Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Marketable retro-fit kits for selected applications

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Deliverable 44.2

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Lead contractor for this deliverable:

- ACCIONA

Project coordinator

- International Union of Railways, UIC

1 Executive Summary

This Deliverable D4.4.2 presents the demonstration of retro-fit kits for existing structures, in order to monitor the risk of track buckling on a railway bridge, the structural health of a long span railway bridge and the track condition at a railway transition zone.

It starts to describe the kits design, development and the field installation zones and it finishes showing some data results acquired from the monitoring systems installed.

The retro-fit kits are based on energy harvesting technologies, wireless power transmission, low-current sensors, low-current measuring and data processing electronics and low-current and wireless data transmission. Two monitoring systems were devised for study the three case studies.

2 Table of contents

3 Abbreviations and acronyms

Abbreviation / Acronym	Description
C4R	Capacity4Rail
km	Kilometre
EH	Energy Harvesting
EHM	Energy Harvesting Module
WPT	Wireless Power Transmission

4 Background

With the constant increase of the traffic volume and loads, rail infrastructure is strongly subjected to further degradation reducing the life expectancy and increase the maintenance costs. The application of long-term monitoring systems can prevent critical damages by showing the evolution of the condition of the most important locations.

The current monitoring systems are expensive and are used for a single location and a specific case. To cover different locations cables for energy and data are need and it became a limitation for the maintainer services, especially in rail area.

To implement innovative monitoring technologies into existing networks, investment has to be low. Therefore these retro-fit solutions have to be developed with the focus on:

• Low-current sensor, measuring and data processing electronics

• Movable frogs in high speed switches have much shorter inspection intervals compared with available modern standard switches. A retro-fit sensor kit will help to monitor the behavior and the safety level of these components. Other areas are settlement monitoring, hang-gliding, and the dynamic monitoring of structures of old bridges.

• Low-current and wireless data transmission. The wireless communication enablers, part of the modular Green boxes will allow the connectivity between trains, infrastructure and e.g. switches, via ad hoc networks. Different monitoring technologies could be envisioned for axle counting, using contact and contactless methods. Additional connectivity to GSM-R is foreseen.

• Maintenance-free boxes using energy harvesting for power supply. The modular Green box is provided with energy harvesting technologies. In the rail environment, energy could be harvested, from wind, light, vibrations, EM fields, etc... While devising rail dedicated energy harvesting technologies, rugged solution will comply with all weather conditions and therefore be equipped with the necessary protections and insolation means. Among the envisioned solutions are solar cells, piezoelectric generators, EM induced currents, etc…

5 Objectives

The general objective of this deliverable is to describe the designed retro-fit kits and demonstrate their application in existing structures, in order to monitor the risk of track buckling on a railway bridge, the structural health of a long span railway bridge and the track condition at a railway transition zone. The main objectives to be archived:

1. To describe the designed retro-fitting kits implemented in the concept demonstrators;
2. To describe the field installation zones;
3. To test the two long-term monitoring systems installed to see the feasibility operation of all subsystems (energy, wireless communication and wireless power transmission);
4. To show some monitoring data from the system.

This deliverable has been structured in sections. Section 6 describes the energy power supplies used, Section 7 describes the processing of electronics, Section 8 the wireless data transmission, Section 9 the sensors used, Section 10 the installation zones identification of the two long-term monitoring systems for the different cases and Section 11 shows some results.

6 Energy Power Supplies

6.1 Energy Harvesting Module

A power supply with energy harvesting inputs and a backup battery input was designed. This power supply is the Energy harvesting module (EHM) and has the ability to harvest energy from up to two different power sources and to charge a secondary backup battery.

The main component of the EHM is the *LTC3331*, an energy harvesting integrated circuit developed by *Linear Technology* [1]. Figure 1 shows the typical application for this integrated circuit with two EH inputs and a backup Li-Ion battery.

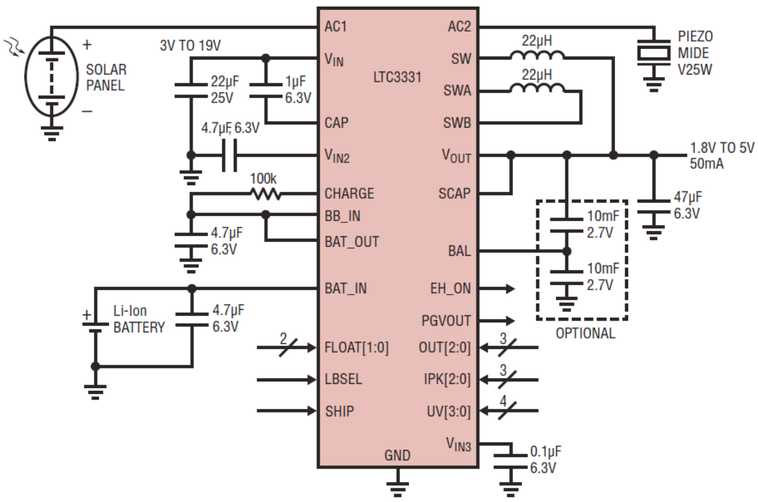


Figure 1 - LTC3331 Typical application [1]

This integrated circuit combines a buck and a buck-boost switching regulators controlled by a prioritizer that selects which converter to use based on the energy available.

Figure 1 shows the CAD representation of this EHM. As it can be observed, it includes the two EH sources input pins (AC1, AC2), a battery input (BAT) as well as a set of configuration jumpers.

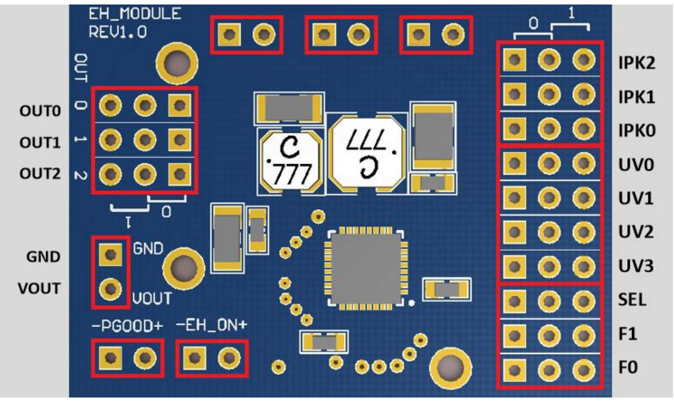


FIGURE 2 - ENERGY HARVESTING MODULE

Overall, the designed module offers great flexibility. Some of its main features are listed below:

- Selectable output voltage that can be configured to 1.8V, 2.5V, 2.8V, 3.0V, 3.3V, 3.6V, 4.5V and 5V. This function makes this EH module compatible with a wide range of microcontrollers and general electronic circuitry.
- Selectable battery float voltage. This function allows the user to trade-off battery runtime and maximum shelf life by defining at which voltage levels it starts and stops charging. These voltage levels can be also adjusted to support different types of battery technologies.
- Undervoltage lockout: Defines the rising and falling voltage input thresholds at which the circuit starts or stops the harvesting operation. This function allows the module to work with different EH sources and different input voltages.
- Integrated low-loss full-wave bridge rectifier that allows the module to harvest from both AC and DC sources.
- PGOOD and EH_ON pins. These can be read by the microcontroller to trigger sensor reading events or to measure the harvested energy.

The maximum output current is 50mA, which is enough to power the microcontroller and wireless transceiver used for the sensor nodes, since it has a peak current consumption of 12mA when transmitting data. The main specifications of this EH module can be seen on table 1.

TABLE 1 - EHM MAIN SPECIFICATIONS

Output Power	Up to 250mW.
Output Voltage	Selectable 1.8V, 2.5V, 2.8V, 3.0V, 3.3V, 3.6V, 4.5V and 5V
AC/DC EH inputs	2 wire-to-board connectors. Supports EH inputs from 3V to 19V
Battery	1 wire-to-board connector. Supports a wide range of rechargeable batteries with selectable float voltages of 3.45V, 4.0V 4.1V and 4.2V
Physical Dimensions	40mm x 30mm

Configuration Jumpers

The EHM has a set of configuration jumpers which enables it to be compatible with a wide range of EH sources, battery technologies and output voltages.

Output voltage

The output voltage can be configured using jumpers OUT[0-2]. This device is able to produce stable output voltages from 1.8V to 5V, making it compatible with most microcontrollers and electronic circuitry. The jumpers' configuration is shown in table 3.

TABLE 2 - OUTPUT VOLTAGE SELECTION

OUT2	OUT1	OUT0	V_{OUT}
0	0	0	1.8V
0	0	1	2.5V
0	1	0	2.8V
0	1	1	3.0V
1	0	0	3.3V
1	0	1	3.6V
1	1	0	4.5V
1	1	1	5.0V

Peak current configuration

Peak output current can be set using configuration jumpers IPK[0-2] shown in table 2. The peak current must be set accordingly depending on the application, maximizing efficiency and offering protection for the electronic circuitry.

TABLE 3 - IPEAK SELECTION

IPK2	IPK1	IPK0	I_{LIM}
ç0	0	0	5mA
0	0	1	10mA
0	1	0	15mA
0	1	1	25mA
1	0	0	50mA
1	0	1	100mA
1	1	0	150mA
1	1	1	250mA

Float voltage

The float voltage configuration pins make the EHM compatible with a wide range of battery types and allows the user to trade-off battery run time and maximum shelf life. A lower battery disconnect threshold maximizes run time since it allows it to full discharge before it disconnects. On the other hand, by increasing the disconnect threshold more capacity remains on the battery when it disconnects, extending its shelf life. Possible combinations are shown in Table 4.

