Etalon
Energy & communication

Testing and Validation of the Proposed Solutions

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Final event

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Grant Agreement
Number: 777576

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WP5 Objectives

➢ Context and related tasks

- T5.1 Development and System Integration OTI Prototype
- T5.2 Specification of test scenarios
- T5.3 Validation of developed solution in Controlled Environment
- T5.4 Validation of developed solution in Relevant Environment
- T5.5 Analysis of Results

➢ Deliverables

- D5.1 OTI prototype
- D5.2 Results and perspectives for OTI
- D5.3 Results and perspectives for TEH

Detail processes, methodology, tools and equipment used for the validation of results for both OTI and TEH prototypes

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OTI Test Scope

<u>The key tests are listed below:</u>

- ✓ Network Discovery (ND).
- ✓ Train Integrity (TI).
- ✓ Loss of Train Integrity.
- ✓ Communication band range (i.e. radio communication link between two OTI nodes).
- ✓ Basic Distance Sensor (DS) functionality.

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OTI Test Methodology plan

Why a progressive test process?
→ Multiscale testing methodology

Power Consumption tests (Southampton, UK)

Lab “corridor” tests (Turin, Italy)

Controlled Environment tests (Barrow Hill, UK)

Relevant Environment tests (Athens, Greece)

- ✓ Detect potential failures and shortfalls at each stage
- ✓ Provide the opportunity to rectify
- ✓ Assess the final configuration for Real Environment testing

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OTI Test Matrix

- Test organization
- Full traceability of requirements through to tests
- Description, measurements, test conditions
- **D5.2 Analysis of OTI prototype test results**

Test Part	Description	Checks/ Measurements/ Verifications	Related Requirement	Test Conditions / Environments NOTE: MoSCoW Priority: M = Must, S = Should, C = Could, W = Would like									
				Lab "corridor" tests (TURIN)		Power Consumption tests (SOUTHAMPTON)		Controlled Environment Tests (BARROW HILL)		Relevant Environment tests (ATHENS)		"Car Park" tests (TURIN)	
				Plan	Com	Plan	Com	Plan	Com	Plan	Com	Plan	Com
2.1.1	Check DS function and result (accuracy at different separations)	For each measurement, measure separation and DS result	SR_DS_1	X	X	M	X	M	X	W	X	W	X
2.2	Check DS function with multiple nodes responding.	For each measurement, measure separation and DS result and node ID	SR_DS_1	X	X	C		C				W	X
5.1.1	Arrangement of nodes representing distribution of nodes on a train. Without adjacent nodes (representing other wagons/trains not in consist)	Confirm topology generation and measure time taken (check less than 60s)		X	X			M	X	M	X	W	X
5.3.1	Respond to automatic (at different intervals) and manual TI confirmation requests (check correct confirmation of TI and that it corresponds to distribution of nodes on virtual/real train)	Check TI confirmed within time limit. Check TI check interval can be set	TI_P_1, TI_P_2, TI_P_3, TI_P_4, TI_FN_1	X	X			M	X	M	X	X	X
5.4	Loss of TI (Nodes working). Increase separation of pair of nodes representing one end of a wagon from the pair on the other virtual wagon whilst carrying out TI check.	• Check that TI is confirmed with small variations from initial measurement (representing difference between min and max coupling extension and curve effects) • Check that TI is not confirmed when distance exceeds threshold.	TI_FS_1, TI_FS_6	X	X			M	X	5.4.1 S 5.4.2 C 5.4.3 S	X X -	X	X
8	Communication band range	Measure maximum range of communication band. Signal quality measurements at different distances		X	X			S		C	X	X	X

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Example - Test for the Relevant Environment

Test Part	Description	Checks/ Measurements/ Verifications
2.1.1	Check DS function and result (accuracy at different separations)	For each measurement, measure separation and DS result
2.2	Check DS function with multiple nodes responding.	For each measurement, measure separation and DS result and node ID
5.1.1	Arrangement of nodes representing distribution of nodes on a train. Without adjacent nodes (representing other wagons/trains not in consist)	Confirm Network Discovery (ND) and measure time taken (check less than 60s)
5.3.1	Respond to automatic (at different intervals) and manual TI confirmation requests (check correct confirmation of TI and that it corresponds to distribution of nodes on virtual/real train)	Confirm Train Integrity (TI) within time limit.
5.4	Loss of Train Integrity (Nodes working). Increase separation of pair of nodes representing one end of a wagon from the pair on the other virtual wagon whilst carrying out TI check.	• Train Integrity (TI) is confirmed with small variations from initial measurement (representing difference between min and max coupling extension and curve effects) • Train Integrity (TI) is **not** confirmed when distance exceeds threshold.
8	Communication band range	Measure maximum range of communication band. Signal quality measurements at different distances

