C4R
Capacity for Rail

Sustainable strategies for monitoring in slab track

WP43. Implementation in new structures

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SEVENTH FRAMEWORK PROGRAMME

Contents

- Motivation, Goals and Tasks
- Identification of Monitoring Needs
- Analysis of Market Available Technologies
- Selection of Technologies
- In-lab tests
- Installation procedures and guidelines
- Conclussions

Motivation

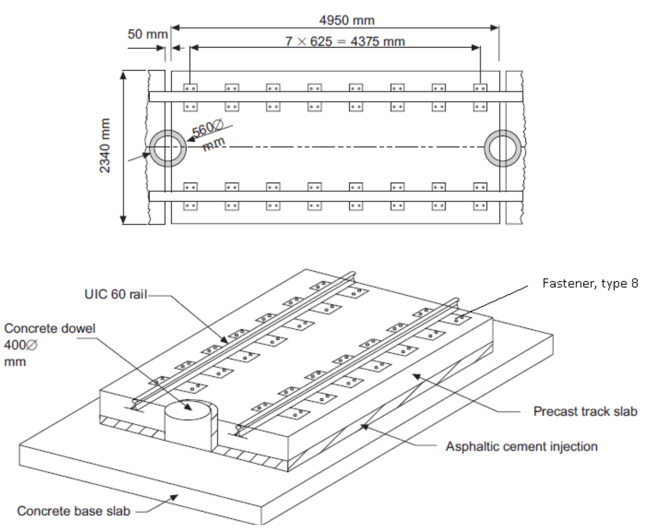
- The state of the rail infrastructure is mostly dependent on the age and local conditions (e.g. ground conditions, construction procedures, load, etc)
- These conditions affect the life expectancy and maintenance requirements

Sustainable strategies for monitoring in slab track

C4R Capacity for Rail

Goal

- Development of a monitoring system embedded in the new concepts of slab track developed within C4R
- Based on market available technologies
- Features pursued:
    - Low cost
    - Easy and rapid to implement during the construction of the infra
    - Easy or none maintenance

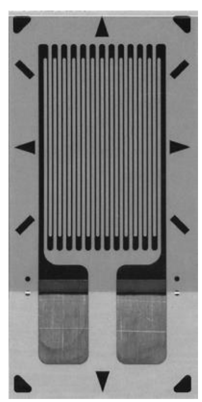


The Shinkansen slab track system

FBB slab track system (Max Bögl)

Tasks for the development of the monitoring system

- Identification of monitoring needs (what to monitor) and requirements (how to do it)
- Analysis of market available sensors and communication technologies
- Selection of most suitable technology according to the main constraints
- In-lab tests
- Drafting of installation procedures
- Deployment at real pilot at CEDEX laboratory



Identification of Monitoring needs

WHY TO MONITOR SLAB TRACKS?

Continuous monitoring may not be necessary because:

- Slab tracks have **very low failure rates.**
- **Track geometry is quite stable** (one of the main advantages of slab track)

But… we need to monitor because:

- In case of failures, repairs are very costly. The early detection of failures could derive in **lower cost repairs**.
- In C4R we aim at **enhancing the infrastructure capacity.** We should avoid track possession booking for inspection.
- In C4R we aim at **improving the competitiveness of railways.** As construction costs in ballastless tracks are high, monitoring is a key factor **to reach the limit of infrastructure utilisation with proper safety.**
- A **better knowledge of track condition** will allow the extension of the life span of the infrastructure and supporting harmful traffic demand, such as higher axle loads, longer trains or mixed traffic.

Identification of railway infrastructure monitoring needs

WHAT CAN WE MEASURE?

1. **Infrastructure condition**
    - Track geometry
    - Rail defects
    - Structural health of the concrete slab and bearing layers
    - Drainage
2. **Operation of rail services**
    - Train detection
    - Train speed measurement
    - Train direction
    - Axle counting
    - Weighing in motion
    - Unbalanced loads
    - Wheel flat detection
    - Single vehicle identification

WHERE DO WE WANT TO MEASURE?

AT CRITICAL SECTIONS, such as transition zones, high embankments, shallow phreatic level, low radii curves…

AT CONTROL SECTIONS

C4R Capacity for Rail

Identification of monitoring requirements (How to measure)

HOW TO MEASURE?

- **Requirements for the integrated monitoring system components**
  - Sensor nodes shall be **low-cost**
  - Sensor nodes shall be **energetically autonomous** (battery-free or energy harvesting methods for self-recharging)
  - Sensor nodes shall be **embedded** in the infrastructure elements (i.e. below some centimetres of concrete)

+

- **Requirements for the Communications systems**
  - **Wireless**
  - **Accuracy** and **precision**
  - Avoidance of **Interferences**

Both **MUST BE compatible**

Analysis of market available technologies

❖ **Study and analysis of wireless communication applications**

- Wi-Fi
- Wi-MAX
- GSM/GPRS
- 3G
- 4G
- BLUETOOTH
- ISM-band
- IEEE 802.15.4
- EPC 18000-6C
- RFID active
- RFID passive

