REPORT D.3.1 and D3.2

Drawbacks of Current Harmonised EMC Approval Tests & Other electromagnetic influences

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Coordinator: CEIT
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<th>Description</th>
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<tr>
<td>AC</td>
<td>Alternating Current</td>
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<td>ATP</td>
<td>Automatic Train Protection</td>
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<td>BAE Systems</td>
<td>British Aerospace and Defence Company</td>
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<td>CE</td>
<td>Conformité Européenne (European Conformity)</td>
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<td>CENELEC</td>
<td>Comité Européen de Normalisation Electrotechnique (European Committee for Electrotechnical Standardization)</td>
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<td>CISPR</td>
<td>Comité International Spécial des Perturbations Radioélectriques (Special international committee on radio interference)</td>
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<td>DC</td>
<td>Direct Current</td>
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<td>EM</td>
<td>Electro-Magnetic</td>
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<td>EMU</td>
<td>Electric Multiple Unit</td>
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<td>European Rail Traffic Management System</td>
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<td>Electro-Static Discharge</td>
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<td>Equipment Under Test</td>
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<td>FFFIS</td>
<td>Form Fit Function Interface Specification</td>
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<td>GSM</td>
<td>Groupe Spécial Mobile (Global System for Mobile Communications)</td>
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<td>GSM-R</td>
<td>Global System for Mobile communication for Railways applications</td>
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<td>HAZID</td>
<td>Hazard Identification</td>
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<td>HV</td>
<td>High Voltage</td>
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<td>ICAO</td>
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<tr>
<td>Acronym</td>
<td>Abbreviation</td>
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<td>IEC</td>
<td>International Electrotechnical Commission</td>
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<td>International Telecommunication Union - Telecommunication</td>
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<td>OFCOM</td>
<td>Office of Communications</td>
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<td>OHLE</td>
<td>Overhead Line Equipment</td>
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<td>OJEU</td>
<td>Official Journal of the European Union</td>
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<td>RFID</td>
<td>Radio-frequency Identification</td>
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<td>RMS</td>
<td>Root Mean Square</td>
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<tr>
<td>S&amp;T</td>
<td>Signalling and Telecommunication</td>
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<td>TREND</td>
<td>Test of Rolling Stock Electromagnetic Compatibility for cross-Domain interoperability</td>
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<tr>
<td>UMTS</td>
<td>Universal Mobile Telephone System</td>
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<td>WIFI</td>
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1. INTRODUCTION

This document is a review of the current relevant railway EMC standards, including the EN 50121-1X: 2006 series, EN 50388, EN 50238 and EN 50122. The aim is to highlight areas of the various parts of these standards that are currently unclear or would need attention should the standards be modified, combined, or if new standards were to be written. Suggestions on how to address any identified issues are outside the scope of this report. The report is split into sections detailing the different parts of the EN 50121 standard separately, then moving on to include the other standards mentioned above. Included in this review are points in the standards that are not well defined, points that are inaccurate or that introduce inaccuracies both in the test method and in the results, points that result in excessive or unnecessary cost to the end user that commissions the testing, and points that impose design limitations on the various systems. These points are addressed within the text rather than in separate sections. Also included are some examples where the standards have proved to be insufficient in ensuring EMC using case studies.

1.1 EMC standards

Official Journal of the European Union

2011/C 214/02 Commission communication in the framework of the implementation of the Directive 2008/57/EC of the European Parliament and of the Council of 17 June 2008 on the interoperability of the rail system within the Community (recast) (Publication of titles and references of harmonized standards under the directive)

1.1.1. EMC on Railways

The European Union periodically publishes the titles and references of harmonized standards covered under the interoperability directive. The standards that are specifically written to deal with the electromagnetic environment in and around the railway environment are listed below:

Cenelec EN 50121-1: Electromagnetic compatibility – Part 1: General

Cenelec EN 50121-2: Electromagnetic compatibility – Part 2: Emission of the whole railway system to the outside world.

Cenelec EN 50121-3-1: Electromagnetic compatibility – Part 3-1: Rolling stock – Train and complete vehicle

Cenelec EN 50121-3-2: Electromagnetic compatibility – Part 3-1: Rolling stock – Apparatus

Cenelec EN 50121-4: Electromagnetic compatibility – Part 4: Emission and immunity of the signalling and telecommunications apparatus

Cenelec EN 50121-5: Electromagnetic compatibility – Part 5: Emission and immunity of fixed power supply installations and apparatus.

Cenelec EN 50122-1 Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: protective provisions against electric shock

Cenelec EN 50122-2: Railway applications Fixed installations - Electrical safety, earthing and the return circuit - Part 2: provisions against the effects of stray currents caused by d.c. traction systems
1.1.2. Summary of the standards

A short explanation of each of the four main documents (EN 50121 –X: 2006 series, EN 50388, EN 50238 and EN 50122) is given in this section also included are the other standards referenced in these main four which refer to electromagnetic compatibility.

**BS EN 50121-1:2006**
Railway applications. Electromagnetic compatibility. Part 1: General

The EN50121-X family is constantly referenced for all the systems and subsystems that are part of the railway, like the spot signalling systems, track circuits, rolling stock, GSM-R and broadcasting services. Consequently, this set has to be analysed.

The first part of this standard is a general introduction to the aspects of EMC within the railway system. It outlines the areas of EMC that are not included as well as introducing the parts of the EN 50121 standard as a whole.

**BS EN 50121-2:2006**
Railway applications. Electromagnetic compatibility. Part 2: Emission of the whole railway system to the outside world

In this standard the emission limits of the whole railway system are detailed. It sets out the limits and the measurement system used along with ideas for non-standard set-ups such as elevated railways. Later parts of this report identify some of the areas of this standard that will benefit from the input of the TREND project.

**BS EN 50121-3:1:2006**
Railway applications. Electromagnetic compatibility. Part 3-1: Rolling stock - Train and complete vehicle

This is the standard used by rolling stock manufacturers for the EMC assessment process of their new vehicles in most cases. This is true not only in the EU, where adhering to the standard represents a way to demonstrate compliance with the requirements of the EMC
Directive 2004/108/EC but also in projects all around the world where the EN 50121 is not compulsory in its application.

**BS EN 50121-3-2:2006**

Railway applications. Electromagnetic compatibility. Part 3-1: Rolling stock – Apparatus

This standard establishes the mandatory requirements that the rolling stock has to fulfil with respect to the apparatus installed on the train. However, it is sometimes the case that it is not enough to ensure the compatibility of the whole vehicle.

This standard sets out the requirements for train borne apparatus. It covers both emissions and immunity of apparatus. Apparatus installed in rolling stock using ‘good engineering’ practice is presumed to confer immunity for the whole vehicle, however this is not always achieved.

**BS EN 50121-4:2006**

Railway applications. Electromagnetic compatibility: Emission and immunity of the signalling and telecommunications apparatus.

This standard concerns the emission and immunity levels for signalling and telecommunications (S&T) apparatus within the railway environment. The EMC Directive states that any apparatus compliant with an OJEU listed standard is conferred with a presumption of conformity to the essential requirements of the EMC Directive, when that apparatus is installed in its intended environment. Another aspect of this Part 4 is that it is often used as the standard to test to for trackside equipment not covered in the other parts that are not designated as signalling or telecommunications, such as equipment that is installed on the platform.

**BS EN 50121-5:2006**

Railway applications. Electromagnetic compatibility. Emission and immunity of fixed power supply installations and apparatus.

This standard concerns the emission and immunity requirements for fixed power supply installations and apparatus within the railway environment, as defined in EN50121-1: 2006. The intention and purpose of the standard is that power supply installations and apparatus compliant with the standard will be conferred with a presumption of conformity to the essential requirements of the EMC Directive 2004/108/EC.