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OTI "corridor" tests (Turin, Italy)

Test and improve main functionalities of OTI system in laboratory scale

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OTI Controlled Environment tests (Barrow Hill, UK)

Test environment involved a train of railway vehicles (incl. locomotive)

- **First installation of Communication Nodes on real Train.**
  - **Locomotive + 4 wagons**
- **Simulated lost of Train Integrity.**

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OTI Test process- methodology used

Power Consumption Tests (Southampton, UK)

Lab “corridor” tests (Turin, Italy)

Controlled Environment Tests (CE) (Barrow Hill, UK)

Car park tests (Turin, Italy)

Relevant Environment Tests (RE) (Athens, Greece)

New power consumption measurements (Turin, Italy)

Mitigation actions have been required and implemented

- CE tests issues: Topology generation issues
- Modifications of the SW of OTI devices
- “Intermediate “ Carpark tests done before RE tests
- RE tests devices → New power consumption measurements

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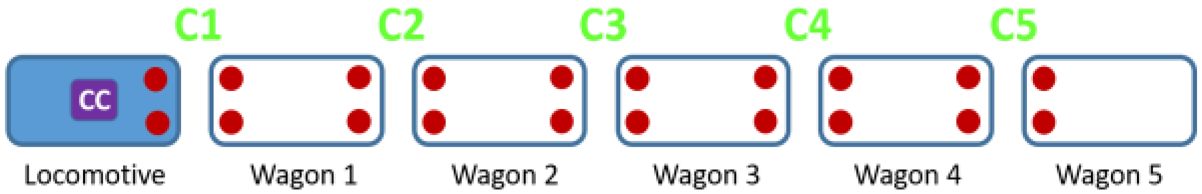
OTI "carpark" tests (Turin, Italy)

- Introduced as mitigation actions to solve issues and drawback encountered during Controlled Environment tests
- Tests performed replicating real train wagons distance
- Verify robustness of the system prior to scaling to Relevant Environment