❖ **Specifications**

- **Range** of measurements
- **Consumption**
- Data rate
- Response time

Analysis of market available technologies

- **Study and analysis of wireless communication applications**
  - Wi-Fi
  - Wi-MAX
  - GSM/GPRS
  - 3G
  - 4G
  - BLUETOOTH
  - ISM-band
  - IEEE 802.15.4
  - EPC 18000-6C
  - RFID active
  - RFID passive
- **Specifications**
  - **Range** of measurements
  - **Consumption**
  - Data rate
  - Response time

Analysis of market available technologies

- **Admissible levels for the studied features**
  - **Range** of measurements: a short distance is good enough (--)
  - Data rate: Not continuos monitoring a low data rate is good enough as only few bytes (-)
  - **Consumption:** as lower as possible (---)
  - Response time: not a major constraint (--)
- **Comparison**

	Wi-Fi	Wi-MAX	Mobile	BLE	IEEE802.15.4g	Passive RFID
Range	-	+++	+++	- -	++	- - -
Data rate	+++	+++	+++	+	+	-
Consumption	++	+++	+++	-	-	- - -
Response time	++	++	++	+	+	- - -

- +++ Very high value (of the feature)
- ++ High value (of the feature)
- + Normal value (of the feature)
- \- Low value (of the feature)
- -- Very low value (of the feature)
- --- Ultra low value (of the feature)

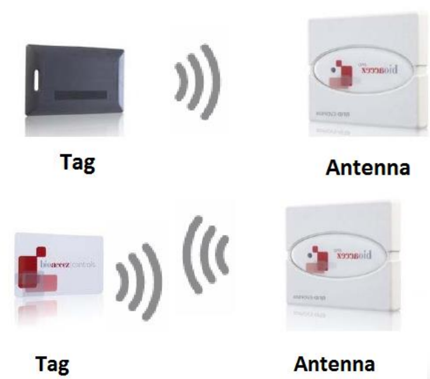
To avoid **interference** with railway infrastructure communication, the reading distance in RFID should be kept below 12 meters

Selected technology: RFID (*Radio Frequency Identification*-Systems)

- **RFID includes:**
  - **Readers**
  - Labels or **tags**

- **Different** ranges of **frequencies:**
  - **Low** frequencies**:** 125-134.2 kHz
  - **High** frequencies**:** 13.56 MHz
  - **UHF:** 868-956 MHz
  - **Microwave:** 2.445 GHz

- **Passive** or **active**
  - **Active***: requires a battery installed in the Tag*
  - **Passive***: power supply is based on the electromagnetic field emitted by the antenna*



RFID (*Radio Frequency Identification*-Systems): Active or Passive systems

RFID sensor tags

Passive RFID (battery free)

- Limited read range
- Discrete measures
- Able to be embedded in the concrete
- Low cost

Research and demonstration within C4R

Active RFID (battery)

- Higher read range
- Ability for continuous monitoring (e.g. accelerations)
- Medium cost

Rechargeable battery

- Able to be embedded in the concrete

Non-rechargeable battery

- In a plug&play monitoring box

Energy harvesting

- Inductive charging with electromagnetic-fields already existing in the railway track

Research but not demonstration within C4R "Vision 2050"

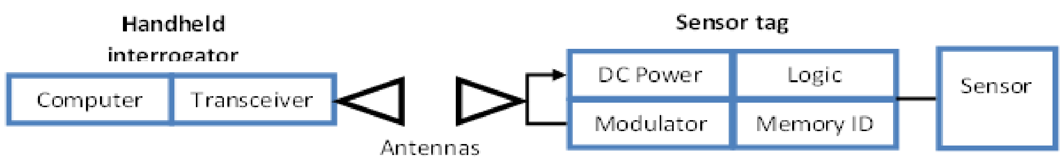
Tag Antenna

Tag Antenna

Selected technology: Passive RFID technology

❖ Limitations of Passive RFID technology

- Do **not** allow **continuous monitoring** → **discrete values** for record parameters
- **Not all devices or sensors** are **compatible** with **RFID** communications → research on relevant sensors
- **Interferences** need to be taken into account



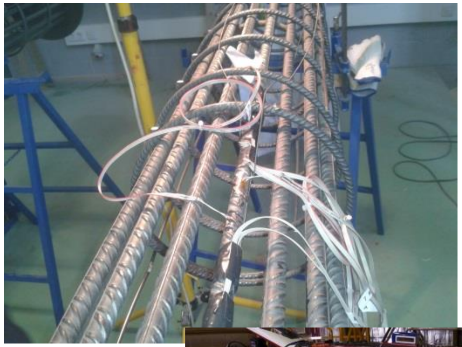
❖ Compatible sensors with passive RFID

- **Needed** of obtaining **relevant parameters** for **Structural Health analysis**
  - **Accelerometers (relevant for modal analysis) are not possible** – they requires continuous or longer times of monitoring
  - **Other critical parameters** must be **considered: strains, moisture, temperatures…**

