C4R

Capacity for Rail

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

Guidelines for installation and maintenance of sensors in new infrastructure

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Deliverable 43.1

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Executive Summary

This Deliverable D4.3.1 presents the results of the research carried out in the following tasks of SP4 Advanced Monitoring - WP4.3 Implementation in new structures:

- Task 4.3.1. Specific monitoring requirements and techniques for the new infrastructure elements.
- Task 4.3.2. Analysis of interaction/interferences between sensors and infrastructure elements.
- Task 4.3.3. Developments of procedures for installation, maintenance and replacement of sensors.

The aim of this deliverable is to design a monitoring system to be easily integrated into the new infrastructure concepts developed in SP1, i.e. a modular slab track, and to compile the information required to assess the structural condition of these assets.

An exploration of existing sensor technologies has been carried out taking into account the findings in WP4.1 and 4.2, as well as the specific requirements of the new infrastructure elements (developed within WP1.1). The RFID powered sensors have been selected as the most promising ones, given their low-cost, low power consumption and the maturity level of this technology.

The existing RFID sensor tags are able to measure effectively the temperature, moisture and other environmental parameters, but there are only a few applications on structural health monitoring. One of the results of this deliverable is a solution to connect strain gauges to multipurpose RFID tags

The application of the RFID sensor tags in the structural health monitoring of tracks requires solving several interferences: Firstly, the geometric interference with the reinforcement bars in the precast concrete element, being sure that the manufacturing process is not disturbed. Secondly, the physical interference with the maintenance procedures, even when maintenance tasks are not very frequent in slab track. Lastly, the electromagnetic interference with signalling, power supply and wireless systems in the surrounding of the track. In order to solve the geometric and physical interferences, the sensor tags have been embedded in the concrete. The electromagnetic interferences have been also investigatedand the RFID communication has proven to be compatible with the railway electromagnetic field.

Finally, a procedure for the installation of sensors have been drafted, although their implementation in the demonstrators of SP1 (planned for the last semester of the project, not yet accomplished at the time of submission of this report) will be a proof of concept and, if necessary, a update of this procedure will be done afterwards once the monitoring system embedded in the prototypes tested at CEDEX Laboratory (Madrid, Spain). Regarding the maintenance and replacement procedures, they are not necessary since the sensor tags are embedded in concrete and their useful life is expected to be, at least, the same that the infrastructure element being monitored.

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Abbreviations and acronyms

Abbreviation / Accronym	**Description**
ADC	Analog Digital Conversion
AMS	Advanced Monitoring System
CPU	Central Processing Unit
DoW	Description of Work
ETSI	European Telecommunications Standards Institute
FEM	Finite Element Method
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
IEEE	Institute of Electrical and Electronics Engineers
LCC	Life Cycle Cost
PBC	Printed Circuit Board
RAMS	Reliability, Availability, Maintainability and Safety
RF	Radio Frequency
RFID	Radio Frequency IDentification
SHM	Structural Health Monitoring
SMS	Short Message Service
SP	Subproject
SPI	Serial Peripheral Interface
UHF	Ultra High Frequency
WP	Work Package
WSN	Wireless Sensor Network

1 Motivation and objectives of the Advanced Monitoring System

Today the availability of rail infrastructure is strongly influenced by the age and the local conditions, such as ground conditions, procedure of construction, and the local load. These factors will affect the life expectancy as well as the required maintenance.

Currently, monitoring systems are used in the railway sector as mandatoryonly in certain singular locations. In other cases, the systems are only installed for a short-period of time or when some failure or defect appears. These few systems are only usually intended as stand-alone solutions, and specifically constructed for each individual case and region.

The general objective of this deliverable is to design a monitoring system able to be integrated in the new infrastructure elements developed in SP1. This system must be able to monitor the most relevant information on infrastructure state for the new concepts of slab track. Moreover, the developed technologies should be low cost, easy and rapid to implement during the construction of the infrastructure and oriented towards a cost-effective, easy and rapid sensor maintenance.

There are several specific objectives to be achieved which are aligned with the DoW:

1. To define the strategy for monitoring the new infrastructure elements, based on the identification of infrastructure weak points, the failure modes, the physical constrains, the data requirements, etc.
2. To design the monitoring system based on low-cost sensor nodes, possible with wireless communication and energy harvesting resources.
3. To analyse possible interferences with the railway electromagnetic field and the maintenance tasks.
4. To draft the installation procedure, compatible with the manufacturing process of the precast concrete elements.

This deliverable has been structured in sections in line with the previous objectives. Therefore, Section 2 deals with the monitoring strategy for modular slab track, Section 3 is about the selection of technologies, Section 4 describes the concept of the monitoring system developed and in Section 5 a procedure for the installation of sensor nodes during manufacturing is described. Finally, Section 6 includes the conclusions and next steps in the design and implementation of the monitoring system.

2 Monitoring strategy for new infrastructure elements

2.1 INTRODUCTION

Structural Health Monitoring (SHM) is a system that diagnoses the condition of structures such as buildings, bridges, tunnels, etc. to detect potential defects. Current SHM systems are usually based on wired measurement equipment. The main drawback of such systems is that the number of sensors is kept limited reducting the possibilities of the system significantly. Especially, wired systems require a non-trivial amount of time and cost for the initial deployment and commissioning. Therefore, evolving from wired sensor systems to wireless would open the possibility of a cost-effective and more complete monitoring system widening the benefits both in the construction and operation phases of the infrastructure and facilitating its deployment, commissioning and maintenance (if any).

The fundamental problems of wireless sensor embedded in concrete are the wireless communication and power consumption. Electromagnetic waves suffer from attenuation in concrete depending on the moisture content, the heterogeneity of concrete, the presence of metal and other factors. Wireless communication implies lack of cables also for power supply, so sensors will require in situ power. Currently, batteries represent the most common portable power source for wireless sensors.

The Advance Monitoring System (AMS) that will be developed in the C4R project for the new slab track concepts developed within WP 1.1 will have to be based on low cost off the shelf sensor technologies, will requires no external power sources (i.e. will be autonomous from an energy perspective) and will be integrated/embedded within the slab track concepts. The fast construction, easy deployment and allowing communication (avoiding different types of interference) are other requirements

The starting point for seeking monitoring technologies is Deliverable 4.1.1, where existing sensors, communication, energy harvesting and management systems have been identified. According to this information, the most promising technology that meets all the requirements listed above is the RFID sensor tags. The communication protocol and power supply of this elements are widely known. The issue is to identify what, where and when to measure, in other words, the first step is defining the monitoring strategy, and then looking for sensors compatible with the RFID possibilities and able to provide the required data (defined in the monitoring strategy).

The following subsections will explain the rough characteristics of the new infrastructure elements, its weak points, the general requeriments for the monitoring system and a overview analysis about the concept of Structural Health Monitoring applied to a particular case of slab track system.

2.2 DESCRIPTION OF THE NEW INFRASTRUCTURE ELEMENTS

As defined in the DoW, task 1.1.2 of the C4R project will generate several concepts for new track systems using concurrent engineering, select the most promising ones through a business model and their potential LCC and RAMS predicted performance, then develop a detailed design for the two most promising concepts.

Two innovative slab track concepts has been developed and are in the process of being prototyped at the moment of submission of this report. These concepts are innovative from many different perspectives. In the design phase, because the same standard elements are suitable for straight lines and curves with radius starting from 500 metres. In the exploitation phase, because in case of damage the systems allow quick repair tasks with a relevant minisation in traffic disruptions.

On the other hand, the use of standard slabs and blocks allow to have a permanent stock in the maintenance base, therefore improves the maintainability of the system.

2.3 IDENTIFICATION OF WEAK POINTS

Based on a preliminary structural assessment, several failure modes could be identified.

Note that structural element dimensioning should avoid all of these failure modes under standard load conditions, even under Ultimate Limit State load combinations.

The target of the monitoring system will be the early detection of the failures which could happen in the weak points.

2.4 LOCATION REQUIREMENTS

The new infrastructure elements are slab tracks, which are originally conceived to have low or none maintenance needs. On the other hand, maintaining good track geometry is one of the main objectives of corrective maintenance, but track geometry is quite stable in slab track systems. Therefore, in principle permanent monitoring may not be necessary.

However, the recent ICT revolution has enabled the massive application of monitoring technologies in civil structures without a significant increment in costs. The proper use of gathered data can improve railway maintenance and operation in many different aspects. For instance, predictive maintenance is possible in continuous condition monitoring. The early detection of failures could derive in lower cost repairs. Besides this, integrated monitoring avoids track occupation for inspection purposes, which contributes to the enhancement of infrastructure capacity. On the other hand, monitoring can help designers to better adjust security factors of the infrastructure, thus to perform a cost-efficient design. Furthermore, a better knowledge of track condition enables extending life span of the infrastructure and supporting harmful traffic demand, such as higher axle loads, longer trains or mixed traffic.

A key factor in low cost monitoring consists in repeatability, i.e. the use of the same sensor nodes for the same infrastructure elements. It is possible in the new slab track design, where slabs and blocks are standard elements. Moreover, the use of many precast concrete elements is an opportunity to embed sensors during manufacturing phase.

The draft of any monitoring strategy requires to define what parameters are going to be measured and then to select the sensor technologies able to measure them in the most efficient way. Within the new slab track concept, there are only a few parameters interesting, such as track geometry, rail defects, structural health of the concrete slab and drainage. These parameters are prone to evolve in critical sections, such as transition zones, high embankments, shallow phreatic level or low radii curves, among others. In straight lines, it is not common to have such an integrated monitoring.

The other type of data that can be monitored is about operation of rail services. These data are gathered in specific control sections, and comprise train detection, train speed measurement, train direction, axle counting, weighing in motion, unbalanced loads, wheel flat detection, single vehicle identification.

With the integration of monitoring system during the manufacturing process of the slab track, there are new possibilities for gathering data.

1) During the installation process, positioning sensors such as inclinometers, accelerometers or distance meters could improve the performance of the construction procedures. Nowadays, the positioning of slabs is a tedious and slow process usually assisted by manual measurement methods (see figure 1). An integrated monitoring system could increase the construction performance, as well as achieve a better initial track quality, which is a key factor in the maintenance needs afterwards.

Figure 1. Installation procedure of a precast concrete slab track

2) During exploitation phase, it is interesting to monitor the position and structural health of the slabs. To this end, the inclination could be monitored by inclinometers, with a typical accuracy of ±0.1º, or by accelerometers, with a typical accuracy of ±1º. The structural health monitoring (SHM) could be done by accelerometers and later vibration analysis. The performance of the drainage system can be assessed by moisture sensors. Finally, the track geometry and defects detection at rails can be only monitored by auscultation vehicles or sensors embarked on commercial trains, but it is difficult to gather this data with sensors embedded in the infrastructure elements.

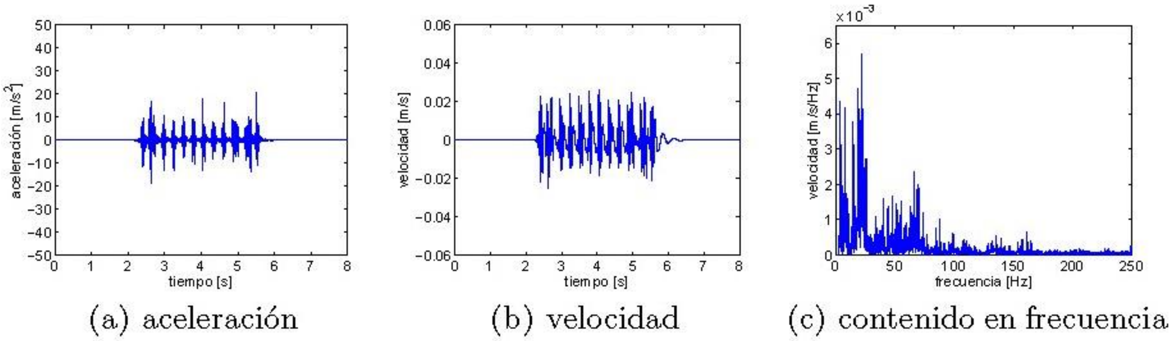
Among the different sensor technologies, the fiber optic distributed sensors is one of the most promising. Although it was considered in the initial stages of development of this project, the last versions of the slab track design were devoted to modular pieces and there is little room for distributed sensors. Therefore, the focus will be on discrete sensors.

2.5 PRINCIPLES OF STRUCTURAL HEALTH MONITORING

The **natural frequency** is the frequency at which a system tends to oscillate in the absence of any driving or damping force, i.e. the amplitude and acceleration increases disproportionately.

The natural frequencies in the structure only depends on its stiffness and integrity. It is **independent from the exciting source**, in our case the passing trains, but this source should have a range of frequencies wide enough to cover the main natural frequencies of the element.

The following picture shows real data gathered from the HS line Madrid-Sevilla (Spain), train ALSTOM running at v=250km/h [1]. The frecuency range is between 0 and 250Hz.



(a) aceleración (b) velocidad (c) contenido en frecuencia

Figure 2 Acceleration data gathered in a High Speed line. ('aceleración' stands for acceleration; 'velocidad' stands for speed; 'contenido en frecuencia' stands for frequencies). [1]

A key factor in SHM is that changes in the natural frequencies of the structures means changes in its stiffness and/or boundary conditions and, by hence, possible defects. However measuring vibrations is costly in time/energy consumption on gathering, transmitting and processing data. There are available technologies based on sensor nodes which only measure when they detect that the train is coming. Furthermore, the data could be pre-processed in-situ by embedded systems and transmit only the frequencies where there are peaks of acceleration, i.e. natural frequencies.

The application of the SHM principles to an infrastructure requires to conceive the monitoring system since the very beginning of the design phase, as well as a proper data management system. The procedures is based on comparison between consecutive measures to detect changes in natural frequencies, and its workflow can be summarized as follows:

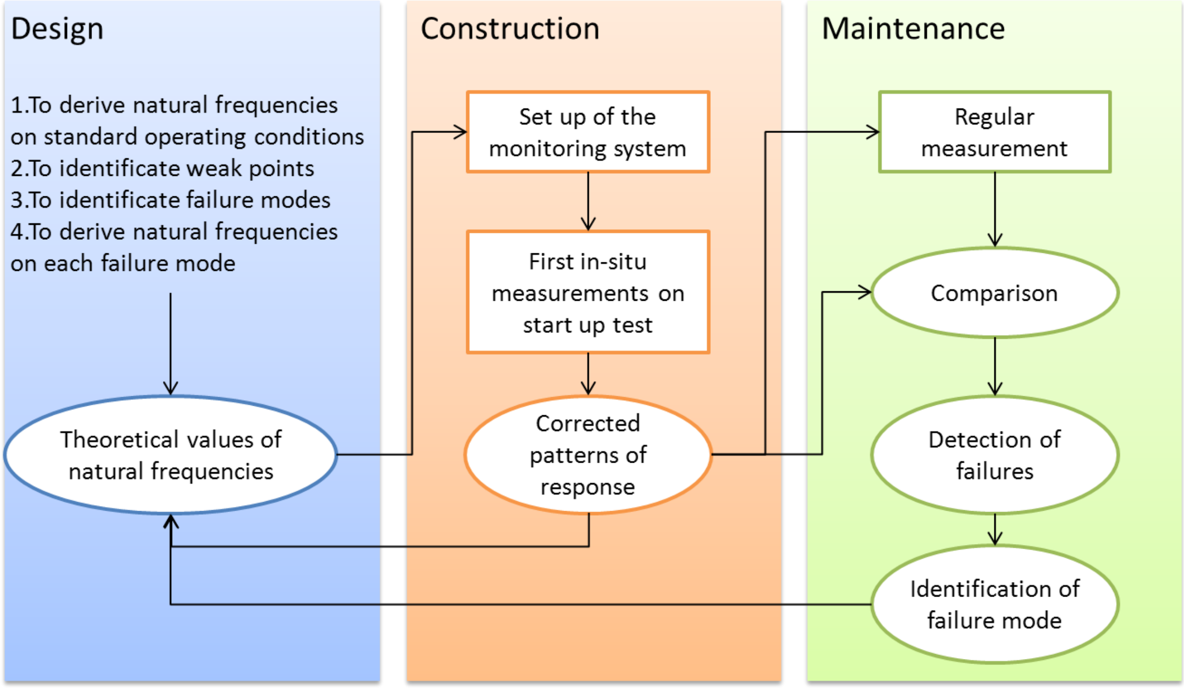


Figure 3. Dataflow for SHM during the life-cycle of a infrastructure

The theoretical natural frequencies can be derived during the design phase, thanks to FEM modelling.

This methodology had been performed in the early stages of the WP.4.3. First theoretical calculations had been made, using a preliminary design for a precast concrete slab with dimensions according to the following figure (Figure 4). The target of these calculations was to check the goodness of this methodology in its directly application to the slab track technology in order to detect potential failures.

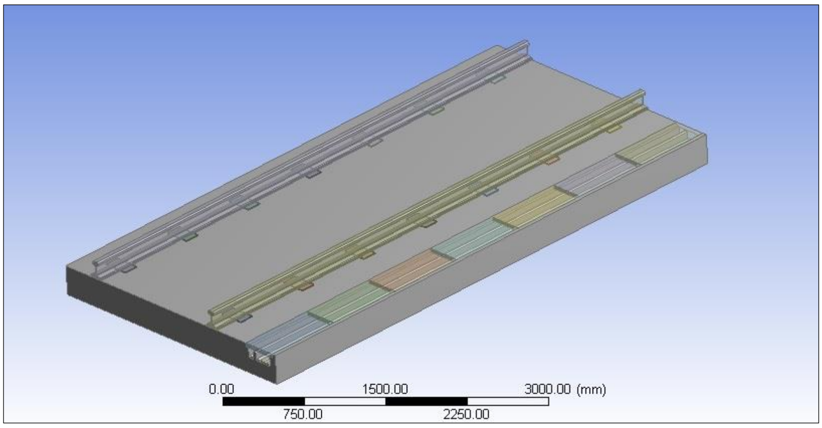


Figure 4. Simplified model of a precast concrete slab

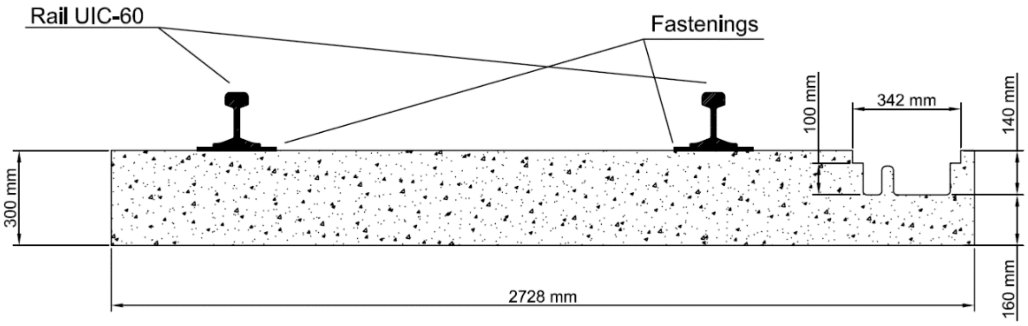


Figure 5 Precast concrete slab used as example for vibration analysis.

After putting several consecutive and connected slabs, a sinusoidal vertical harmonic load acts in the central slab (on the rails) as excitation source. Then a unlimited number of vibration modes appear, being the most relevant the first three ones, shown in the next figure:

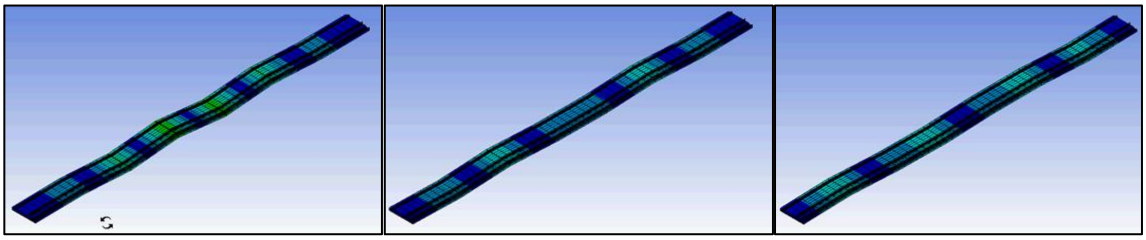


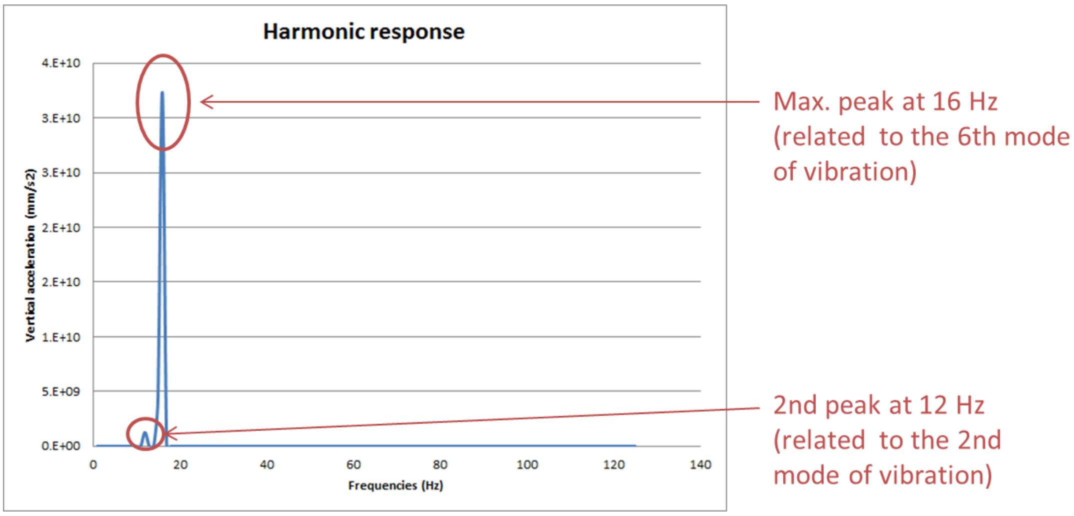
Figure 6 Vibration modes 1, 2 and 3

The following table shows the characteristic frequency of the first ten vibration modes. Vibration modes from 1 to 6 refers to deformations in slabs, while modes from 7 downwards are related to deformations in rails and fastenings.

Table 1. Frequencies of the main vibration modes

Mode	Frequency (Hz)
1	10,65
2	12,72
3	14,21
4	15,14
5	15,75
6	16,02
7	109,7
8	109,9
9	110,1

The relative importance of these nodes is conditioned by the amplitude of the vibration. For instance, in the previous list vibration mode #6 has the biggest amplitude, being the 2nd mode insignificant compared to the previous one.



Max. peak at 16 Hz (related to the 6th mode of vibration)

2nd peak at 12 Hz (related to the 2nd mode of vibration)

Figure 7 Analysis of harmonic response (frequency domain)

During the de exploitation and maintenance phase, when a defect occurs there will be a change in the mechanical behaviour of the infrastructure, a change in the stiffness and, as a consequence, a change in the natural frequencies. The following pictures represent a loss of vertical support and transversal cracks which are some of the possible failure modes.