**BS EN 50122-1:2011**

Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: protective provisions against electric shock

This standard specifies requirements for protective provisions relating to electrical safety in fixed installations associated with a.c. and d.c. traction systems and to any installations that may be endangered by the traction power supply system.

It also applies to all fixed installations, which is necessary to ensure electrical safety during maintenance work within electric traction systems.

**BS EN 50122-2:2010**

Railway applications Fixed installations - Electrical safety, earthing and the return circuit - Part 2 : provisions against the effects of stray currents caused by d.c. traction systems.

This standard specifies requirements for protective provisions against the effects of stray currents that result from the operation of d.c traction systems.

This standard applies to all metallic fixed installations that form part of the traction system, and also to any other unrelated metallic components located in any position in the earth, which may carry stray currents resulting from the operation of the railway system.
It also applies to all new electrification of d.c. railway systems. The principles may also be applied to existing electrified systems where it is necessary to consider the effects of stray currents.

**BS EN 50122-3:2010**

Railway applications Fixed installations - Electrical safety, earthing and the return circuit - Part 3 : mutual interaction of a.c. and d.c. traction systems

This European Standard specifies requirements for the protective provisions relating to electrical safety in fixed installations, when it is reasonably likely that hazardous voltages or currents will arise for people or equipment, as a result of the mutual interaction of a.c. and d.c. electric traction systems.

It also applies to all aspects of fixed installations that are necessary to ensure electrical safety during maintenance work within electric traction systems.

Scope is limited to basic frequency voltages and currents and their superposition. This European Standard does not cover radiated interferences.

**BS EN 50125-1:1999**

Railway applications. Environmental conditions for equipment: Equipment on board rolling stock

This standard defines the surrounding environmental conditions in 14 environmental parameters. The 12th of these parameters is the threat level of ambient electromagnetic noise to on board equipment. This point defines EN 50121-3 as the reference to follow.

**BS EN 50125-3:2003**

Railway applications. Environmental conditions for equipment: Equipment for signalling and telecommunications

This standard, approved by the technical committee TC 9X and closely related to EN 50125-1, specifies the environmental conditions for the Signalling and Telecommunication electronic equipment. EN 50125-3 proposes to follow the testing requirements laid out in EN50121-4, but on-board equipment is required to comply with the surge requirements of EN 50155. The surge requirements of EN50121-4 were revised for the 2006 version of the standard and these requirements are now more stringent than those required by EN50155.

**BS EN 50155:2007**

Railway applications. Electronic equipment used on rolling stock

Subsection 5.5 explains that the equipment has to be protected against radiated and conducted emissions: the tests are defined in 12.2.8.1 and 12.2.8.2. Surges, electrostatic discharge and transient bursts are dealt with in 5.4 with test specified in 12.2.7. All the specified tests in these two sections in this standard call on the EN50121-3-2 with no additional test information other than the requirement that equipment is set up as it would be in the installed condition.

**BS EN 50159-1:2001**

Railway applications. Communication, signalling and processing systems: Safety-related communication in closed transmission systems

This European standard is applied to communication between safety critical equipment. In the case of the spot signalling systems like Eurobalise, on-board transmission equipment and the KER balises, these are included in the closed transmissions systems. However, the level of interest of this standard is far away from the physical layer, and no considerations are taken for the electromagnetic interferences in the receiving/transmitting path of the signal.
BS EN 50215:200

Railway applications - Rolling stock - Testing of rolling stock on completion of construction and before entry into service

As stated in the introduction of the document, this European standard specifies general criteria to demonstrate by testing that newly constructed complete railway vehicles conform with standards or other normative documents. That means that the large list of tests that the manufacturer has to undertake are related to the specific standard or norm to follow. Separated between static tests and dynamic tests, the electromagnetic compatibility is in the latter list, in the section 9.15, but also the “Interruption & voltage jump and short circuit tests” explained in section 9.16 should be taken into consideration from the point of view of this project.

BS EN 50238:2003

Railway applications - Compatibility between rolling stock and train detection systems

The scope of this European Standard is to describe a procedure for mutual acceptance of rolling stock to run over specific routes. It describes the methods of measurement of interference currents, the methods of measurement of the susceptibility of train detection systems, the characterisation of traction power supplies and the procedure for acceptance. The result of the acceptance procedure is a structured justification document referred to as a “compatibility case”, which documents the evidence that the conditions for compatibility have been satisfied.

This European Standard is not generally applicable to those combinations of rolling stock, traction power supply and train detection system which were accepted as compatible prior to the issue of this European Standard. However, as far as is reasonably practicable, this European Standard may be applied to modifications of rolling stock, traction power supply or train detection systems which may affect compatibility.

The scope of the compatibility case is restricted to the demonstration of compatibility of rolling stock with a train detection system’s characterisation (e.g. gabarit). Radio based signalling systems are not within the scope of this European Standard.

BS EN 50388:2005

Railway applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability

This European Standard is sets out the requirements for the acceptance of rolling stock on infrastructure.

This standard deals with the definition and quality requirements of the power supply at the interface between traction unit and fixed installations.

The standard specifies the interface between rolling stock and electrical fixed installations for traction defined as “the supply system”.

2. **EN 50121 –1: 2006: GENERAL**

This first part of the EN 50121: 2006 [1] standard is a general introduction to the aspects of EMC within the railway system. It outlines the areas of EMC that are not included as well as introducing the parts of the EN 50121 standard as a whole.

In this introduction to the standard set, there is no mention of whether the standard should be updated as more modern railway apparatus and systems are utilised. The disclaimer that the limits are set from measurements at the time when the EMC directive was developed is fair, but perhaps there needs to be some concession to the changing of not only the railway system but the surrounding EM environment. One of the issues with railway EMC is introducing new systems such as rolling stock to older track and signalling systems, and it is probably necessary to include some time aspect in this standard.

The EN 50121 –1: 2006 states that adherence to both the immunity and emission limits in this standard does not “guarantee that the integration of the apparatus within the railway will necessarily be satisfactory” or that “the immunity and emission levels do not of themselves guarantee that the railway will have compliance with its neighbours”, however the standard also states that “compliance with this Standard has been judged to give satisfactory compatibility”. As it is unreasonable to expect the standards to account for all eventualities in the extremely varied railway EM environment, the first two statements are a sensible disclaimer. However, the third statement seems to contradict this, giving an impression that the compatibility is satisfactory overall, when in reality this may not be the case. Clarification of this point, or an expansion of the standard to be able to state that compatibility in the real world is likely to be achieved if the requirements of the EN 50121-x series of standards have been met. This may also need additional requirements for the specific environment, for example, national technical rules regarding different track circuits in different countries.

### 2.1 Scope

In this section, there is a list of the aspects that are not covered by the EN 50121 set:

- Nuclear EM pulse
- Abnormal operating conditions
- Direct lightning strike induction
- Emissions from intentional transmitters, pacemakers, biological effects and safety.

Not mentioned, but perhaps should be added, is intentional interference with the idea of deliberately causing a malfunction, for example an act of terrorism, and the necessary requirements to avoid this. Abnormal operating conditions are not defined, and it is unclear whether this simply refers to malfunctions of equipment that cannot realistically be accounted for in the standard. Medical awareness becomes more important, but since the EMC standards for industry etc are clearly separated from medical aspects, it is reasonable the EMC standards for railways should also be separated from medical issues. If EMC standards for railways cover all frequency ranges between DC and a certain maximum frequency, that would give a good framework for medical expertise to work with – concerning exposure times etc. (In a railway environment, you can expect maximum electromagnetic fields of the following magnitudes, etc.). The levels of exposure are controlled in applying the standard 50500 but in practice, this is applied only to DC-20kHz. So this standard does not cover the frequencies considered in TREND. **EN 50500**: Measurement procedures of magnetic field levels generated by electronic and electrical apparatus in the railway environment with respect to human exposure – September 2008
Since 2006 there has been more research on the biological effects, driven by the mobile telephony companies, among others, so a more informed view if not an in depth treatment could perhaps be included. See Section 9 for a note on EM safety.