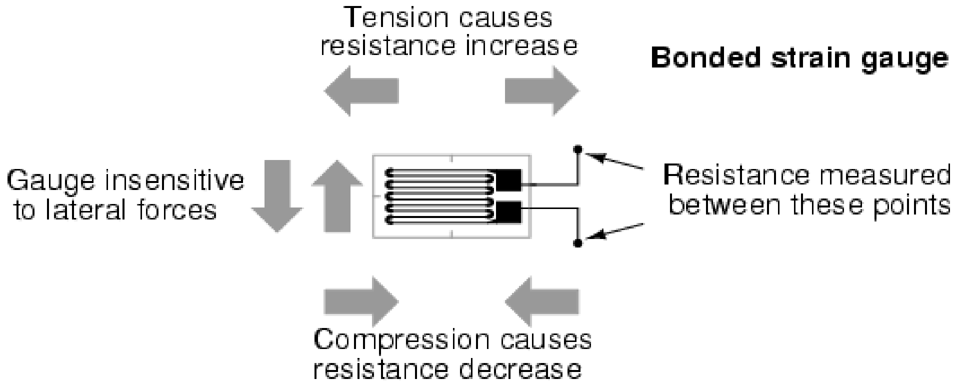
Market available RFID technology and strain gauges

❖ Strain Gauges

- **Strain** measurements
- **Widely spread** in industry
- High level of **reliability** and **accuracy**
- Great **number of** different **applications**

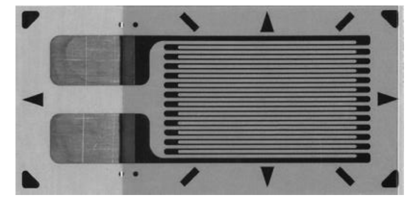


❖ Operating principles

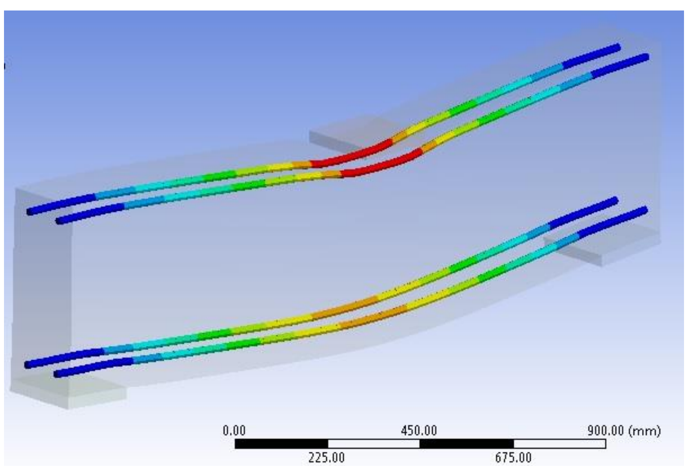


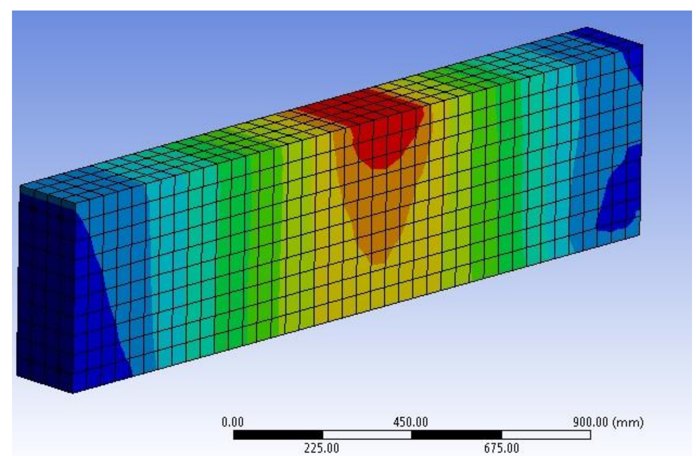
Market available RFID technology and strain gauges

- **Strain Gauges**
  - **Strain** measurements
    - ✓ Strain/deformation in the <u>reinforcement bars</u> of the concrete slab



From the strain determination in the reinforcement bars and through the use of FEM models it is possible to identify the state of stress in a slab or in a beam.

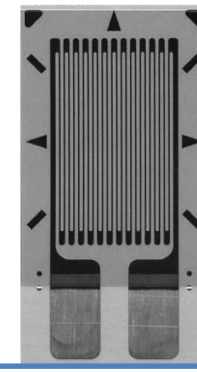




Market available RFID technology and strain gauges

❖ RFID Strain Gauges Restrictions

- Needed of Voltimeter to read results → Vmeter RFID
- Embedded in the concrete block
- Connection between strain gauges and voltmeter are required
- Wireless communication system to send results is a prescription of the system



- Price: 14,50 € (>25 units)

- Vmeter-DCLV10
- Low voltage DC metering
- Voltage range: 0V to 1.5V
- Voltage resolution: from 1.5mV (Gain=1) to 1.5µV (Gain=1000)
- Price: 10.11€ (>500 units)

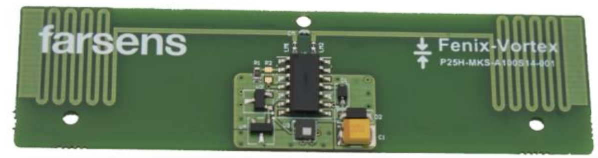
- Price: 3,00 € (>30 units)

Material cost less than 35 € /Passive tag

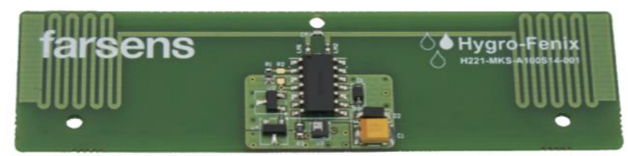
Market available RFID technology

❖ Other RFID compatible sensors

- **Temperature** measurement
  - ✓ Changes in concrete behaviour (<u>sensor embedded</u> in the concrete slab)
- **Moisture** measurement
  - ✓ Detection of possible cracks or failures in the slab (<u>embedded</u> in concrete)
  - ✓ Failures in the performance of the drainage system