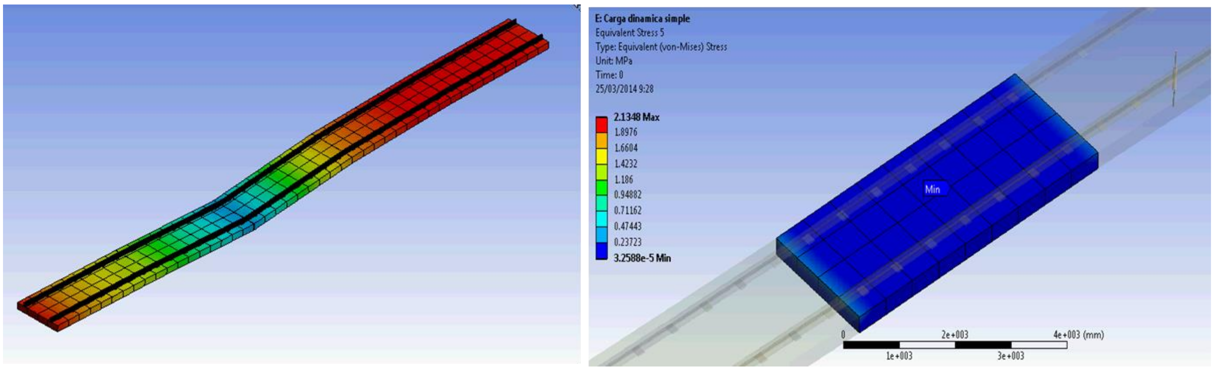


Figure 8 Possible failure modes (Left: Loss of vertical support; Right: Transversal cracks)

The appearance of the crack implies a change in the natural frequencies, in particular, it means an increase in the frequency for the first dominant peak of vertical acceleration (from 16Hz to 58Hz) and a change in the relative order of vibration modes (from 6th to 7th).

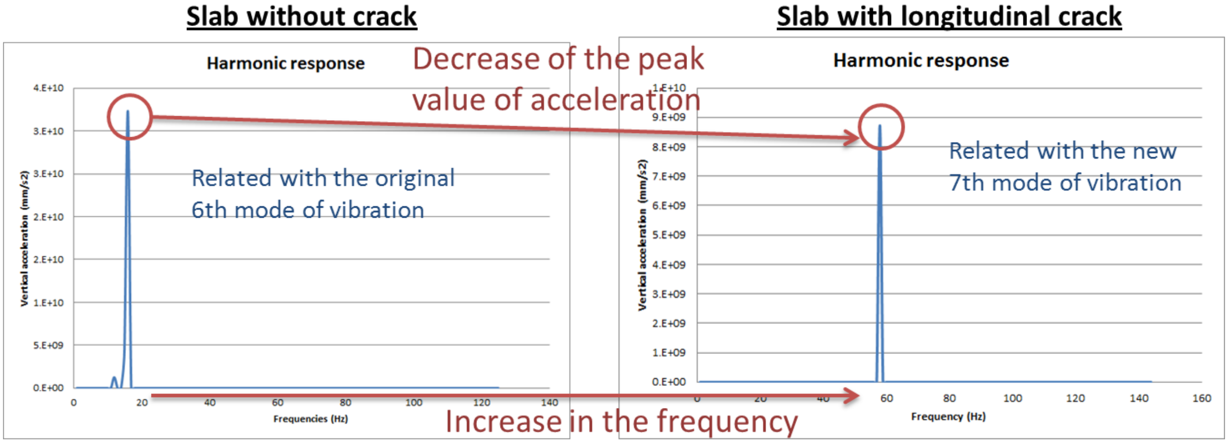


Figure 9 Changes in the natural frequency of a damaged slab

The results show a clear conclusion. In order to apply the principles of Structural Health Monitoring in a slab track system, it is needed a complete database which includes the more relevant expected failures along with the changes in the vibration modes related to these failures. These changes in the vibration modes and peak frequencies due to failures, could be obtained through the use of FEM dynamic analyses, together with the use and analysis of historical records in existing monitoring systems in slab track.

3 Analysis of current technologies in communications in the railway industry

3.1 INTRODUCTION

This section highlights current market available communication together with the analysis of interferences in the railway system.

Communications play a crucial role in terms of safety, security and analysis of performance in the railway system. There are a wide range of different available technologies which are objected of study during this chapter. Communication technologies that may concur in a railway environment are very broad covering those related to train operation (e.g. analogue communication, GSM-R) as well as the typical related to end-users (or general public) applications (e.g. WIFI, GSM, GPRS, 3G)

The knowledge of them, allow a better analysis in order to select the most appropriate communication architecture for the monitoring system developed during the task.

On the other hand in the rail domain, due to its particular characteristics, there are many sources of interference to wireless communications. These interference sources could come from train operation (motion, vibration, etc.), railway infrastructure (tunnels, terrain, etc.) and nature (rain, temperature, humidity…). Due to this fact, a deep study of the potential interferences must be done in order to avoid this issue.

However, due to limitations of the electromagnetic spectrum, it is important to note what frequency ranges are used by common existing communication technologies and it is also useful to identify potential interferences from the technologies with which the WSNs (Wireless Sensor Network) will share the spectrum. Moreover, standards and legislation according to the deployment of any kind of equipment within rail applications will be taken in account.

3.2 COMMUNICATIONS

In this chapter the main communication technologies availables for the application requested in C4R project are reviewed. This study will give us an idea about the saturation of existing spectrum, which will provide us more information for a later technology selection for WSN and the more adequate frequency bands; also, existing interference sources will be studied.

Although it is not purpose of this deliverable a detailed description of all nowadays existing communications technologies has been done in order to give a global vision.

The content of the chapter is structured in relation to the purpose of communication: train operation or end-user applications, where common communication technologies (like WiFi or Bluetooth, for instance) will be also described.

Special focus will be done in those technologies with lowest power consumption and easiest maintenance mechanism; these technologies will be described in more detail than the other ones as low power consumption and easy maintenance is at the heart of the monitoring system developed by the C4R project.

3.2.1 OPERATIONAL APPLICATIONS

For rail operation different communication systems are used for the positioning and location of the train in the rail network. These systems provide information about different parameters such as speed, GPS coordinates, driver assitance and so on, helping in the management of block sections and by hence in the optimisation of the traffic. These systems are considered basic for the security and safety of rail traffic.

The European Standard for operational communiocation is the ERTMS system which consist of two main components:

- a train protection system called European Train Control System (ETCS)
- and a radio communication system named GSM-R based on GSM standard and technology for railways application.

This implies that ERTMS needs of GSM-R to communicate the trackside subsystem Radio Block Centre (RBC) with the on-board subsystem in the trains.

Today, GSM-R is the most important communication system used in railway applications, both for voice and data transmission between track and trains. It is a fundamental system for communication between train protection devices (track and on board on trains) as well as in order to communicate the staff from the Control Centre with the train crew (including the driver).

The technical document ERTMS Subset 026 [2] is indicated that the GSM-R radio communication network is used for the bi-directional exchange of messages between on-board sub-systems and RBC or radio infill units.

Under the umbrella of the International Union of railways (UIC), it was developed the project called EIRENE [3] (European Integrated Railway Radio Enhanced Network) that defined both Functional and System Requirements Specifications for a standard for Radio Communication in railways. This standard defines the requirements of a radio system able to satisfy the mobile communications needs of the European railways. EIRENE project addresses track-train voice and data communications, requirements in the based mobile communications between workers and stations, and communication between railway personnel.

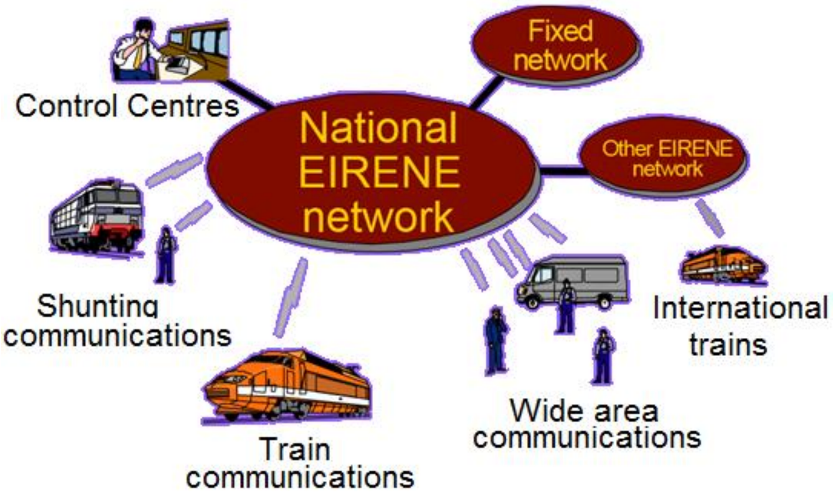


Figure 10: EIRENE [3] architecture

The frequencies used by GSM-R Applications are indicated in the Technical Specification 'ETSI TS 102 932-1 V1.1.1 (2011-11)':

- Railways GSM 900 Band, R-GSM (includes Standard and Extended GSM 900 Band):
    - For Railways GSM 900 band, the system is required to operate in the following frequency band:
        - 876 MHz to 915 MHz: mobile transmit, base receive;
        - 921 MHz to 960 MHz: base transmit, mobile receive.
- Extended Railways GSM 900 Band, ER-GSM (includes Standard and Extended GSM 900 Band):
    - For Railways GSM 900 band, the system is required to operate in the following frequency band:
        - 873 MHz to 915 MHz: mobile transmit, base receive;
        - 918 MHz to 960 MHz: base transmit, mobile receive.

NOTE 1: The term GSM 900 is used for any GSM system, which operates in any 900 MHz band.

NOTE 2: The Base Transceiver Station (BTS) may cover a complete band, or the BTS capabilities may be restricted to a subset only, depending on the operator's needs.
The carrier spacing is 200 kHz.

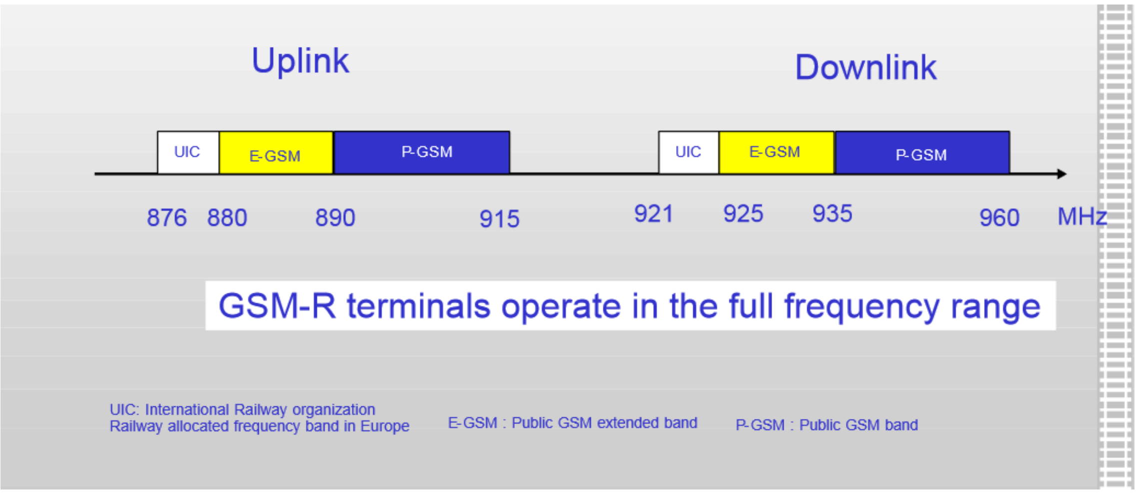


Figure 11: GSM-R Frequency Ranges

Before the establishment of EIRENE as standard for radio communications in railways, trains have used other radio communication systems to support voice communications between Control Centre staff and train driver.

For example in Spain this former Radio Communication system is called Tren-Tierra (Ground - Train), and it allows communications between the Radio Central Point (located in the Control Centre) and:

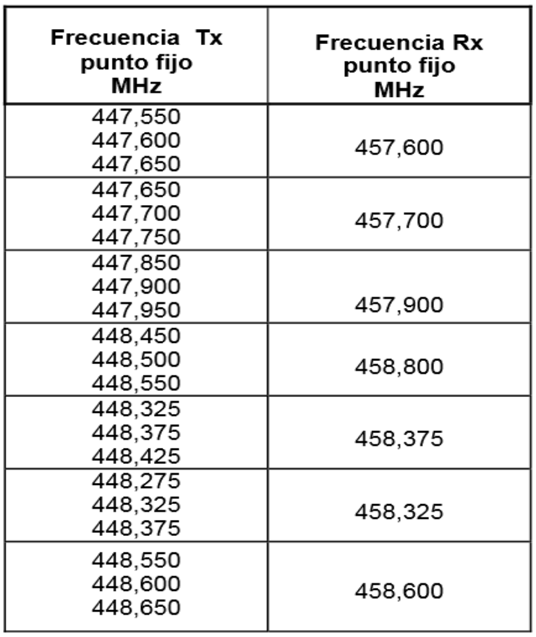
- Radio Mobile Points (located on power-heads or locomotives).
- Radio Portable Points (Maintenance personnel carry this devices).

This system is considered a Railway Safety Issue, and as consequence, not much information is available for this system.

Nevertheless, the Spanish Ministry of Industry, Energy and Tourism released the document 'CNAF Notes 2013' with some reserved frequencies for several devices or environments. One of these devices is the Tren-Tierra subsystem.

The next table (Table 2) shows the reserved frequency range for Tren-Tierra:

Table 2. Reserved frequencies for tren-tierra



Frecuencia Tx punto fijo MHz	Frecuencia Rx punto fijo MHz
447,550 447,600 447,650	457,600
447,650 447,700 447,750	457,700
447,850 447,900 447,950	457,900
448,450 448,500 448,550	458,800
448,325 448,375 448,425	458,375
448,275 448,325 448,375	458,325
448,550 448,600 448,650	458,600

3.2.2 END USERS APPLICATIONS

As mentioned, the electromagnetic spectrum is shared by many different communications technologies, both for individuals and for specific applications such as military, security, etc.

It is not aim of this deliverable to make a study of each of these potential technologies, since communications developed in C4R project are placed in specific frequency ranges (typically around 868MHz and / or 2.4GHz). For this reason, we will focus only on the most common wireless technologies existing in these frequency ranges.

However, a record of all applications and technologies in other frequency bands will be left. For an overview of the occupation of the radio spectrum in Europe, it is only need to see the above table (Table 2).

Having said that, around 868MHz and 2.4GHz bands existing technologies are related to common user applications, such as communications Wi-Fi or Bluetooth.

A brief description is shown later, for further information please refer to deliverable D42.2 'Recommendations and guidelines for the next generation monitoring and inspection'

3.2.2.1 Wi-Fi (IEEE 802.11)

IEEE 802.11 is a set of media access control (MAC) and physical layer (PHY) specifications for implementing wireless local area network (WLAN). They are created and maintained by the IEEE LAN/MAN Standards Committee (IEEE 802).

The 2.4 GHz band is divided into 14 channels spaced 5 MHz apart, beginning with channel1 which is centred on 2.412 GHz. The latter channels have additional restrictions or are unavailable for use in some regulatory domains.

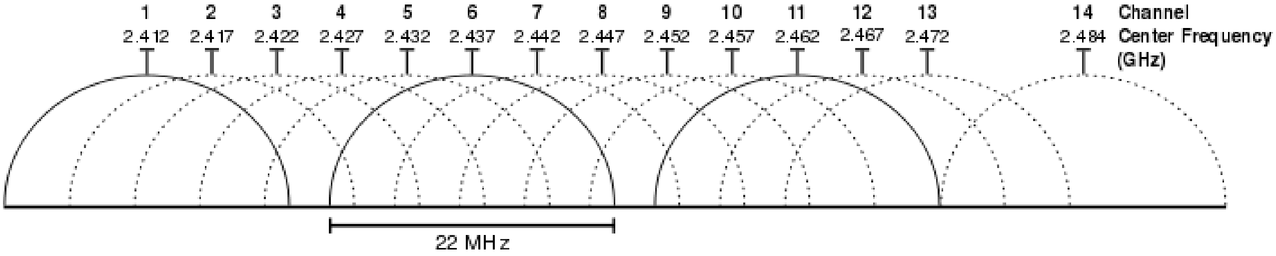


Figure 12 Graphical representation of Wi-Fi channels in 2.4 GHz band

The current 'fastest' norm, 802.11n, uses double the radio spectrum/bandwidth (40 MHz) compared to 802.11a or 802.11g (20 MHz). This means there can be only one 802.11n network on the 2.4 GHz band at a given location, without interference to/from other WLAN traffic. **802.11n can also be set to use 20 MHz bandwidth only to prevent interference in dense community**.

Coexistence of WIFI with IEEE 802.15.4 Wireless Data Networks

IEEE 802.15.4-based wireless data networks operate in the 2.45–2.4835 GHz band, and so are subject to interference from other devices operating in that same band. To avoid interference from IEEE 802.11networks, an IEEE 802.15.4 network can be configured to only use channels 15, 20, 25, and 26, avoiding frequencies used by the commonly used IEEE 802.11 channels 1, 6, and 11.

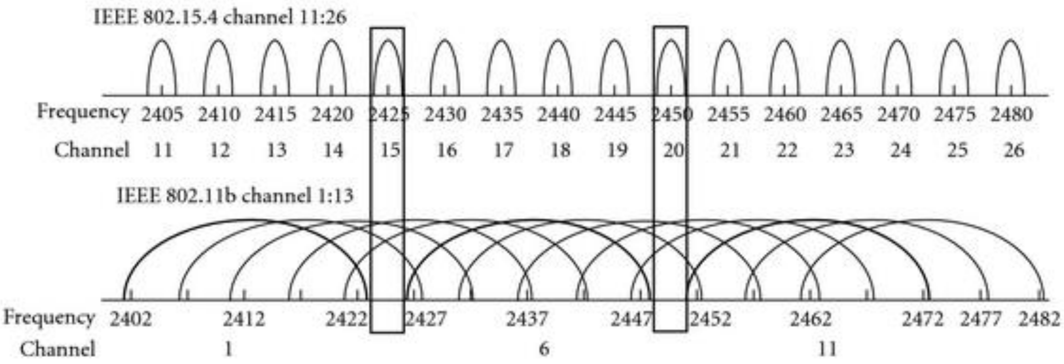


Figure 13 802.15.4 vs 802.11 Frequency Channels at 2,4 Ghz

3.2.2.2 Wi-MAX

WiMAX is a technology standard for long-range wireless networking. WiMAX equipment exists in two basic forms - base stations, installed by service providers to deploy the technology in a coverage area, and receivers, installed in clients.

WiMAX signals can function over a distance of several miles (kilometers) with data rates reaching up to 75 megabits per second (Mb/s). A number of wireless signaling options exist ranging anywhere from the 2 GHz range up to 11 GHz.

The main specifications for WiMAx are the following:

Table 3 WiMax (802.16a) main features

Feature	WiMax (802.16a)
Primary Application	Broadband Wireless Access
Frequency Band	Licensed/Unlicensed 2 G to 11 GHz
Channel Bandwidth	Adjustable 1.25 M to 20 MHz
Half/Full Duplex	Full
Radio Technology	OFDM (256-channels)
Bandwidth Efficiency	<=5 bps/Hz
Modulation	BPSK, QPSK, 16-, 64-, 256-QAM
FEC	Convolutional Code Reed-Solomon
Encryption	Mandatory- 3DES, Optional- AES
Range	10 kilometres
Data rate	Up to 75Mb/s
Frequency ranges	2 to 11 GHz

3.2.2.3 GSM/GPRS

GSM (Global System for Mobile communications) is an open, digital cellular technology used for transmitting mobile voice and data services. It supports voice calls and data transfer speeds of up to 9.6 kbps, together with the transmission of SMS (Short Message Service).

GSM was expanded over time to include data communications: first by circuit-switched transport and then packet data transport via GPRS (General Packet Radio Services).

GPRS is a packet oriented mobile data service on the 2G and 3G cellular communication system's global system for mobile communications (GSM). GPRS was originally standardized by European Telecommunications Standards Institute (ETSI) and it is now maintained by the 3rd Generation Partnership Project (3GPP).

There are fourteen bands defined in 3GPP TS 45.005, which succeeded 3GPP TS 05.05:

Table 4 GSM frequency bands

System	Band	Uplink (MHz)	Downlink (MHz)	Channel number
T-GSM-380	380	380.2–389.8	390.2–399.8	dynamic
T-GSM-410	410	410.2–419.8	420.2–429.8	dynamic
GSM-450	450	450.6–457.6	460.6–467.6	259–293
GSM-480	480	479.0–486.0	489.0–496.0	306–340
GSM-710	710	698.2–716.2	728.2–746.2	dynamic
GSM-750	750	747.2–762.2	777.2–792.2	438–511
T-GSM-810	810	806.2–821.2	851.2–866.2	dynamic
GSM-850	850	824.2–849.2	869.2–894.2	128–251
P-GSM-900	900	890.0–915.0	935.0–960.0	1–124
E-GSM-900	900	880.0–915.0	925.0–960.0	975–1023, 0-124
R-GSM-900	900	876.0–915.0	921.0–960.0	955–1023, 0-124
T-GSM-900	900	870.4–876.0	915.4–921.0	dynamic
DCS-1800	1800	1,710.2–1,784.8	1,805.2–1,879.8	512–885
PCS-1900	1900	1,850.2–1,909.8	1,930.2–1,989.8	512–810

The transmission power in the handset is limited to a maximum of 2 watts in GSM 850/900 and 1 watt in GSM 1800/1900. GSM-900 and GSM-1800 are used in most parts of the world: Europe, Middle East, Africa, Australia, Oceania (and most of Asia).

- GSM-900 uses 890–915 MHz to send information from the mobile station to the base station (uplink) and 935–960 MHz for the other direction (downlink), providing 124 RF channels (channel numbers 1 to 124) spaced at 200 kHz. Duplex spacing of 45 MHz is used. Guard bands 100 kHz wide are placed at either end of the range of frequencies.
- GSM-1800 uses 1,710–1,785 MHz to send information from the mobile station to the base transceiver station (uplink) and 1,805–1,880 MHz for the other direction (downlink), providing 374 channels (channel numbers 512 to 885). Duplex spacing is 95 MHz. GSM-1800 is also called DCS (Digital Cellular Service) in the United Kingdom.