TABLE 4 - FLOAT SELECTION

LBSEL	FLOAT 1	FLOAT 0	FLOAT	CONNECT	DISCONNECT
0	0	0	3.45V	2.35V	2.04V
0	0	1	4.0V	3.03V	2.70V
0	1	0	4.1V	3.03V	2.70V
0	1	1	4.2V	3.03V	2.70V
1	0	0	3.45V	2.85V	2.51V
1	0	1	4.0V	3.53V	3.20V
1	1	0	4.1V	3.53V	3.20V
1	1	1	4.2V	3.53V	3.20V

Undervoltage lockout (UVLO)

UVLO configuration jumpers are used to define the rising and falling thresholds for the input buck converter, depending on the EH sources used. When the input voltage from any of the EH sources rises above the UVLO rising threshold, the input buck converter is enabled and charge is transferred from the input capacitor to the output capacitor. Input voltages bellow the UVLO falling disable the input buck converter.

This configuration allows the overall efficiency of the EHM to be maximised for a given EH source.

TABLE 5 - UVLO SELECTION

UV3	UV2	UV1	UV0	UVLO RISING	UVLO FALLING
0	0	0	0	4V	3V
0	0	0	1	5V	4V
0	0	1	0	6V	5V
0	0	1	1	7V	6V
0	1	0	0	8V	7V
0	1	0	1	8V	5V
0	1	1	0	10V	9V
0	1	1	1	10V	5V
1	0	0	0	12V	11V
1	0	0	1	12V	5V
1	0	1	0	14V	13V
1	0	1	1	14V	5V
1	1	0	0	16V	15V
1	1	0	1	16V	5V
1	1	1	0	18V	17V
1	1	1	1	18V	5V

The first fully functional prototype of this EHM is shown in Figure 3.

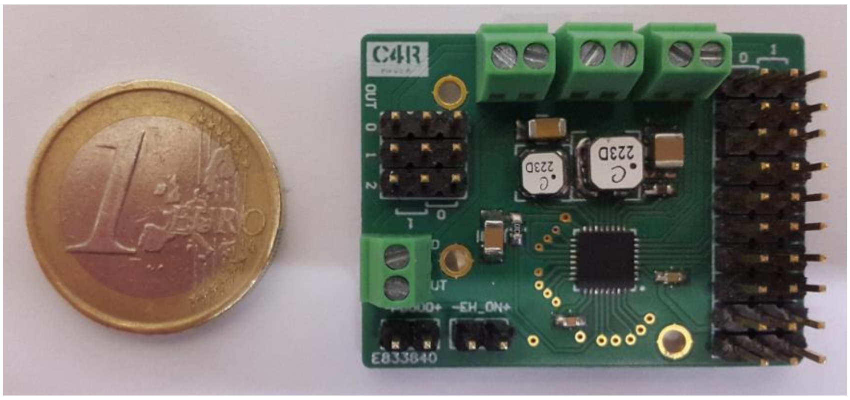


FIGURE 3 - EH MODULE PROTOTYPE

6.2 WIRELESS POWER TRANSMISSION

An alternative to the EH module from the previous section is the EH RF module which is capable of harvesting energy from common ambient RF sources or from a dedicated RF power transmitter. There are currently commercial RF harvesting products like the P2110b module developed by *Powercast Corporation. Porwercast* developed a complete kit (figure 4) that contains an RF energy harvesting platform with efficiencies of up to 70 per cent.

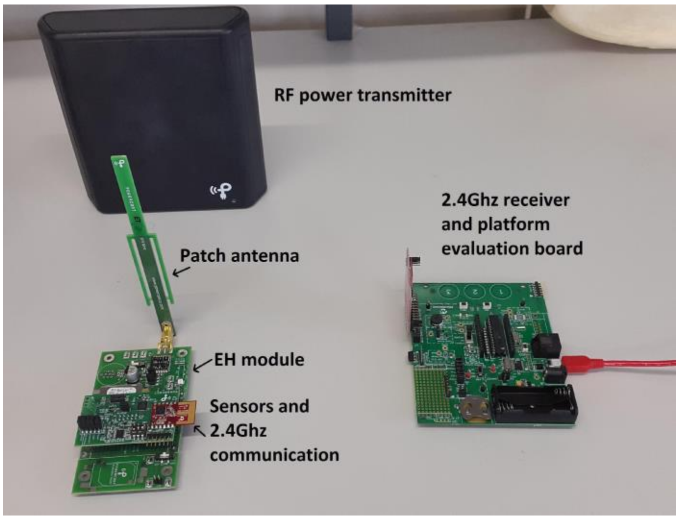


FIGURE 4 - POWERCAST WPT MODULE

Based on the P2110b integrated circuit from *Powercast*, a Wireless power transmission EH module was designed.

This RF EHM is able to operate in a wide RF range and stores the harvested energy in a 50mF supercapacitor. Its output voltage ranges from 2V to 5.5V, configurable via the R1 resistor shown in

Figure 5. For applications where sensor data is sampled at higher frequencies, the total energy required is also higher. Thus, the amount of time the wireless transceiver is on will increase, and since the data transmission represents most of the node's energy needs, EH from a continuous source like this one is recommended. The main specifications for this RF EH module are summarized in Table 6.

This module uses the same *p2110b Powerharvester* from *Powercast and its* CAD representation is shown in Figure 5. Figure 6 shows the first prototype of this WPT EH module.

When the energy storage capacitor achieves the minimum threshold voltage (1.02V), the module boosts this voltage to usable levels and enables the output VOUT. Pins DSET, RESET and DOUT can be used by a microcontroller to optimize the power usage and obtain information about the harvested energy.

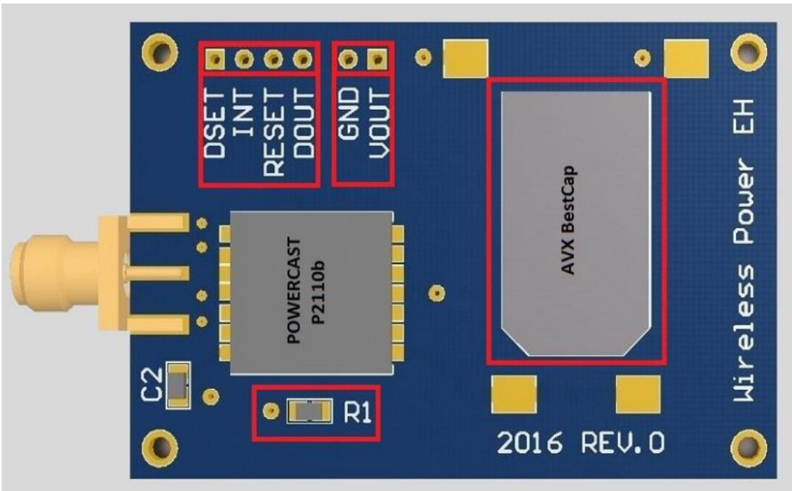


FIGURE 5 - WPT EH MODULE CAD REPRESENTATION

Some of the main features of this WPT EH module are listed below:

- High conversion efficiency;
- Converts low-level RF signals which enables long range applications;
- Regulated output voltage up to 5.5V, making it compatible with most low power electronics circuitry;
- Up to 50mA of output current;
- Wide range of RF operation: from 902 to 928 MHz;
- Dimensions: 38mm x 56mm.

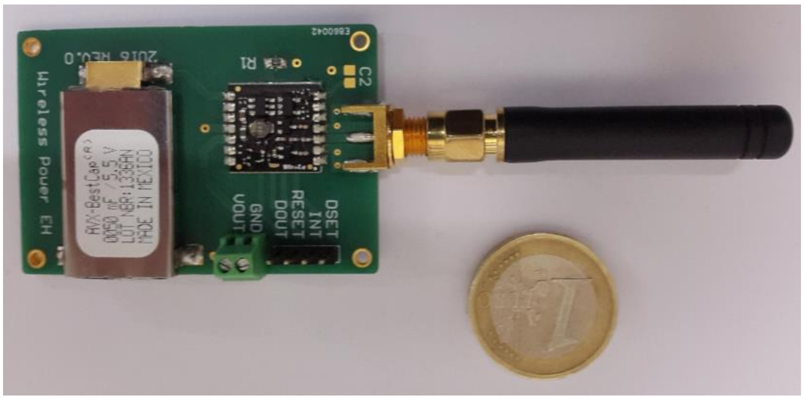


FIGURE 6 - WPT EH MODULE PROTOTYPE

TABLE 6 WPT EH MODULE MAIN SPECIFICATIONS

RF Input Power	-12dBm to 10dBm
RF Frequency	902Mhz to 928Mhz
Output Power	Up to 275mW
Output Voltage	Selectable from 2V to 5.5V
EH inputs	1 SMA male connector for a 50 Ω antenna
Storage	1 50mF supercapacitor. An external backup battery can be connected.
RESET, INT	Reset and interrupt pins for microcontrollers
Physical Dimensions	56mm x 38mm

7 Processing electronics

The processing unit used for these sensors is the SAMR21G18A from Atmel. The Atmel® SAM R21 Xplained Pro evaluation kit, shown in Figure 7, is a hardware platform to evaluate the ATSAMR21G18A microcontroller. This evaluation board is supported by the Atmel Studio integrated development platform, providing easy access to the features of the Atmel ATSAMR21G18A. An on-board embedded debugger is included and no external tools are necessary to program or debug the microcontroller ATSAMR21G18A. This kit also offers additional peripherals to extend the features of the board and ease the development of custom designs.