- Fenix-Vortex-P25H
- Temperature and pressure sensor
- Temperature range: -30ºC to +85ºC
- Pressure range: 260mbar to 1260mbar
- Price: 13€ (>500 units)



- Hygro-Fenix-H221
- Temperature and humidity sensor
- Temperature range: -30ºC to +85ºC
- Humidity: 0% to 100% (ambient)
- Price: 13€ (>500 units)

All of RFID devices require a **interference assessment analysis** in reinforced concrete (RC) elements

Development of the sustainable monitoring system based on RFID technology

❖ IN-LAB TESTS

A number of in-lab test were performed in order to study the behaviour and performance of passive RFID in real environment

❖ **Purpose of tests:**

- **Analysis of signal attenuation:** due to concrete, steel and PVC coating
- **Different technologies of antennae:** fixed and handheld.
- **Comparison** with active RFID

❖ **Parameters analysed**

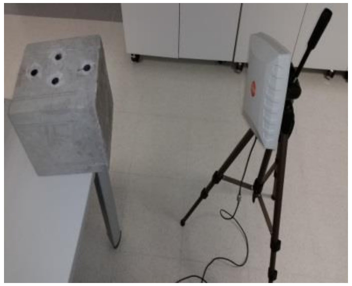
- **Power** of antenna
- **Thickness** of **concrete**
- **Detection distance**
- Maximum **reading distance**
- **Influence of PVC coating** and **steel**

→ **Different test campaigns**

Development of the sustainable monitoring system based on RFID technology

- **IN-LAB TESTS**

- **Attenuation signal analysis**
  - Different concrete thickness
  - Possible steel interferences
  - PVC coating for RFID sensor



Development of the sustainable monitoring system based on RFID technology

❖ **IN-LAB TESTS**

❖ **Different technologies of antenna**

- Fixed antenna: directional and cylindrical
- Handheld mobile RFID reader

	Directional antenna	Cylindrical antenna
Frequency	860 – 970 MHz	860-960 MHz
Gain	6 dBi	6 dBi
E-plane beam width	60°5°	67°5°
H-plane beam width	74°5°	69°5°
Nominal read distance	8 m	5 m
Polarisation	Directional	Cylindrical

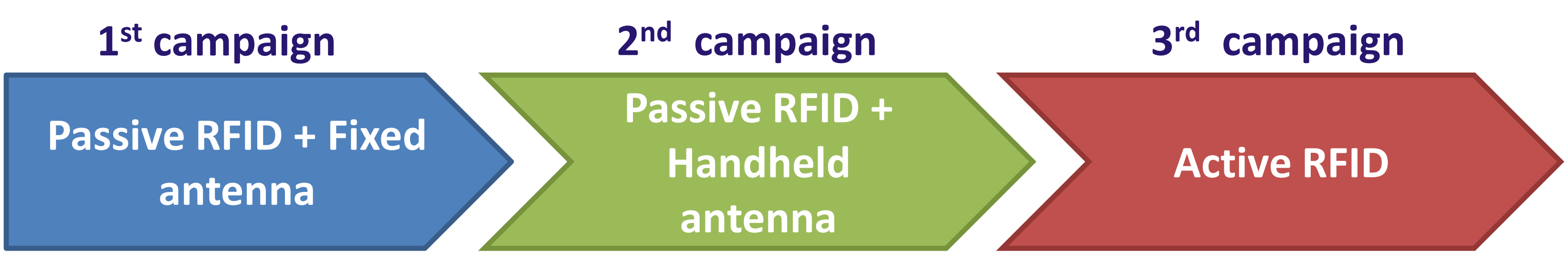
Development of the sustainable monitoring system based on RFID technology

- **IN-LAB TESTS**

- **Summary of test campaigns**

Objectives

- 1st campaign → Passive RFID + Fixed antennae
- 2nd campaign → Passive RFID + Handheld antenna
- 3rd campaign → Active RFID



Development of the sustainable monitoring system based on RFID technology

- **IN-LAB TESTS**
- **Test campaigns**

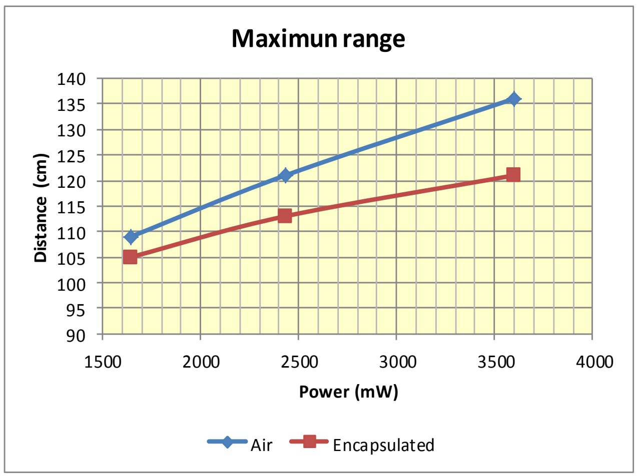
	Concrete	Steel	PVC coating	Air
Passive RFID + Fixed Antennae	X	X	X	X
Passive RFID + Handheld Antennae	X		X	X
Active RFID	X			