Because of being a well working communication technique, the number of high speed on-board train users demanding broadband data services, is increasing due to the high penetration rate of smartphones, tablets, and laptops. In addition railway environments are EM hostile environments for communications, due to factors such as propagation, fast changes in channel due to high speeds, etc. In order to overcome these constraints and to reduce deployment infrastructure costs, telecommunications companies usually co-locate commercial systems in the same places where GSM-R ones are deployed. The co-location of cellular commercial systems in the same sites as GSM-R system, may lead to interference issues if both kinds of systems are deployed in adjacent frequency bands [4] [5] [6]. Besides, the potential interference issues gain in importance regarding the spectrum digital dividend process, where new broadband systems like LTE can be deployed in the

800 MHz band. When assessing coexistences between LTE and GSM-R, it is important to remark that railway industry is considering the migration towards new broadband and reliable communication system, like LTE [7]. It is expected that for a midterm scenario, both systems will coexist in railway environments, leading to harmful interference situations.

Under this scope, it is important to perform an assessment process on coexistence between commercial communication systems and GSM-R. The outcome of this assessment process shall cover to the definition of several key planning and dimensioning parameters for minimizing the interference between both systems in the 900 MHz frequency band and/or the establishment of a coordination measures between railway operators and public mobile broadband services operators that minimize the risk for harmful interferences [4].

This work is in progress but more is to be done since railways are registering an increasing number of interferences to the GSM-R systems. By January 2011 there was an identified number of 252 interference locations in Germany (compared to 58 locations in 2006) - where interference from public mobile GSM networks have been measured. Unwanted emission coming from the public base stations (GSM, UMTS900, LTE900) may leak into the GSM-R band and therefore raise the noise floor. Cumulated interferences signal level, due to high transmitting levels from public transmitters. In addition installations close to railway lines without coordination will cause severe interference to the GSM-R communications on railways lines [8].

3.2.2.4 3G

3G, short form of third Generation, is the third generation of mobile telecommunications technology. This is based on a set of standards used for mobile devices and mobile telecommunications use services and networks that comply with the International Mobile Telecommunications-2000 (IMT-2000) specifications by the International Telecommunication Union. 3G finds application in wireless voice telephony, mobile Internet access, fixed wireless Internet access, video calls and mobile TV.

Currently, CDMA2000 network infrastructure and user devices are available in most of the IMT-2000 frequency bands designated by the ITU, including the 450 MHz, 700 MHz, 800 MHz, 1700 MHz, 1900 MHz, AWS and 2100 MHz bands.

3.2.2.5 4G

4G is completely based on the IP protocol, and can be used by wireless modems, smartphones and other mobile devices.

What is new, is that its radio interface is based on OFDMA for the downlink and SC-FDMA for uplink. The modulation selected for 3GPP technologies makes different antennas (MIMO) have a greater ease of implementation

Some of the most important features are:

- High spectral efficiency
- Adaptative Bandwith: 1, 4, 3, 5, 10, 15 y 20 MHz.
- It can work in many different frequency bands.

- Simple protocol architecture.
- Compatibility with other 3GPP technologies.
- Peak data rates:
  - Uplink: 86.5 Mbps.
  - Downlink: 326.5 Mbps with 4x4 antennas, 172.8 Mbps with 2x2 antennas.
- Optimal for displacements up to 15 km/h. Supports up to 500 km/h.
- Optimal cell size 5Km.

It exists different frequency bands depending on the country or area where they are used**:**

LTE Bands	Uplink (MHz)	Downlink (MHz)	Duplex Spacing (MHz)	BW (MHz)	Duplex Mode	Deployment in the world
Band 1	1920 -1980	2110 -2170	190	60	FDD	China, Japan, EU, Asia, Australia
Band 2	1850 -1910	1930 -1990	80	60	FDD	North/South America
Band 3	1710 -1785	1805 -1880	95	75	FDD	EU, China, Asia, Australia, Africa
Band 4	1710 -1755	2110 -2155	400	45	FDD	North/South America
Band 5	824 -849	869 -894	45	25	FDD	North/South America, Australia, Asia, Africa
Band 6	830 -840	875 -885	45	10	FDD	Japan
Band 7	2500 -2570	2620 -2690	120	70	FDD	EU, South America, Asia, Africa, Australia
Band 8	880 -915	925 -960	45	35	FDD	EU, South America, Asia, Africa, Australia
Band 9	1749.9 -1784.9	1844.9 -1879.9	95	35	FDD	Japan
Band 10	1710 -1770	2110 -2170	400	60	FDD	North/South America
Band 11	1427.9 -1447.9	1475.9 -1495.9	48	35	FDD	Japan
Band 12	698 -716	728 -746	30	18	FDD	North America
Band 13	777 -787	746 -756	31	10	FDD	North America
Band 14	788 -798	758 -768	30	10	FDD	North America
Band 17	704 -716	734 -746	30	12	FDD	North America
Band 18	815 -830	860 -875	45	15	FDD	North/South America, Australia, Asia, Africa
Band 19	830 -845	875 -890	45	15	FDD	North/South America, Australia, Asia, Africa
Band 20	832 -862	791 -821	41	30	FDD	EU
Band 21	1447.9 -1462.9	1495.9 -1510.9	48	15	FDD	Japan
Band 22	3410 - 3500	3510 - 3600	100	90	FDD	
Band 24	1626.5 -1660.5	1525 -1559	101.5	34	FDD	
Band 33	1900 -1920		N/A	20	TDD	
Band 34	2010 -2025		N/A	15	TDD	China
Band 35	1850 -1910		N/A	60	TDD	
Band 36	1930 -1990		N/A	60	TDD	
Band 37	1910 -1930		N/A	20	TDD	
Band 38	2570 -2620		N/A	50	TDD	EU
Band 39	1880 -1920		N/A	40	TDD	China
Band 40	2300 -2400		N/A	100	TDD	China, Asia
Band 41	2496 -2690		N/A	194	TDD	
Band 42	3400 -3600		N/A	200	TDD	
Band 43	3600 -3800		N/A	200	TDD	

Figure 14 Frequency bands and regions

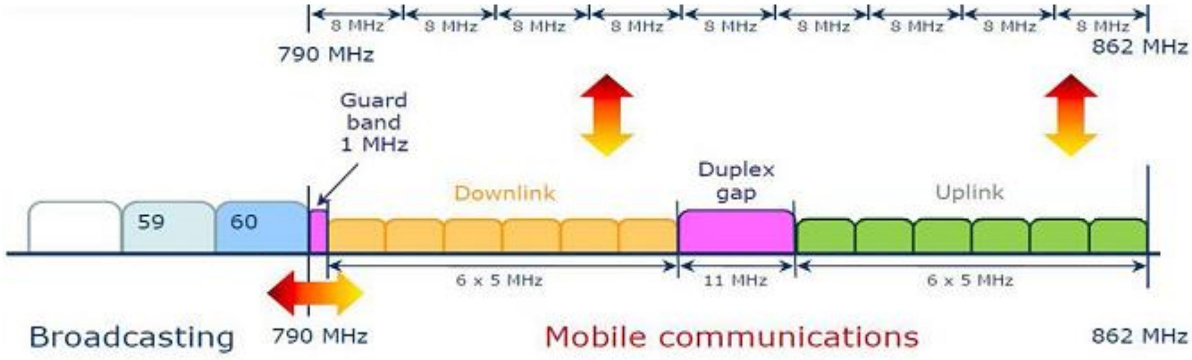


Figure 15 LTE Band 20

As it shown, it exists In EU some bands for 4G communications in the range of frequencies close to 800MHz where several wireless communications commonly works.

3.2.2.6 BLUETOOTH

The key features of Bluetooth technology are low power, and low cost. The Bluetooth Specification defines a uniform structure for a wide range of devices to connect and communicate with each other.

The range of Bluetooth technology is application specific. The Core Specification mandates a minimum range of 10 meter, but there is no set limit and manufacturers can tune their implementations to provide the range needed to support the use cases for their solutions.

An overview about the main Bluetooth specifications is:

- **Spectrum**

  Bluetooth technology operates in the unlicensed industrial, scientific and medical (ISM) band at 2.4 to 2.485 GHz, using a spread spectrum, frequency hopping, full-duplex signal at a nominal rate of 1600 hops/sec. The 2.4 GHz ISM band is available and unlicensed in most countries.

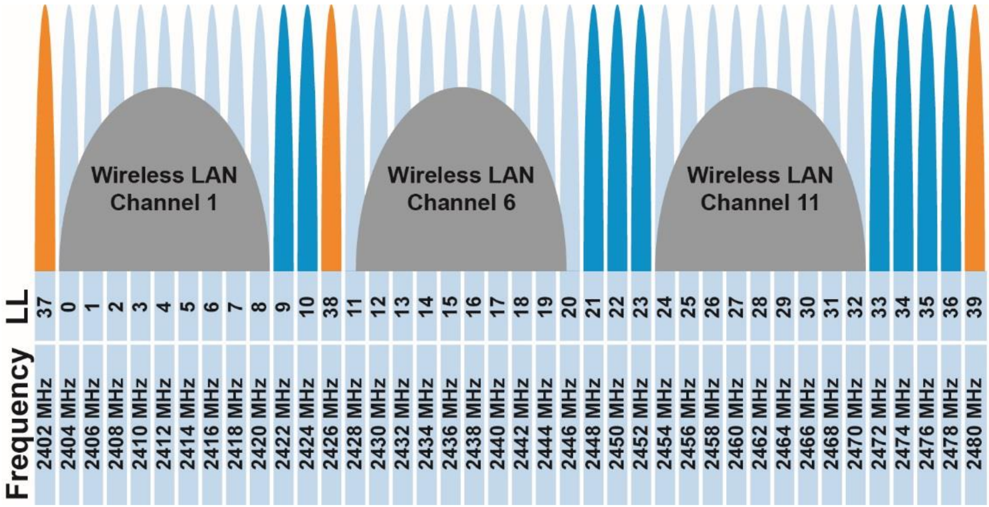


Figure 16: Frequency Bands in Bluetooth

Bluetooth technology's adaptive frequency hopping (AFH) capability was designed to reduce interference between wireless technologies sharing the 2.4 GHz spectrum.

AFH works within the spectrum to take advantage of the available frequency. This is done by the technology detecting other devices in the spectrum and avoiding the frequencies they are using. This adaptive hopping among 79 frequencies at 1 MHz intervals gives a high degree of interference immunity and also allows for more efficient transmission within the spectrum. For users of Bluetooth technology this hopping provides greater performance even when other technologies are being used along with Bluetooth technology.

It exists a variant of Bluetooth named Bluetooth Low Energy (BLE) with improve the range and especially the power consumption compared to “classical” Bluetooth technology.

However, the range in this communications is quite short to monitor areas in rail infrastructure, even if the communication is made directly between the train and the track, the time consuming for the data exchange and pairing of the devices is quite long to use this technology of C4R applications.

3.2.2.7 ISM-band

The ISM-band has been used for communication of data concerning structure health monitoring sensing of railway wagons [9]. It has also been used for communication of data from sensors along the track.

However the large use of the ISM-band also implies the risk of interference. Consequently there is the risk of interruption of the operating of the railway and thus accident occurrence due to disconnection and communication interruption between different railway radio systems, In addition there exists a risk of frequency interference and cross talk between commercial network and existing railway radio system in case of unlicensed band of ISM 2.4 GHz WiFi uses.

ISM band operation suffers many types of interference from:

- Other WLANs of the same type on the same channel (e.g. both 802.11 and Bluetooth).
- Other WLANs of a different type on the same channel (e.g. mixed 802.11g and 802.1 I b).
- Other WLANs on nearby channels.
- External sources (e.g. Microwave ovens).
- Other users of the (unlicensed) ISM band (e.g. video transmitters).

In relation to operating railway systems applications concerns has been raised of RF interference on application that needs a very high degree of safety like e.g. the operation of communication based train control (CBTC) equipped trains [10]. While interference is a possibility it can be mitigated using spread spectrum (SS) radios and error detection and correction coding techniques can be considered as part of e.g. the overall CBTC system. SS-radio can be divided into two techniques i.e. direct sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS). A FHSS radio operates on a given frequency for a specific period of time (dwell time) and then changes (hops) to another frequency and keeps changing (hopping) in this fashion. The pattern of these changing frequencies is the hop sequence. The hop sequence between FHSS transmitter and receiver must be synchronized. If a given frequency is occupied by another user (the interferer), the FHSS radio might lose some data while it occupies this same frequency but will eventually hop away to another frequency once the dwell time expires. In this scenario, only the data transmitted during one dwell time is at risk of interference.

3.2.2.8 IEEE 802.15.4(g)

IEEE 802.15.4 main features are easy installation, reliable data Exchange, medium range, low cost, long battery life and:

- Data rates from 20kbps to 250 kbps.
- Operating frequencies:
    - 868MHz (1 channel)
    - 915MHz (10 channels)
    - 2.45GHz. (16 channels)
- Different topologies: star and mesh topology.
- Collision avoidance through CSMA-CA.
- Low energy consumption.
- Power emission control.

Thanks to the different available network topologies in IEEE802.15.4 it is quite easy to cover large areas using this communication technology.

A special case of peer-to-peer topology is the cluster tree or tree network where most nodes are sensors. Multiple blocks of this type can be added to grow longer-range networks. The main issue of having a network with a broad coverage radius is that the message latency significantly increases.

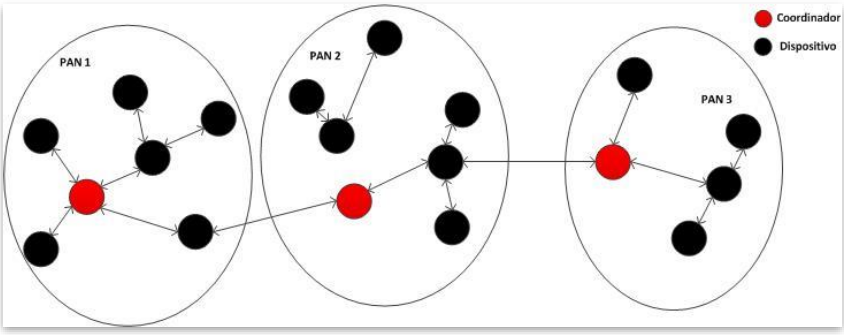


Figure 17 Diagram of a cluster tree network

Moreover, IEEE 802.15.4g task group within the IEEE 802.15 working group was created to cover long range applications, but ensuring coexistence with the other systems operating in the same band including 802.11, 802.15 and 802.16 systems.

This standard review allow covering larger areas using one single network, despite its low power consumption, energy harvesting techniques are recommended in order to extend the battery life and minimize maintenance operation.

3.2.2.9 EPC 18000-6C

This is a standard ratified in December 2004 as UHF Generation 2 Air Interface Protocol. It was created from the best features of Generation I, both Class 1 and 2 and ISO protocols (ISO 180000 series).

It had a firm commitment to improve the previous standards, which was developed in collaboration with leading RFID manufacturers, users and institutions of standardization, under the coordination and supervision of EPCglobal.

The standard specifies the characteristics of the tags as well as the communication protocol to ensure interoperability with EPC readers

RFID tags can communicate at any frequency between 860-960 MHz, this requirement also applies to RFID readers. The labels (tags) will be able to understand three different modulation schemes:

- DB-ASK (Double Sideband-Amplitude Shift Keying)
- SS-ASK (Single Sideband-Amplitude Shift Keying)
- PR-ASK (Phase-Reversal Amplitude Shift Keying)

Readers will determine which scheme is used, taking into account the radius of each government regulations and environmental conditions. The tags can transmit at different speeds, specifically four 80 Kbps, 160 Kbps; 320 Kbps or 640 Kbps. The readers determine that speed use; improving GEN1 features (from70 and 149 Kbps).

The Gen2 tags provide EPC (Electronic Product Code) of 256 bits (Gen1 supported up to 96 bits); Gen2 also includes a method for supporting multiple readers and reduce interference between them (Dense-Interrogator channelized signalling).

This mode is used in areas where multiple readers work simultaneously. It is important to know that this mode is optional for readers, according to the specification. The behaviour in the real environment depends on many factors, including external interference from other devices, such as cordless phones UHF, industrial equipment or wireless LAN equipment.

Below a table with the main features of this standard is shown:

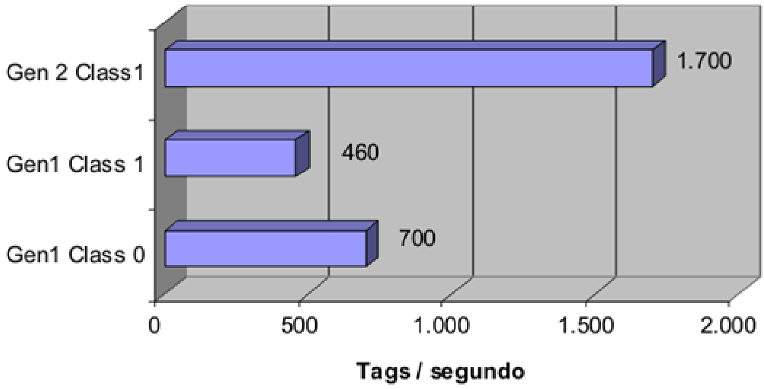
Table 5 EPC GEN2 main features

EPC GEN2	
EPC	96/256 bits
Data rate	80/640 Kbps
Tags data rate	EU ETSI – 460 tags/s
Write rate	5 tags/s
frequency	860 -960 MHz
security	16 bits CRC

Reading modes	EU ETSI – simple, multiple and dense

Generation 2 offers a top speed of 640 Kbps, while generation 1 had 80 Kbps in class 0 and 140 kbps in class 1, this means 8 times more speed.

Table 6 Tags reading data rate



3.2.2.10 RFID

RFID acronyms refer to Radio Frequency Identification. An RFID system consists of the readers or (Interrogators) and labels (tags or transponders). an RFID system generally consists of several RFID readers, either static or moving positions and a number of tags attached to objects that want to be identified with those tags. So the reader has the possibility of establishing a wireless communication with any RFID tag that is in its coverage range.

Passive tags are characterized by having no internal power supply. They collect the electromagnetic (EM) field transmitted by the reader as power supply (by the technique of "backscatter") to transmit data to the reader. These tags are the simplest and therefore turn out to be the cheapest in the market.

As for the classification of RFID systems, there are four types of systems as four different frequency ranges are offered:

- Systems Low Frequency (LF): 125 - 134.2 KHz
- High Frequency (HF) 13.56 MHz
- UHF (UHF): 868 - 956 MHz
- Microwave: 2.445 GHz

Low and high frequency tags can be used globally without any license. This is not possible with UHF tags because there is no single global standard. In fact, there are several depending on the geographical position.

We can distinguish between these geographical areas North America (908-928 MHz), Europe (865.6 - 867.6), China, Japan, Australia and New Zealand. Similarly there are various regulations related to health and environmental conditions.

As is well known, passive RFID tags do not have an own power supply, so that the range of this systems directly depends on the field radiated by the reader. The energy received on the tags is rectified and amplified to power up the internal circuitry of the tag. Normally this coupled energy is rectified by a half-wave rectifier Greinacher multi-stage, as shown in the following figure.

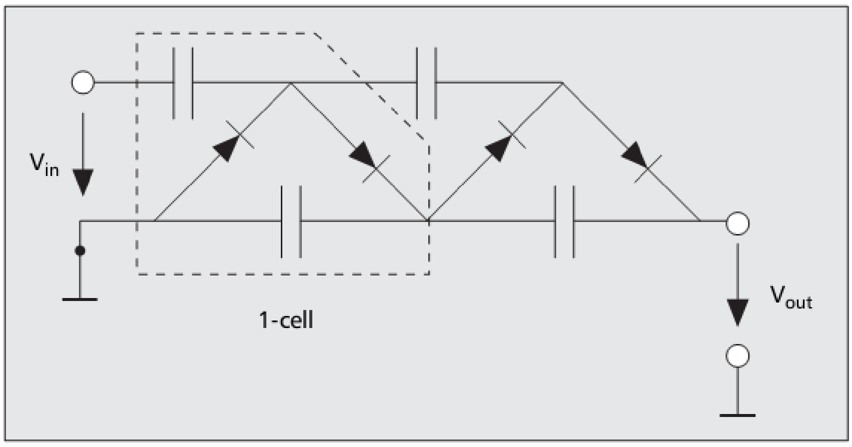


Figure 18 Two stages half-wave rectifier Greinacher

In relation to the types of coupling there are two passive tags for:

- Near field coupling
- Far field coupling

Near Field Coupling Passive RFID

Electromagnetic fields in the near field is reactive in nature because the electric and magnetic fields are orthogonal and quasi-static. Thus, depending on the type of antenna either a dipole electric field or a magnetic field coil will be dominant. Most nearfield tags use the magnetic field and hence the inductive coupling coil in the tag. This mechanism is based on the principle of magnetic induction by Faraday

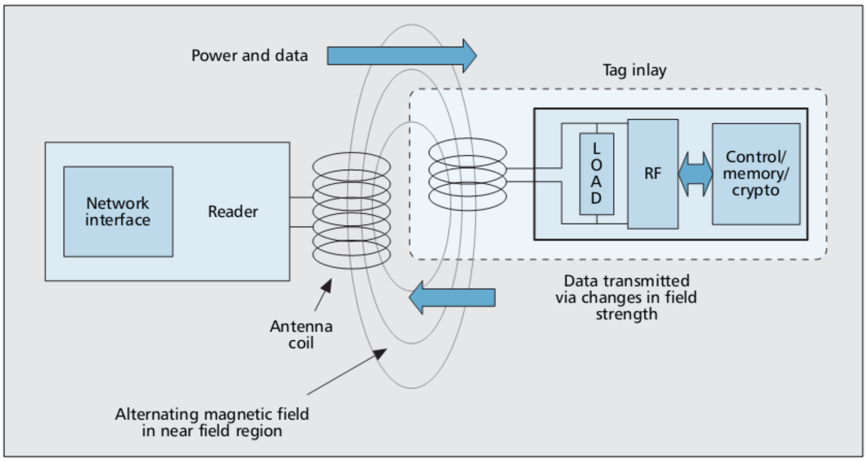


Figure 19 Inductive coupling in nearfield applications

Figure 19illustrates the performance of the system. The current through the reader coil generates a magnetic field around it. This field will generate a small current through the coil of the tag if this is within the scope of this magnetic field.

Once the tag circuit is fed the communication between tag and reader starts; this communication is done through a mechanism called load modulation. Any variation in the current in the coil of the tag causes a small current variation in the reader coil because inductive coupling between the two coils (reader and tag) is mutual and therefore the reader detects these changes in current.

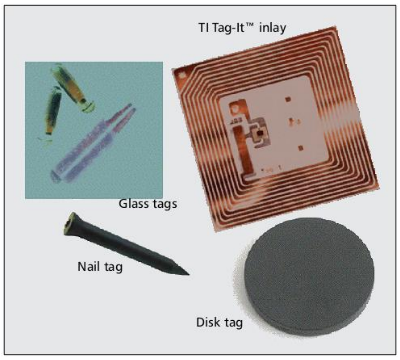


Figure 20 Nearfield tags examples

The boundary between the near and far field is inversely proportional to the frequency and approximately equal c / 2πf, where c is the speed of light. Therefore, for nearfield applications it is necessary to use carrier frequencies low. The most common frequencies are 128 kHz (LF) and 13.56 MHz (HF). For example, to 13.56 MHz theoretical range may be about 3.5 m.