The performance criteria outlined in EN 50121 –1: 2006 are mostly derived from the product description and documentation, however it is not specifically mentioned what to do in the case of each type of failure, i.e. whether or not an immunity test is passed or not. It is given that if the apparatus becomes unsafe or dangerous then it will have failed the test. This would seem to imply that some realisation of the safety critical systems is required, but safety critical systems are stated as not being included. Addition of some safety information may aid in the definition of critical performance loss as a result of poor EMC. The safety aspect issue may have resulted from the EMC Directive, 2004/108/EC being defined by the EC as “not a safety directive", whereas the interoperability directive, which requires conformance to be demonstrated by the same series of standards, is regarded as a safety directive.

2.2 Annex A: the Railway System

Within this annex is a list of what the on board electrical supply on the train is used for. Not included in this list are passenger services such as laptop charging points and on board WIFI. No mention is made of the effects of EMI on humans in the railway environment, as stated earlier; this is not present in this standard.

Phenomena for immunity are listed as: Conducted low frequency, radiated low frequency, conducted high frequency and radiated high frequency. This covers all of the potential incoming radiation to the railway system. Emissions, however, only have limits applied to magnetic fields up to 9kHz, radio frequency fields (taken as between 9kHz and 2.5GHz) and voltage fluctuations.

This misses out a large portion of the EM spectrum, namely any E fields below 9kHz and any conducted emissions that might occur. The voltage fluctuations mentioned are only those that stem from power frequency and harmonic currents and not from any other source. The radio frequencies are stated as "radio frequencies from trains" and there appears to be no mention in this part of radio emissions from other areas such as OHLE (Overhead Line Equipment). The test methods are only present up to 2.5GHz, and in the modern environment (including, for example, 4G networks operating at 2.6GHz) this is not a high enough upper limit.

The phrase “produce energy” used in this section should be reworded, perhaps to ‘create noise’ or similar. The overheads in an AC railway are recognised as acting as an antenna however no mention is made as to what the main emission threat frequencies are from OHLE. Trackside equipment effects on the other aspects of the railway is given, however there is nothing about trackside immunity to the railway system in this section. If this is not the place for such detail then there needs to be a reference to the area where this is given. In addition to the external sources of disturbance section, there should probably be a victim circuit to highlight the issues met/ systems likely to be interfered with as a result of high train emissions.

2.3 Useful additions to the EN50121-1

This standard is understood as the main reference for establishing the framework to manage the EMC for railways, and, as such, should to give the normative references needed to fulfil all the requirements regarding EMC in order to have a completely safe and functional railway system. Currently it is possible to miss some standards during the validation process. Normative references that are not present in Part 1 include:

- EN 50122-1
- EN 50122-2
There are some figures from the given normative references that could be considered useful for inclusion in the general part of EN50121.

In the standard EN 50238 [2], Figure 1 describes the different systems found on the railway system and its influences between them (see paragraph 4.9, EN 50238). This standard is meant to manage the influences between the rolling stock and the train detection systems, but it is also valid for any kind of auxiliary electronic equipment (signalling and telecommunication systems, rail switches detectors, etc).

It would be useful to include it in the standard EN 50121-1 as a standard procedure to show the different interactions that should be taken into account when establishing the EMC framework on the railway environment.

![Diagram of railway systems](image)

**Figure 1: Influences between systems [10]**

Also in EN 50388 there is a flow diagram describing the process to follow when introducing a new element on the railway network (see Figure 2). This standard is for the power supply but the process shows the framework for adding any new infrastructure component within the existing traction unit(s) and power supply network (see paragraph 10.2; EN 50388). It also describes the acceptance procedure, compatibility study, tests and test methodology. It would also be useful to include it in the standard EN 50121-1 as the standard procedure to follow in the case of introducing new electronic equipment on the infrastructure network.
Figure 2: Procedure for compatibility study of harmonics and dynamic effects when adding a new element to the railway system. [11]

EN 50121-2:2006 [3] details the emission limits of the whole railway system. It sets out the limits and the measurement system used along with ideas for non-standard set-ups such as elevated railways. This part of this report hopes to identify some of the areas that will benefit from the input of the TREND project.

### 3.1 Emission Limits

EN 50121-2:2006 states that for a non-electrified line, the limits for a 750V DC railway system should be applied. Possibly a new set of limits for non electrified lines could be established, as some limits may be too harsh for a diesel traction system, and equally some may be too lax as diesel traction can emit at different frequencies and powers to DC traction. This may be required for both power and brake testing, as some diesel-electric traction units are fitted with regenerative braking. Since regenerative braking feeds current back to the catenary, additional magnetic fields are created in this process. There is no mention of regenerative braking in EN 50121-2:2006, however there is an area of the test which requires emissions to be measured at 80% braking efficiency.

The frequency limits for EN 50121-2:2006 are set between 9kHz and 1GHz. Apparatus limits go up to 2.5GHz. The standard mentions that sensitive frequencies should be tested, but if these are below 9kHz or over 1GHz then there is no measurement or test method neither given nor inferred. Below 9kHz it is said that the EM environment is too noisy to correctly isolate railway emissions. These limits can leave testers in the dark when it comes to testing outside the frequencies, an issue of increasing size as, for example, onboard WIFI among other potentially high emitters (WIFI is not specifically mentioned, though presumably covered as an “intentional transmitter” in Part 1) working at frequencies in excess of 1GHz. Dependent on equipment being used on-board rolling stock or identified victims in the external environment, testing for emitted frequencies outside of the range specified may be required. However, the standard provides no information on how this might be carried out. In practice, measurements have been conducted to EN 50121-2:2006 with the frequency range extended up to 6GHz using suitable receivers and horn antennas. Therefore, given the frequency limits, suitable measuring methods should be proposed.

The substation emissions are well defined, but there is no mention of the environment in which the substation or the other fixed installations are present, for example trackside or in another particularly harsh EM environment. These limits are applied to “other fixed installations” but no mention of what sort of fixed installation (trackside box, signalling unit or substation) or reference to EN 50121-5:2006 which deals specifically with these power systems. As EN 50121-5:2006 will need to be adhered to in the case of a substation or other fixed installation being present, perhaps just a reference to EN 50121-5:2006 is needed rather than stating the same limits in the two different areas. Nor is there any mention of conducted emissions from substations or directly from trains.

A standardized hazard identification procedure, to be used whenever a change is made, may be one way of handling this issue. Usual practice in the UK is to perform hazard identification (HAZID) of the EM environment either before a new railway is constructed or prior to upgrading of an existing section of railway. This information is used to inform both design and measurement requirements over and above EN 50121- 2 or –5 requirements. Sweden has an equivalent for implementing railways next to airports: according to a Swedish regulation electrified railways are not allowed to be built close to airports without special permission, and not without an analysis of potential electromagnetic interference. There have been studies in Norway and Germany that have resulted in the conclusion that railways can be built as close as
300-500 meters to airports without electromagnetically affecting flight traffic. In Sweden, there are regulations, dating from 1957, in which overhead power lines for power distribution and rolling stock should not be built closer than 4 kilometers to airports (“Starkströmsförordningen” SFS 2009:22 published by "Elsäkerhetsverket").

According to a document from International Civil Aviation Organization (ICAO), railways are considered to be as a physical obstacle and not a source of electromagnetic interference. Measurements taken by "Trafikverket", verified that there was no EM radiation risk from railway tunnels to instruments or people in terminals.