Development of the sustainable monitoring system based on RFID technology

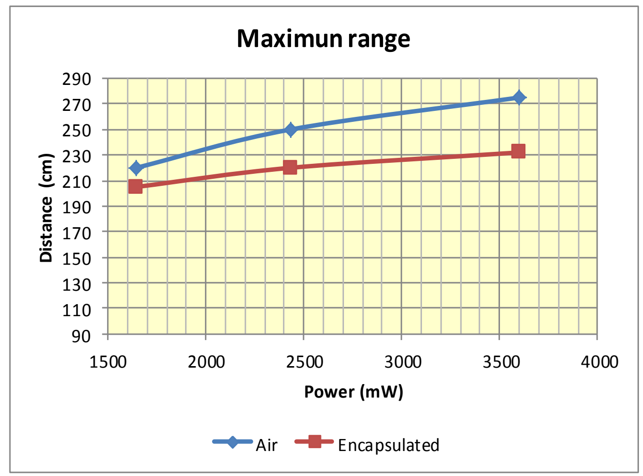
IN-LAB TESTS: 1st CAMPAIGN. FIXED ANTENNAE

- Results for **maximum range** (*maximum measurement distance)*

Cylindrical antenna



Directional antenna



- **PVC encapsulation** of RFID tag resulted in **decreases of around 10%** in maximum range
- **Directional antenna** offers notably **better results (increases of more than 70% for both conditions)**

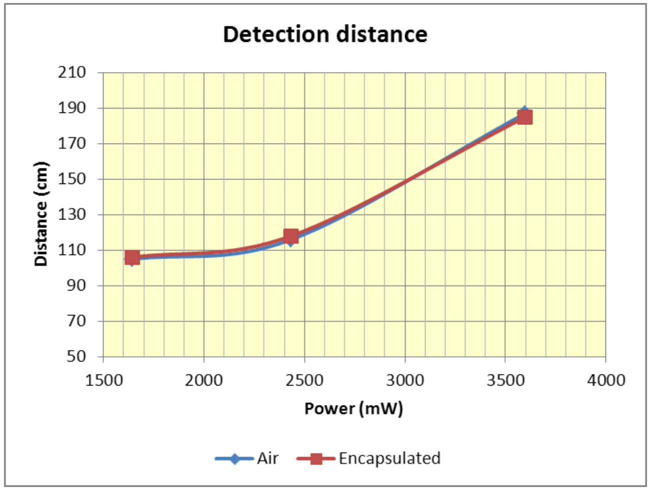
C4R Capacity for Rail

Development of the sustainable monitoring system based on RFID technology

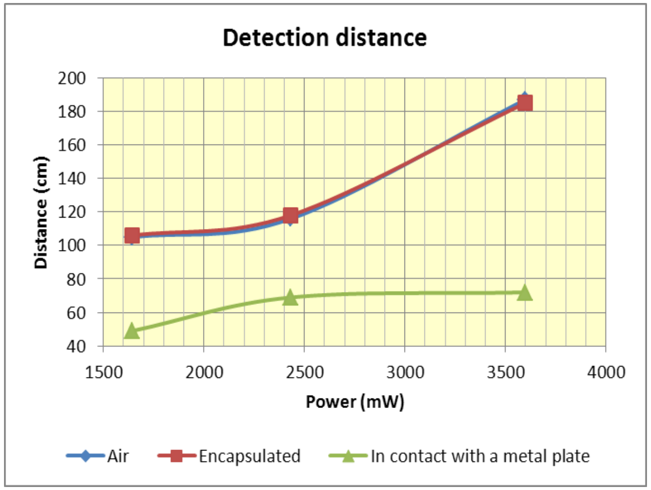
❖ IN-LAB TESTS: 1st CAMPAIGN. FIXED ANTENNAE

- Results for **detection distance** (*distance at which reader recognize the RFID tags*)

Cylindrical antenna



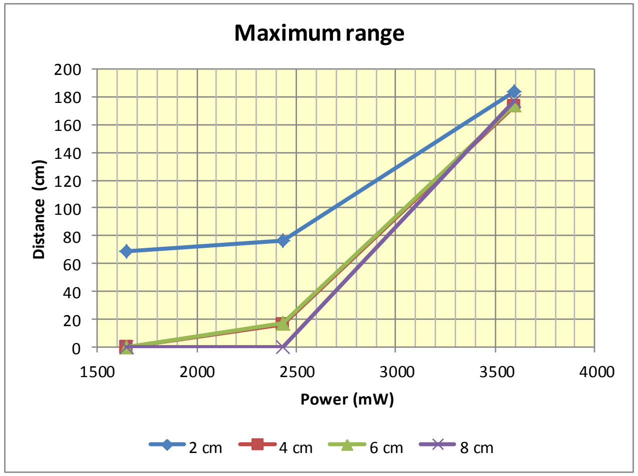
Directional antenna



- **PVC encapsulation** of RFID sensor does not show any effect on the detection distance
- **The contact with a steel plate** shows a high level of **attenuation** in the signal
- **Directional antenna** shows a better performance