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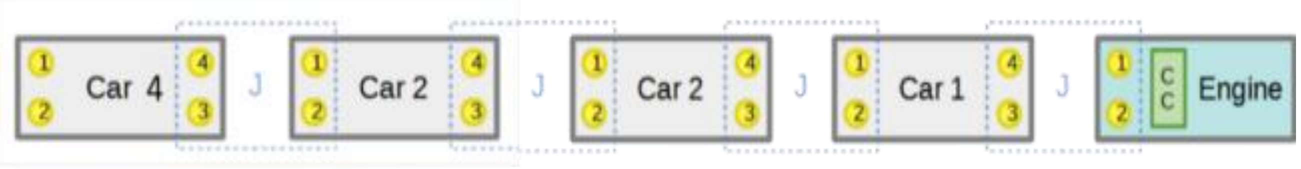
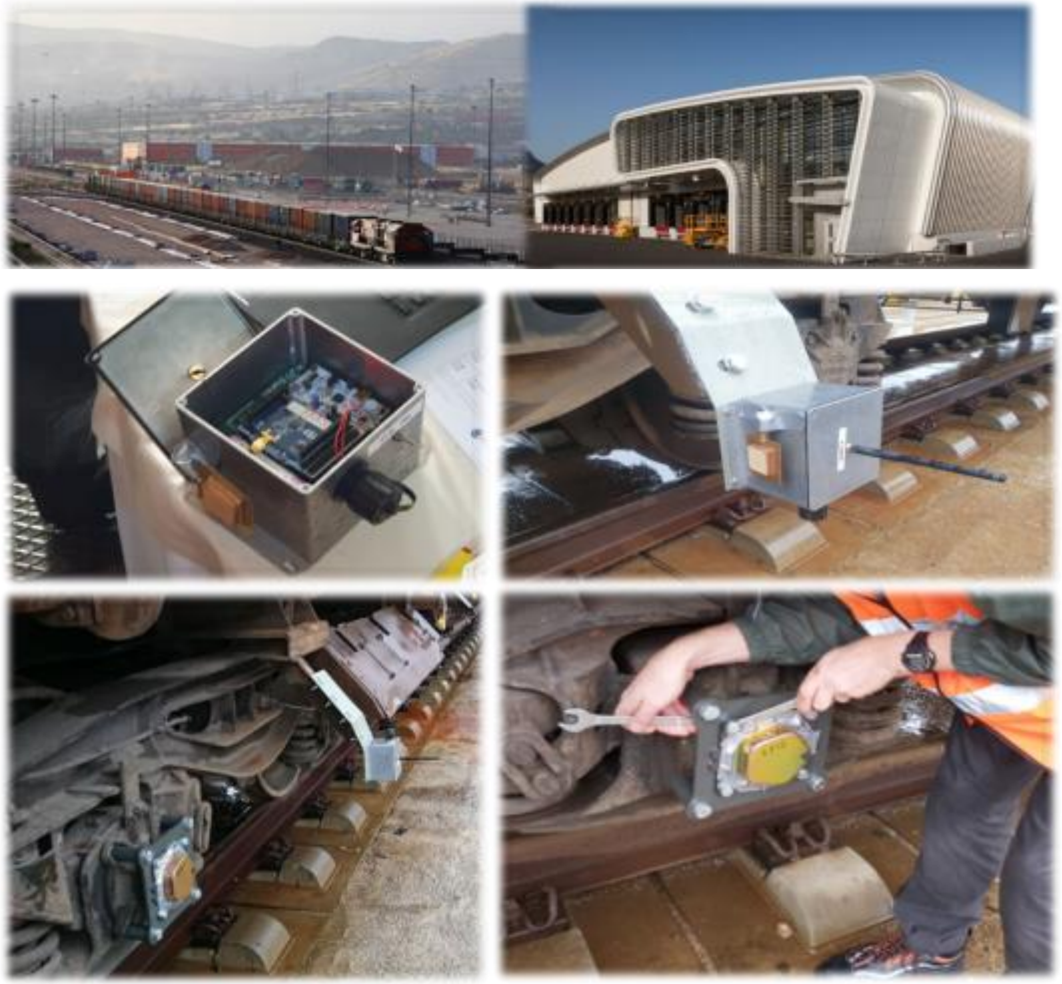
OTI Relevant Environment tests (Athens, Greece)

- ✓ OTI devices fitted to railway vehicles
- ✓ Real train circulation conditions
- ✓ Tests done according to OTI test Matrix
- ✓ Energy Harvester power tests





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OTI test process - Results

- **EH Power Output test:** 56mW, at a vibration level representing 100km/h and 49mW, at a vibration level representing 80km/h.
- **Estimated OTI power requirements based on individual components measurements:** 37mW
- **Laboratory "corridor" tests:** Enhancement OTI system → tuning specific parameters
- **Controlled Environment tests:**
  - Issues with Network Discovery (ND) – robustness of communication.
  - Loss of Train Integrity (TI) tests successful.
- **Pilot-scale "car park" tests:** A better radio link (mitigation action).
- **Relevant Environment tests:**
  - Train Integrity (TI) functionality validation - Integrity monitoring, detection of loss of train integrity
  - Vibration Energy Harvester power tests
- **New consumption tests: Higher** Average power consumption: 353mW and 379mW (4V used Voltage), when running OTI checks as tag/anchor (due to mitigation action)

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OTI tests Conclusions

OTI communication system

- ✓ Successfully demonstrated OTI functionality working in different scenarios
  - UWB distance measurement shown to be capable and suitable in railway environment
- ✓ Wagon permutation functionality was demonstrated in Turin to S2R-IP2 partners
- ✓ Power consumed by the OTI prototypes is greater than an energy harvester can support
  - Electronics not optimised - unnecessary functions consuming power
  - Further work likely to be able to reduce power consumption to levels suitable for vibration energy harvesters - efficient electronics, removing unnecessary features
- ✓ Overall: demonstrated as capable and suitable for performing On-Train integrity checks

On-Train Energy Harvesting

- ✓ Vibration energy harvester platform demonstrated to support communication system with power requirements similar to optimised OTI

Integrated EH powered OTI system

- ✓ Overall test results indicate that VEH maybe able to power an optimised OTI design, however further research work and experimental tests are required to demonstrate this.