EMC measurements in such areas will be very costly for the railway industry and the rolling stock owners currently present in Sweden. It would be much more cost-effective and eco-friendly for Sweden as a whole to run operations/services by having railways closer to airports, a situation achievable by proper EMC analysis. Such kind of analysis is currently not present in Sweden.

The standard EN 50121-2 is the only EMC standard which deals with emission of the railway system to the outside world. Despite this, EN 50121-2 has no directives for infrastructure owners to build railways near the airports in Sweden, other than the clause that mentions the special environments requiring more attention. This constitutes an issue for infrastructure; rolling stock owners are enforced to carry out unnecessary and costly EMC measurements. A reference of how the construction of the railway in the surroundings of sensitive areas like airports, or other areas sensitive to electromagnetic influences, would it make easier for the infrastructure manufacturers to deal with the limitations that can appear.

A suggestion is that all these cases might be added to a guidance document, which would set out the need for hazard identification and then demonstrate how the risks are mitigated.

There is no mention of attempting to separate transient and continuous emissions by either measurement or analysis. This is due to the fact that it is unable to distinguish between these types of emission with a simple peak measurement. The 2006 update to the EN50121-3-1 involving the different moving test methods (slow speed, against mechanical brake etc.) attempts to distinguish continuous emissions from transient using the quasi-peak method (for stationary vehicles): it is designed so that a vehicle that passes Part 3-1 will also pass Part 2 (note this is not necessarily achieved in practice due to resonance in the OHLE system).

### 3.2 The Measurement System

EN 50121-2:2006 uses the peak measurement system with the measurement time as a function of the measuring set. A recommended value of the measurement time is given as 50ms in clause 5.1.1. The standard also mentions correctly in 5.1.4 that the “noise may not attain its maximum value as the traction vehicle passes the measurement point” This suggests that the measurement set should be “active for a sufficient duration” which would certainly be longer than 50ms. One of these systems should be decided on, preferably the latter. On-site line-side tested in UK has shown that interference from the OHLE can occur well before and after the train has passed the measurement point.

Clause 5.1.6 in EN 50121-2:2006 states that the 10m measurements should be taken from the mechanical centre of the antenna, however the phase centre is potentially a more useful datum point (particularly for immunity measurements). Antennas are calibrated, and there is a mention of obtaining a background trace of EM noise when a train is not present to allow identification of environmental EM noise. It is not mentioned what should be done in the case where a large amount of EM noise is present in the background scan from the railway system in this part (this is referred to in part 3-1, but only says to not test if the noise is greater than 6dB below the limit, and there is no reference to this in this section of part 1). This may be useful to obtain the worst-case scenario with emissions from OHLE or conducting rails when a train is not present. Standard practice is to run the test (over a particular frequency) band for an amount of
time before and after the train passes. This automatically provides ambient measurements both before and after the train is present.

The current EN 50121-2:2006 is not set up to obtain a worst-case scenario with regards to the supply system. This is manifested by actively avoiding the areas that would cause the highest emissions, for example stating that, for an OHLE railway, measuring at mid points between support masts away from the discontinuities, and for a trackside conductor, 100m from any gaps. This is done to “avoid inclusion of the transient fields associated with the make and break of collector contact”. However, in a real environment these transients are present (for example at sets of points or other crossover areas) and as such should be tested, in the pursuit of a worst-case scenario and reasonable train immunity. Single side tests are suggested as “the majority of the emission is produced by the sliding contact if the train is moving”. This is fine if the system is symmetrical as in an OHLE set-up, but in the case of a third rail system symmetry is not present so either both sides or, as suggested, the collector side should be measured. It is also the case that the majority of low frequency emissions do not stem from the sliding contact.

A large issue is the factor used to modify the measured electric field to the 10m electric field values. In the provided table, no frequencies lower than 150kHz are given, there is not even a suggestion of whether to carry on with the value for 150kHz or extrapolate the factor for lower frequencies. This causes a potentially large issue when testing to this standard, as measurements are sometimes carried out down to 9kHz.

Resonance effects are “recognised” in Clause 5.1.9, but there are no limits or specifications for them, only that if present, they are noted in the test report. Clause 5.3 states that any transients resulting from switching (such as power circuit breakers) should be disregarded when selecting the maximum signal level. If this is a regular occurrence in real world usage then perhaps this should be included in the emission limits.

One of the major problems with on site testing of railways is that of the weather, which can have a huge impact on the variation of the emissions. EN 50121-2:2006 states that measurements should be taken “after 24 hours during which not more than 0.1mm rain has fallen”. However, as testing and/or track possession is often booked well in advance, this is very rarely met. However, the tests are still carried out: so weather conditions are recorded at the time of testing as stated in EN 50121-2:2006. It would be beneficial to have a set of weather dependent emission limits, or a list of the changes in uncertainty/test levels caused by the weather conditions. This should include variables such as humidity, temperature, the dielectric constant of the ground and the state of the pantograph can be defined.

The weather is one of the largest effects causing differing test-to-test emission values and will need to be addressed in order to reduce the uncertainties and therefore tighten up the limits. Testers need to be in a position of knowing the potential effect of the weather conditions. One of the problems of reducing the test uncertainty is alluded to in Annex B.12.3, in that there may be other units operating in the area that are currently within the repeatability error of the current measurement system. If the repeatability error is reduced then this may become a problem. Since electromagnetic emission from the arcs at the sliding contacts are due to the distance between the (carbon)contact and the (copper) wire, there is one way of standardizing measuring procedures: A thin film of isolating material (plastic) can be attached to the carbon contact. This will give a continuous arcing, making is possible to standardize the measurements. In cold climate, with ice on the catenary, electric arcs can go as long as the ice is there.

Two test conditions are set out in EN 50121-2:2006, one where the traction is moving at over 90% of the maximum service speed at maximum rated power, and another at maximum rated power at a selected speed. There is no specific statement involving regenerative braking given, though if electric braking of any type is possible then it should be tested during the 80% brake efficiency test. Magnetic brakes/eddy current brakes are not mentioned. Stated in Annex
B: “there is as yet no method by which this [the worst-case scenario for emissions under power] can be defined”. This will also need some work.

It is not mentioned if the “outside world” referred to in this standard includes the inside of the train. If not then it is suggested that a test method is designed to obtain the field strengths inside passenger carriages, both for safety purposes and the availability of both passenger and train services.

In Annex B, there is no mention of multiple power units / traction at both ends of the train though multiple pantographs are mentioned. It is suggested that higher noise emission may result from the trailing pantograph, which has a disturbed contact with the catenary in the double pantograph scenario. EN 50121-2:2006 seems to suggest that the emission limits can be relaxed with respect to multiple pantograph arrangements, either a double pantograph on one unit or coupled unit of two or more single pantograph locomotives. If the emissions are higher than single pantograph limits then surely the unit, as a whole, should fail the test, as the limit is set to stop interference irrespective of the pantograph system. There is also no specific mention of multiple units such as EMUs (electric multiple units) or trains with traction at both ends. If coupled units are to be used extensively then a fixed limit for the emissions is needed. This is evident in the case study in Deliverable D2.1 of this project, in section 1.3, where the addition of multiple units under heavy load caused interference on telephone lines in Sweden. These traction units would have passed the EMC tests singularly, but obviously not as a group, and hence problems occurred with overwhelming the ground return paths. Both the pantograph effects and the increased return currents would have to be investigated in this modification to the standard to take into account multiple traction units, or to reflect real world usage.

There is no mention of testing in a different manner or indeed calculations for either single track or more than dual tracks (for example 4 tracks). It might be necessary for different emission limits to be applied to 4 track railways, or railways with 4 track sections – the current requirement is to test 10 m from the centre of the outer track: as long as any higher emissions resulting from multiple trains only appear on inner lines then that is reasonable. Levels on inner lines could be calculated and dealt with if too high. Calculations for the limits at 10m (Annex C) assume that the radiation is being measured in the far field, which will not be the case for low frequency emissions from the overheads. This may cause an issue where the measurements are not representative of the actual emissions due to near field issues.