Development of the sustainable monitoring system based on RFID technology

- **IN-LAB TESTS: 1st CAMPAIGN. FIXED ANTENNAE**
  - Results for maximum range for different concrete thicknesses – 2, 4, 6 and 8 cm)



- The greater the power, larger distances no matter concrete thickness
- 2 cm (a usual covering for reinforced concrete) allows measuring at reasonable distances
- For the maximum power **– RFID is able to be read through 8 cm of concrete.**

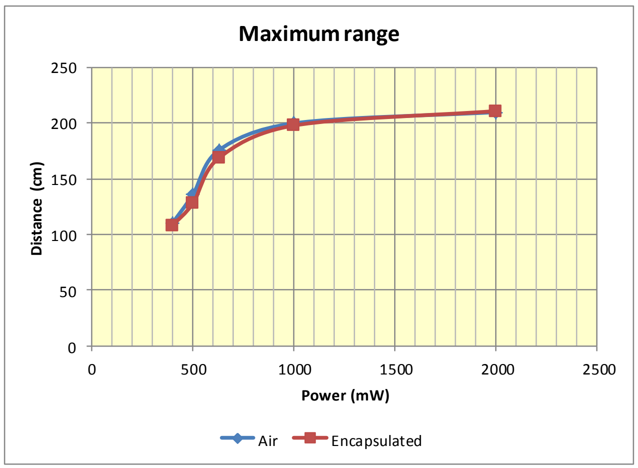
C4R Capacity for Rail

6. ADVANCED MONITORING SYSTEM BASED ON RFID TECHNOLOGY

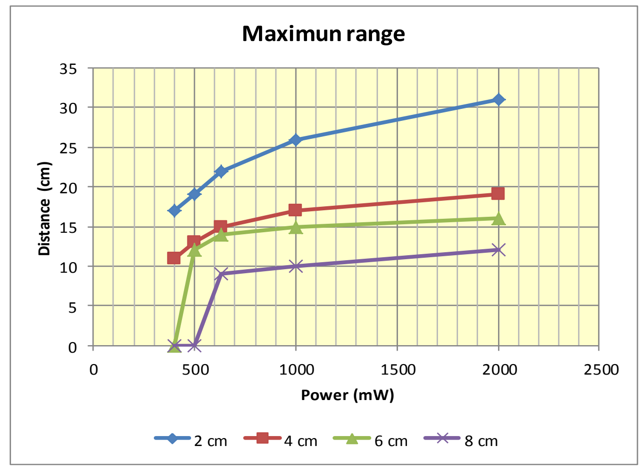
❖ IN-LAB TESTS: 2ND CAMPAIGN. HANDHELD ANTENNA

- Results for maximum range in different environment

Without obstacle (air) – PVC coating



Different concrete thicknesses



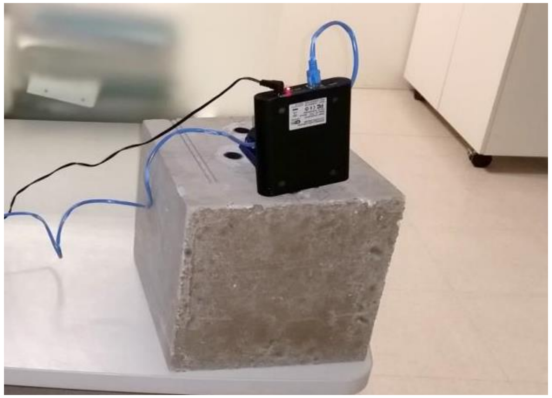
- Similar **maximum range with/ without obstacles and PVC coating**
- **Maximum ranges** are around **25% lower** than the obtained with fixed antennae but lower power
- Handheld reader is able to measure through more than 5cm thickness of concrete at a total distance of 10-15cm

Development of the sustainable monitoring system based on RFID technology

❖ IN-LAB TESTS: 3RD CAMPAIGN. ACTIVE RFID

- Comparison w.r.t. passive RFID
- Maximum range for different concrete thickness

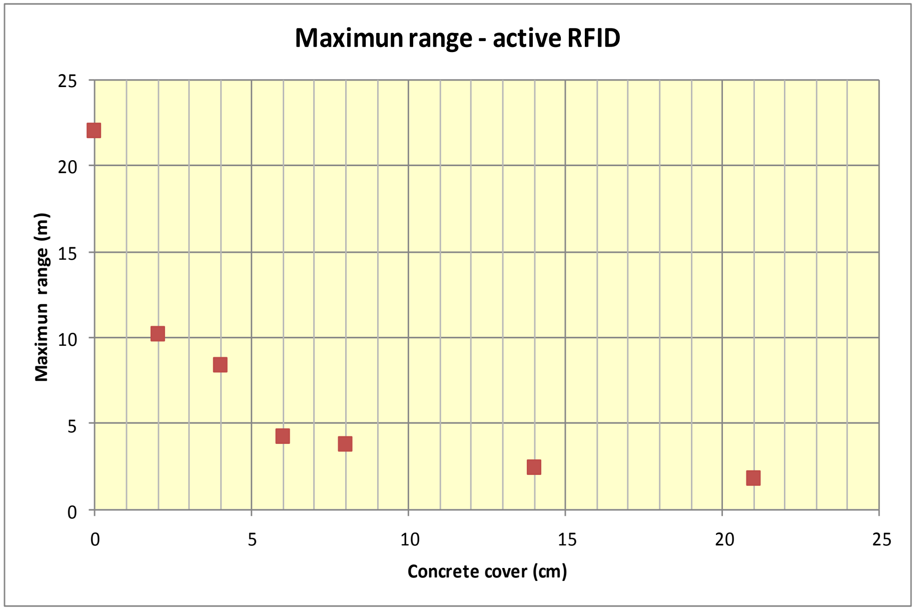
Direction	Unidirectional
Range	30-50 m indoor
Frequency	2.4 GHz
RF Output Power	0 dBm
Sensitivity	-85 dBm
Data rate	1 Mbps