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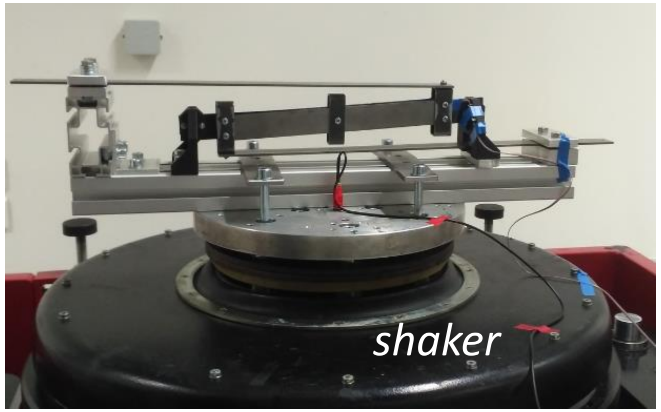
Trackside Energy Harvesters - Test Scenarios

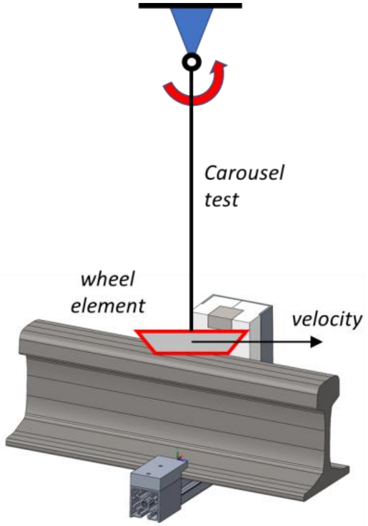
Vibration (V) TEH



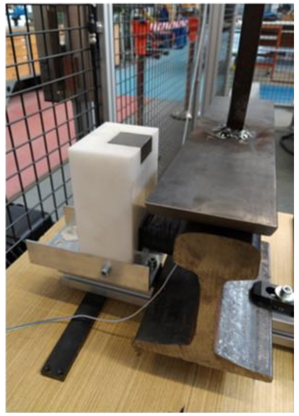
Shaker lab tests of V TEH:
- Resonance/pulse operation

Shaker test of train vibrations:
- Load + Power management electronics
- Energy storage elements
- Communication modules

Variable Reluctance (VR) TEH

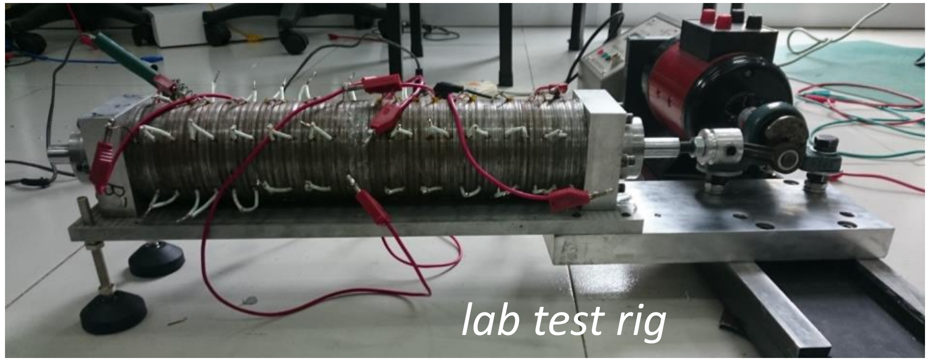


speed test rig



- **Low speed robotic test**
  - up to 3.5 m/s
- **High speed test rig**
  - up to 25 m/s
- **Validation of parameters**
  - Magnetic losses

Linear Generator (LG) TEH



Prototype LG - Stage 1Test
- Validate constructions of linear generator
- Simple to set up test rig
- Shaft continuous reciprocating motion
- @ 400rpm (max. test speed)