EN 50121–3-1: 2006 [4] is the standard used by rolling stock manufacturers for the EMC assessment process of their new vehicles in most cases. This is true not only in the EU, where adhering to the standard represents a way to demonstrate compliance with the requirements of the European Directive 2004/108/EC (the harmonised standard for the railway environment), but also in projects all around the world where the EN 50121 is not compulsory in its application.

However, this standard itself is not enough to completely assess new rolling stock with respect to EMC, as there are many aspects not covered. Currently, there are different working groups focussed on this issue and it is expected that this standard will be modified, and at the same time, other new standards may appear.

The following sections describe the drawbacks found in the standard EN 50121-3-1 according to experience in recent projects.

4.1 General issues of the EN 50121-3-1

First of all, the repeatability of the result of the measurements is not clearly assured. The conditions for the test to be performed are not properly defined in the standard. Some examples of that are the following sentences directly taken from the standard:

“Measurements shall be performed in well-defined and reproducible conditions. It is not possible to totally separate the effects of the railway system and the stock under test. Therefore the operator and the manufacturer have to define in the contract the test conditions and the test site for compatibility with signalling and communication systems and for interference on telecommunication lines”.

For the radiated emission test: “Since resonances may occur in the overhead line at radio-frequencies, it may be necessary to change the test site.” This means that the train manufacturer could chose the most convenient emplacement, which could make it easier to pass the tests from the point of view of the manufacture, but it might not ensure EMC in all situations, for example Alstom and the initial testing of the Class 390 Pendolinos. Train operators or infrastructure administrators could choose an area with the worst EM environment area in the infrastructure, which may be excessive and result in the train being more expensive and less efficient.

Apart from these two examples there are other factors not specified in the standard which might contribute to the uncertainty of the results:

Weather conditions on the test day and for some time previously (and thus ground conditions) will affect the result of the test. EN 50121-2 defines some conditions for the radiated emission test described in this part of the standard. However, EN 50121-3-1:2006 does not include any reference to weather conditions. During the winter and depending on the country where the new vehicles have to be validated it might be difficult to find perfect weather conditions to perform the tests. Finally, if exactly the same train is marketed in two different countries for two different customers, the standard does not make it clear if it is necessary to repeat all the tests according to country of supply. It is not clearly specified and the costumer could ask that all the tests must be performed again, with all associated costs. The testing might not have to be repeated for CE marking purposes, but another operator might insist on tests being repeated to ensure that the rolling stock will run satisfactorily on his line. This may result in vehicle(s) passing EN 50121-3-1, but when measurements are performed to EN50121-2 (the railway emissions to the outside world), these limits may not be met. Hence we should calculate worst-case resonance conditions and make the 50121-3-1 tests under these conditions.
4.2 Compatibility with signalling and communication systems

The CENELEC Technical Specification CLC TS 50238 [2] cover the requirements relating to track circuits and axle counters currently in use. However, only certain preferred types of track circuits and axle counters are included in this standard. Therefore, there are still several types of train detection systems used in the different infrastructures and not covered by the current standards.

For the case of cab signalling and ATP systems used in different infrastructures the standard EN 50121-3-1:2006 does not specify any special requirements. This equipment shall fulfil the requirements of the standard EN 50121-3-2:2006 [5] and the train shall fulfil the requirements of the standard EN 50121-3-1:2006. However, it can be the case that this is not enough and problems can appear affecting the availability and the safety of the vehicles, such as loss of cab signalling systems.

The same situation occurs with the ERTMS (European Rail Traffic Management System) including the ETCS and GSM-R. It is not clear if the requirements of the standards EN 50121-3-2:2006 and EN 50121-3-1:2006 are enough to prevent EMC problems affecting the availability and the safety of the vehicles as a result of interference from GSM transmitters. GSM-R and other on board transmission equipment are exempt from emission limits as they are designated as “intentional transmitters”.

4.3 Interference on non-railway telecommunication lines

This section is divided in two parts: digital telecommunication lines and analogue telecommunication lines.

For the case of digital telecommunication lines, EN 50121-3-1:2006 does not define any test set-up, test procedure, or limit to be applied. Moreover, it does not include any reference to other known standards. For the case of analogue telecommunication lines, EN 50121-3-1:2006 does include a reference to the ITU-T (International Telecommunication Union – telecommunication Standardization sector), which describes a method based on the measurement of the psophometric current. However, there is not any emission limit defined for the different types of rolling stock or infrastructure in order to achieve compatibility with non-railway telecommunication systems in this standard. Limits, tests and details of and for railway signalling and telecommunication apparatus is detailed in EN 50121-4:2006.

As a consequence, in most of the projects for the development of new rolling stock material, the purchaser does not know how to proceed in order to meet the standards. It is only because the EN 50121-3-1 standard includes a reference to this test that the purchaser asks to perform an analysis of compatibility with signalling and communication systems. Nevertheless, the method to follow and the limits to be applied are unknown and what normally occurs is that test procedures and limit values taken from past projects are applied. This means the test is without the certainty that it is necessary or indeed convenient for the project under development. This could create disputes between the purchasers and the contractors of the different project, which adds extra cost; it also could create non-compliances that unnecessarily delay the development of the project, add extra cost, and reduce the efficiency of the vehicles, as modifications such as extra filtering might need to be installed.

Another issue to be considered is the fact that most of the telecommunication lines, which run parallel to the railway tracks, are no longer conventional analogue lines. Most of these lines use digital transmission and in some of the cases are optical signal rather than electrical. This is the reason why the compatibility test described by the ITU-T is not valid for those lines. In some cases, it is only the subscriber line between the commuter centre and the customer where analogue signals are transmitted. This means that only the urban vehicles are able to interfere with these communication lines due to their location.
Therefore different types of communication arrangement should be studied if this test is to be included in the standard. If it is necessary, there must be more details regarding test set-up and limits for the different types of rolling stock and infrastructure, not only for compatibility with analogue telecommunication lines, but also with digital telecommunication lines. Moreover, the applicability of this test must be different for the different types of rolling stock.

4.4 Emissions

The radiated emission requirements of EN50121-3-1 are divided in two parts: a stationary test and a slow moving test. Thus, two different sets of limits are described. For the case of stationary test, the limits are divided into two categories: trams/trolleybuses for use in the city streets, and other rail vehicles. In the slow moving test, the limits are divided into three categories depending on the supply voltage: a) 20/25 kV AC; b) 15 kV AC, 3 kV DC and 1.5 kV DC; c) 750 V/600 V DC, including trams/trolleybuses for use in city streets and diesel and diesel electric locomotives and multiple units. Moving at slow speed should limit sliding conductor arcing and so attempt to eliminate transients. The Quasi-Peak measurements are carried out with the vehicle stationary, and were introduced in response to CISPR's input when the EN50121-X standards were turned into IEC standards. The Quasi-Peak measurement aligns with, for example, CISPR 11 (EN55011) and is there to demonstrate that emissions will not affect radio and broadcast services.

The division of the limits for the stationary test has sense as the street vehicles run closer to other potential victim equipments, and therefore the application of a more restrictive limit might be necessary. It could be said (due to higher emissions and relaxed limits) that 25kV railways should have a greater distance to nearby infrastructure (domestic buildings) than 1.5kV dc. Also it could be argued that for a city 750V dc might be the only appropriate electrification to minimise interference to the surrounding infrastructure.