Development of the sustainable monitoring system based on RFID technology

❖ IN-LAB TESTS: 3RD CAMPAIGN. ACTIVE RFID

- Results for the different concrete thicknesses (0, 2, 4, 6, 8, 14, 21 cm)

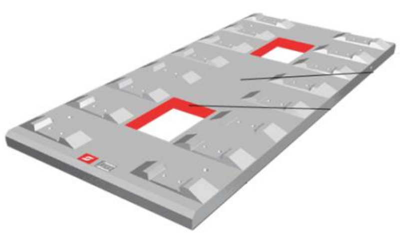


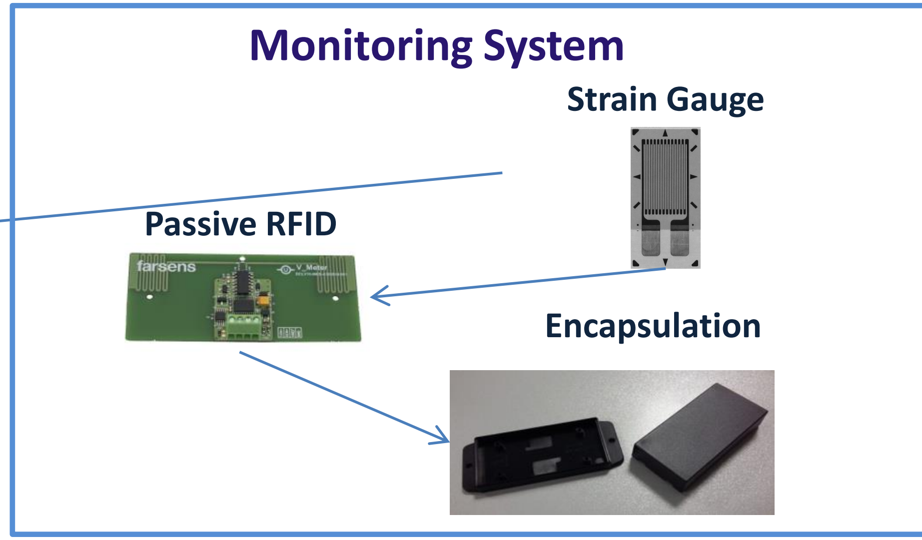
- Results were as expected:
  - Able to read at much **larger distances**
  - Attenuation dependent of inverse square distance