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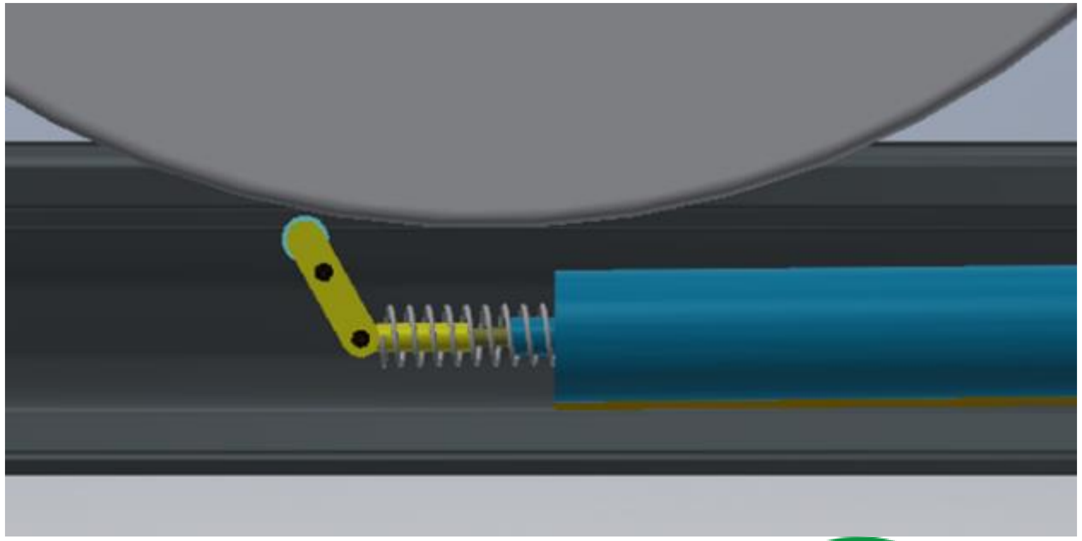
Testing Linear Generator TEH

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
- Test rig designed to replicate linear generator motion as in LG TEH
  - Cam with 2 lobes separated by base radius
  - Intermittent actuation with pause between return stroke
    - Representing pause between wheels of passing train



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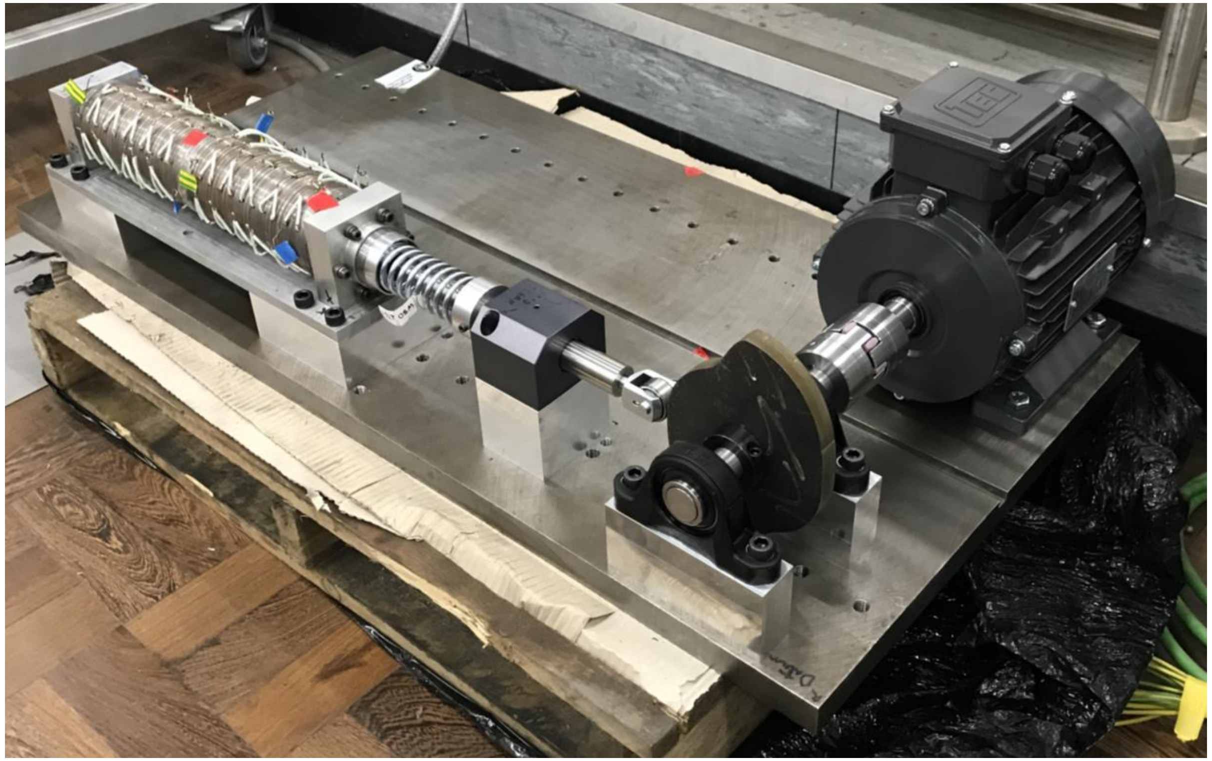
Linear Generator TEH - Test Results