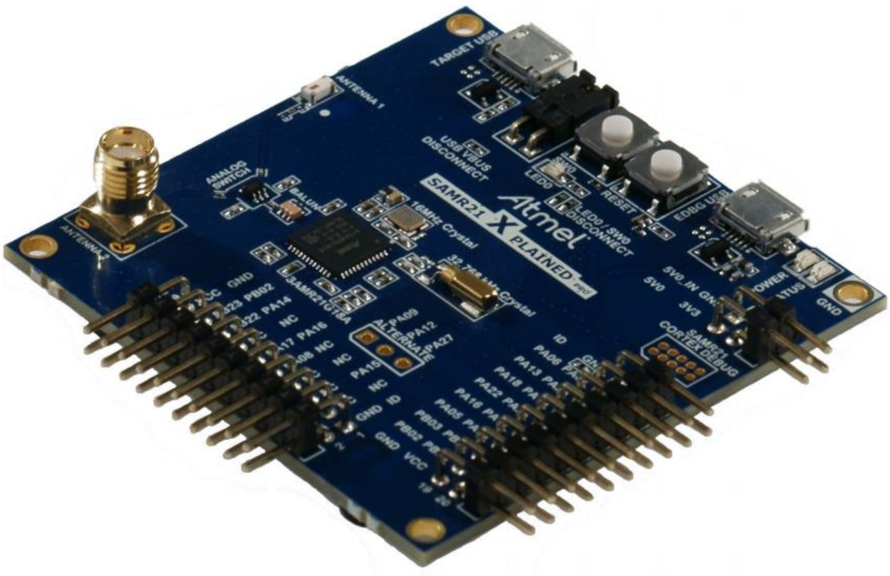


FIGURE 7 - SAM R21 XPLAINED PRO

This microcontroller has a set of key features which make it a suitable option for wireless sensor networks. These main features are listed below:

High performance

- 48MHz operation;
- 2.14 CoreMark/MHz;
- Single-cycle IO access;
- 12-channel event system;
- 12-channel DMA.

Low power

- <70uA/MHz;
- <3.5Ua RAM retention and RTC;
- Internal and external oscillators;

- On-the-fly clock switching and prescaling.

Robust peripheral set

- Ultra-low-power 2.4GHz transceiver;
- Up to five serial communication modules (SERCOM) configurable;
- as UART/USART, SPI or I2C;
- Up to three 16-bit Timer/Counters;
- Peripheral Touch Controller that supports buttons, sliders, wheels and proximity with up to 48 channels;
- Real Time Clock (RTC) and Calendar with leap year correction and 1ppm calibration;
- 12-bit 300kbps ADC;
- Full Speed USB device and host.

8 Wireless data transmission

Gathered data from the sensors is sent via 2.4Ghz wireless using an *Atmel* proprietary protocol called lightweight mesh. It is designed to address the needs of a wide range of wireless connectivity applications and it is suitable for this specific project.

This mesh protocol has some of the following features:

- Simplicity of configuration and use;
- Up to 65535 nodes in one network (theoretical limit);
- Up to 65535 separate PANs on one channel;
- 15 independent application endpoints;
- No dedicated node is required to start a network;
- No periodic service traffic occupying bandwidth.

Network topology

The implemented network topology and possible device types are illustrated in Figure 8. Nodes shown in blue are routing nodes; they form a core of the typical network and expected to be mains-powered. Nodes shown in green are non-routing nodes; they are part of the network and they can send and receive data as long as they are in range and have the radio turned on, but they are not expected to be available all the time.

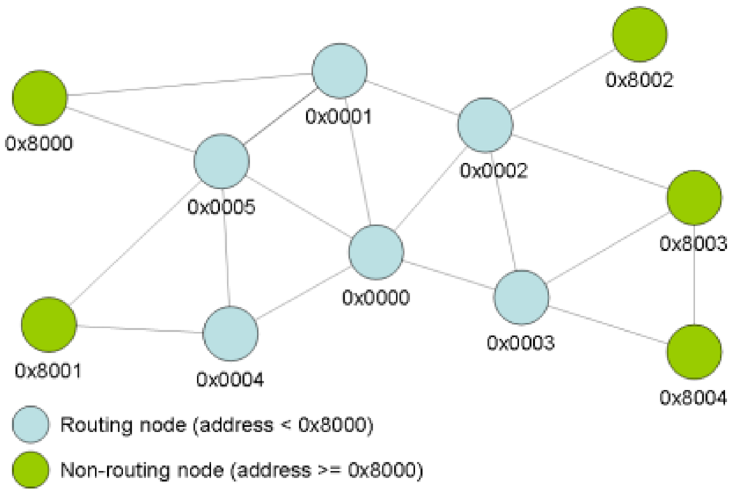


FIGURE 8 - NETWORK TOPOLOGY

A basic set of services are provided by this lightweight mesh topology, like send and receive data and acknowledgements, basic security, routing, power management, etc.

Architecture

The high level architecture of the Lightweight Mesh stack is presented in Figure 9. Lightweight Mesh code is separated into a number of logical levels each providing a set of APIs accessible for the user. The Stack is designed to provide only functions absolutely necessary for wireless communication, and it is expected that the rest will be created by the user, or provided by third-party libraries if required.

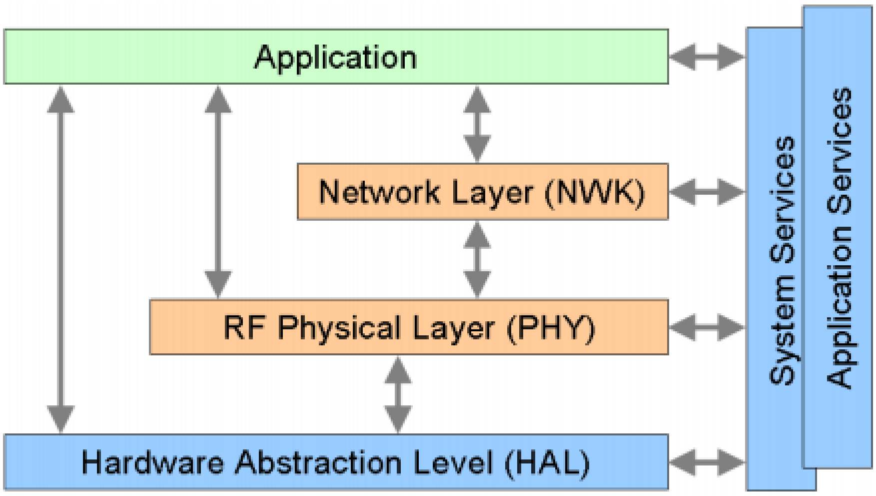


FIGURE 9 - NETWORK ARCHITECTURE

The different layers of the high level architecture are listed below:

- Hardware Abstraction Layer (HAL) which is able to provide basic hardware functionalities, like GPIO access, timers, sleep and deep sleep control, etc;
- Radio physical layer (PHY) provides functions for radio transceiver access;
- Network layer (NWK) that provides the core stack functionality;
- System services provide common functions for all layers, which are necessary for normal stack operation. System services include basic types and definitions, software timers, default configuration parameters, encryption module access, etc;
- Application services include modules that are not required by the stack, but are common for most applications. Currently the only service of this type is Over-The-Air upgrade (OTA). Application services are out of the scope of this document.

Frame Format

The Lightweight Mesh network header and application payload are encapsulated inside the standard IEEE 805.15.4 data frame payload. Figure 10 illustrates a general frame format composed of an IEEE 805.15.4 MAC header, network header, application payload, optional message integrity code (MIC) and a check sum (CRC).

16	8	16	16	16	8	8	16	16	4	4	0/16	Variable	0/32	16
Frame Control	Sequence number	PAN ID	Destination Address	Source Address	Frame Control	Sequence number	Source Address	Destination Address	Source Endpoint	Destination Endpoint	Multicast Header	Variable	MIC	CRC
MAC Header					Network Header							Payload	MIC	CRC

FIGURE 10 - FRAME FORMAT

9 Sensors

9.1 Strain and temperature sensor

Two different versions of a strain and temperature sensor module where designed. Figure 11 shows the first prototype of these sensor boards which were developed in such way that they can be easily integrated and connected to the SAMR21 microcontroller platform.

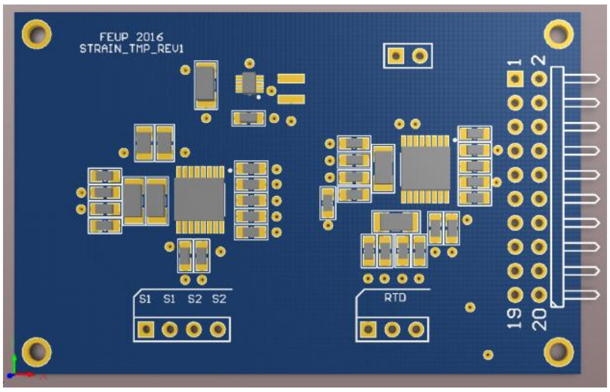


Figure 11 - Strain and Temperature module

The sensor board use two 24 bit analog-to-digital converters in order to read temperature and strain. The first ADC is configured to measure temperature from an RTD external sensor using a 3-wire configuration. It has dual-matched programmable current sources and a programmable gain amplifier which make these board compatible with a wide range of RTDs. A simpler 2-wire configuration can also be used.

As for the second ADC, it is configured for a half-bridge strain gauge circuit. The sensor board has an integrated half-bridge made of two 350Ω resistors with a 0.01% precision that can be completed with two external strain gauges.

Both strain and RTD sensors use an ADC ADS1220 that communicate via SPI protocol to the SAMR21 microcontroller platform.

The current consumption of this sensor board can be as low as 6µA on sleep mode since all of the excitation sources used for the sensor readings can be turned off. When measuring, a special duty cycle mode can be activated, sampling at a maximum of 250Hz with a current consumption of about 150µA. Table 7 summarizes the main specification of this sensor board.

Sampling Rate	20Hz up to 2kHz
Resolution	24 bits
Current consumption	6 µA (standby), 150 µA (duty cycle mode), 12mA (sending data)
Sensors	Integrated temperature sensor Support for one external RTD sensor Support for half bridge strain gauges
Power	Supports external power (regulated 3.3V)
Physical Dimensions	60mm x 38mm

TABLE 7 – STRAIN AND TEMPERATURE SENSOR MODULE SPECIFICATIONS

Figure 12 shows the first prototype of these strain and temperature module developed.

