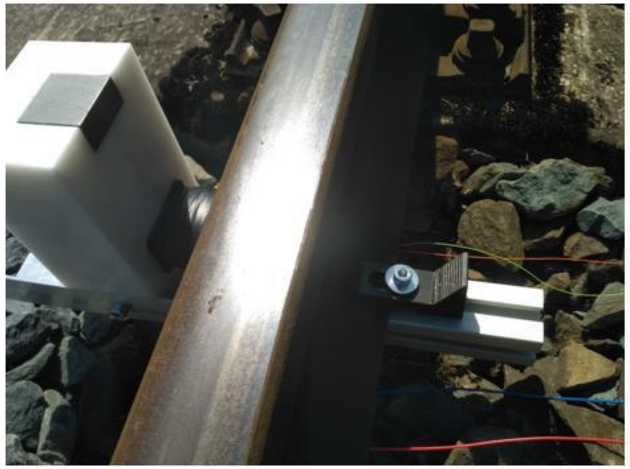
Variable reluctance implementation

2D FEM simulations under D4.1







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Energy Storage Options: types and examples

Type	Energy density	Degradation mechanism	Charge/Discharge rate	Cost	Leakage (relative to other technologies)	Duty cycle (full charge/discharge cycles)
Capacitor	Very Low	Electrolytic (drying)	High	Low	Low	High
Supercapacitor	Low	Electrolyte loss (20yr life possible)	High	High	High (low compared with power harvester output)	Medium
Hybrid layer capacitor (HLC)	Medium	Electrode loss (20yrs), over discharge	Low	Very high	Very low	Medium
Lithium rechargeable	Very high	Charge/ discharge cycles	Medium	High	High	Low
NiMH rechargeable	High	Charge/discharge cycles	High	Low	Low	Low

Capacitors/J Electrolytics, 16-10V discharge range, 20mF	Super-capacitors/J 4.5 - 1V discharge range, 1F	HLC (Tadiran)/J 3.7V, 155mAh	Rechargeable lithium/J 3.7V, 2500mAh	Rechargeable NiMH (AA)/J 1.2V, 2500mAh
1.56	9.625	2064.6	33300	10800

Device care notes affecting usability:

Rechargeable batteries offer good energy density **BUT** complete discharge can destroy the device, affecting reliability.

Supercapacitors offer the best compromise between capacity and care in these environments. The energy stored can deliver substantial communication without discharging.

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Energy Harvester Development Conclusions

- A vibration energy harvester mounted on the axlebox is capable of driving communication for on-board train integrity.
- The same device can provide condition information for the wheel and bearing.
- Mechanical contact and vibration energy harvesting are both capable of powering low power communication trackside.
- In both cases, multiple redundancy of harvesting and communication devices must be coupled with enough energy storage capacity to provide reliable operation.
- Additional devices using solar PV harvesting can provide background energy supply when no train motion is available.

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