Energy output based on initial tests:

- @ 400rpm max continuous power output 5.62W
- Equivalent LG shaft speed to train passing LG TEH at 4.5 km/h
- 0.85J per wheel pass
- For 968 Axle daily traffic @ 4.5km/h: 821J/day
- <u>0.23Wh/day</u>



Energy output based on Stage 2 test pending analysis of results

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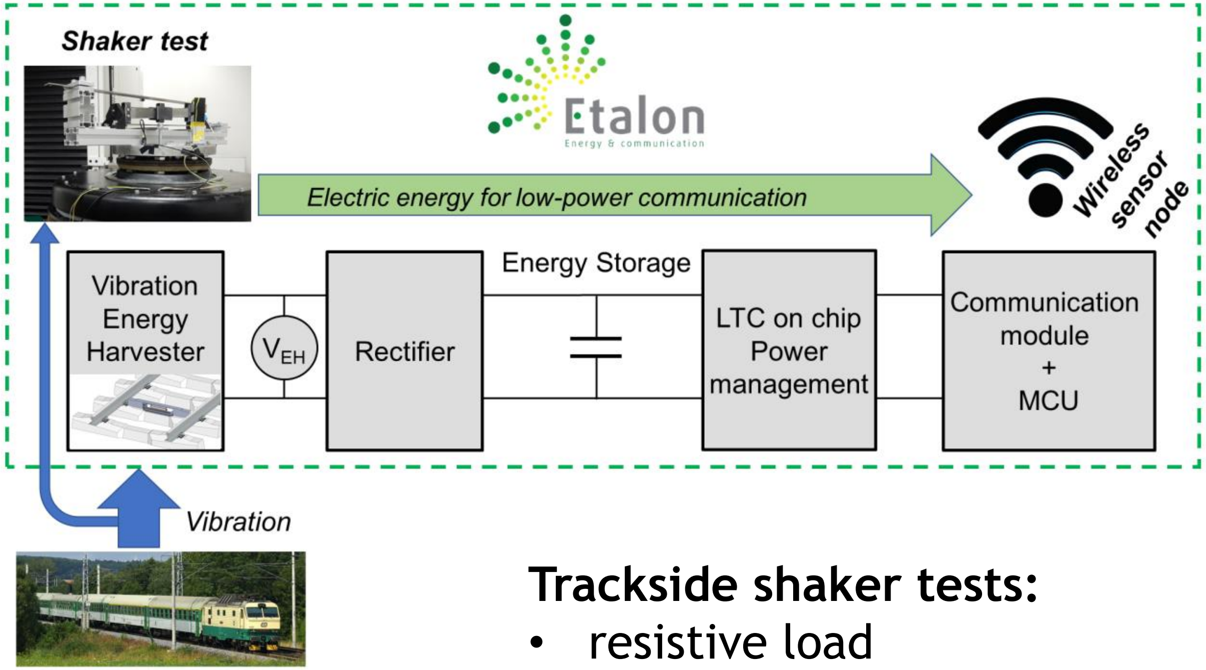
Vibration TEH Test Sequence shaker test + communication

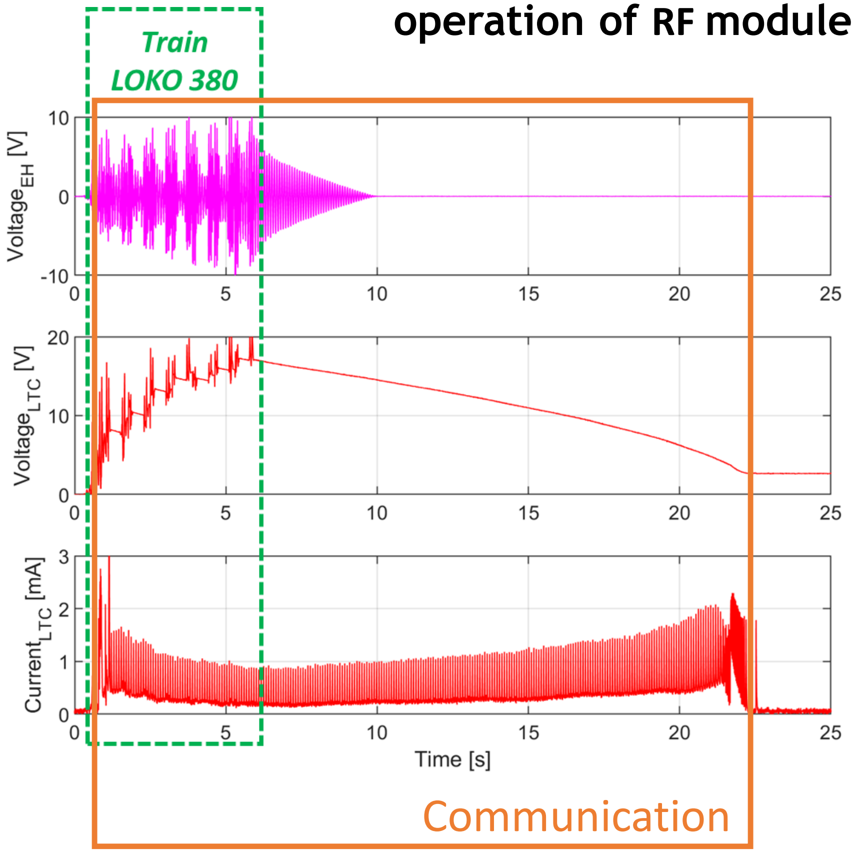
Vibration sequences:
- LOKO 150 (Regional train 80 km/h)
- LOKO 380 (Express train 130 km/h)