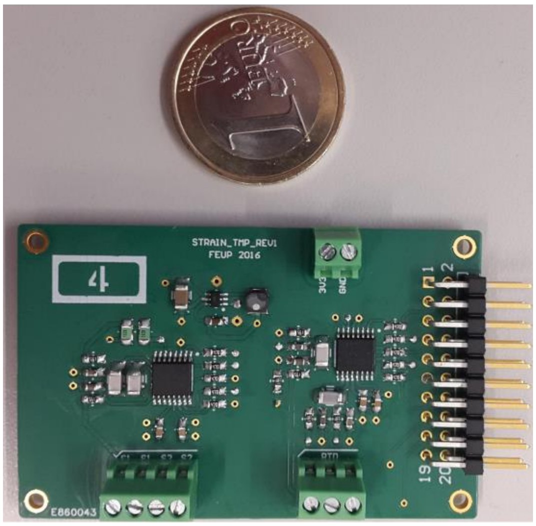


FIGURE 12 - STRAIN AND TEMPERATURE MODULE - FIRST PROTOTYPE

9.2 ACCELERATION AND TEMPERATURE SENSOR

An accelerometer module with integrated microcontroller and 2.4Ghz antenna was designed and it can be seen in Figure 12. This module features a temperature sensor and a 3-axis MEMS accelerometer with a measurement range of ±16g and a maximum output Data Rate of 3200Hz. The microcontroller, an ARM SAMR21 from *Atmel,* features an integrated wireless transceiver which allowed to reduce the component count and therefore the overall size of the module.

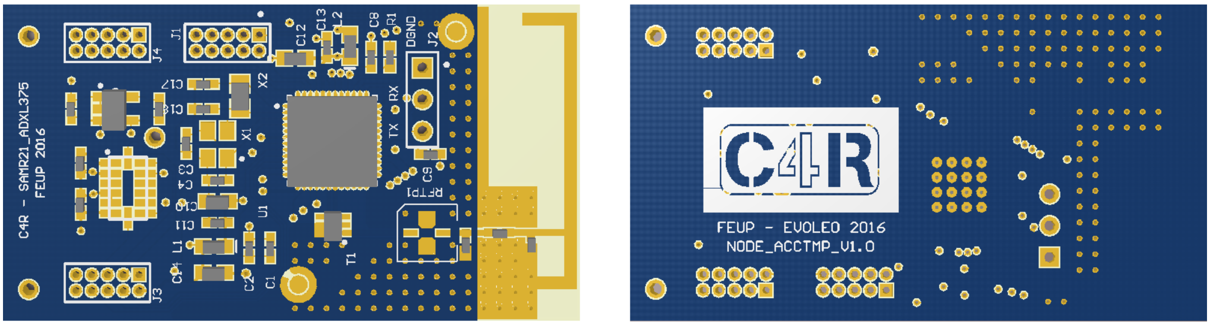


FIGURE 13 - ACCELERATION AND TEMPERATURE SENSOR MODULE

This module uses an ADXL345 accelerometer from analog devices. The ADXL345 is a small, thin, ultralow power, 3-axis accelerometer with high resolution (16-bit) measurement at up to ±16 g. Digital output data is formatted as 16-bit twos complement and is accessible through 4 wire SPI . It measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock. Its high resolution (3.9 mg/LSB) enables measurement of inclination changes less than 1.0°. Also, activity and inactivity sensing detect the presence or lack of motion by comparing the acceleration on any axis with user-set thresholds. These activity and inactivity functions can be mapped individually to either of two interrupt output pins which are used to interact with the microcontroller.

An integrated memory management system with a 32-level first in, first out (FIFO) buffer is also used to store data to minimize host processor activity and lower overall system power consumption. It also has a set of low power modes which enable intelligent motion-based power management with threshold sensing and active acceleration measurement at extremely low power dissipation.

Both of these main components are ultra-low power and have the ability to enter sleep and deep-sleep modes. For this particular application, the accelerometer will be constantly monitoring vibrations at a 12.5Hz rate and will trigger an interrupt to wake up the microcontroller when it detects activity. This kind of approach allows us to measure vibrations at 3.2kHz every time a train passes over with minimal power consumption and without the need for an external trigger, thus simplifying the installation process. Figure 14 shows the developed sensor board.

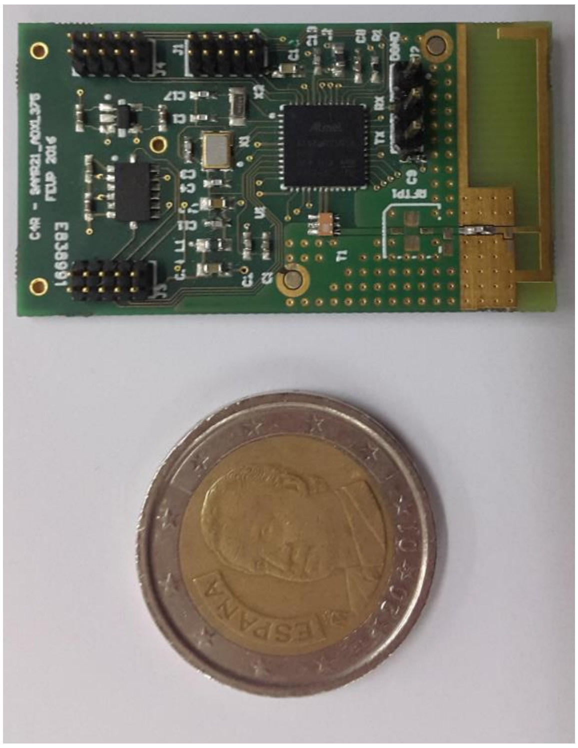


FIGURE 14 - ACCELEROMETER SENSOR BOARD PROTOTYPE

The main features for this module are shown in Table 8.

TABLE 8 - MAIN FEATURES OF THE ACCELERATION SENSOR MODULE

Sampling Rate	3200Hz
Measurement Range	±16g
Current consumption	0.2 µA (standby), 140 µA (measuring), 12mA (sending data)
Other Features	Programmable via Atmel-ICE debugger Extra inputs for external triggers, extra sensors, etc.
Physical Dimensions	25mm x 46mm

Power modes

The ADXL345 automatically modulates its power consumption in proportion to its output data rate. If additional power savings is desired, a lower power mode is available. When using this low power mode, the internal sampling rate is reduced, allowing for power savings in the 12.5 Hz to 400 Hz data rate range at the expense of slightly greater noise. Table 9 shows the current consumption for normal and low power modes and its relation to the output data rate.

TABLE 9 - DATA RATE VS. CURRENT CONSUMPTION

Output Data Rate	Current consumption (µA) Normal mode	Current consumption (µA) Normal mode
3200	140	-
800	140	-
400	140	90
200	140	60
100	140	50
50	90	45
25	60	40
12.5	50	34
(…)	(…)	-
0.1	23	-

Auto Sleep Mode

Additional power can be saved if the ADXL345 automatically switches to sleep mode during periods of inactivity. Current consumption at the sub-12.5 Hz data rates that are used in this mode is typically 23 µA for a VS of 2.5 V.

Standby Mode

For even lower power operation, standby mode can be used. In standby mode, current consumption is reduced to 0.1 µA (typical). In this mode, no measurements are made.

Noise and offset performances

The ADXL345 offers a large number of output data rates and bandwidths, designed for a large range of applications. However, at the lowest data rates, described as those data rates below 6.25 Hz, the offset performance over temperature can vary significantly from the remaining data rates. When using the lowest data rates, it is recommended that the operating temperature range of the device be limited to provide minimal offset shift across the operating temperature range. Due to variability between parts, it is also recommended that calibration over temperature be performed if any data rates below 6.25 Hz are in use.

10 Monitoring use cases

10.1 Case Study

The Alcácer do Sal railway bridge is part of the new Alcácer railway line, located between Pinheiro station and kilometer (km) 94 of the South Line, which connects Lisbon to the Algarve. The Sado river crossing is located between km 8 + 530 and km 11 + 265 of the variant, with a total development of 2735 m, consisting of the main bridge and two access viaducts.

The structure is designed for passenger trains with speeds of up to 250 km/h and freight trains with a maximum axle load of 25 tonnes. Figure 15 shows an overview.