Finally, it should be noted that the fact of using a low frequency carrier limits the system because the bandwidth is low and therefore the data rate is very low (about 1 Kbps).

Table 7 Inductive coupling communication restrictions

Frequency	**Magnetic field**
119 – 135 kHz	66 dBµA/m a 10 m
13,553 – 13,567 Mhz	42 dBµA/m a 10 m

Far Field Coupling Passive RFID

Unlike it occurs in near-field systems, in far-field coupling EM energy is captured and detected in the tag antenna as a potential difference. Part of the incident energy on the tag antenna is reflected back due to the mismatch between the impedances of the antenna and the load circuit. Changing or adding load to the antenna the amount of reflected energy may vary. This technique is called backscattering and it is the principle on which the RFID far field communications are based.

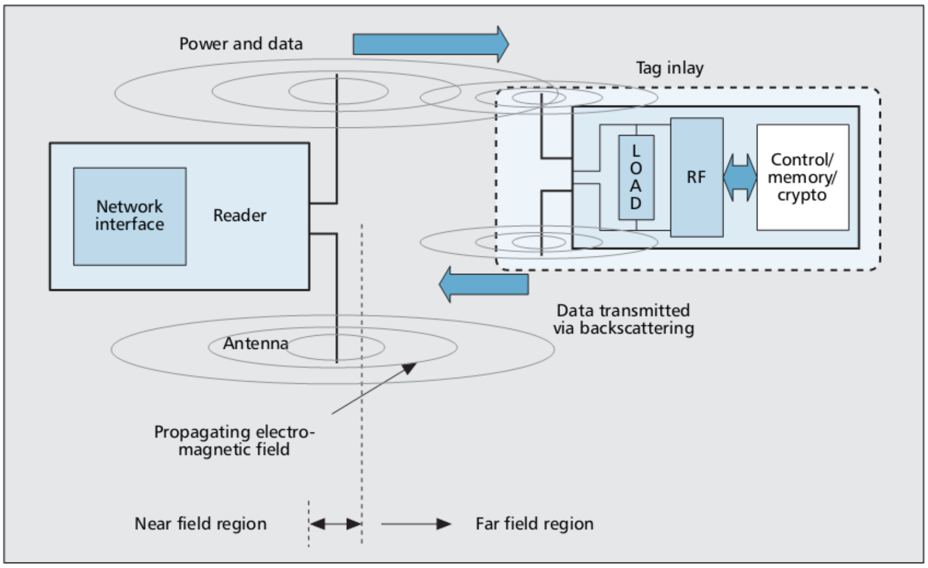


Figure 21 Backscattering communication in far field RFID devices

The far field coupling is commonly used for long-range RFID systems (5-30 m) and unlike with the near field coupling, there is no restriction in relation to the controllable field range; the attenuation of EM fields in the far field region is proportional to $1/r^2$.

Far field systems have as advantage over near field, because they operate at high frequencies, the antenna size is significantly smaller, thereby decreasing manufacturing costs. In addition, several design techniques, combined with the advances in silicon manufacturing technologies, the passive farfield tags are obtained with a power consumption of the order of μW.

Regarding working frequencies, these tags usually operate in the UHF (860-960 MHz) bands and Microwave (2.45 GHz). To meet the needs of each application the shape of the antenna could be modified.

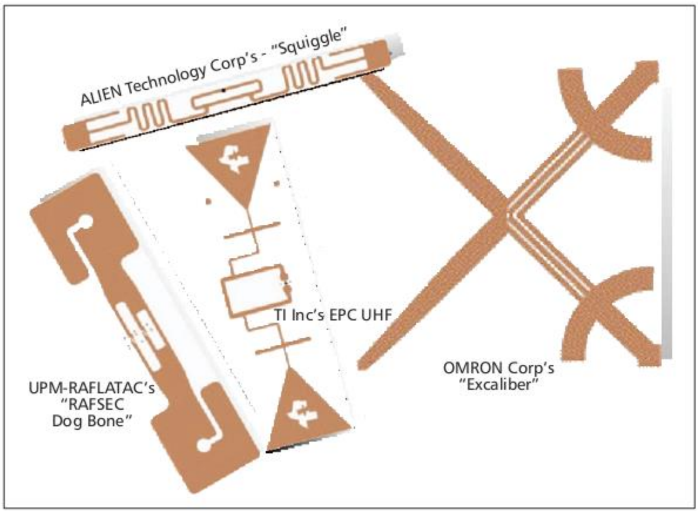


Figure 22 UHF tags

The band RFID 3 (865-868 MHz) is regulated by the note A - 135 CNAF. The CNAF authorized facilities radio frequency identification devices with the following characteristics:

Table 8 RFID Band3 specs

Frequency bands	**Channel spacing**	**Max Power**
865 – 865,6 MHz	200 kHz	100 mW (p.r.a.)
865,6 – 867,6 MHz	200 kHz	**2 W** (p.r.a.)
867,6 – 868 MHz	200 kHz	500 mW (p.r.a.)

The band RFID 4 (2446 - 2454 MHz) is regulated by the note A - 129 of CNAF. Radiofrequency identifiers devices can use the ISM frequency band 2446-2454 MHz without any restriction in the duty cycle. A maximum isotropic radiated power equal authorized 500mW.

The technical standard of reference for these devices is EN 300 440. Other features of use shall be in accordance with Annex 11 of the ERC / REC 70-03 Recommendation CEPT.

The labels or tags in passive RFID systems do not have an own power supply, so that the range of such systems depends directly on the field radiated by the reader. The energy received on the label is rectified and amplified to power the internal circuitry of the tag.

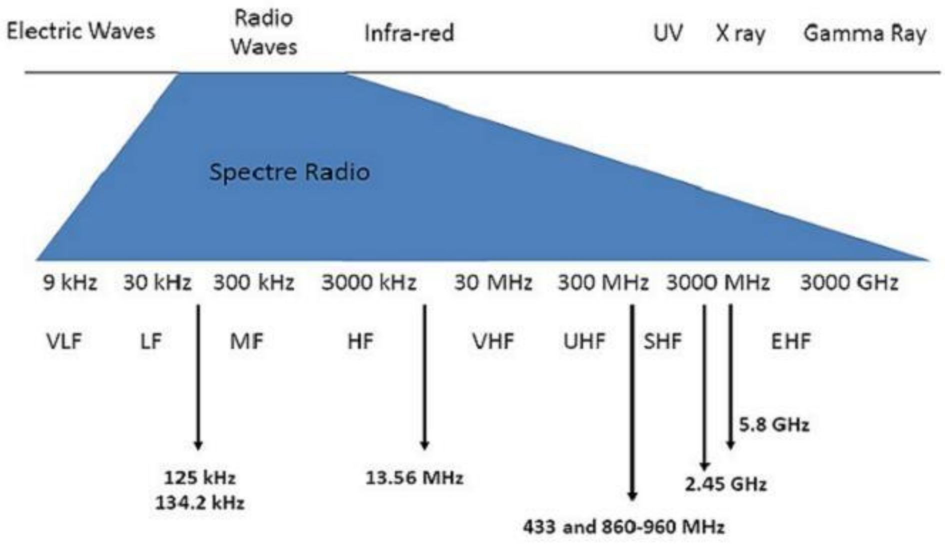


Figure 23: RFID Frequencies Spectrum

Mayor handicap for RFID communications are its very short range, so it is not possible to create a wireless network sensor using this technology; but its best strength is based in its completeabsence of batteries or power supply to communicate.

This makes possible to minimize the maintenance tasks, thanks to the creation of unattended systems able to operate for years without batteries.

Regarding the possible interferences, low frequency RFID operating in the 30 KHz to 300 KHz is not very sensitive to radio wave interference. High-frequency RFID operating between 3 to 30 MHz is moderate sensitivity to interference. The largest sensitivity to interference and also largest operating range is the ultra-high frequency (UHF) RFID which covers the range from 300 MHz to 3 GHz. Most of the UHF Generation 2 RFID systems in most countries operate between 900 and 915 MHz. The read range of passive UHF systems can be as long as 12 m.

Because of the use of wireless transmission it is important to consider whether there is a risk of interference between RFID and other technologies in the workplace or the datacenter. This is particularly true where certain classes of RFID technology are used and where the consequences of interference with other systems and equipment are likely to be serious.

Two classes of interference could be considered; firstly interference that prevents correct data being transmitted and/or received and as a result degrades the performance of one or other wireless systems; and secondly the risks that signals from one system will be interpreted incorrectly as valid data by another system. The areas where interference is most likely to occur is between RFID systems and wireless local area networks (WLAN/“WiFi”) or personal area networks (WPAN) such as Bluetooth and then only when devices share common or closely adjacent frequency bands. Possible interference for ISO18000-6 type A standard is the IEEE802.15 WPAN (Zigbee @ 868 & 915 MHz) [8].

The interference can also be mitigated using highly directional antennas with narrow horizontal half-power beam width. The antennas can prove very useful not only in reducing radio interference but also in increasing the RFID reader’s read range.

3.3 COMMUNICATION TECHNOLOGIES COMPARATIVE

As said before, there are many wireless technologies used in applications concerning monitoring that initially could be used for C4R project, including: Bluetooth, IEEE802.15.4, Wi-Fi, RFID, GSM / GPRS / 3G, etc.

But if we focus on the application to be developed in this WP, and make a preliminary reading of the requirements needed, we can easily conclude that only a few of the identified technologies could comply with the requirements identified.

Table 9 presents with a comparison between the requirements needed for C4R and the most relevant specifications of the technologies described.

Mobile communications have been integrated in the same category because their features are similar to those sought by this project. For Bluetooth and IEEE802.15.4 communication systems, only the best types regarding power consumption and range are taken into account. Finally, only Passive RFID is include in the table because Active RFID may not sense for this project as it needs batteries as other technologies with worse range performance.

For the AMS to be developed for this project, the minimum admissible levels in the following features are:

- Range (distance between sensor and data reader): a short distance is good enough. The reader could be a handheld device, a fixed antenna close to the sensors or an antenna on board of passing trains (in future developments, out of the scope of this project).
- Data rate: a low data rate is good enough as only few bytes are sent in each measure.

- Consumption: the power consumption should be as low as possible to avoid maintenance activities (such as battery replacement). This will be the major feature which will decide on the technology used.
- Response time: for the current application this is not a major constraint as the tags will be read using fixed or handheld antennas. For future application in which the antennas are onboard the train this will be a more important feature to be taken into account.

Table 9 analyse the performance of different analysed technologies with respect to the features (minimum values) required by the C4R AMS. Each feature is categorized as:

- **+++** 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)

Table 9. Comparison between the requirements needed for C4R and specifications for studied technologies

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

Because of the limitation on power consumption, *Passive RFID* has been selected for the C4R project. This technology is the one that present a better performance (as it is passive) in relation to consumption. It is god enough to meet the other requirements (in relation to range, data rate and response time).

4 Design of an integrated monitoring system

In this section, the design and basis for the new and integrated Advanced Monitoring System (AMS) will be described. For this goal, a number of different steps have been followed: from the selection of the most appropriate technology, based on the previous research, to the identification of the different physical parameters to assess the new concepts of slab track developed in SP1. Finally a number of in-lab tests have been performed to prove the performance of the system. A real validation of the AMS developed within this WP will be embedded in the two slab track concept prototypes. At the momento of the submission of this report, the two slab concepts are in the process of being prototyped and manufactured to be tested at CEDEX Laboratory. will take place once the prototypes are finally manufactured and deployed in the Laboratory facilities at CEDEX (Madrid, Spain). Practical issues that may arise during the manufacturing process (in relation to the embedding of the monitoring system or the measurement process) will be reported in deliverable D.4.3.2.

4.1 REQUIREMENTS FOR THE INTEGRATED MONITORING SYSTEM

As already mentioned, the C4R AMS for the new slab track concepts have to meet the following requirements:

- The sensor nodes will be low-cost, i.e. based on mature technologies that are already available in the market at a competitive cost.
- The sensor nodes will be energetically autonomous, i.e. battery-free or with a battery provided with energy harvesting methods for self-recharging.
- The sensor nodes will be embedded in the infrastructure elements, i.e. below some centimetre of concrete that could impede the communication.

It can be observed that accuracy is not included in the previous list of requirements. It is due to the fact that market available sensors were developed for monitoring purposes in the automotive, aeronautics and telecommunication sectors, among others, where the accuracy requirements are much more severe than in infrastructures sector.

4.2 SELECTED TECHNOLOGY: RFID

As explained above, passive RFID technology has been selected for the C4R project AMS. RFID sensor nodes generally require an active power source to function effectively. One of the challenges of this work package is to use passive RFID sensor tags which are battery-free. Another option would have been the use of Active RFID together energy harvesting technologies to recharge batteries. The following figure shows the different strategies to power the sensor tags which depends on the type of measurements that are planned.

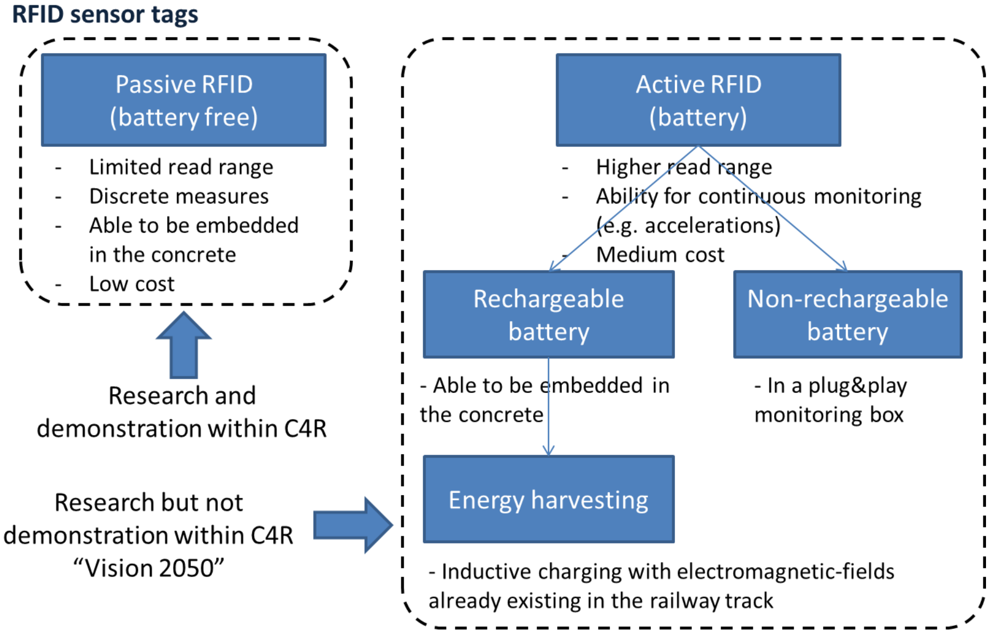


Figure 24. Possible technologies for powering the sensor nodes

One option to power the sensor tags is to tap into the systems used to power the trains. A range of voltages are used in the European rail network being the most common voltage 25kV AC overhead lines. The fundamental drawback of this approach is the need of laying cables from the power line to the sensor nodes embedded within the slabs and handling very high voltage. There is also the need to address practical issues such as maintenance of cables, safety and waterproffing.

The full benefit of wireless sensing cannot be achieved unless the power source is also wireless or self-contained. A practical option for making sensors nodes truly "wireless" is to use batteries. Batteries are a low cost, mature technology and widely available with high rate of reliability. The main problem with a battery is that current technology is getting close to the limit of the chemical energy density possible for primary cells, which means that higher battery capacity would require a larger battery size. The battery size often becomes the dominating factor in determining the sensor node size. Nevertheless, it is unrealistic to expect a normal battery-powered sensor node to last over 30 years and a special design is required. The battery used would have to be either very large in size or be recharged/replaced form time to time. Replacing or recharging batteries embedded in slab track is a management overhead that cannot be overlooked.

The third option is energy harvesting, which converts ambient energy into electrical energy for powering sensor nodes. Compared to the battery option, energy harvesting presents the advantage of being maintenance-free (i.e. no need to replace or recharge the batteries) and also environmentally friendly (i.e. batteries contain chemical and metals that can be harmful to the environment and hazardous to human health). Energy harvesting has been a hot topic for study and research in recent years and it is expected to advance rapidly in the near future since scavenging ambient energy to recharge or replace built-in batteries is a key enabler for practical long lasting monitoring systems. Energy harvested, using various technologies, already exceeds the power requirements for some infrastructure monitoring applications. In the case of slab tracks systems, solar panels are a relatively cheap and mature technology, but they rely on the availability of sunshine and panel cleanliness, which are difficult to guarantee in a railway environment. They are also prone to theft if they can be easily dismantled form their fixings. Another source of ambient energy for harvesting is a track vibrations caused by passing trains. It has been reported that the energy harvested by a passing train could provide power for monitoring tunnels [11], but further studies and developments are required to make it a practically viable solution.

The chosen solution for the monitoring system developed within this project is to use the RFID tags for harvesting energy from the radio frequency (RF) field created by RFID readers and use that power to drive sensors, actuators or other electronics effectively creating battery-free devices. One of the most important criteria for selection of the RFID chip is the amount of energy that can be harvested for the rest of components. Unlike other power sources, the RFID will provide a variable energy depending on different situations. The variables influencing the amount of energy that can be harvested are, among others, the read range, the output power from the RFID reader, the reader antenna and tag antenna gain, the materials involved in the system and so on.

The RFID sensor tags used in this project have an UHF RFID chip with advanced capabilities for developing battery-free sensor tags, named ANDY100 [12]. This device features a master SPI port for communication with external devices and power outputs for driving those external devices from the energy harvested from the UHF RF field.

The tag is compatible with EPC C1G2 RFID commercial readers. No custom hardware or custom commands are required. The ANDY100 is ideal for developing battery-free devices such as sensors, actuators or displays. These devices will help in asset or process monitoring applications as they provide a unique identification number plus data from the associated sensor without the need for batteries.

The ANDY100 IC includes a RF frontend for UHF RFID power harvesting and communication, a power supply module to generate the required voltage levels, an EPC C1G2/ISO18000-6C digital processor including a trimmed clock oscillator, a non-volatile memory and a SPI master module. The SPI master module can be controlled via EPC C1G2 standard memory access commands.

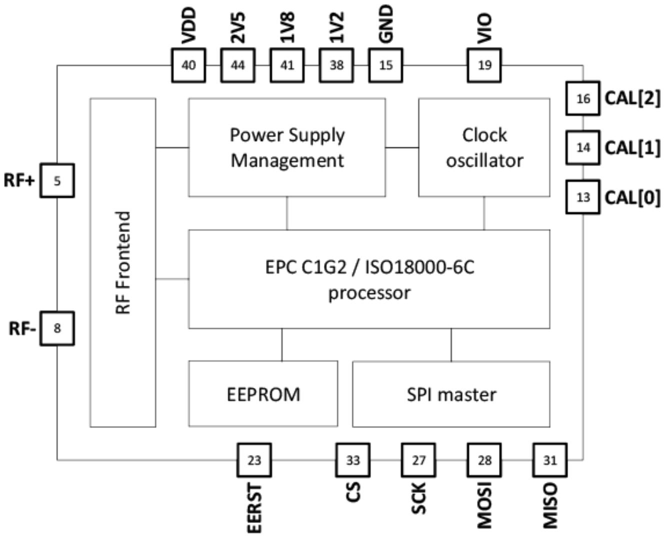


Figure 25 RFID chip used for energy harvesting

With this configuration, the ANDY100 chip [12] can harvest around 10µA@2.5V continuously when working at 2W ERP, 2.7dBi tag antenna gain and at 2 meters distance in free air.

4.3 RFID SYSTEM ARCHITECTURE

The design of the system architecture is tightly linked to the selection of technology: RFID in this case.

According to the restrictions, the selected technologies will be based on integrating a sensor with a commercial radio-frequency identification (RFID) chip (also called a tag because of its widespread use in inventory control). The chip is passive and is activated by inductively coupled power from a remote interrogator/reader. When activated, the chip responds with a digitally encoded signal that not only identifies the sensor, but also contains information about the sensor state.

These RFID sensor tags are already available in the market, although there is only a few experiences with its application in structural health monitoring. It is necessary to adapt the design for embedding the system in concrete and for reading low-cost sensors typically used in civil structures.

The principle of operation of an RFID sensor tag is illustrated in Figure 26. The operation of this system can be described as follows. First, the radio-frequency (RF) transceiver (called an interrogator or reader) illuminates the embedded microsensor. The power incident on the microsensor is rectified to produce the DC power needed to operate the microsensor. Next, the backscatter from the microsensor antenna (coil) is modulated by the RFID chip according to the ID code and sensor state in the RFID memory. Finally, the transceiver demodulates the received backscatter and reports the ID and sensor state to the computer. If desired, the computer can then update a database for the structure being monitored and flag particular locations for further inspection and/or maintenance.

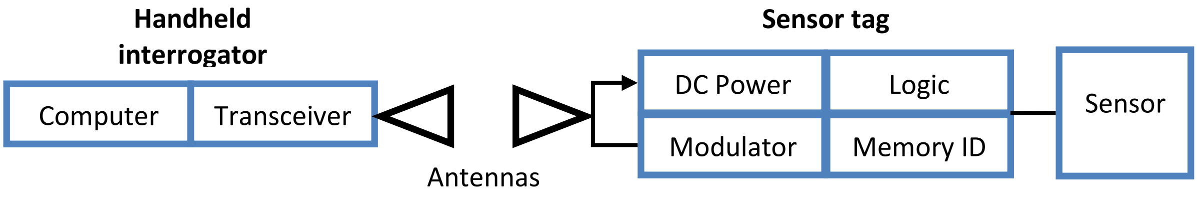


Figure 26 Principle of operation of an RFID sensor tag

An electrical equivalent circuit for the system schematized in Figure 26 is shown in Figure 27. The inductive coupling between the reader and the sensor tag is represented in this circuit by the mutual inductance M21. The inductance in the reader circuit is series resonated to maximize the current through the reader antenna. This technique maximizes the magnetic field generated at the sensor tag antenna. In contrast, the inductance in the sensor tag circuit is parallel resonated to maximize the voltage across the antenna. This technique maximizes the peak RF voltage that is rectified to power the RFID chip.