shaker can reproduce vibrations measured on the trackside

Trackside shaker tests:
- resistive load
- power management electronics + energy storage
- communication module 2.4 GHz
- communication module LoRa

Response of Vibration TEH + operation of RF module



Vibration TEH - Test Results

- **Max continuous power output at 150 Ohm are:**
  - Passenger train 140km/h - 29.3 mW (harvested energy 167 mJ)
  - Passenger train 80km/h - 9.1 mW (harvested 77 mJ)
- Average power in time of passing train could be in range 5 – 50 mW (it depends on track quality and train type).
- **Efficiency of developed energy storage electronics is around 50 % for continuous operation** (it allow employing of ultra-low power electronics)
- **Both trains generate enough energy for RF communication**
  - **Power consumption of communication module was around 4.5 mW**
  - **6 sec of train vibration = 22 sec of communication**
- **Both trains generate enough energy for Lora communication**
  - possible to send one message using harvested energy from passing train
- Useful source of energy for trackside monitoring application *(operation just in time of passing train)*.

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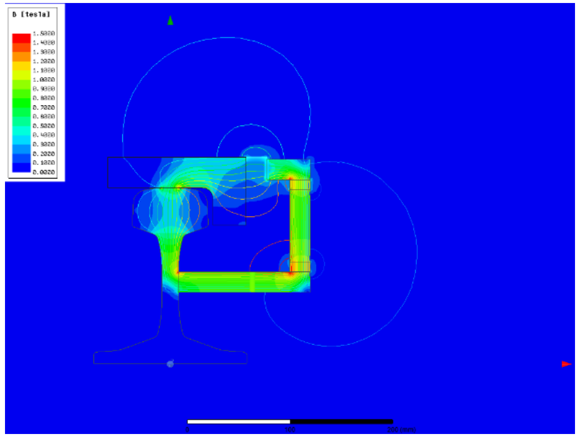
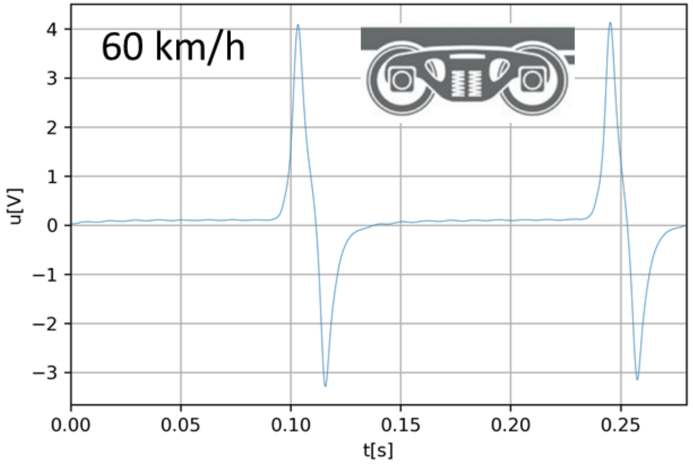
Variable Reluctance TEH – Conclusions of low speed and high speed tests