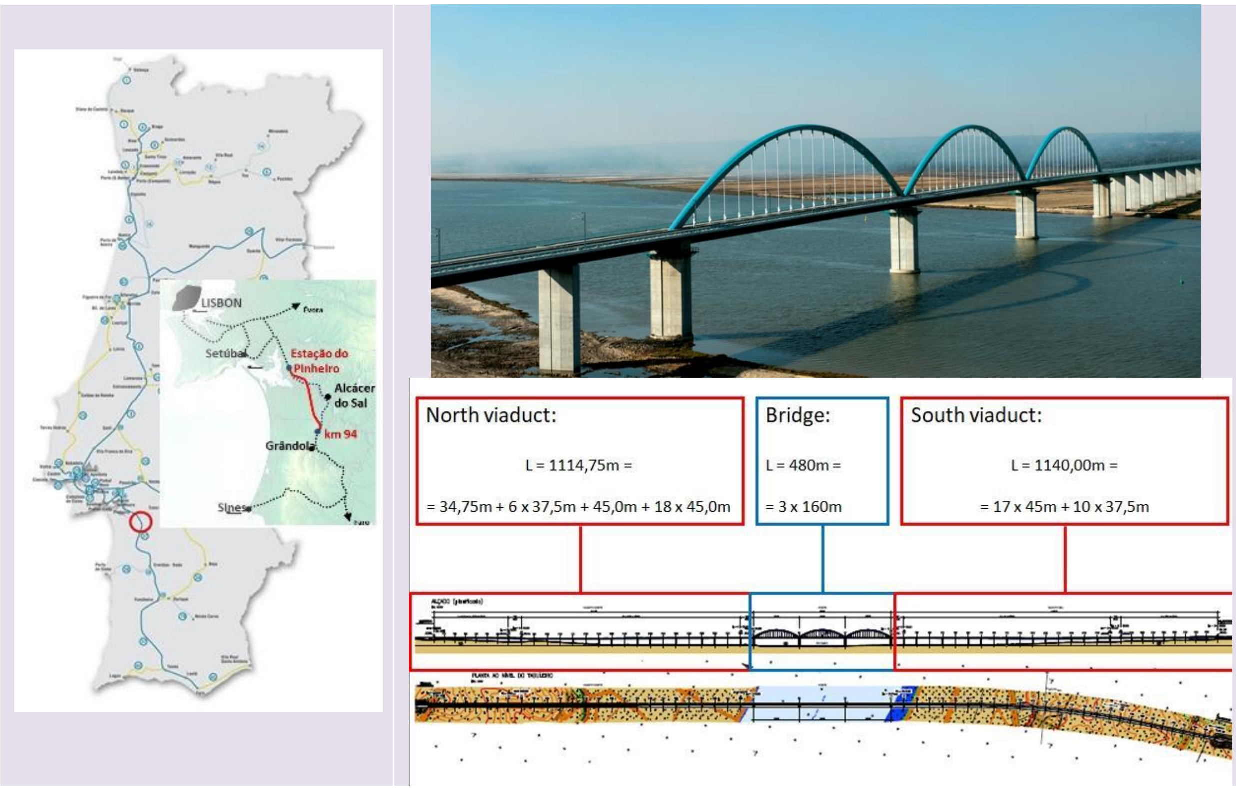


Figure 15 – Location and general view of the railway bridge of Alcácer do Sal

Since several experimental studies have already been conducted in this bridge it has been chosen to implement and test the innovative long-term monitoring system. In this way, two locations were selected as can be seen in Figure 16.

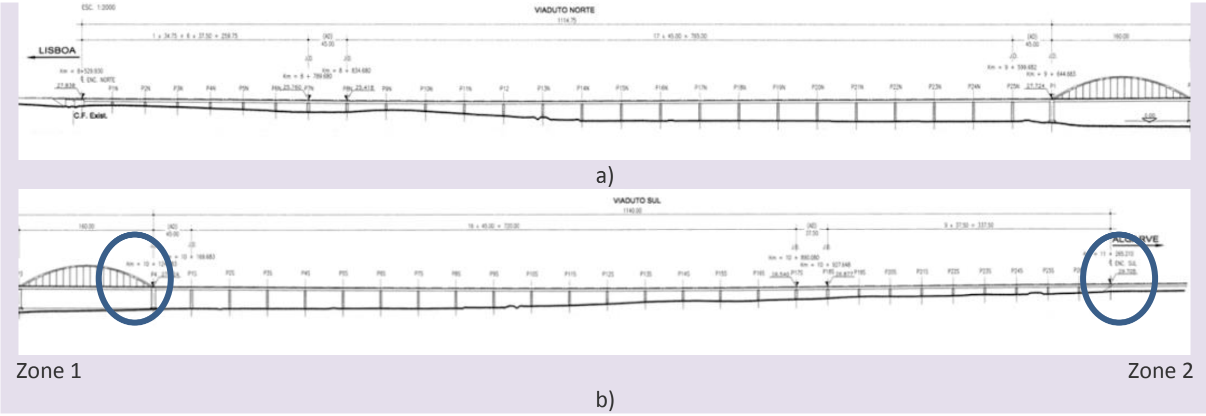


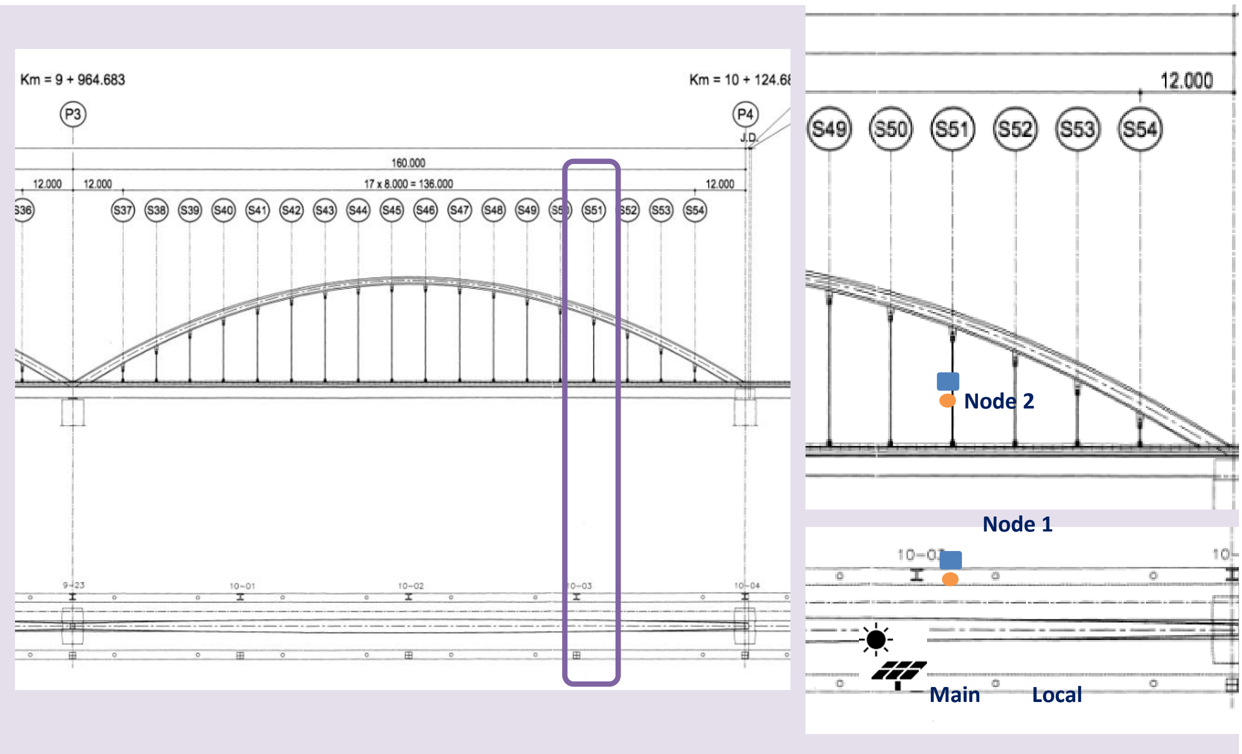
FIGURE 16 – BRIDGE ACCESS VIADUCTS: A) NORTH AND B) SOUTH AND MONITORING ZONES.

In zone 1, the risk of track buckling and the structural health of one hanger were monitored. In zone 2, the track condition at transition zones were monitored. In each of these locations, it was implemented a long term monitoring system compose by a local main station and two nodes (zone 1) and one node (zone 2). The systems will be described in more detail in the following chapters

10.2 MONITORING THE RISK OF TRACK BUCKLING

On a continuous welded rail track, where the expansion of the rails is hardly possible, high compressive stresses occur when there is a significant temperature increase. These compressive stresses may result in track buckling that can be prevented by monitoring the rail temperature and longitudinal strain.

In this way, one sensor node was mounted on the rail aligned with the hanger 51 at zone 1 (Node 1). Figure 17 shows the location in detail. The Node 2 corresponds to the structural health monitoring described in next chapter. Both locations (Node 1 e Node 2) were adopted considering previous studies that have already been carried out in the same alignment and the new data can be compared.

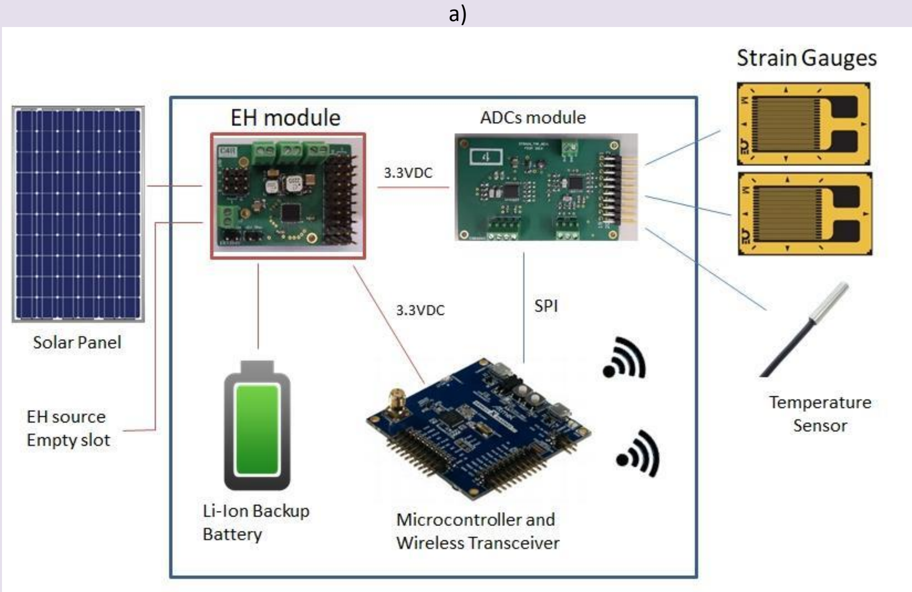


a) b)

FIGURE 17 – EXPERIMENTAL CONFIGURATION AT ZONE 1: A) HANGER ALIGNMENT, B) INSTRUMENTED LOCATIONS

This sensor node includes two weldable strain gages, one temperature sensor (RTD), an energy harvesting module, a ADCs module, a microcontroller and wireless transceiver module, a solar panel and a battery. The sensors were welded (strain gages) and glued (RTD) directly in to the rail and properly protected. The electronic modules were inserted into a small box (125 x 85 x 55 mm) glued to the rail web. The solar panel were fixed in the top of the box. The energy harvesting unit was capable of receiving power from different types of local sources, whoever in this case only a solar panel was installed for generate energy for the sensor node. Figure 18 a) shows the installation illustration and b) the scheme of the node.