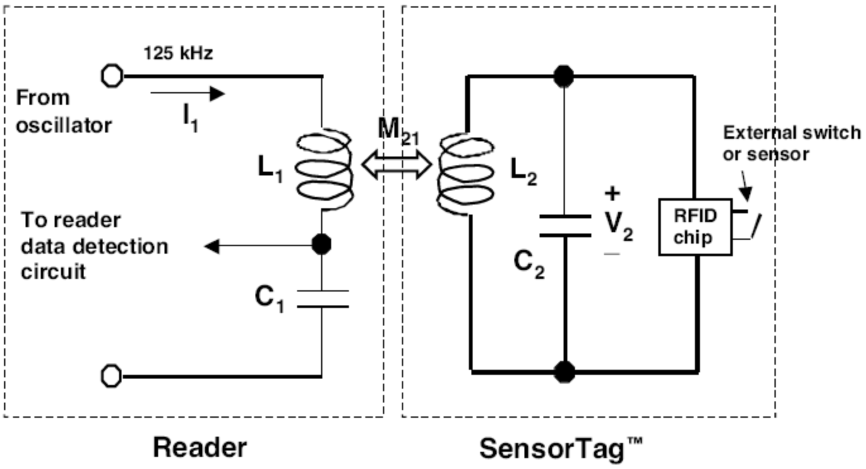


Figure 27 Equivalent circuit

The design of the antenna coils is driven largely by the desire to maximize the mutual inductance between them. To illustrate the coil design parameters that come into play, consider the equation for the mutual inductance between two coaxial coils, viz.,

$$M_{21} = \frac{\mu_{eff}\mu_0 \pi R_1^2 R_2^2 N_1 N_2}{2(D^2 + R_1^2)^{3/2}}$$

Although this mutual inductance depends on the effective permeability, $\mu_{eff}\mu_0$, of the tag coil core and the distance between coils, D, the most important intrinsic tag coil parameters are its radius, R_1, and its number of turns, N_1. Thus, we want to make the tag coil diameter and number of turns as large as possible without exceeding space limitations or causing the coil to be self-resonant at the operating frequency. A further constraint is that the self-inductance of the tag coil should not be so large that the resonating capacitor is too small to be practical (i.e., it should be at least 10 pF).

Finally, the concept of "tag collision" should be mentioned. In practice, more than one sensor tag may be in the reader's interrogating field at one time. The overlapping signals that this situation produces can lead to reader confusion and prevent a reading from taking place. Hence the name tag collision. It is important, therefore, to implement a method for distinguishing between different, but adjacent, sensor tags. Such a method is called an anti-collision algorithm. Different RFID tag manufacturers have implemented different anti-collision algorithms, but the details are often proprietary. One approach would be to have each tag transmit in a random time slot and have the reader search in different time slots and reject multiple readings of the same tag. Obviously, having an anti-collision capability is extremely important for most applications.

Using this principle, any sensor based on voltage changes is able to be connected to a RFID sensor tag. The problem arises when the measurement is based on resistance changes. Since the voltage within the RFID tag is fixed to 1,5V, small changes in resistance are hardly detectable. The designed solution consists of a Wheatstone bridge to create a circuit that varies its voltage output based on the resistance change. In order to keep the power consumption low enough, high value resistors may be used in series within the Wheatstone bridge to lower the current. However, high value resistors are also less accurate, so the challenge is to find the balance between the power consumption and performance of the system.

Figure 28 shows a possible way to connect a resistance based sensor (strain gauge) to a RFID tag with a Wheatstone half-bridge. A variable resistor is used to correct the unbalance of the bridge due to the offset of the gauge and the accuracy of the resistances.

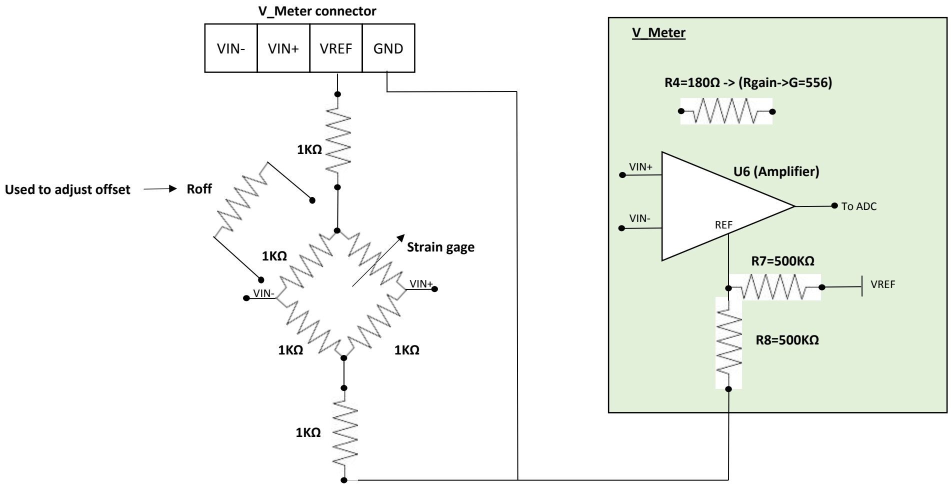


Figure 28. Scheme of the strain gauge connected to a RFID sensor tag

In the previous figure, the RFID tag showed within the green box correspond to the model V-Meter by Farsens [13], which will be more detailed in the following sections.

Other sensors, such as thermistor or humidity sensors, are rather easy to connect to the RFID tags. Indeed, there are commercially available solutions offering these features (see section4.2).

4.4 SELECTION OF SENSORS

Sensing technology has been an intensive research area in the recent years and more intense research is expected in the near future. There are a wide variety of sensors and sensor types being produced and sold already. However, finding appropiate sensors to be embedded in slab tracks is a challenging issue. For this application, sensors must be robust, durable, reliable, low cost, energy efficient, and most important, effective in detecting critical events.

A critical event may be detected directly by a specialised sensor or inferred by analysing measurement data from more general purpose sensors. Specialised sensors such as concrete carbonisation and steel corrosion area are expensive and bulky. More resesarch and development effort is required for them to become suitable for using within slab track. On the other hand, more general, main stream sensors such as strain gauges, termistors, pressure cells and accelerometers are relativelly mature and cheap, but using these sensors to infer critical events can be a complex process. This is due to the mechanisms which governs the behaviour of slab tracks such as their vibration, robustness and longevity are complex. Extensive experiments are required inolving both sensor data collection and sensor data analysis for slab tracks in different conditions to determine a robust relationship between critical events and sensor data signatures.

4.4.1 STRAIN MEASUREMENT

For the monitoring purpose of the slab track, since it is a reinforced concrete structure, it has been selected a number of sensors that directly or indirectly are able to survey the stress state and deteriorarion phase of the element. In order to measure stresses, the most common sensors are strain gauges. Through the Hooke's Law strains, that are easier to measure, are translated into stresses. Stresses are spread on the structural element through the concrete, which is jointly fixed to the reinforcement steel bars. Therefore, strain gauges strategically located on reinforcement bars (rebars) are a typical configuration to monitor using RFID reinforced concrete elements.

Weldable strain gauges are commercialy available from many manufacturers. One of the main technical requirements for this element is a sufficient resistance, at least 1000Ω, in order to have the necessary voltage difference in the Wheatstone bridge, so that the RFID sensor tag is able to measure with accuracy enough. Although this high resistance is not so common, fortunately it could be found in the catalog of an European manufacturer.

The stragin gauge selected belong to the so-called universal general-purpose strain gauges group. It consist of a constant grid completely encapsulated in polyimide, with large, rugged coppercoated tabs. It is primarily used for static and dynamic stress analysis. Table 10shows the datasheet of this strain gauge and Figure 29 below shows an augmented picture of the strain gauge.

Table 10 Technical specifications of the strain gauges

Manufacturer:	Vishay Precision Group (VPG)
Brand:	Micro Measurement
Strain type:	General Purpose Strain Gauge – Linear Pattern
Model:	CEA-06-250W-10C
Resistance:	1000Ω±0.3%
Strain range:	±5%
Temperature range:	-75ºC to + 175ºC
Dimensions:	6.35x11.43mm

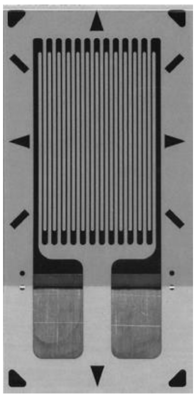


Figure 29. Strain gauge CEA-06-250W-10C

The RFID sensor tag used to power and to collect data from this strain gauge is the V-Meter-DLCV10 manufactured by Farsens [13]. The VMETER-DCLV10 tag consists of a RFID chip (ANDY100D [12]) for energy harvesting and wireless communication, a start-up circuitry based on a voltage monitor, a micro-controller with integrated voltage reference and ADC (10 bits) and signal conditioning circuitry for measuring low voltage values.

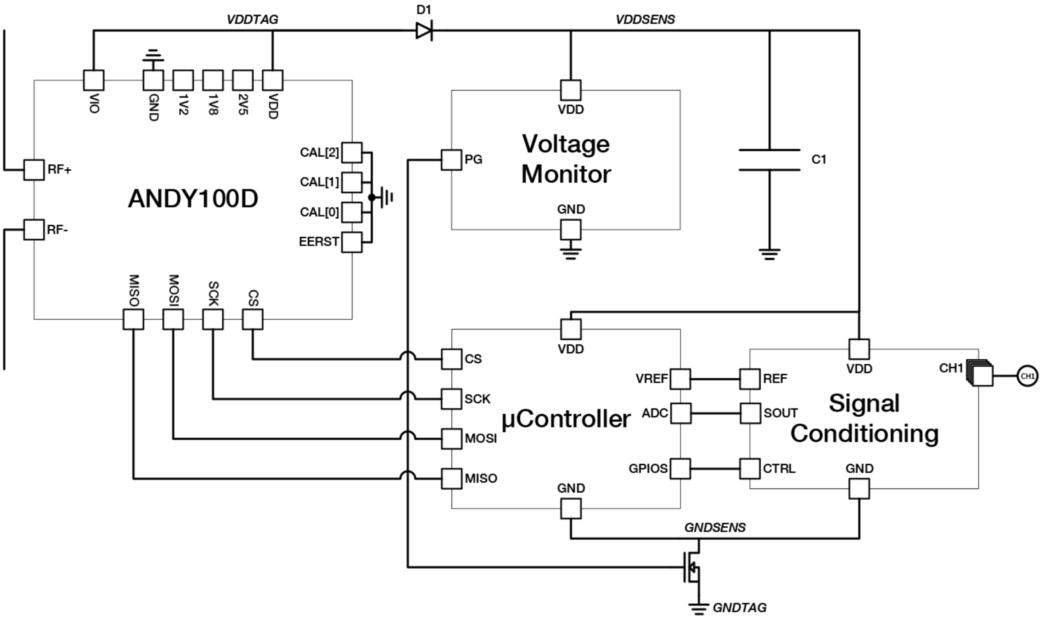


Figure 30 Basic scheme of the VMeter-DLCV10 RFID sensor tag [13]

The operation of measuring low voltage values is controlled with a micro-controller. Besides the CPU, the flash memory and the RAM memory the micro-controller includes a SPI (Serial Peripheral Interface, which is a communication protocol foe sensors, actuactors, microcontrollers or other external devices used by ANDY 100 chip)) module , GPIOs, a 1.5V voltage reference and a 10 bit SAR ADC.

Finally, the signal conditioning is based on an instrumentation amplifier. The amplifier can be configured to have any gain between 1 and 1000 by setting the appropriate value of a resistor. The signal conditioning circuitry can be enabled/disabled with a NMOS switch in order to reduce power consumption when no measurements are being made.

Upon receiving a SPI directed read request from the UHF RFID reader, the ANDY100 generates SPI signaling towards the micro-controller. Given that the RFID communication protocol specifies timing restrictions for answer, the micro-controller returns the measurement value stored in a buffer and triggers a new measurement. Thus, the answer of the tag to the reader includes the value of the previous measurement.

In order to perform a new measurement, the micro-controller enables the signal conditioning and waits for the stabilization of the amplifier. After waiting the sensor stabilization time, an ADC measurement is taken using the 1.5V reference. Finally, the signal conditioning is disabled again to minimize power consumption. [13]

4.4.2 TEMPERATURE AND HUMIDITY MEASUREMENT

In order to measure temperature and humidity, which are two relevant variables for degradation prediction, it is possible to use commercially available termistors and moisture meters and connect them to the same RFID sensor tag used for the strain gauge. However, there are already in the market RFID sensor tags provided with these sensors.

Table 11**Erreur ! Source du renvoi introuvable.** and Figure 31 shows the main characteristics of the RFID sensor tag manufactured by Farsens [14], which already meets all the requirements for the monitoring system stated in this deliverable.

Table 11 Technical specifications of the temperature and humidity RFID sensor ta

Manufacturer:	Farsens
Sensor type:	RFID sensor tag, PCB format
Model:	Hygro-Fenix-H221
Operation frequency:	860-960MHz
Communication protocol:	EPC Class-1 Generation 2
Humidity range:	0 to 100%
Humidity accuracy:	±4.5% (from 20% to 80% rH)
Temperature range:	-30ºC to +85ºC
Temperature accuracy:	±0.5ºC (from 15ºC to 40ºC)
Temperature resolution:	0.016ºC
Temperature range:	-75ºC to + 175ºC
Dimensions:	21x76mm

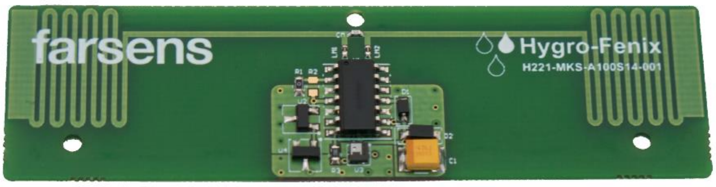


Figure 31. Hygro-Fenix-H221 RFID sensor tag [14]

The HYGRO-FENIX-H221 tag consists of an RFID chip for energy harvesting (see section 4.2) and wireless communication, a start-up circuitry based on a voltage monitor and a HTS221 relative humidity and temperature sensor.

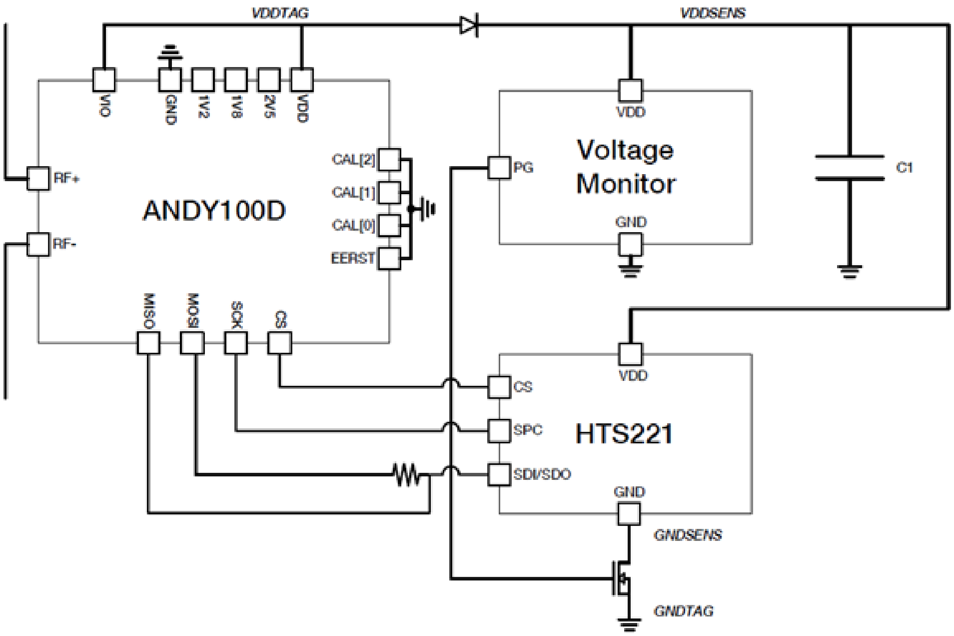


Figure 32. Basic scheme of the Hygro-Fenix-H221 RFID sensor tag [14]

The humidity sensing element HTS221 consists of a polymer dielectric planar capacitor structure capable of detecting relative humidity variations. The measurement chain includes a low-noise capacitive amplifier, which converts the capacitive imbalance of the humidity sensor into an analog voltage signal. The output of the humidity and temperature sensors is multiplexed to an operational amplifier, and the data is digitized with the integrated ADC. A digital control logic is included for averaging filter to remove the high frequency component. Finally, the data is made accessible through a SPI/I2C compatible interface. [14]

4.5 ENCAPSULATION

While sensors, such as strain gauges, are designed to be in contact with concrete, at least with a proper installation and protection procedure, RFID tags are electronic components not prepared to be embedded in this material. They require a protection.

There are several studies performed to find out a good solution for the encapsulation. For instance, Lesthaeghe et al (2013) [15] embedded RFID tags in small concrete slabs using several protective materials, such as epoxies, plastic, paper, cardboard, wax paper and several types of foam. Figure 33 shows these tags after being encased in therir espective protectant materiales.

Figure 33. RFID tags encased using extruded polystyrene (centre) and polyurethane spray foam (right) [15]

In this study [15], RFID tags protected with a hard and relatively thick material functioned properly after being embedded in concrete. It was found that materials that were particularly absorbent would not function after exposure to the hydrated cement mixture or salt water, in spite of the fact that the tag inside was still functional, as determined by later cutting the tag out of the material. As can be observedn in Figure 33, the best results came from tags protected with certain kinds of foam, such as polyurethane spray foam and extruded polystyrene. It is also worth noting that these materials have low relative permittivity values, also making them ideal.

Table 12. Tag performance after encasement in various materials [15]

Tag protectant	Performance
Normal epoxy	Not functional
Five minute epoxy	Poor performance
Plastic	Good performance
Paper	Non functional
Card board	Good performance
Latex foam	Bad performance
Polyurethane foam	Good performance
Extruded polystyrene	Good performance

Unfortunately, these types of encapsulations are not suitable for RFID sensor tags, those which have sensors included in the printed circuit board-PCB, because they are usually designed to measure in open air. Therefore, a 3D space must be created. There are several requirements for this encapsulation:

- Minimal size: The encapsulation needs to be as small as possibl in order to minimize the physical interferences with the steel frame.
- Good impact resistance: The pouring of concrete is a harsh scenario where any fragile electronic instrument will be likely be destroyed.
- Avoid electromagnetic interference: The material should be one of the mentioned in [16] with good performance. Metalic encapsulation, for instance, is not possible.

- Waterproof: During the time when the concrete is fresh, there is an excess of water in the mixture. In order to prevent corrosion, the encapsulation should avoid water for being in contact with the RFID sensor tag.
- Heat and moisture conductive: The temperature and humidity measured by RFID sensor tags needs to be representative of the concrete in the close areas of installation.
- Low cost: The encapsulation doesn't have to increase significantly the costs of the monitoring system.

According to previous requirements, a possible encapsulation is a PVC tube with taps, as shown in Figure 34. There are several possible diameters, the issue is to select the one that better fits to the size of the RFID sensor tag. In case that an external sensor is connected, such as a strain gauge, the cable can easly go through the tap and the encapsulation keeps waterproof.

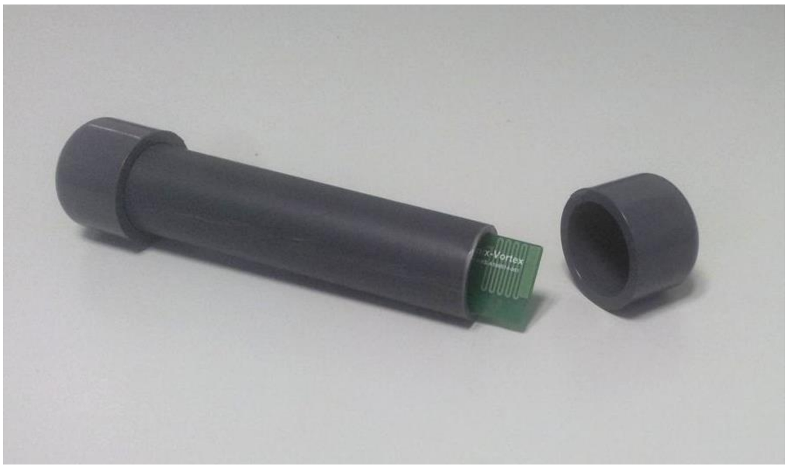


Figure 34. PVC encapsulation selected for RFID sensor tags

4.6 RFID ENVIRONMENTAL RESTRICTIONS

The idea of embedding RFID tags in concrete is not a new one [16]. Several projects in the past have produced sensors that utilize RFID technology, for instance, to passively report the level of chloride ingress in bridge decks [15]. Some projects have also done in-depth studies using RFID technology in a wide variety of sensor applications [9]. However, these methods typically have a much higher level of cost associated with them than the method being explored in this project.

The main issue surrounding the use of embedded RFID tags in concrete is the environmental restrictions due to the interactions between the different materials (concrete, steel…) which could result in a number of phenomena. Among the most important ones, it is remarkable the signal attenuation due to the concrete material and the magnetics effects on the performance of the RFID communications.

In this section, the theoretical framework for the more relevant issues mentioned above will be reviewed. Complementary, a number of in-lab tests have been performed in order to check the behaviour of the RFID tags in a reinforced concrete structure in a controlled environment. The results are presented in the next section.

4.6.1 ATTENUATION BY CONCRETE

There are some difficulties associated with embedding RFID tags in concrete. As previously mentioned, this project utilized passive sensor tags. This is based on the principle of mutual inductance, whereby some of the magnetic field lines induced by a loop of current in the reader antenna also pass through the tag antenna and create a loop of current in the tag. This is illustrated in Figure 1.

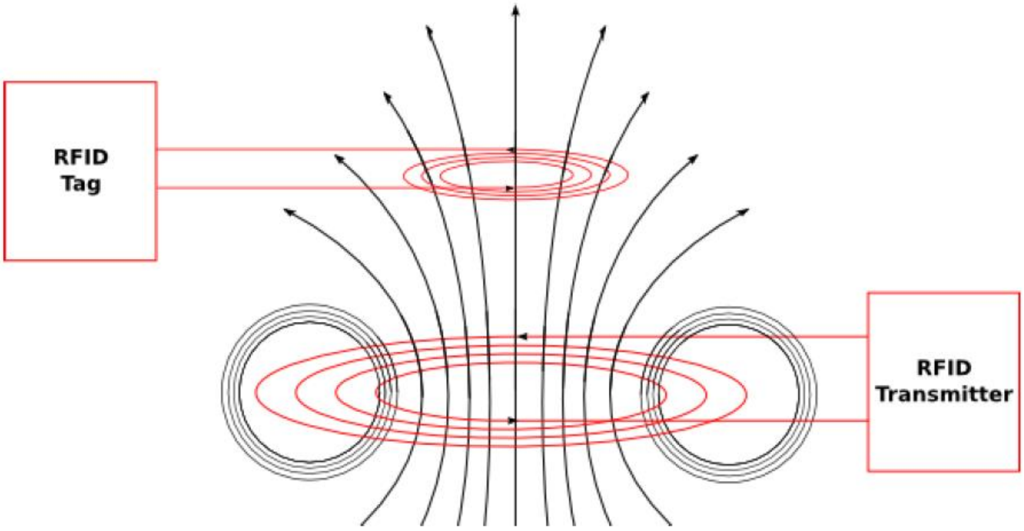


Figure 35 Mutual inductance in RFID near field communication [15]

Communication with the tag is governed by the laws of electromagnetics, as they apply to the tag and the concrete above the tag, and by the resonant circuits that are the tag antenna and the reader antenna. Specifically, the key material properties of the concrete are its electrical permittivity ε and its conductivity σ. These are compared to the permittivity of the surrounding air, the physics constant Farads/meter, and the zero conductivity of the surrounding air. The remaining key electromagnetic property, magnetic permeability μ, is roughly the same for concrete as for empty space [6]

The permittivity ε affects electrical capacitance. The tag antenna is a tuned resonant circuit where energy oscillates between being stored in the electric field of the antenna capacitance, C and the magnetic field of the antenna inductance, L [6]. The resonant frequency is as follows:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

To design the depth to which the sensors can be embedded, it is required to know the relative permittivity (dielectric constant) and conductivity of concrete. It is well known that the propagation of electromagnetic waves will be affected by the presence of moisture in the concrete. The real part of the complex permittivity and the effective conductivity of concrete have a fundamental role in assessing the ability of concrete to inhibit the propagation of electromagnetic waves.