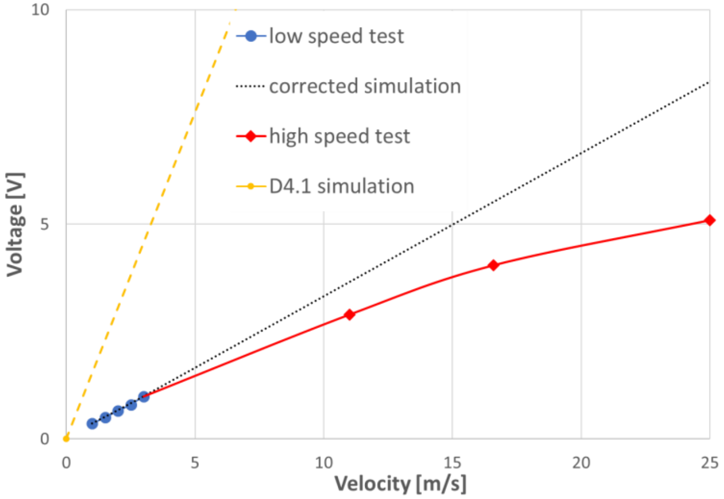
- Simulation model of magnetic circuit provide much more optimistic outputs of magnetic field that were measured on installation test.
- Under development process magnetic losses in the order of a few percent were considered, but in fact cumulatively these losses are enormous.
- Voltage peaks in range of 3 – 5 V are generated, maximal power is around 10 mW, harvested energy per wheel is in range 0.3 - 0.9 mJ
- **Both speed tests show that this solution does not provide effective energy harvesting technology for trackside.**



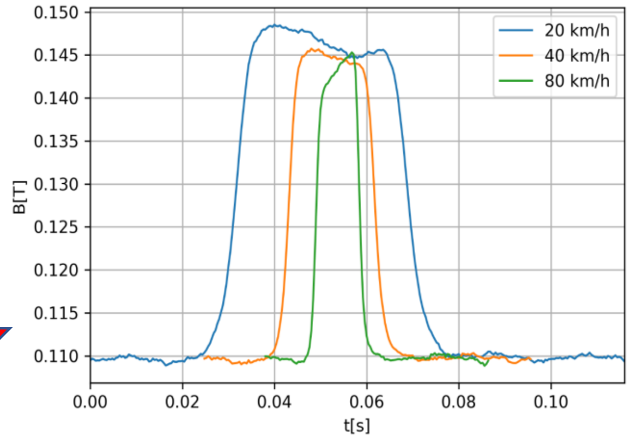
Unexpected magnetic losses in system

Electrical measurements





Magnetic measurements



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Comparing TEH Test Results

TEH Technology	Abbreviation	Energy Harvested per wheel	Conditions
Variable Reluctance TEH	VR TEH	Approx. 0.3 - 0.9 mJ per wheel	speed in range 40 - 90 km/h
Vibration TEH	V TEH	Approx. 2 mJ per wheel set	80 km/h passenger train
Vibration TEH	V TEH	Approx. 6 mJ per wheel set	130 km/h passenger train
Linear Generator (contact) TEH	LG TEH	Approx. 0.85J per wheel	4.5km/h train
Linear Generator (contact) TEH	LG TEH	Approx. 0.47J per wheel	3.4km/h train

- VR and LG energy harvesting related directly to wheels passing harvester
- Vibration dependent of type of train as well as speed
- Vibration is net effect of whole train – more difficult to estimate per axle
- LG TEH requires direct contact between wheel and generator, others are passive
- Test conditions for each TEH technology not directly comparable

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TEH - Test Conclusions

- TEH technologies investigated, developed and tested
  - Variable reluctance from passing wheels limited by clearances required (TRL5)
  - Vibration device provides energy for communication just when train is passing (TRL4)
  - Linear generator, higher output, issue with acceptance of wheel contact (TRL4)
- Low levels of power, suitable for intermittently powering microelectronics achievable
- Investigated technologies, or similar unlikely to be efficient or effective for powering trackside equipment
- Renewable energy sources (solar, wind) potentially more effective for efficient reliable power source

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WP5 Conclusions

- OTI monitoring system developed and tested in railway environment
  - Wireless communications for OTI messages along train
  - Distance measurement for detecting Loss of Train Integrity
- On train energy harvesting for powering OTI devices feasible
  - Energy harvester powered wireless communication along train was demonstrated
- Trackside energy harvesting technologies have been developed
  - Energy harvested unlikely to provide sufficient power for current trackside object controller or continuous communication
  - Ultra-low power trackside object controllers that could exploit trackside energy harvesting can now be developed.

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Thank you for your attention!

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