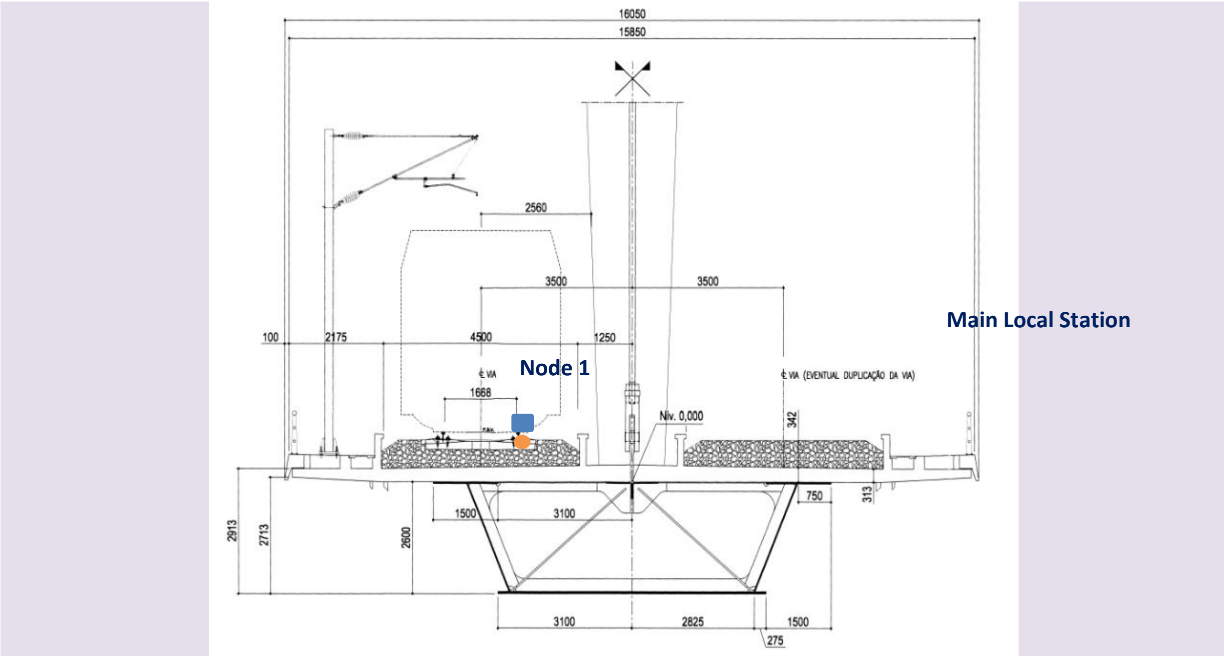
a)



b)

FIGURE 18 – SENSOR NODE 1 INSTALLATION A) AND SCHEME B)

To receive the data from the nodes 1 e 2, the main monitoring system (main local station) was installed on the board walk side, opposite at the railroad traffic, Figure 19 a). A metal structure was developed to hold a solar panel (130W, 1300x655mm) and an industrial enclosure (500x700mm ABS IP65). This structure consisting on a base and a pole was attached to the stud bolts of the catenary posts, Figure 19 b).

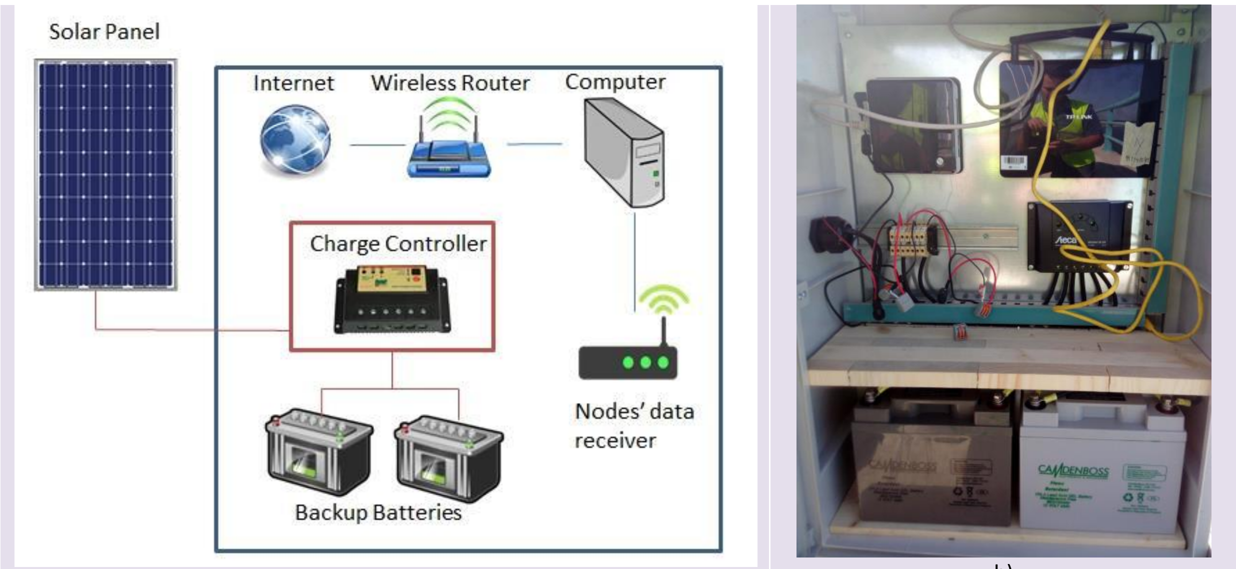

16050
15850
2560
3500
3500
Main Local Station
100
2175
4500
1250
Node 1
℄ VIA
℄ VIA (EVENTUAL DUPLICAÇÃO DA VIA)
1668
Niv. 0,000
342
750
313
1500
3100
2913
2713
2600
3100
2825
1500
275

a)

b)

FIGURE 19 – LOCATION OF THE MAIN LOCAL STATION A) AND ILLUSTRATION OF INSTALLATION B)

The main local station components are a minicomputer, a node data receiver, a 3G/4G router, a charge controller, a solar panel and 2 batteries, and other auxiliary accessories. Figure 20 shows the system scheme and installation illustration. The node receiver collects the data from node 1 and 2 and saves in a database on the computer which can be accessed via internet.



a) b)

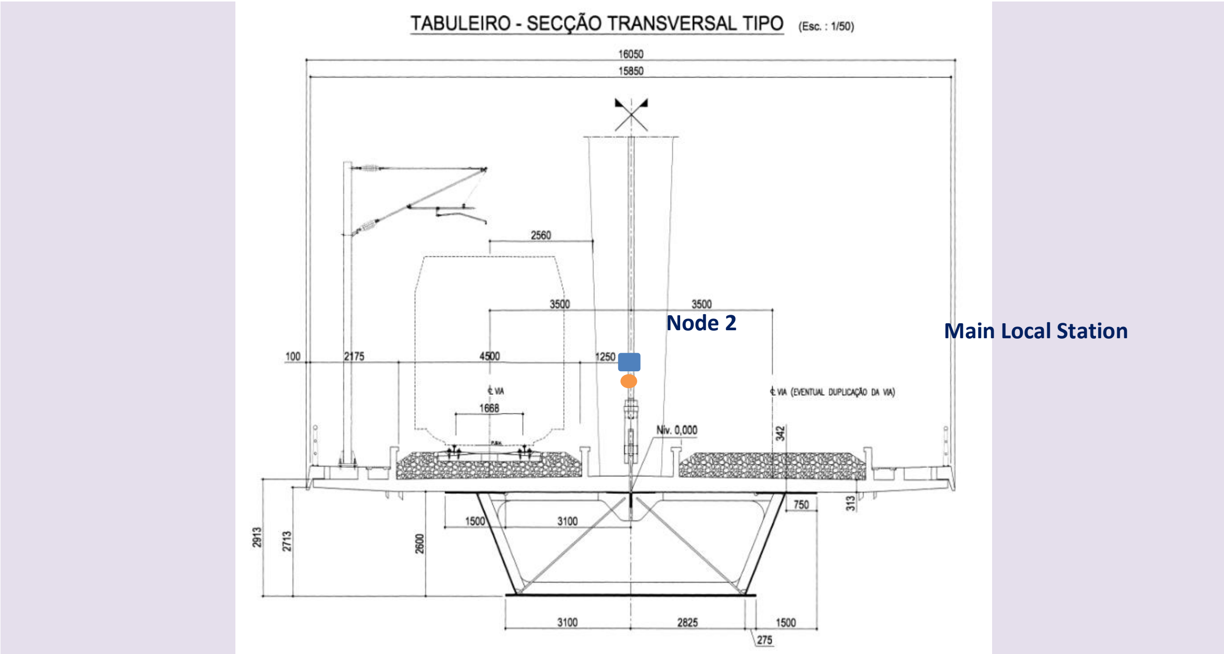
FIGURE 20 – MAIN LOCAL STATION AT ZONE 1 SCHEME A) AND ILLUSTRATION B)

10.3 STRUCTURAL HEALTH MONITORING OF RAILWAY BRIDGES

The Structural Health Monitoring of a long span railway bridge is important to prevent the failure of critical components of the bridge due to for example fatigue crack propagation.

In this case, a similarly node with the same configuration (to previous case of risk of track buckling – Node 1) was installed on the hanger S51 (Node 2) at zone 1, but now to study the vertical strains/forces of the hanger. Two strain gages, one temperature sensor (RTD), an energy harvesting unit, a ADCs module, a wireless transceiver module, a solar panel and a battery was also used (Figure 18). The installation process was the same instead of the strain gages that were glued in this case.

The node was installed at 2.7 m from the hanger base and the box, with the fixed solar panel, oriented to the maximum solar incidence. Besides of using only the panel solar, the energy harvesting unit was also capable of receiving power from different types of local sources. The main local station to receive the data from Node 2 was the same used for Node 1. In Figure 21 a) it can be seen the scheme of Node 2 and main local station location and b) there illustration.