Development of the sustainable monitoring system based on RFID technology

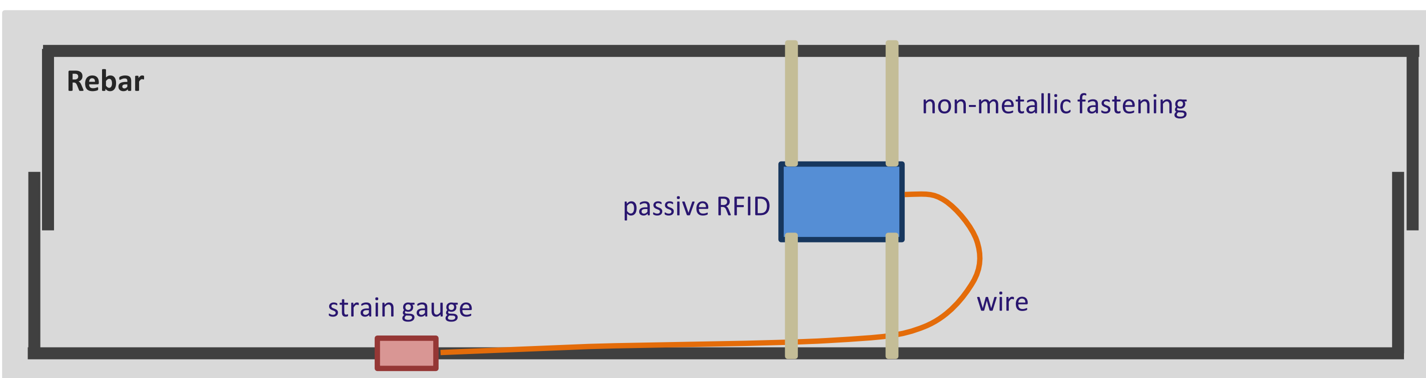
- ASSEMBLY OF SYSTEM

Prototypes SP1



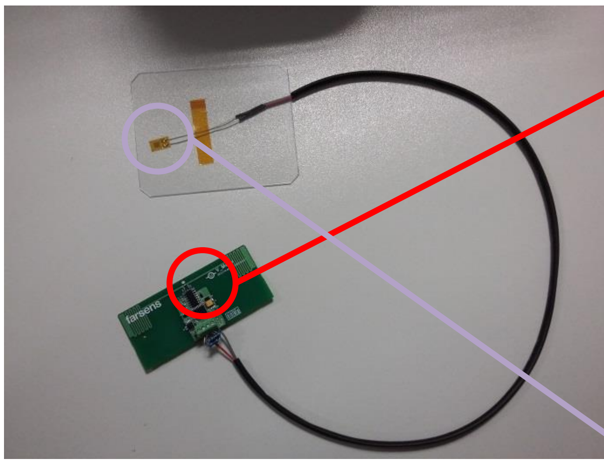


Reinforced Concrete Element

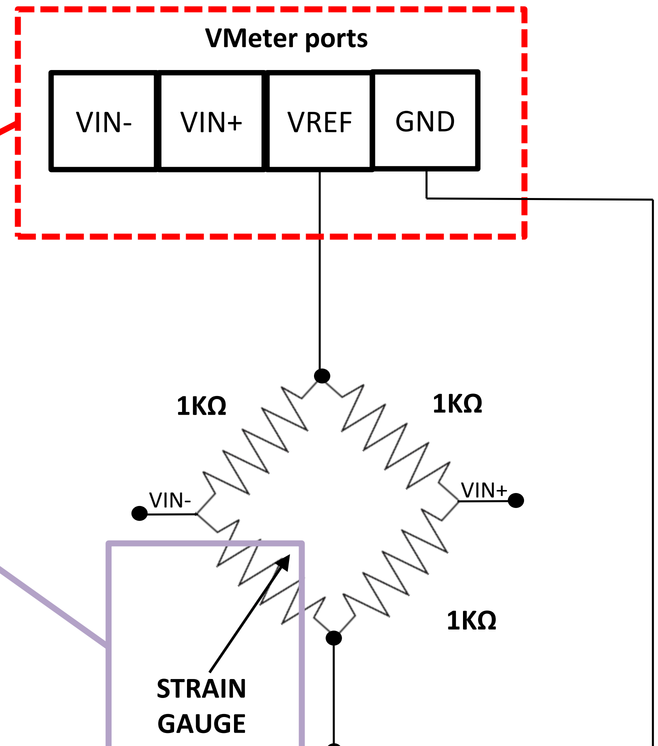


Development of the sustainable monitoring system based on RFID technology

Connections



Vmeter + Wheastone Bridge with Strain Gage

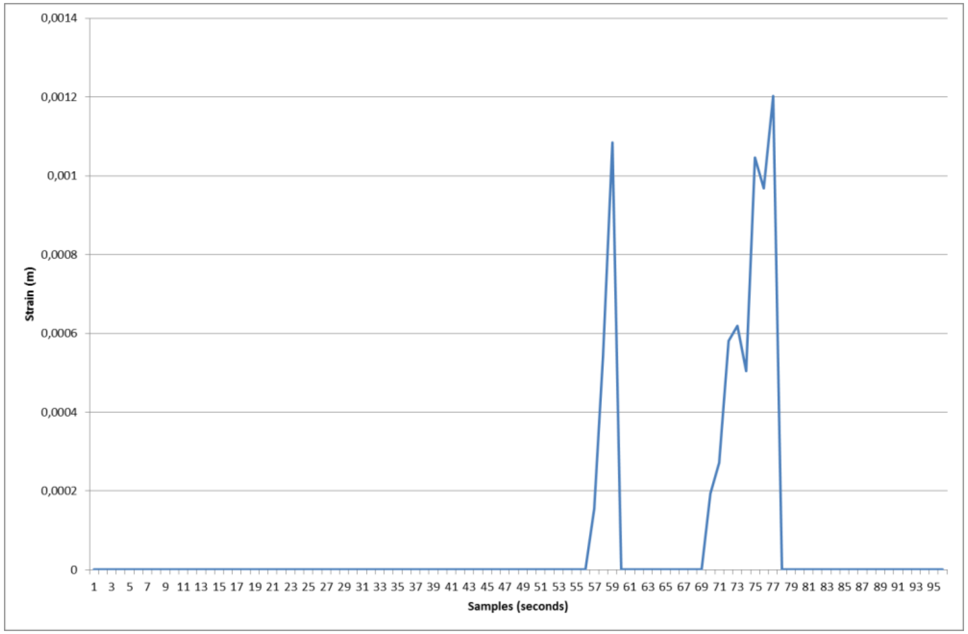


$$\epsilon = \frac{\Delta R/R}{\text{Gauge factor}}$$

$$\Delta R = \frac{4RV_m}{V_R - 2V_m} \qquad \text{Where } Vm := V_{IN-} - V_{IN+}$$

Testing of the monitoring system

Test: puntual stressing of strain gauge



Deployment at real pilot at CEDEX laboratory

INSTALLATION AND
TESTS IN PROTOTYPES SP1
AT CEDEX INTEROPERABILITY RAIL LABORATORY (MADRID, SPAIN)

Summary

- Development of a **monitoring** system for the slab track concepts developed within C4R
- Based on **Passive RFID technology**
- Shows **adequate performance** especially in relation to **measurement distance and energy consumption**
- **Signal attenuation and interference** with other infrastructure communication system analysed
- **Low cost** (less than 35 € per tag), easy deployment, no maintenance

Thank you for your kind attention

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