However, the division of the limits for the slow moving test is not reasonable. The limit line C, which is the most restrictive, must be applied to all the vehicles supplied by 750 and 600 V DC lines, as well as diesel and diesel electric vehicles. In the case of electric vehicles supplied by 750 and 600 V DC lines are also included some Metro vehicles which sometimes run exclusively underground and far from other victim devices. Therefore, the application of such a restrictive limit could reduce their efficiency and increase their cost due to the necessity of stronger filtering. The same occurs for diesel and diesel electric vehicles. Although they are supposed to generate lower electromagnetic noise, they still include high power switching devices, which normally generate electromagnetic noise. Again the application of a more restrictive limit increases the cost of the vehicle and reduces its efficiency. A potential solution to this is to have a different limit for underground services or diesel services, but this could also increase cost. There is no mention of whether the manufacturer of the rolling stock needs to define a worst case possible scenario at which the train can be tested, for example maximum emissions may not be at 90% load but at some other traction load setting.

It is defined in EN50121-3-1 that the vehicle should be producing 1/3 of it’s total tractive effort in an attempt to maximise emissions by power electronics being on 'partial' conduction, however it would be best to measure the worst case scenario, which might be able to be predicted by modelling.

EN50121-3-1: 2006 does not take into account, or have any explicit requirement for, vehicles fitted with regenerative braking. The slow moving test permits emission measurements to be made under accelerating conditions and also decelerating conditions. It should be made mandatory that vehicles fitted with regenerative braking should be tested for emissions explicitly when the vehicle is decelerating under the influence of the regenerative brake, as well as the standard deceleration test. In the case of regenerative braking, the EN50121-3-1 option of replacing the slow moving test with a stationary test where brakes are applied is inadequate, as the regenerative brake will not be active and therefore not tested. Testing traction at 1/3 of
tractive effort against mechanical brakes is specified in EN50121-3-1: to properly categorise this, there needs to be an indication of whether this is a realistic test environment. For example, testing a DC locomotive against a mechanical brake is unnecessary as the DC motors will not be turning so there will be no source of commutator emissions.

4.5 Immunity

Section 5 of EN50121-3-1 states ‘the vehicle can be deemed to be immune to a level of 20V/m over the frequency range 0.15MHz to 2GHz’ if individual apparatus is tested to EN50121-3-2: 2006. This is inaccurate. Inspection of EN50121-3-2: 2006 indicates that the assumption can be applied only in the frequency range 80MHz to 1000MHz, meaning that immunity cannot be assumed over 1000MHz. There is no requirement to immunity test the entire vehicle once assembled.

There does not appear to be any formal requirement in EN50121-3-1 for immunity testing of traction motors or auxiliary motors and their associated circuitry. In particular, EN50121-3-1 references EN50121-3-2, where there is no explicit requirement for a test involving a temporary interruption of the electric traction supply from, for example, a 25kV overhead power line. This has the potential to switch the motor into generator mode, which might inject high voltage onto, for example, a dc bus and stress semi-conductors with reverse voltages.

This oversight is merely reinforced by an informative Annex (Annex A) of EN50121-3-2, which explicitly considers traction motors and auxiliary motors and simply states in Table A.1 that there are ‘no test requirements’ for immunity (or indeed emissions). This table should be amended to reflect modern technological advances.'

4.6 Transients

Rare voltage peaks, with levels much higher than the average signal amplitudes, do occur in railway systems. Long cables can act as antennas and receive electromagnetic pulses from various sources. Thorough shielding and grounding can minimize the impact or damage done by transient voltage peaks, but transients can still cause interruptions to services, black out video screens, give false alarms for hot bearings, etc.

Transients of high magnitudes have been reported, having very long time intervals. Transients may occur once an hour, once a week and in some cases once a month. Therefore special measuring methods should be proposed and tested for future EMC standards.

The main problem that a train manufacturer might find in this part of the standard is that its suppliers normally try to do only what is mandatory according to this standard. However, it can occur that it is not enough to ensure the compatibility of the vehicle.

5.1 Emissions

EN 50121-3-2 does not establish any requirements within the frequency band between 9kHz and 150kHz neither for conducted nor radiated emissions. However, EN50121-3-1 effectively considers this in the context of the whole vehicle by stating ‘emission requirements shall be specified according to the type of signalling and communication systems used (see EN50238.)’ If the train manufacturer finds an EMC issue in the radiated emission test in this frequency band, it could be due to the emission of one of the pieces of equipment installed on-board. It is always more expensive and less efficient to solve the problems in the late stages of the projects, making it sensible to reduce emissions in the frequency range below 150kHz before testing of the whole vehicle. However, there might be problems when determining the responsibility for this EMC problem, as the on-board equipment supplier will protest that its equipment fulfils the requirements of the standard EN 50121-3-2 and therefore it is trains manufacturers responsibility, which will delay the solution of the problem.

Additionally, it is said in note 2 of the table 6 that “The traction converters and auxiliary converters over 50 kV need not be tested individually but when the vehicle is tested as a whole in accordance with EN 50121-3-1”. The problem with this is that this type of equipment is deemed to be the main source of radiated emissions from the complete vehicle. Again, it will be more expensive and less efficient to solve the problems in the late stages of the projects, so this needs to be tackled early on in the design process.

One of the objectives of the standard EN 50121-3-1 is to separate the effects of the infrastructure when testing the new vehicles. Therefore, the test campaign for the on-board equipment is the best chance to define repeatable conditions and eliminate any effect of the infrastructure. This is why there must not be exceptions to the tests to be performed according to the standard EN 50121-3-2, as this is the best scenario to ensure repeatability and independency from other external factors.

5.2 Immunity

There is no immunity requirement stated for rolling stock in the frequency range below 150kHz. This is a surprising anomaly given that a train unit would normally be expected to be able to deal with high magnetic fields in this frequency range. In addition, there are actually no emission limits below 150kHz. At the very least, some regulation should at least be provided in the way of immunity at these frequencies to ensure EMC, even if it is currently difficult in many cases to measure/limit emissions at these frequencies. Particular attention should be paid to sensitive areas such as 50Hz and 16 2/3 Hz as well as other frequencies of relevance to traction motors.

It is noted that most equipment on board the train will fall within the 3m zone as considered in EN50121-4:2006. As such, special consideration may be appropriate through application of the relevant magnetic immunity tests given in sections 1.3 and 1.5 of Table 1 in EN50121-4:2006. This may give a base for which limits can be obtained.
5.3 On board Spot Signalling Systems

With regards to the on-board spot signalling system, EN50121-4 would seem to be the standard to follow, as it is the most applicable to signalling and telecommunication (S&T) apparatus installed in the railway environment. As the S&T equipment is physically on-board, however, it has to fulfil the EN50121-3-2 standard and as such should be tested to that.

This means that the main standard and testing procedure for on-board spot signalling systems is contained in the EN50121-3-2 document. The application of tests shall depend on the particular apparatus, its configuration, its ports, its technology and its operating conditions. If a port is intended to transmit or receive for the purpose of radio communication, then the emission and immunity limits in this standard at the communication frequency do not apply, i.e. the in-band frequencies. The disturbances radiated to the whole system that are sufficient to distort the receive communication path of the spot signalling system are the RF electromagnetic fields defined in table 9 of [5], in page 15. Following the generic EMC EN61000-4-3 standard (Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test), an 80% AM (1KHz) signal from 80MHz to 1000MHz is radiated with an effective value of 20V/m. It should be pointed out that no frequencies below 80MHz are considered for this test.

In the Annex B of EN50121-3-1, conducted interference generated by power converters are analysed from 9KHz to 30MHz. This informative annex doesn’t apply for the spot signalling system and the spot signalling system is not considered. Unfortunately, as seen in some of the EMC cases gathered in the deliverable D2.1 of this project, the positioning of the antenna on the train body close to the motor cables could cause interference. Therefore the antenna positioning for the spot signalling system should also be taken into consideration with regard to this frequency range (which, moreover, contains the working frequency of the Eurobalise on-board transmission equipment signalling system). This may require an additional section in the apparatus immunity section of EN50121-3-2.