TABULEIRO - SECÇÃO TRANSVERSAL TIPO (Esc. : 1/50)
16050
15850
2560
3500
3500
Node 2
Main Local Station
100
2175
4500
1250
1668
Niv. 0,000
342
750
313
1500
3100
2913
2713
2600
3100
2825
1500
275

a)

b)

FIGURE 21 – LOCATION OF THE NODE 2 A) AND ILLUSTRATION OF INSTALLATION B)

10.4 TRACK CONDITION MONITORING AT RAILWAY TRANSITION ZONES

The variation in the subsoil stiffness when changing from one structure to another produce greater stress on the infrastructure. These differences along with the uneven settlement (as “Bump´s” and “Dip´s”, Figure 22) might increase the dynamic loads on the railway components and put in risk the traffic safety.

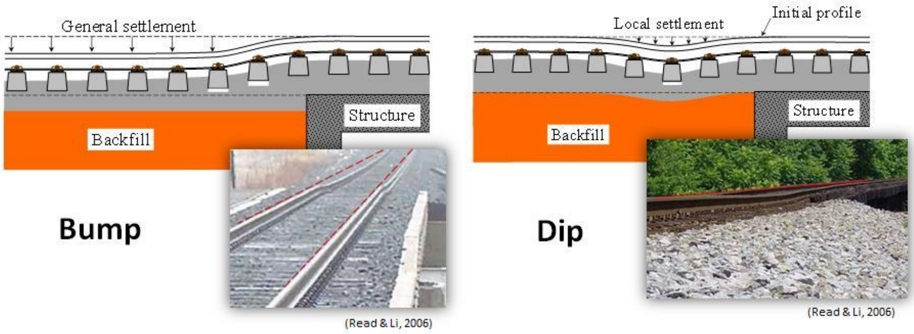
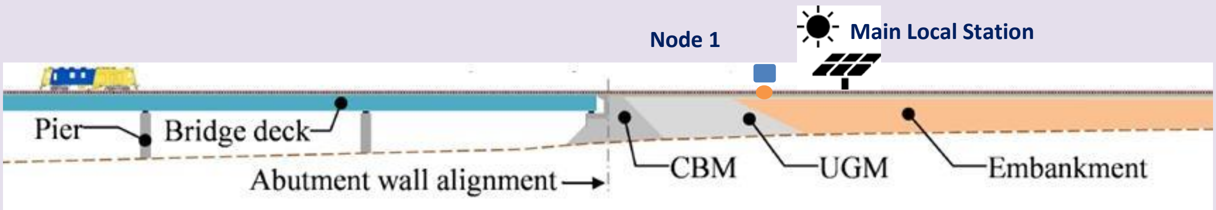


FIGURE 22 – TRANSITION ZONES SETTLEMENTS: GENERAL A) AND LOCAL B)

To study these settlements a several measurements can be taken as sleeper accelerations, rail-sleeper relative displacements, rail and sleeper vertical displacements, wheel loads and rail seat loads. Short term monitoring with this measurements was already conducted in the transition of Zone 2 in the south access viaduct of Alcácer do Sal Railway Bridge, Figure 23 a). In this way this location was adopted to install the new long term monitoring system for transition zones. A sensor node was installed in a sleeper in the end of the transition zone to measure the accelerations.

a)



b)

FIGURE 23 – SOUTH ACCESS VIADUCT ILLUSTRATION A) AND LATERAL SCHEME B)

The sensor node (Node 1 of Zone 2) includes an energy harvesting module, a wireless Power transceiver module, a microcontroller and wireless transceiver, a MEMS accelerometer, a battery and a solar panel, Figure 24. All the modules and the sensor were inserted into a small box (125 x 85 x 55 mm) glued on one end of the sleeper. The wireless power receiver antenna stay outside the box as it can be seen in Figure 24 a).

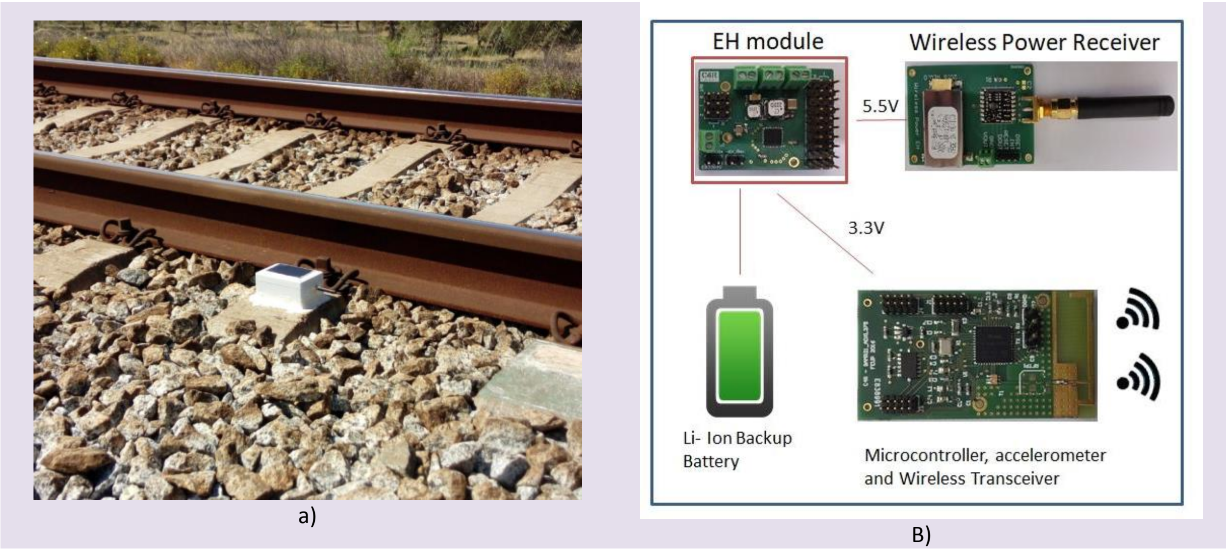


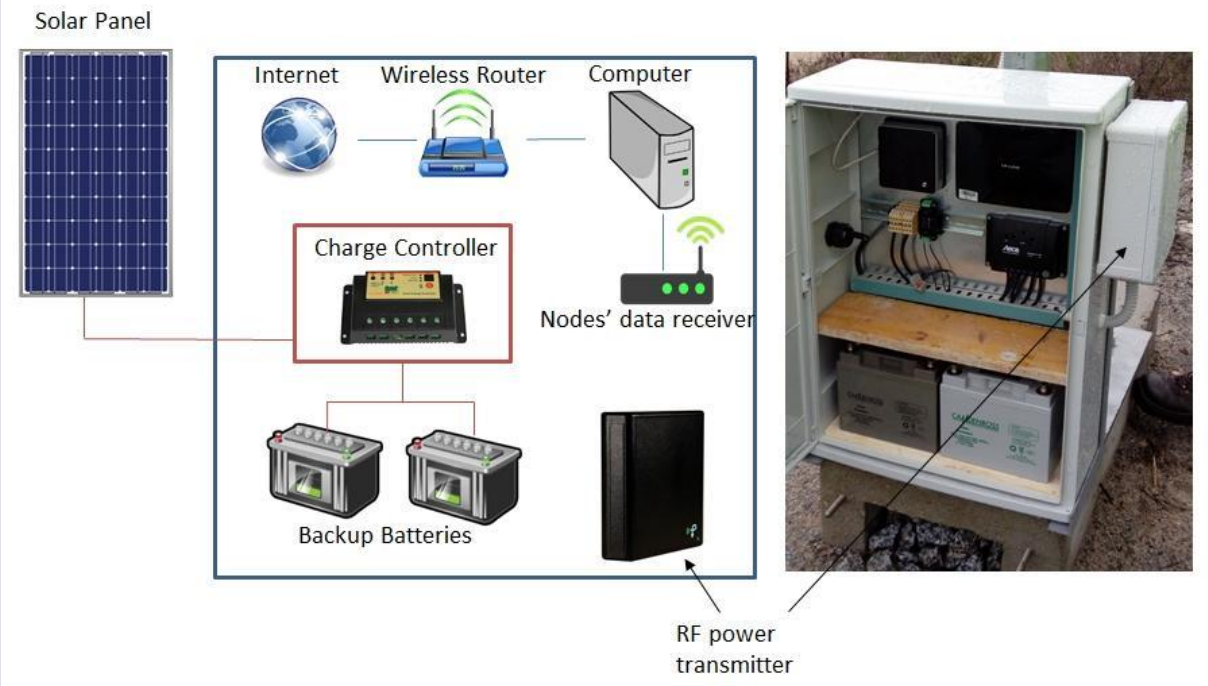
FIGURE 24 – SENSOR NODE 1 INSTALLATION A) AND SCHEME B) AT ZONE 2

The accelerometer sensor was triggered by the vibrations on the sleeper and samples the data as the train passes over. The energy harvesting unit was also capable of receiving power from different types of local sources but here is mainly energy was provided by wireless power transmission using an RF antenna installed on the main local station.

The main local station was installed in a concrete base placed on the trackside platform at 4 meters from the nearest rail and the same alignment of the Node 1. In the same way as in zone 1, an equal metal structure was developed to hold a solar panel (130W, 1300x655mm) and an industrial enclosure (500x700mm ABS IP65). Here, the base and the pole were fixed to concrete base, Figure 25.

FIGURE 25 – MAIN LOCAL STATION ILLUSTRATION AT ZONE 2

The main local station components are a minicomputer, a node data receiver, a 3G/4G router, a charge controller, a solar panel, 2 batteries, a RF power transmitter and other auxiliary accessories. Figure 26 shows the system scheme and installation illustration.



a) b)

FIGURE 26 – MAIN LOCAL STATION AT ZONE 2 SCHEME A) AND ILLUSTRATION B)

The RF power transmitter module was inserted in a box fixed to the industrial enclosure and vertically aligned with the sleeper. The receiver node collects the data from node 1 and saves in a database on the computer which can be accessed via internet. In Figure 27 shows the sensor installation location (FEUP Node 1) and the nodes from University of Birmingham that use the same box power.