The inherently lossy nature of concrete is taken into account by a complex permittivity:

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

In order to measure this loose, a test campaign was carried out at CEMOSA's laboratory. The methodology, used equipment and results are described in section 5.7..

4.6.2 EFFECTS OF REBARS

Rebar is ferromagnetic, so it attracts the magnetic field lines away from the RFID tag, reducing the distance at which the tag can be read. Previous work has shown that rebar can greatly reduce the read distance; however, these effects can be reduced by proper tag placement.

In order to check the proper behaviour of the RFID tags used in contact with steel, some tests have been done. The purpose of these tests was to identify and determine the potential reductions in the read distance which is referred in the literature. The results of such laboratory tests are shown in the next section.

4.7 RFID LABORATORY TESTS

The aim of these laboratory tests is to analyse the reading range of different antennas under de absence of obstacles (sensor on air), in case of a PVC encapsulation of the RFID tags and, through different thickness of concrete. Reading range is referred to the maximum distance at which it is possible to read data from the sensor. Additionally, the parameter 'detection distance' has been studied. This parameter is referred to the distance at which the data reader (antenna) is able to detect the signal of the sensor. Both parameters –reading range and detection distance- are closely related, but they do not have to match even though for some devices present the same value.

The considered variables are:

- Power of the antenna
- Thickness of concrete
- Detection distance
- Maximum reading distance
- Influence of encapsulation
- Influence of close objects

According to the different typologies of RFID technologies, the different tests were divided in three test campaings. While the two first campaings were focus on the analysis of passive RFID, the last one was focus on the active RFID in order to compare the performance between both technologies (active and passive RFID). In every phase, the parameters 'reading range' and 'detection distance' were analysed. The equipment and technologies employed is listed below:

- First test campaing: passive RFID, two kind of fixed antenna (unidirectional and cylindrical) and RFID data reader.
- Second test campaing: passive RFID and a mobile reader device (antenna and reader integrated in same device).
- Third test campaing: active RFID and reader device.

4.7.1 First Test Campaing: Performance of Passive RFID and fixed antennas

For this first test campaign, it was used a CAEN RFID reader R4300P Ion UHF Long Range reader with the following characteristics:

Table 13 Technical specifications of the fixed reader

Frequency Range	902÷928 MHz (FCC part 15) / 865.600÷867.600 (ETSI EN 302 208)
RF Power	Up to 32 dBm (1.6W) conducted (ETSI) / Up to 30 dBm (1W) conducted (FCC)
CPU	Intel Atom E3815 CPU @ 1.46Ghz
Memory	2Gbytes RAM, 8 Gbytes MicroSD
Operating System	Linux (Debian)
Scripting	Java Virtual Machine
Host Interf. Protoc.	CAEN RFID host-to-reader protocol, EPCGlobal LLRP RFID host-to-reader protocol
Antenna Connector	4 TNC Reverse Polarity
Receiving Capability	Gen 2 Dense Reader Mode Management, Data rate up to 400 Kbits/s
Std. Compliance	EPC C1 G2/ISO 18000-6C
Digital I/O	13 GPIO pins, TTL level
Connectivity	RS232 Serial Communication (DB9); USB 2.0 High Speed Host Port; Ethernet 10/100BASE-T (RJ45)
Wireless Comm.	GSM/GPRS (SMA) (optional), WiFi (SMA) (optional)
Internal Interfaces	MicroSD slot, SIM card housing (optional)
IP Rating	IP42
MTBF	135’000 hours
Dimensions	(W)275 x (L)155 x (H)39 mm3 / (10.8 x 6.1 x 1.5 inch3)
DC Power	9÷36 VDC(30W)
Operating Temp.	20 °C to 55 °C
Weight	1.3 kg

Two different types of antennas were used together with this reader, a directional antenna and a cylindrical antenna. The technical characteristics of the antennas are listed in next table (Table 14).

Table 14 Technical specifications of fixed antennas

	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	Linear	Circular

Figure 36 shows the two antennas and the reader used during these tests.

Figure 36 Used equipment (clockwise) in tests: a) Directional antenna; b) Cylindrical antenna; c) RFID Reader

The first tests were done in air, according to the configuration showed in Figure 37 (left). However, the proximity of furniture and other elements demonstrated to have very negative impact in the results, so the RFID tag was hanged, as shown in Figure 37 (right).

Figure 37. Test for reading distance without obstacles

The passive RFID tags were also put inside a PVC coating, consisting of 25mm diameter tube with two caps that could be a solution to embed the sensor in concrete. The RFID tag used for laboratory testing perfectly fits inside this tube. Figure 38 shows the PVC coating. Figure 39 shows the configuration for testing the reading range in air with this coating.

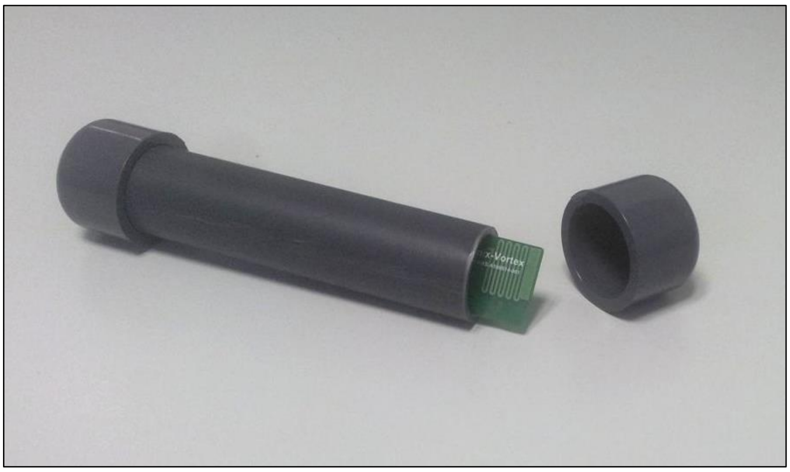


Figure 38. PVC coating with the RFID sensor tag inside

Figure 39. Test for reading distance without obstacles except the PVC coating

The measurements consisted of determining the maximum reading range and the detection distance of the sensor. The power of the antenna was adjusted using the software provided with the device. This software offers the possibility of changing the value of power although it does not include the gain of the antenna. The gain is defined as the ratio of the power produced by the antenna from a far-field source on the antenna's beam axis to the power produced by a lossless isotropic antenna. For that reason, the values of the power must have been corrected taking into account this parameter which is equal to 6 dBi for both studied antennas.

Figure 40 shows the results obtained for the maximum reading range achieved by the cylindrical antenna and the directional antenna. It can be seen that in both cases the coating reduces a 10% the reading distance. Besides, the range of the directional antenna is roughly two times the range of the cylindrical antenna. In the first case the reading range is about 1 metre while in the second case it is about 2 metres.

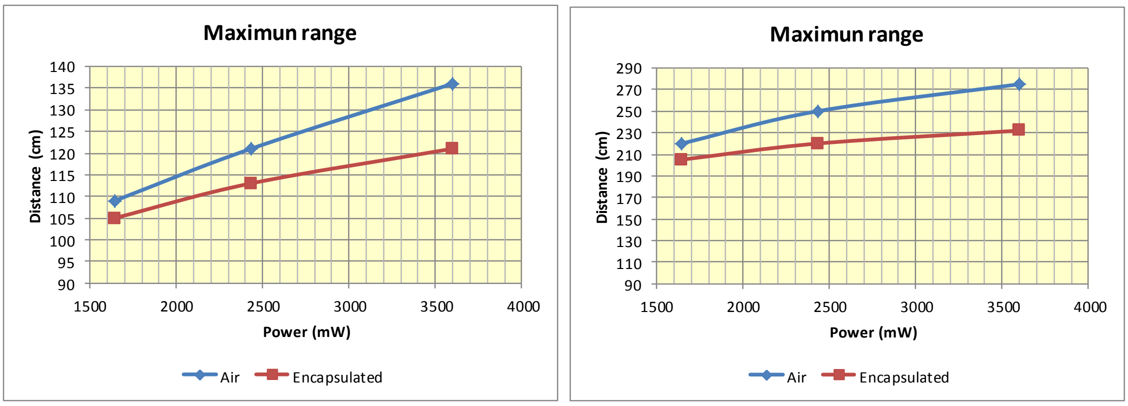


Figure 40. Maximum reading range for cylindrical antenna (left) and directional antenna (right)

As for the detection distance, some slight differences are observed, as shown in Figure 41. Directional antenna shows a similar behaviour regardless the environment (air or encapsulated), meanwhile cylindrical antenna achieves a 10% higher distance in case of the direct contact (air). One more time, the values for unidirectional antenna are notably higher than the values achieved by the cylindrical antenna.

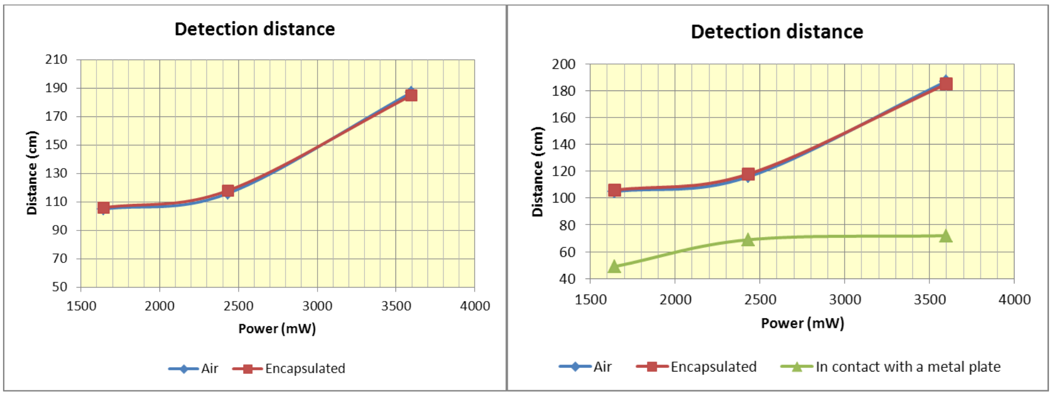


Figure 41 Detection distance for cylindrical antenna (left) and directional antenna (right)

The previous figure (Figure 41) also includes the results of the detection distance when there is a metal plate close to the RFID sensor tag. It demonstrates a strong effect, around a 70% reduction of the maximum reading distance and a 45-55% reduction of the detection distance. Figure 42 shows the configuration of this test.

Figure 42 Test for reading distance with the influence of a metal plate

This phenomenon should be taken into account in the case of using the sensors in environments where it could be expected the presence of pieces of metal, particularly if the contact between the sensor and the piece of metal are likely. A case in point is the use of sensors in reinforced concrete beams or pillars, where the presence of the reinforcement bars could have negative effects on the reading distance of the sensors. Section 4.6.2 above explained this issue.

The reading and detection distance were also measured placing concrete in between the antenna and the RFID sensor tag. The main objective of this test phase was to measure the reduction of these values due to the attenuation of concrete. The firsts tests were carried out placing 2cm concrete slabs in different configurations (see Figure 43). The results were not conclusive because the electromagnetic wave usually found the tag through the most energy-efficient way and not through the concrete.

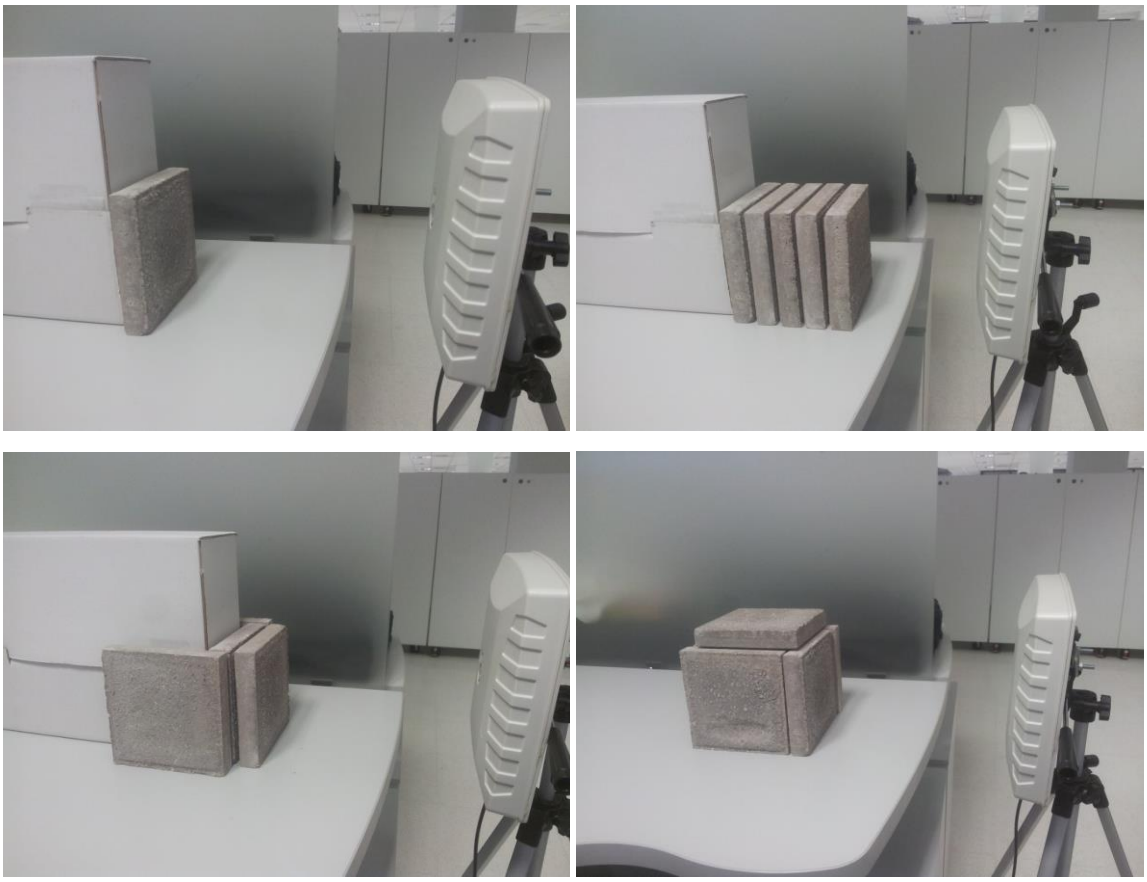


Figure 43. Different unsuccessful configurations to test the attenuation of concrete

Since it was not possible to measure the reading range through the concrete with additional precast slabs, a in-situ concrete box was designed and manufactured. It includes four tubes to place inside the RFID sensor tags in several positions, as shown in the next figure:

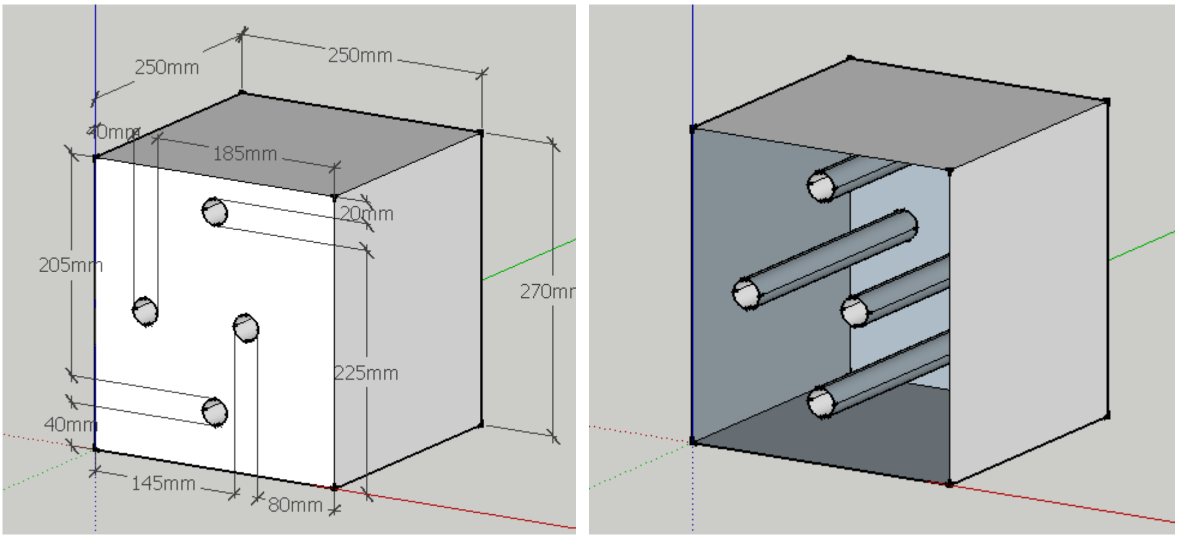


Figure 44. Design of the concrete box for laboratory testing

It can be shown in the previous figure that there is a wide variety of distances to measure through the concrete: 20, 40, 60, 80, 145, 185, 205 and 225 mm.

The following pictures show the formwork used to manufacture the concrete box and the final aspect of the box.

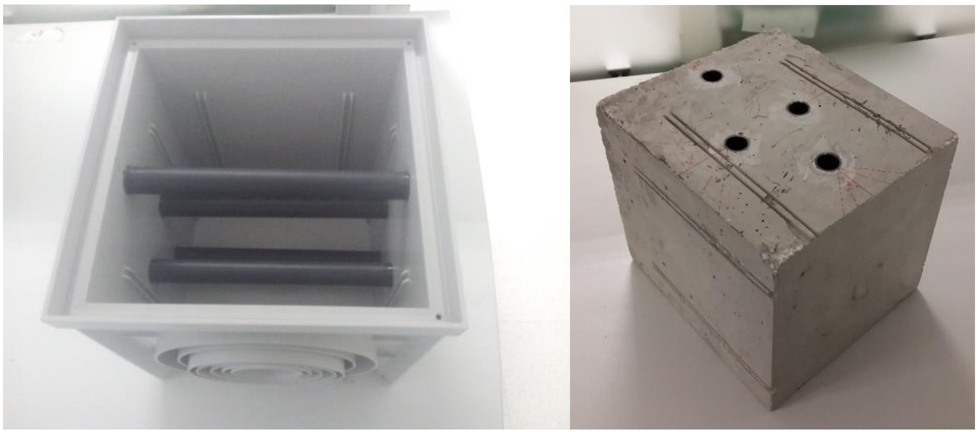


Figure 45. Formwork (left) and concrete box (right) for laboratory testing of reading range

For these tests, due to the results obtained in the previous phase, only the directional antenna was used. The concrete block was placed on a table, next to the edge, facing to the antenna. The block remained in the same position, while the antenna on a tripod was sequentially moved away until achieving the loss of the signal. The maximum reading range was established just before at the distance at which the signal was lost.

Figure 46 Configuration to test the attenuation of concrete

Figure 47 shows the maximum reading range and detection distance through different thickness of concrete (2, 4, 6 and 8cm). The trend showed by both parameters is quite similar. On one hand, the maximum range appears to converge in a same value for the maximum power of the antenna regardless the thickness of concrete cover considered. On the other hand, detection distance shows a similar pattern; even though, the values for the greatest thicknesses of concrete are slightly lower than the values for a concrete thickness of 2 cm.

Compared to the reading distance in air, the attenuation of concrete, whatever the cover thickness is, implies a reduction of 90 cm for the maximum antenna power, which is around a 33% reduction. In contrast, the detection distance is hardly reduced.

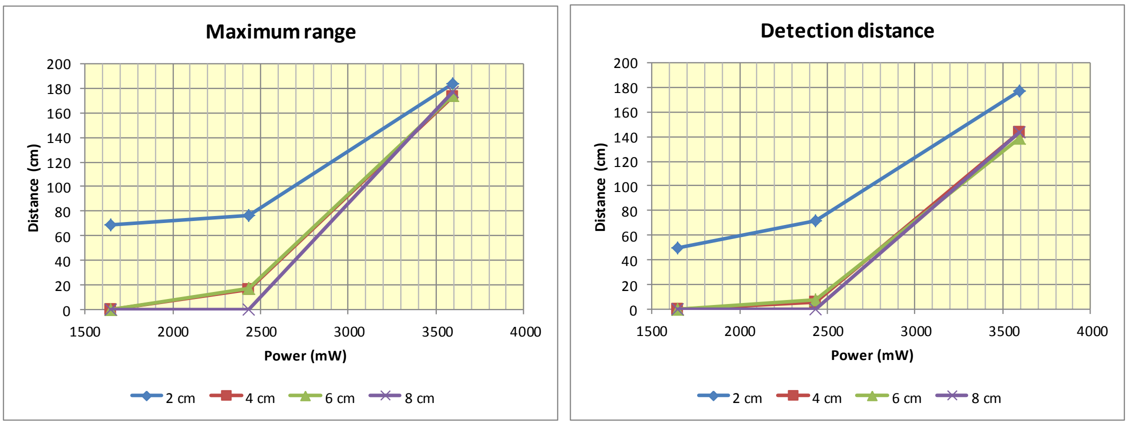


Figure 47. Results of maximum reading range and detection distance through concrete

Most of reinforced concrete elements present a concrete cover of around 5 cm, what means that the maximum reading range would be approximately 1,8 meters in case of using the maximum antenna's power.

4.7.2 SECOND TEST CAMPAING: PERFORMANCE OF PASSIVE RFID AND MOBILE READER

The device used to perform the test was the model Nordic ID Merlin Cross Dipole One-series EU HT00101. This device provides fast and accurate RFID reading in long-range. The cross dipole antenna enables to read tag regardless the tag position. The technical specifications are shown in the following table:

Table 15 Technical specifications

Supported standard	ISO 18000-63 (EPC Class 1 Gen2 V2)
RF Power:	ERP +33 dBm (2W)
Frequency	865.6-867.6 MHz
Nominal reading distance	7 m

Figure 48. Handheld RFID reader (Nordic ID Merlin UHF RFID cross dipole One)

During the test, the maximum range in different environment was determined following the same procedure established in the previous trials. In this case, the direct reading without obstacles (only air) and using a PVC tube as encapsulation resulted to be nearly the same, as shown in the Figure 49, which means that there is not a significant attenuation by the encapsulation.