Another conclusion of the analysis of the current approval test norms is that the transients are not taken into consideration. Not in the EN50121-3-2 neither in the EN50121-3-1, in which the complete vehicle is considered as a whole.

First, the transient signal captured during the rolling stock EMC approval tests defined in this document are hidden by the max-hold function of the capturing during the train passing. And secondly, subsection 6.1 explains that the requirements for the compatibility of the rolling stock with the signalling and communication systems should take into account other kinds of interferences, such as transients due to discontinuities, etc. But, unfortunately, no limits, neither test procedure is defined for these interferences.

6.1 **EN50121-4: 2006**

This standard concerns the emission and immunity levels for signalling and telecommunications (S&T) apparatus within the railway environment, as defined in EN50121-1:2006. The intention and purpose of the standard is that S&T apparatus compliant with the standard will be conferred with a presumption of conformity to the essential requirements of the EMC Directive 2004/108/EC. This intention and purpose is made clear by the fact that both EN50121-4:2006 and EN50121-1:2006 are listed in the Official Journal of the European Union (OJEU). The EMC Directive states that any apparatus compliant with an OJEU listed standard is conferred with a presumption of conformity to the essential requirements of the EMC Directive, when that apparatus is installed in its intended environment. Another aspect of this Part 4 is that it is often used as the standard to test the trackside equipment not covered in the other parts that are not designated as signalling or telecommunications, such as equipment installed on the platform. Examples of pieces of equipment that are tested in this way are ticket machines, station lifts and other trackside electronic apparatus such as axle counters. In order to allow testing this equipment, specific limits have to be incorporated into the 50121 standard, in an added section. It would be helpful to have these limits within the 50121 standard, even though this equipment has passed industrial standards, to avoid unnecessary gap analysis.

Drawbacks and limitations to the EN50121-4: 2006 [6] standard are summarised in Sections 6.2 (emissions) and 6.3 (immunity).

6.2 **Emissions**

EN50121-4:2006 states ‘Apparatus which complies with the emission levels of EN61000-6-4 will meet the emission requirements of this standard providing that emissions from any DC power port are within the emissions limits for AC power ports.’ (It is noted that EN61000-6–4 is the generic industrial emissions standard, currently listed in the OJEU as EN61000-6-4:2007+A1:2011). In other words, it is recognised that the nature of the railway environment is that it is electromagnetically harsh. Apparatus conforming with the generic industrial emissions standard is therefore likely to provide levels of emissions which are somewhat below those expected in the railway environment, and therefore apparatus compliant with EN61000-6-4 can be presumed to be benign in the railway environment.

Unfortunately, the nature of most signalling systems (in the UK at least) is that their associated track circuitry operates at relatively low frequencies (less than 10kHz), which are outside the range of emission frequencies considered by EN61000-6-4 (the latter standard does not concern itself with emission frequencies below 150kHz). Although EN50121-2:2006 does require magnetic field measurements to be made from the railway as a whole down to a frequency of 9kHz, many common track circuits use frequencies that are even lower than this.

There is therefore a significant region of the frequency spectrum up to 150kHz which is highly relevant to signalling and telecommunications apparatus, and for which there is no regulation on emissions within EN50121-4:2006. Note that this spectrum of frequencies also encompasses base band audio frequency telecommunications, including base band voice transmissions on telephone lines. Significant audio frequency (psophometric) noise emitted by rolling stock and its apparatus has the potential to render voice communications unintelligible.

This oversight in the EN50121-4:2006 standard is merely reinforced by the statement ‘No measurements need to be performed at frequencies where no requirement is specified.’ In view of the preceding paragraphs, this statement is clearly reinforcing the poor practice of ignoring
the potential interference of S&T apparatus to other existing S&T apparatus, the very type of apparatus for which the standard was written.

With regard to intentionally radiating apparatus in the railway environment (e.g. a transponder system), EN50121-4:2006 states ‘the emission and immunity limits in this standard at the communication frequency do not apply.’ This statement does not take cognisance of the fact that an intentional transmitter sited too closely to other S&T or other generic industrial apparatus may cause interference if the impinging level of irradiation is above that to which the victim apparatus has been tested. It would be prudent to address this problem with a supplementary statement in the standard regarding the necessity to maintain an adequate protection distance from other victim apparatus, according to the immunity level of the victim apparatus at the transmission frequency. This could be easily done through reference to Annex E of EN61000-4-3:2006, where an explicit method is provided to establish an appropriate protection distance.

6.3 Immunity

EN50121-4:2006 states ‘The immunity levels of EN61000-6-2 will also be adequate except for the special case of apparatus as defined in note 1 of Table 1.’ Note 1 appears beside a number of immunity tests indicated in Table 1, and states ‘The tests given apply to apparatus inside [sic] 3m - zone and vital equipment such as interlocking or command and control which are mounted in areas where a high risk of interference from mobile radio telephones has been identified.’ This form of wording concurs with the zoning scheme adopted by a number of UK railway projects (e.g. Crossrail, Thameslink Programme), whereby the first 3m from the centre line of an electrified railway are considered to be particularly electromagnetically harsh. At distances beyond 3m, the level of immunity required for apparatus is identical to that of the generic industrial immunity standard EN61000-6-2:2005. EN50121-4:2006 makes special provision for safety critical apparatus through application of additional radiated immunity tests at VHF frequencies between 800MHz and 2.5GHz, encompassing hand held mobile phone frequencies. The immunity levels required by EN50121-4:2006 in this frequency range are more stringent than those required by the generic industrial standard EN61000-6-2, resulting in a gap analysis being required.

Section 6.2 of EN50121-4:2006 states that ‘voltages induced by traction currents are not treated here. They have to be covered by the functional specification.’ It may be prudent to pre-empt mitigation against EMC problems for S&T apparatus connected to significant lengths of metallic cabling running parallel to electrified rails, by requiring conducted immunity testing in the frequency range 0-150kHz as covered in EN61000-4-16. For example, there is already such a requirement in London Underground standard G-222, Manual of EMC best practice.

It is noted that radiated immunity at 4G mobile phone frequencies (2.6GHz band) are not considered by EN50121-4:2006. The standard only requires testing up to 2.5GHz.
7. **EN 50121 –5: 2006**

This standard concerns the emission and immunity requirements for fixed power supply installations and apparatus within the railway environment, as defined in EN50121-1: 2006. The intention and purpose of the standard is that power supply installations and apparatus compliant with the standard will be conferred with a presumption of conformity to the essential requirements of the EMC Directive 2004/108/EC. Drawbacks and limitations to the EN50121-5: 2006 [7] standard are summarised in Sections 7.1 (emissions) and 7.2 (immunity).

### 7.1 Emissions

Regarding emissions from the substation to the outside world (section 5.1), there is a significant region of the frequency spectrum up to 9kHz which is highly relevant to signalling and telecommunications apparatus, and for which there is no regulation on emissions within EN50121-5:2006. Note that this spectrum of frequencies also encompasses base band audio frequency telecommunications, including base band voice transmissions on telephone lines. There should be a requirement during testing to measure the magnetic emissions below 9kHz (e.g. down to 5Hz) and d.c. track circuits (which are present in some counties like Sweden), even if no explicit limits for these emissions are given. This will assist in the necessary studies to be performed which aim to establish that EMC will exist between local signalling systems and the substation. The measurements will also assist in any necessary psophometric noise studies to establish that induced psophometric noise into telephone wires will be below the ITU-T recommended level of 1mV_p. It is worth noting that most psophometric noise will be excited by the rolling stock with negligible noise from the substation.