FIGURE 27 – SENSORS DISTRIBUTED IN THE TRANSITION

10.5 RESULTS

In this section it can be seen some results from the monitoring system installed in a transition zone. The Figure 28 shows a lot of accelerations of the sleeper (FEUP Node 1 – raw data) in the end of the transition zone with a passage of Alfa Pendular train.

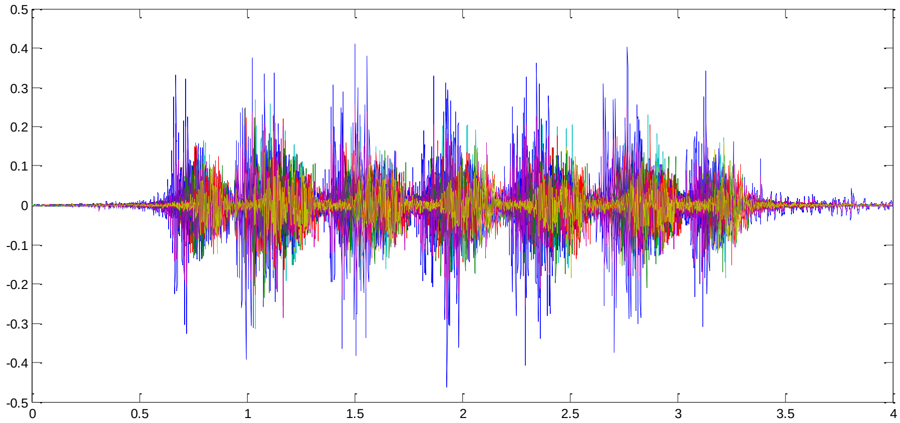


FIGURE 28 – SLEEPER ACCELERATION INDUCED BY PASSAGES OF ALFA PENDULAR TRAINS

In Figure 29 it can be seen in detail the acceleration records due to 20 passages of Alfa Pendular trains with a low pass filter at 80Hz applied.

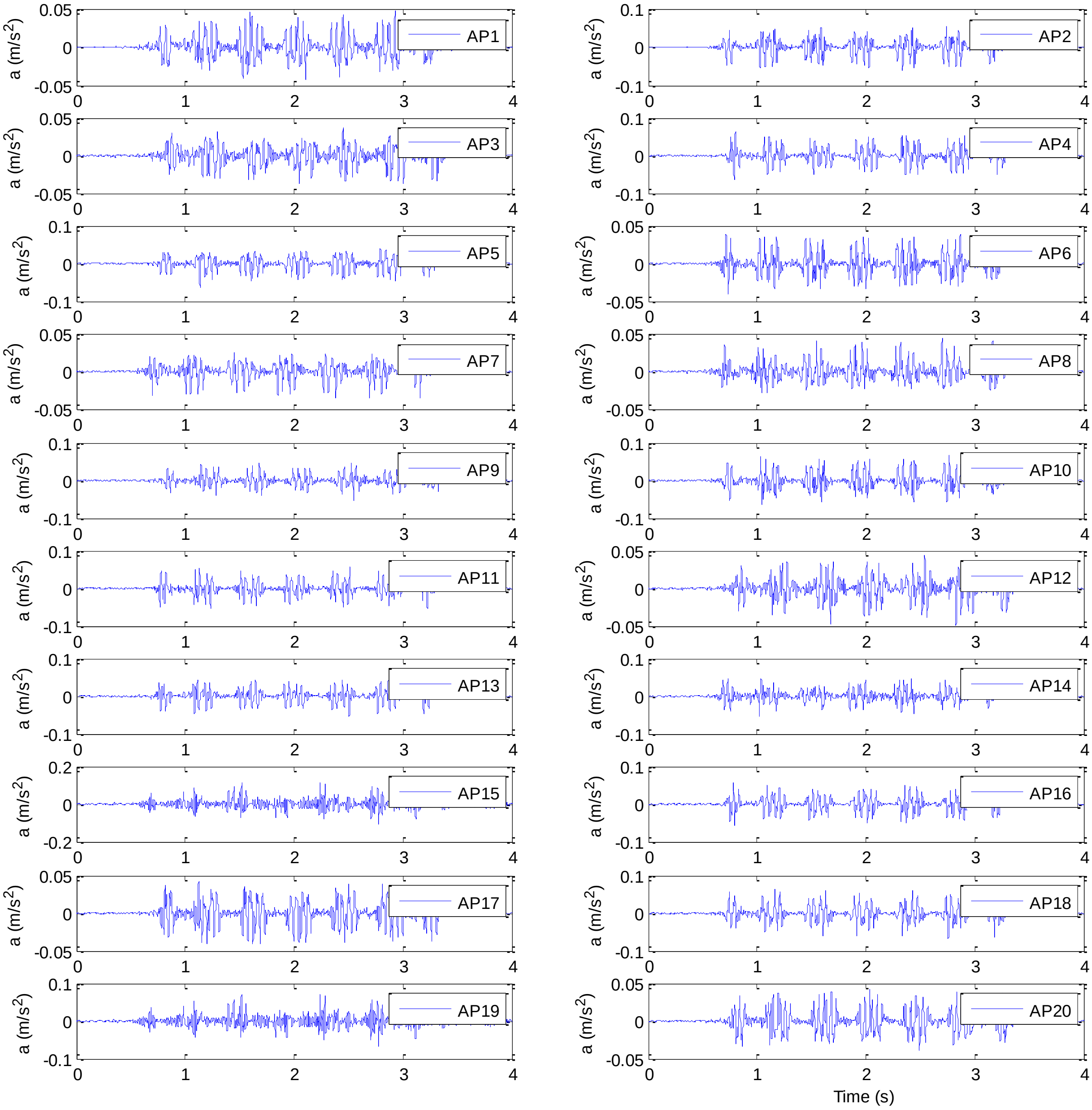


FIGURE 29 – SLEEPER ACCELERATION INDUCED BY PASSAGES OF ALFA PENDULAR TRAINS

11 Conclusions

The results and operation tests of the two devised long-term monitoring systems were shown to have potentials for the application in the concept demonstrator's cases and also for other types of applications.

The energy harvesting modules developed demonstrates to be efficient and guarantee the power to the sensors, microcontroller and wireless data communication. For static monitoring systems (case of zone 1) the use of only one solar panel was sufficient. For dynamic monitoring systems (case of zone 2) the use of wireless power transmission technology possibly the necessary energy. In both cases, the energy harvest module has the ability to collect energy from other sources simultaneously. The acquisition and wireless communication modules demonstrate to collect correctly the data from sensors and the data communication from the nodes to the receiver location (main station) was stable.

These monitoring systems have the potential to be implemented in several applications. Examples of future applications are the condition monitoring of pantograph-catenary interaction (Figure 30), Weighing in motion and wheel defect detection systems (Figure 31) and bogie condition monitoring on freight trains (Figure 32).

FIGURE 30 – CONDITION MONITORING OF PANTOGRAPH-CATENARY INTERACTION

FIGURE 31 – WEIGHING IN MOTION AND WHEEL DEFECT DETECTION

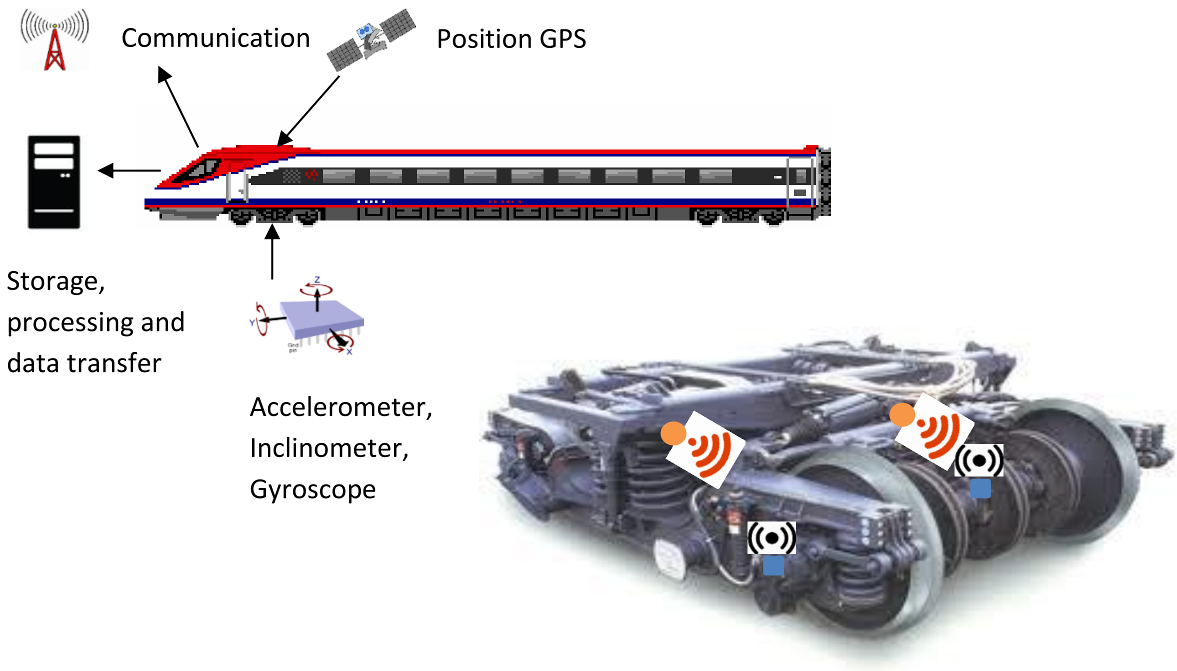


FIGURE 32 – BOGIE CONDITION MONITORING

12 References

[1] Linear Technology Corporation, *Datasheet - LTC331, Nanopower Buck-Boost DC/DC with Energy Harvesting Battery Charger,* 2014.

13 Appendices