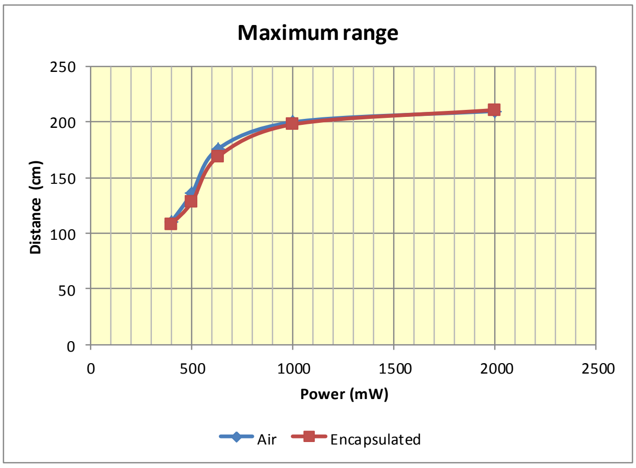


Figure 49. Maximum reading range with the handheld device

It should also be noted that the curve presents an asymptote for a distance of 200cm, which could be caused by the size of the antenna. In previous tests with larger fixed antennas it didn't happen. Higher power always entailed longer reading distances. On the other hand, the maximum reading range is around a 25% lower with the handheld device, but this is not a significant drawback for the purposes of the monitoring system being designed.

The next step was to perform tests reading through concrete in order to check the attenuation given by this material. By using the same concrete block described in the previous chapter, the power of the antenna was ranged from 500 to 2000mW. As shown in Figure 50, the maximum reading range increases with the antenna power and decreases with the concrete thickness.

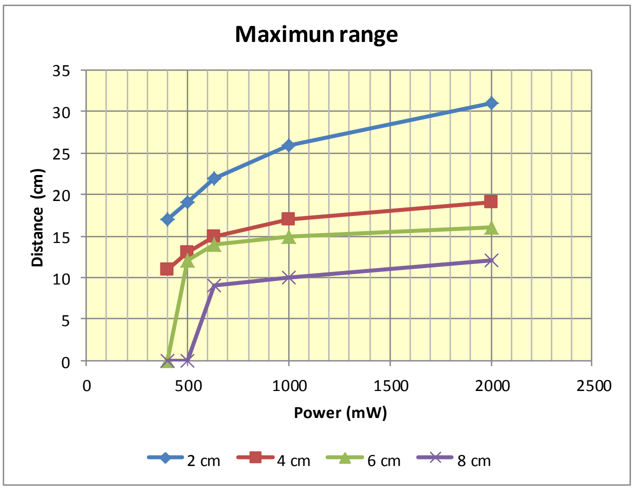


Figure 50. Maximum reading range through the concrete with the handheld reader

It is relevant in the previous figure that a power of 500mW or lower cannot go through thickness of concrete greater than 6cm. The curve shows an approximate logarithmic shape. What concerns to the monitoring system being designed is that the handheld reader is able to measure through more than 5cm thickness of concrete at a total distance of 10-15cm, what is enough to carry out the structural health inspection of the slab track by the maintenance staff.

4.7.3 THIRD TEST CAMPAING: PERFORMANCE OF ACTIVE RFID AND FIXED ANTENNA

To contrast the results obtained with a passive RFID system, the third phase of the tests consisted of the performance of the same kind of trials through the use of an active RFID.

The equipment used in these tests consist in an active RFID reader, several active RFID tags (without sensors) and an Ethernet cable to connect the reader with a laptop (

Figure 51. Equipment used for tests with active RFID

Technical specifications for the active RFID reader are listed in the following table (Table 16):

Table 16. Technical specifications for Active RFID Reader

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

The tests followed the same procedure than for passive RFID, the variables were the maximum reading distance, the detection distance and the thickness of concrete. In this case the power of the antenna could not be changed. The major difference was that the holes in the concrete block didn't allow placing the RFID tags inside the concrete. Instead, the antenna was put inside the hole as shown in Figure 52.

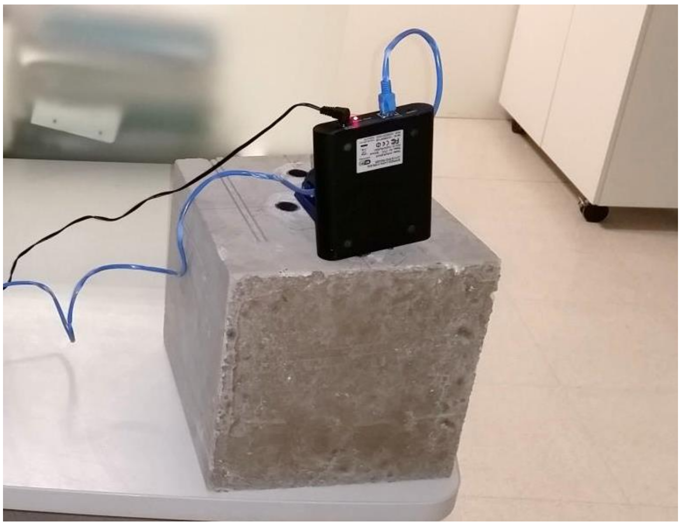


Figure 52. Antenna of the active RFID reader inside the concrete block

In order to avoid possible interferences produced by walls, ceilings or furniture, the tests were performed outside, in a space free of any obstacles. The block of concrete with the RFID active reader was placed on a base to keep away from the floor, and remained in the same position during the whole trial. On the other hand, the sensor was placed on the top of a tripod to achieve the same height of the block.

With this configuration, the tests consisted in the registration of measurement distances for each one of the different concrete covers pre-defined in the block. Figure 53 shows the results obtained in these tests.

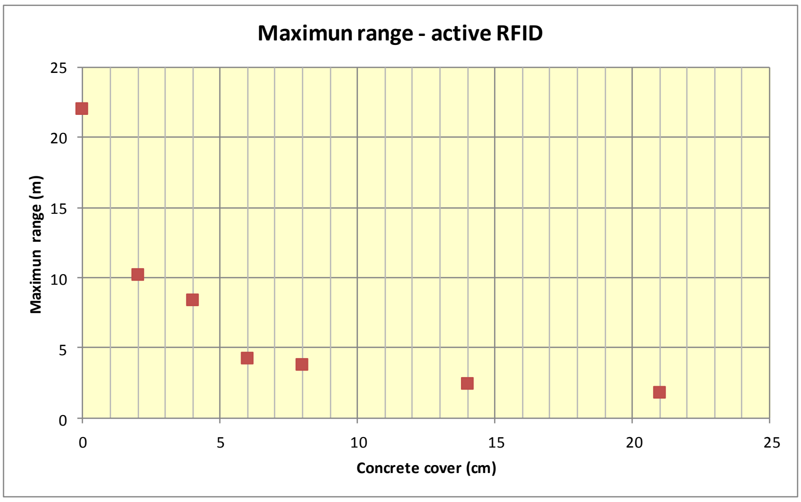


Figure 53. Maximum reading range with active RFID

As it can be observed in the figure above, the maximum reading range varies from 3 to 22 metres, which are about ten times the values obtained with passive RFID.

4.7.4 CONCLUSIONS OF THE IN-LAB TESTS

The comparison among the different systems of passive RFID studied during this task is essential to analyze the benefits and drawbacks for the different analyzed devices (fixed antennae -cylindrical and directional-, and mobile reader). To do that, all the data collected during the tests has been pooled to ease the analysis tasks.

Firstly, it is done the analysis of the maximum reading range and detection distance for the directional and cylindrical antennas. In each case, it has been analysed in different graphics both parameters in an environment without obstacles between the antenna and the sensor (air) and with the sensor inside of a PVC coating (encapsulated). According to the results showed in Figure 54. Detection distance for cylindrical and directional fixed antennas, the performance of the directional fixed antenna is notably better than the cylindrical. The detection distance is roughly the same than in air when the PVC encapsulation is used.

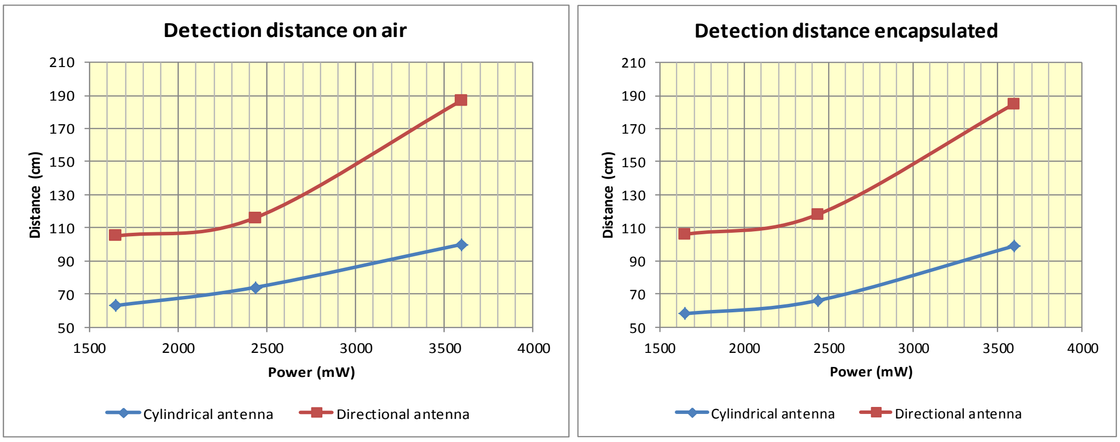


Figure 54. Detection distance for cylindrical and directional fixed antennas

The maximum reading range is also much higher for directional antennas than for cylindrical ones. Figure 55 includes these results, as well as the results obtained with the handheld device. It can be observed that the curves are overlapped, which means that for the same value of power the performance is quite similar in fixed and mobile antennas.

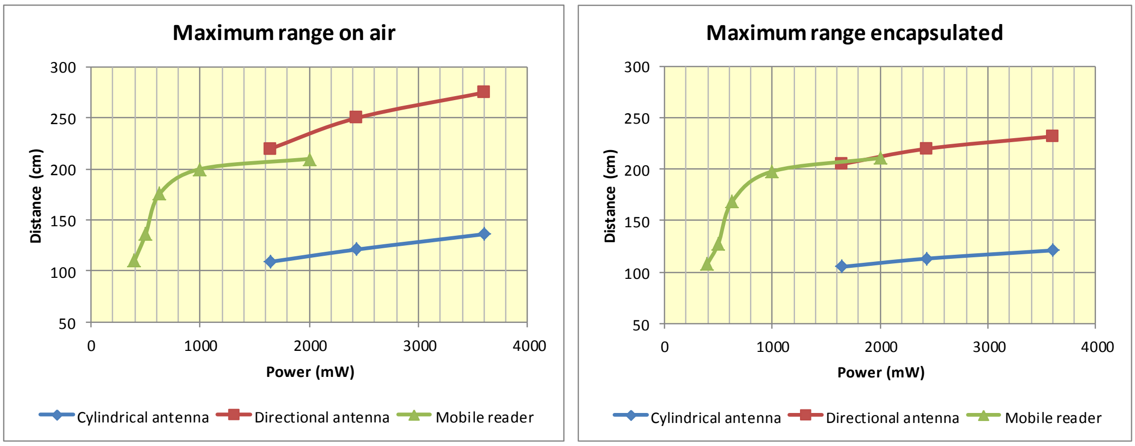


Figure 55. Maximum reading range for fixed and mobile antennas

The maximum reading range for passive RFID readers is proportional to the antenna power from 1000mW onwards, while for lower power there is a high reduction of the distance.

The tests with active RFID resulted in reading distances up to 10 times higher than passive RFID. However, this technique implies larger RFID tags and, what is the major drawback, the presence of batteries inside the tags. It is against the requirement of maintenance-free sensors established for this project.

As a conclusion, it can be said that the handheld reader is a good option to read the RFID sensors used to monitor the slab track. The reading distance is about 25cm when the RFID is below 5cm of concrete, while this distance increases to 200cm when there aren't any obstacles in the middle or just a PVC encapsulation. The fixed antennas have a higher performance due to its better gain, achieving up to 140cm reading distance for RFID embedded in concrete.

Fixed antennas are recommended for critical sections, when continuous monitoring is required or the access of maintenance staff for inspection is difficult. In any case, the embedded RFID sensors will not affect maintenance tasks. Handheld readers are very versatile and can be always used to complement regular visual inspection by maintenance staff.

5 Procedure for the installation, operation and maintenance of the monitoring system

A key factor in new monitoring techniques is to follow the same prescriptions of the whole new infrastructure design, such as cost savings, low, rapid and easy maintenance and rapid construction. In this sense, it is necessary to define the particular installation procedures during the construction and also the maintenance procedures during the whole service life of the infrastructure.

Given the particular features of the monitoring system being designed, the installation shall be compatible with the manufacturing of concrete slabs, with minimal impact to the construction performance. The operation will be as easy as measuring RFID tags, which equipment and procedures are widely known in the manufacturing sector. Lastly, the maintenance procedures are not necessary for the RFID tags, since they will be embedded in concrete and will not have batteries or movable elements to replace. Regarding the RFID reader and antennas, the maintenance will be the typical for electronic components. Within this chapter, the manufacturer recommendations for every commercially available component of the system are described.

5.1 INSTALLATION PROCEDURE

This section refers the procedure for the installation of RFID tags and strain gauges connected to the reinforcement bars in the new concepts of slab track developed in the WP1.1. where the monitoring system is going to be tested. At the time of submission of this report the manufacturing of the two slab concepts prototypes to be tested (including the embedded AMS developed) is not finished. Issues that may arise during the manufacturing and validation will be reported in D4.3.2.

5.1.1 INSTALLATION OF RFID TAGS IN REINFORCED CONCRETE

This section will be integrated in the deliverable D.43.2 'Demonstration of new monitoring techniques'.

5.1.2 INSTALLATION OF STRAIN GAUGES ON REINFORCEMENT STEEL BARS

Reinforcement bars are subjected to mechanical abrasion and a moist, corrosive environment. According to the instructions given by the manufacturers [17] , the following steps are required:

1. **Surface preparation**

The initial step is to thoroughly degrease the surface with solvents. A specific degreaser for the surface material is preferred whenever possible since they may be sensitive to strong solvents. The use of 'one-way' container, such as a aerosol can, is highly advisable for this application. The degreaser has to be used over at least a 150mm length of the bar at the proposed gauge location. The rebar has to be descaled and smoothed around its circumference with a grinder wheel (aluminium oxide or silicon carbide abrasive of approximately 50 mesh is preferred).

Figure 56. Surface preparation

After that, a wet abrade with a conditioner and a 220-grit silicon carbide wet-or-dry paper is required. The conditioner avoids material from drying on the rebar surface while abrading. With a clean gauze sponge, the surface is wipe dried, then a new abrade is made and the surface dried again.

Surface finish should be 1.6 to 3.2 micrometres rms at the completion of the second wet-abrading operation. Then, with a 4H (hard) drafting pencil on aluminium or a ballpoint pen on steel, the alignment marks for gauge location are burnished in the specimen. The installation area is scrubbed with a conditioner and a cotton applicator. A new wipe dry is done with a gauze sponge.

Following, the area is scrubbed thoroughly with a neutralizer and a cotton applicator, and wipe dried with a gauze sponge as previously noted. This step must be accomplished thoroughly to neutralize all traces of conditioner. In this step it is important to keep the surface wet. IF an evaporation of the cleaning material occurs in the specimen surface, it would leave a thin, unwanted film between the adhesive and the specimen.

Finally, the installation area has to be masked with tape to minimize flow-out of adhesive for subsequent protective coating application.

2. Adhesive selection

Figure 57. Adhesive

When selecting a strain gauge, it is most important to consider the adhesive that will be used to bond the gauge, since the adhesive becomes part of the gauge system and correspondingly affects the performance of the gauge.

The selected adhesive needs to cure at room-temperature in a few hours. Two-component, 100%-solids epoxy systems are recommended. They are usually transparent, medium viscosity. Its cure time is as low as six hours at 24ºC, although elevated-temperature postcure is always recommended for maximum stability. These adhesives are highly resistant to moisture and most chemicals, particularly when postcured. For maximum elongation, the bonding surface must be roughened according the procedure stated in the paragraph above.

The elongation capabilities varies from 1% at -195ºC to +15% at +95%. At room-temperature (+24ºC) elongation is around 6 to 10%, quite similar to rebars elongation, which makes it very convenient for gluing to steel bars in concrete. Elongation capability at the same temperature can be obtained by extending the cure time to 24 to 48 hours. Figure 58 shows the glueline temperature with respect to the cure time [18].

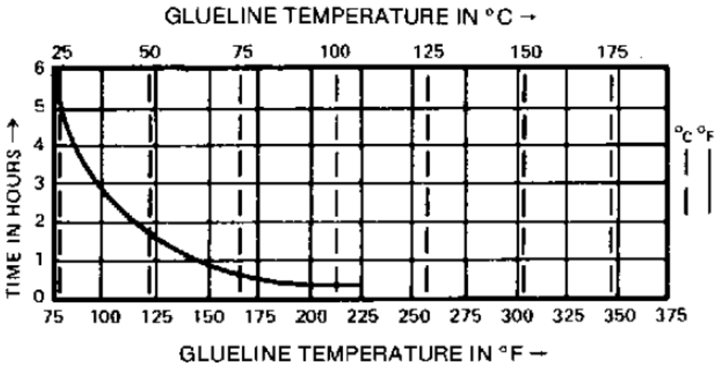


Figure 58. Glueline temperature of the adhesive [18]

3. Adhesive application

The procedure starts with the mixing of the resin with the curing agent. Immediately after that, the bottle have to be capped to avoid moisture absorption. It has to be mixed throughly for 5 minutes, using one plastic stirring rod. It is convenient to allow the freshly mixed adhesive to stand an additional five minutes before use.

During storage, crystals may form in the resin. These crystals do not affect adhesive performance, but should be reliquefied prior to mixing by warming the resin to jar to +50ºC for approximately one-half hour. The resin must be allowed to return to room-temperature before adding curing agent, because excess heat will shorten mixed pot life.

The pot life or working time after mixing is 15 to 20 minutes. The pot life can be prolonged by occasionally stirring to prevent localised exotherm in the centre of the resin system, or by pouring in out onto a chemically clean metal plate. In contrast, the pot life could be shortened if mixed quantities are large, for instance greater than 10 grams.

4. Leadwire installation

When utilizing one active strain gauge (quarter-bridge configuration), it is good practice to use a three-leadwire system. Some manufacturers supply strain gauges with a preattached three-leadwire cable to eliminate the need for attaching leadwires at the job site, and to reduce installation time.

Alternately, leadwires may be soldered to the strain gauge tabs after gauge bonding. If a parallel or twisted cable is used, separate the individual (leadwire) conductors for a distance of about 1 in (25 mm) from the cable end and insulate with a teflon or vinyl based solution. These materials should not be allowed to flow onto the bare strands of the conductors.

After allowing the insulation liquid to air dry for at least two hours at room temperature, thermally strip the leadwire ends and tin and solder the wires to the strain gauge tabs. Carefully remove all rosin flux from the soldered connections using rosin solvent before applying the protective coating.

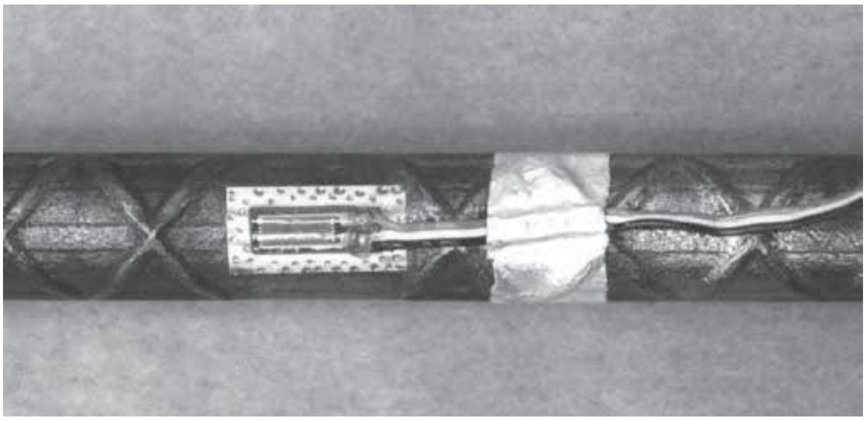


Figure 59. Weldable strain gauge after leadwire installation

5. Environmental protection

A coating shall be applied to the gauge carefully. The coating should be built up to provide approximately 1⁄4 in (6 mm) thickness completely surrounding the rebar at the gauge location, and should be carried back far enough to cover the leadwire area. Normally, the coating needs 24 hours for curing at room temperature(+24ºC), but it could be reduced to 4 hours with higher temperature.

As a final step, the instrumentation leads extending from the gauge to the RFID sensor tag, inside the PVC encapsulation. It should be placed in conduit to prevent mechanical damage to the leadwire system. It is advisable to check every sensor system before the concrete is poured. A properly installed and protected strain gauge is capable of many years of service on embedded reinforcing bars, providing data about load effects throughout the life of a concrete structure — from initial construction forces to unexpected severe loading conditions.

5.2 OPERATION PROCEDURE

The selected RFID sensor tags can be measured with any RFID reader available in the market. This chapter describe the operation procedures for the two readers used in this project, one for fixed antennas (CAEN R4300P ION) and one integrated in a hand-held device (Merlin Nordic ID Cross Dipole One).

5.2.1 USING FIXED ANTENNAS

The CAEN R4300P ION reader use a software named CAEN RFID Easy Controller provided by the manufacturer and available at http://www.caenrfid.it/.

The first step is to connect the CAEN RFID reader to the PC and launch the software application. Then, on the main screen, click on File -> Connect, as shown in Figure 60.

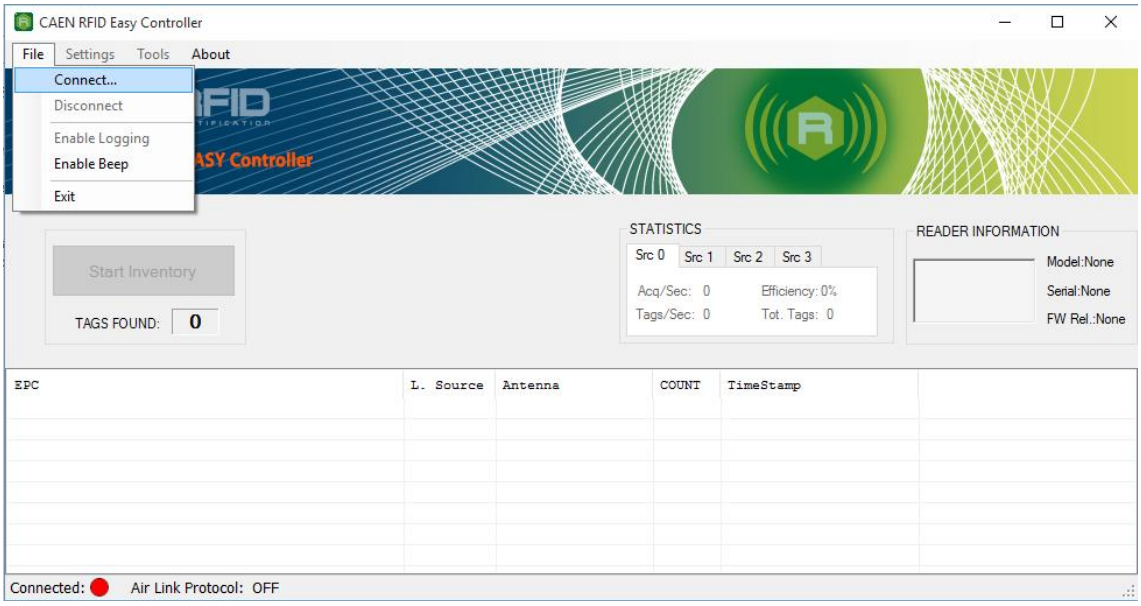


Figure 60. Connecting the RFID reader

A connection window will open, which allow selecting RS232 connection or Ethernet. The tests within this project were carried out using a laptop, so Ethernet connection was selected (see Figure 61).

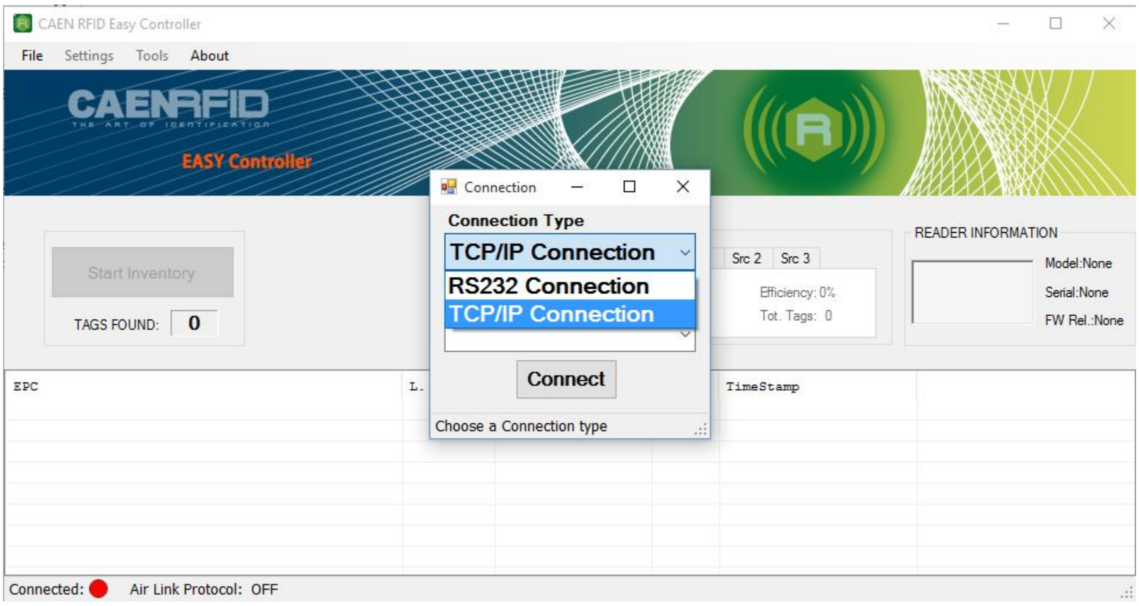
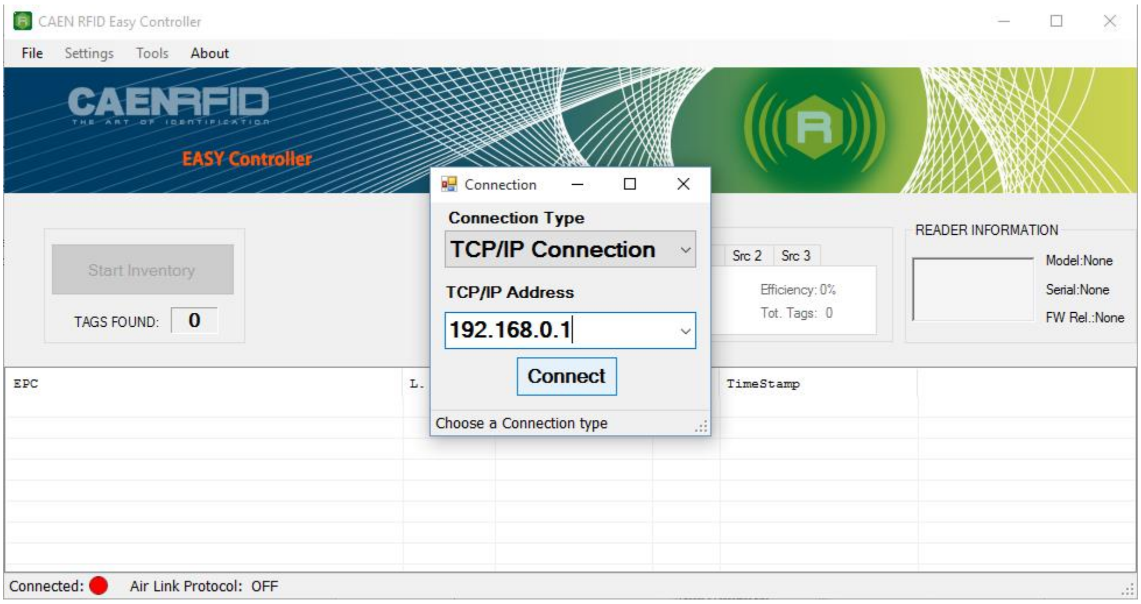


Figure 61. Selecting the connection type.

The IP for this configuration is 192.168.0.1, as shown in Figure 62. It should be ensured that the laptop is able to use the same value for the gateway.



Connection Type: TCP/IP Connection

TCP/IP Address: 192.168.0.1

Choose a Connection type

TAGS FOUND: 0

Efficiency: 0%
Tot. Tags: 0

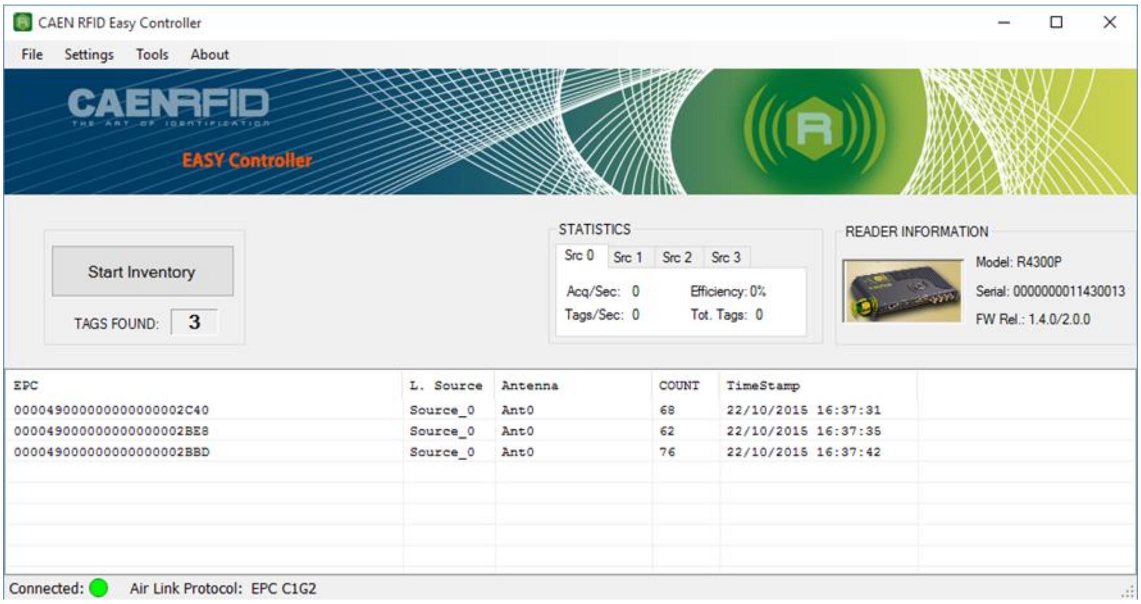
Model:None
Serial:None
FW Rel.:None

Connected: ●
Air Link Protocol: OFF

Figure 62. Configuration of the IP of the reader

After choosing the type of connection and the address/port, click on the Connect button to connect the reader. Any problem arising during the connection will be reported in the status bar located at the bottom of the window.

To verify if the connection with the reader is established, check the green dot down on the left side of the sidebar (see Figure 63). Once clicking the button ‘Start Inventory’, the information retrieved from the tags in the reading range is showed in the main window. In the TAGS FOUND text box the number of detected tags is shown.



TAGS FOUND: 3

Acq/Sec: 0
Tags/Sec: 0
Efficiency: 0%
Tot. Tags: 0

Model: R4300P
Serial: 0000000011430013
FW Rel.: 1.4.0/2.0.0

EPC	L. Source	Antenna	COUNT	TimeStamp
000049000000000000002C40	Source_0	Ant0	68	22/10/2015 16:37:31
000049000000000000002BE8	Source_0	Ant0	62	22/10/2015 16:37:35
000049000000000000002BBD	Source_0	Ant0	76	22/10/2015 16:37:42

Connected: ●
Air Link Protocol: EPC C1G2

Figure 63. View of the interface once several RFID tags are detected.

After the inventory has started, on the lower half of the main window you can find a table containing the following parameters:

- EPC: EPC code of the inventoried tag. (tag ID)
- L. Source: source of identification.
- Antenna: Antenna of the source that has identified the tag.
- TID: TID of tag, if available (default is TID reading off).
- RSSI: Received Signal Strength Indicator (as 16 bit signed form).
- COUNT: number of time the tag has been read
- TimeStamp: timestamp associated with the time of first identification of tag

Using the context menu you can select the ones you want to be displayed in the table (right click with the mouse on the table and check/uncheck them). Finally at the bottom of the main window you can find a status bar displaying the connection status (green dot = connected, red dot = not connected) and the anti-collision algorithm (air protocol) in use.

During the inventory cycle you can check the following parameters inside the Statistic box:

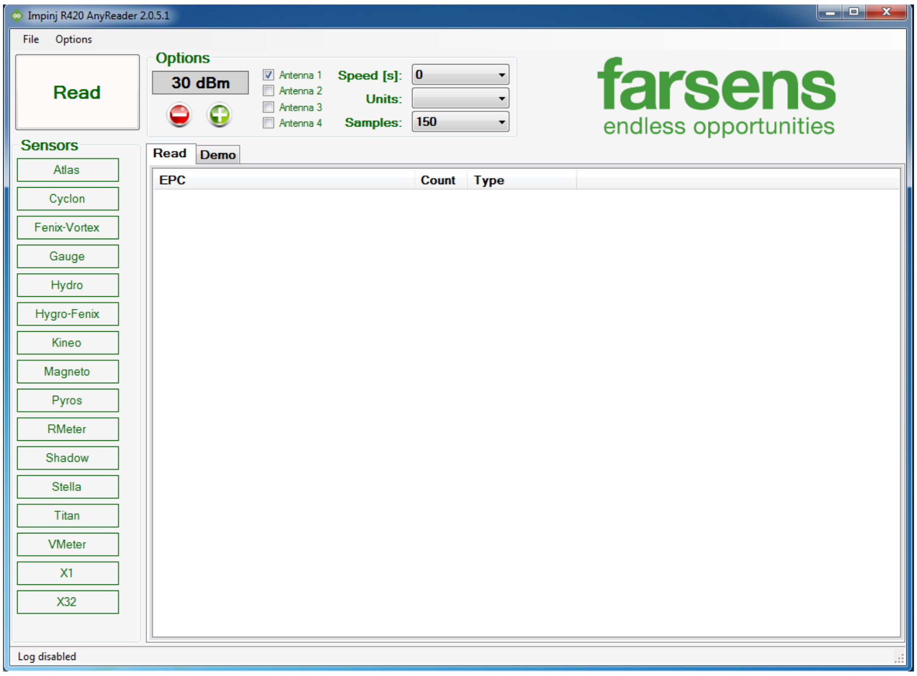
- Acquisitions per second (Acq/sec): the number of acquisition cycles per second.
- Tags per second (tags/sec): the number of tags detected per second
- Efficiency (Efficiency): is the value calculated by a Simple Moving Average algorythm using Acq/sec and tags/sec parameters.
- Tot tags (Tags found): maximum number of tags detected for each inventory cycle.

With an appropriated plugin or routine implemented in the reader software, the values provided by the RFID sensor tag can be translated into the physical properties being measured. This code has not been developed for the CAEN reader because the hand-held device already includes a software provided by the manufacturer of the RFID sensor tags to this end, as shown in the next chapter.

5.2.2 USING A HAND-HELD DEVICE

The software provided by the manufacturer of RFID sensor tags [19] supports the use of different commercial readers to discover surrounding tags and retrieve sensor data from the selected tag. Other functionality of the software is the capability of changing output power level, enabling or disabling antennas or logging the data to a file.

Once the application is launched, the first step is to establish connection with the reader. Once connected to the reader, the main window will be displayed.



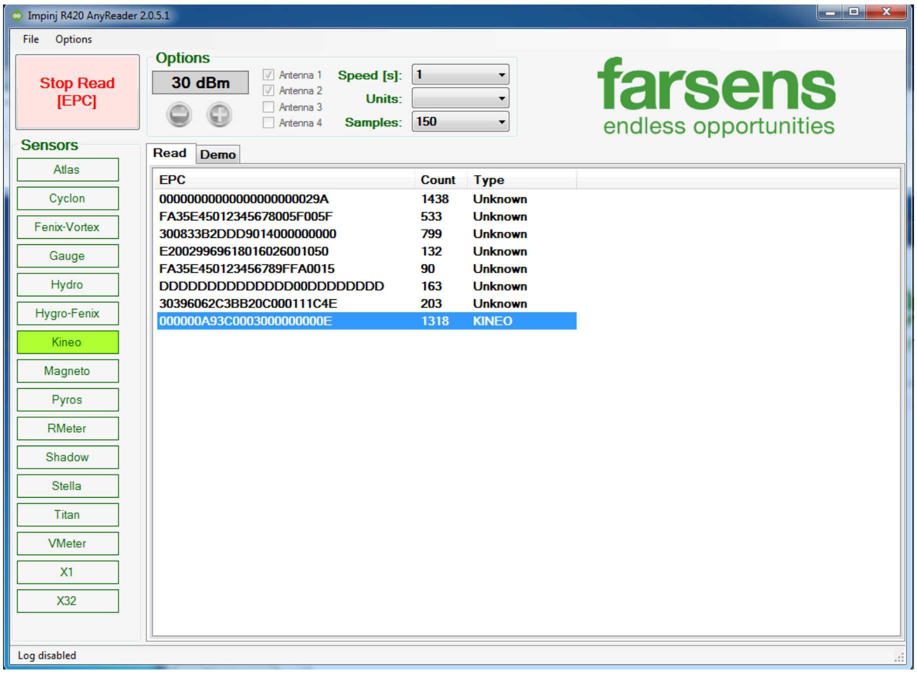
30 dBm

☑ Antenna 1
☐ Antenna 2
☐ Antenna 3
☐ Antenna 4

Speed [s]: 0
Units:
Samples: 150

Figure 64. Connection to the reader established [19]

Click on the Read button to start reading tags. The reader will discover surrounding tags and the software will show their Electronic Product Code (EPC) in a list. The reader will keep on performing consecutive inventory rounds, so that visible tags will be read repeatedly. The list includes a Count field, where the number of times that each tag has been read is shown (Figure 65).



30 dBm

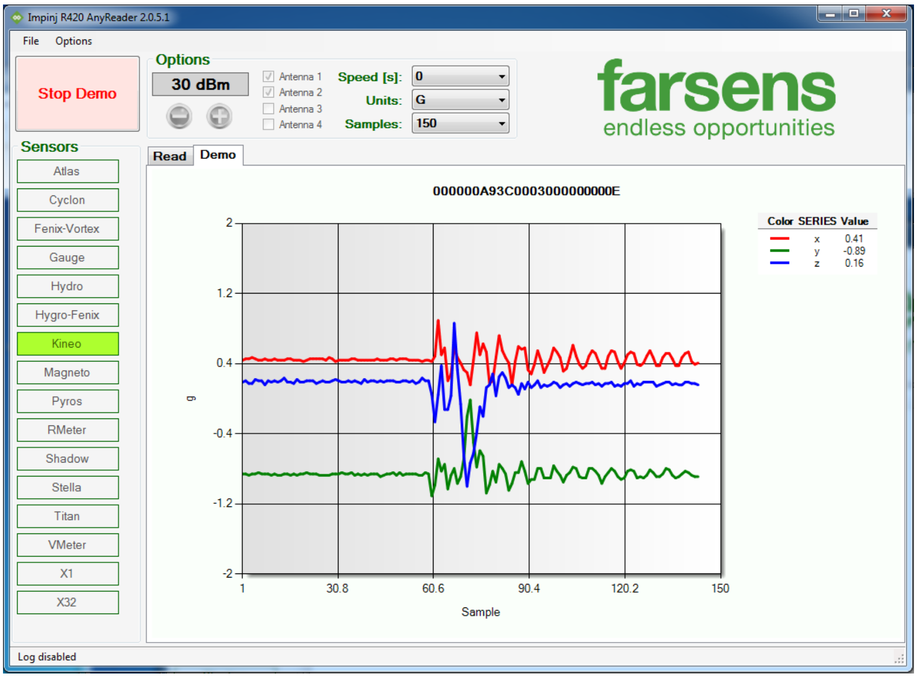
☑ Antenna 1
☑ Antenna 2
☐ Antenna 3
☐ Antenna 4

Speed [s]: 1
Units:
Samples: 150

EPC	Count	Type
0000000000000000000029A	1438	Unknown
FA35E45012345678005F005F	533	Unknown
300833B2DDD9014000000000	799	Unknown
E20029969618016026001050	132	Unknown
FA35E450123456789FFA0015	90	Unknown
DDDDDDDDDDDDDD00DDDDDDDD	163	Unknown
30396062C3BB20C000111C4E	203	Unknown
000000A93C0003000000000E	1318	KINEO

Figure 65. Select RFID sensor tag [19]

Click on the corresponding sensor button for that evaluation tag to start retrieving sensor data. This will automatically change the tab and start drawing a graph for visual inspection. In this interface, several parameters can be configured. For example, the Speed combo box allows selecting between different read speeds to obtain different data rates. The Samples combo box allows configuring the number of points plotted in the graph. An example is shown in Figure 66.



Options
30 dBm
☑ Antenna 1
☑ Antenna 2
☐ Antenna 3
☐ Antenna 4
Speed [s]: 0
Units: G
Samples: 150

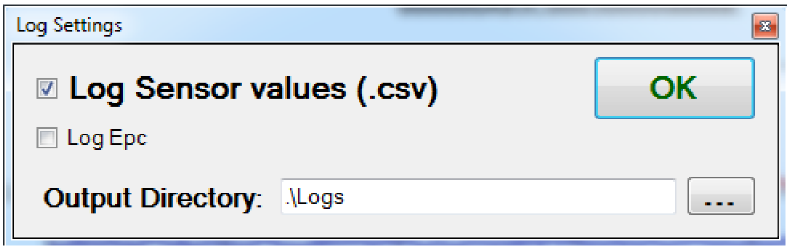
000000A93C0003000000000E

Color	SERIES	Value
🟥	x	0.41
🟩	y	-0.89
🟦	z	0.16

Log disabled

Figure 66. Graphical interface of the hand-held software [19]

In order to log data to a csv file, click on the Log check-box. The log will only contain the data retrieved after the Log check-box was activated. To do so, click on the Log button inside the Options menu. A new window will appear, letting the user enable the logging and selecting the output directory for the logs. By default, the reading of EPCs will not be saved. If needed the user can enable it. by clicking on Log Epc.



Log Settings

☑ Log Sensor values (.csv)

☐ Log Epc

Output Directory: .\Logs

Figure 67 Enabling data logging [19]

To stop reading the sensor and search back for new tags the Stop Demo button should be clicked, which will make the application go back to the main tab. To stop reading tags click the Stop Read button.

5.3 MAINTENANCE PROCEDURE

No maintenance needed for sensor tags because they are battery-free and are embedded in the concrete.

The maintenance procedure for fixed antennas and the hand-held device is described by the manufacturers, and they are the typical for electronic devices used in open environments.

6 Conclusions and next steps

According to the objectives of WP4.3, a monitoring system has been designed for being easily integrated into the new infrastructure concepts developed in SP1, i.e. a modular slab track, to compile all the information on the structural condition of these assets.

The sensor and communication technologies has been selected taking into account the findings in WP4.1 and 4.2, as well as the specific requirements of the new infrastructure elements. The Passive RFID technology have been identified as the most promising one, given their low-cost, low power consumption and the maturity level of this technology. In fact, almost all components of the monitoring system were already available in the market, so the research has been focused on the innovative application to structural health monitoring with the accomplishment of the requirements stated for precast concrete slab track.

Only strain gauges heve been integrated in the Passive RFID monitoring system. They provide relevant information in relation to the infrastructure condition. Temperature and moisture sensors can also be easily integrated although these sensors haven't been included in the monitoring system prototyped to be embedded in the two slab track prototypes.

Unfortunately other sensors such as accelerometers which provide very relevant information for Structural Health Assessment (as explained in 2.5) have not been incorporated in the AMS due to the need of obtaining measurements records during long periods of time which it is not operational with the RFID technology (gathering punctual measures)..

For the connection of strain gauges to multipurpose RFID tags, some developments were performed to increase the sensibility in the voltage measurements in order to detect small changes in gauge resistance. To this end, a voltage meter RFID tag was connected to strain gauges using a Wheatstone half-bridge. This allows to measure resistance changes in the gauge with the required precision to monitor strains in the reinforcement bars of the concrete element.

The application of the RFID sensor tags in the structural health monitoring of tracks required to solve several interferences: Firstly, the geometric interference with the reinforcement bars in the precast concrete element, being sure that the manufacturing process is not disturbed. Secondly, the physical interference with the maintenance procedures, even when maintenance tasks are not very frequent in slab track. Lastly, the electromagnetic interference with signalling, power supply and wireless systems in the surrounding of the track. In order to solve the geometric and physical interferences, the sensor tags have been embedded in the concrete. The electromagnetic interferences have been also investigated, supported by in-field measurements, and the RFID communication has proven to be compatible with the railway electromagnetic field.

Finally, a procedure for the installation of the AMS have been drafted, although its final implementation in the demonstrators of WP1.1.hasn't been deploy yet due to the delay in the prototyping and manufacturing of the slab track concepts developed within WP1.1. Updates related to the practical issues that may arise during the manufactuting and validation at CEDEX laboratory will be reported in Deliverable D4.3.2.

The operation of the montiring system has been described using the references given by the manufacturers of the RFID readers. Regarding the maintenance and replacement procedures, they are not necessary since the sensor tags are embedded in concrete and their useful life is expected to be, at least, the same that the infrastructure element being monitored.

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