Regarding intentional radio transmitters, EN50121-5: 2006 states 'the limits in this standard do not apply to intentional communication signals'. This statement does not take cognisance of the fact that an intentional transmitter sited too closely to power supply or other apparatus may cause interference if the impinging level of irradiation is above that to which the victim apparatus has been designed for and tested to. It would be prudent to address this problem with a supplementary statement in the standard regarding the necessity to maintain an adequate protection distance from other victim apparatus, according to the immunity level of the victim apparatus at the transmission frequency. This could be easily done through reference to Annex E of EN61000-4-3: 2006, where an explicit method is provided to establish an appropriate protection distance. Emissions from substations are also within the scope of EN50121-2: 2006 using a measurement distance of 10m.

### 7.2 Immunity

Section 6 of EN50121-5: 2006 states that 'voltages induced by traction currents are not treated here. They have to be covered by the functional specification. It may be prudent to pre-empt mitigation against EMC problems for power supply related apparatus connected to significant lengths of metallic cabling running parallel to electrified rails, by requiring conducted immunity testing in the frequency range 0-150kHz as covered in EN61000-4-16. For example, there is already such a requirement in London Underground standard G-222, Manual of EMC best practice.

It is noted that radiated immunity at 4G mobile phone frequencies (2.6GHz band) are not considered by EN50121-5:2006, as the standard only requires testing up to 2.5GHz.
8. ON-SITE TESTING

On-site testing is carried out to Part 2 (Emissions of the Whole Railway System to the Outside World) and Part 3.1 (Rolling Stock – Train and Complete Vehicle). Testing to Part 3.2 is carried out in a laboratory. The on-site testing is usually performed:

- to verify that the EMC Management plan for a system has been adhered to, and that EMC has been achieved between the whole railway and the outside world
- in the case of pt 3-1, rolling stock meets the prescribed emission limits in order to meet:
  - interoperability requirements,
  - safety requirements or
  - CE marking requirements under the EMC Directive

This is needed in order for the rolling stock to be used on the railway system.

The following points are taken from first hand experience from real on site test measurement sessions.

The 10m antenna distance is rarely practicable due to constraints on the test site, resulting in reliance on normalising measurements to 10m as quoted in Part 2. Normally measurements have to be taken at 3m. The far field approximation becomes unreasonable at lower frequencies for larger sized emitters at this distance. The statement that both sides of the train do not need to be independently tested is often adhered to, not because it is stated in the standard, but because it is not possible for various reasons (including health and safety) to test both sides of the track. This may be important: because for a pantograph OHLE railway the symmetrical aspect is valid, for a third rail arrangement with the contact off centre, it is not. Some of the requirements in the standard have to be ignored; an example is the requirement that other locomotives are at least 20km away. This is normally unrealistic while testing on a real railway unless operating under a track possession with a requirement that all vehicles within a prescribed area have their pantographs down, often only possible during a nighttime possession.

The substation testing procedure is noted as being particularly long winded, especially if the substation is large, necessitating a measurement from each side and from each corner. Again this can be limited by the available space around the substation, which is often less than 10m. It can take up to three days to effectively test a large substation.

Often the customer will ask for more tests than are present in the standard. The most requested extra test is to perform emissions measurements at over the stated 1GHz limit. This is usually carried out to 3GHz in order to encompass the current spectrum usage.

Immunity measurements on the actual train may prove too challenging to include in a measurement campaign or test method, as the normal way of testing immunity is not immediately obvious (no ports to induce transients on, ESD to train body does not make sense etc). Immunity is conferred on rolling stock by meeting EN50121-3-2: 2006 and by maintaining the integrity of the immunity of the individual on-board systems by installing using ‘best practice’. Whole vehicle immunity testing is not possible without access to an extremely large anechoic chamber (e.g. the BAE systems chamber at Warton used for Eurofighter/Typhoon aircraft) with rail access (and including a dynamometer), otherwise radiated immunity testing would extensively disrupt broadcast services and the test set-up would represent an illegal generator. On-board immunity testing can be devised, for example to test second-hand rail grinders imported for use on Network Rail, but must be used with caution. Deserving of a mention is the particularly harsh environment encountered on the roof of a train, particularly on an OHLE
railway. Different immunity limits need to be applied for any equipment that is to be situated in this area.

For the substation tests in EN50121-2, the test method stated in clauses a) to e) in Annex A in EN50121-2 can be refined. The procedure involves finding the frequency of the maximum emission in the range 0.12MHz to 2MHz and treating the quasi-peak measurement as the “maximum radio emission at a frequency in the neighbourhood of 1MHz” required by the standard. A similar routine can be carried out for the “maximum radio emission at a frequency in the neighbourhood of 350MHz” with the frequency band of 300MHz to 400MHz.

In the case of 9kHz to 150kHz one minute of measurements are taken with a peak detector then compared to the limit line. Any emissions above the line are then treated with a quasi peak measurement after discarding bona fide radio transmissions. This is repeated for 150MHz to 30MHz, 30MHz to 300MHz and 300MHz to 1GHz. This procedure is more detailed than that given in the standard, and results in a more representative emission profile for substations.
9. EN 50122-1: RAILWAY APPLICATIONS – FIXED INSTALLATIONS. PART 1: PROTECTIVE PROVISIONS RELATING TO ELECTRICAL SAFETY AND EARTHING

In this section the drawbacks, missing information and some improvements to the EN 50122 [8] standard are detailed.

9.1 Scope

This standard is primarily involved with the provisions relating to electrical safety with respect to people rather than electronic equipment. The EN 50124:2005 standard is involved with clearances and creep age distances for electrical and electronic equipment.

In the title it is specified that the scope is safety and earthing, however, when reading the document, the scope is only focused on the safety of people, and is not concerned with the earthing and protection of the equipment. This can cause malfunctions of the different apparatus that can be really sensitive to EMI, even when it is of no harm to people.

9.2 Ground currents

In Annex C of EN 50122-1, a test for the voltage can be found for the case of having a double track section (see Figure 3). This Annex is only informative, not normative.

![Figure 3: Potential decrease test for double track sections and average soil earthing resistance.][9]

This kind of test would prevent having transients that could provoke a malfunction on the equipment dependent on the surroundings.

EN 50122-1 only references the double track section scenario, but no reference is made to other scenarios, for example single track. The most common situation in Sweden. The most suitable change to this standard would be to change the Annex to normative in order to help reduce transients by ground currents due to lack of isolation, and take into account all the scenarios possible when performing the tests.

Another point to mention is that there are not maximum limits for ground current return specified, which should be present in order to help diagnose malfunctions with the earthing that can trigger failures on the equipment, or even cause safety issues.
10. **EN 50215: RAILWAY APPLICATIONS – TEXT OF ROLLING STOCK ON COMPLETION OF CONSTRUCTION AND BEFORE ENTRY INTO SERVICE**

In this generalist standard, 2 sections are directly related to the electromagnetic compatibility and the issues with the signaling systems: 9.15 and 9.16. These are the points that are going to be shortly presented and analyzed in that section of the document.

### 10.1 Scope related to EMC

9.15 section presents 5 points on electromagnetic compatibility (type tests only). Each of those points is addressed to the specific standard that has to be fulfilled, but some comments could be proposed from the TREND project point of view.

The first subsection states that to verify that all equipment functions correctly after installation, without interference effects, these equipments should have passed the EN 50121-3-2 standard with a sufficient margin between the electromagnetic emissions and their immunity levels. This margin is not specified and no measurement of the radiated emissions has been done inside the vehicle.

The second and the third subsections explain that the external interferences produced by the vehicle including the radio frequency interferences (both safety related) have to follow the EN 50121-3-1 standards, as expected. The forth and the fifth subsections deal with external interferences to the vehicle and a voluntary test of electrostatic discharge. Both points address the standard EN50 121-3-2 to prove the immunity of the complete vehicle, and in that case, again, problems may arise due to the fact that no tests are performed inside the vehicle.

### 10.2 Supply issues and transients

The objective of section 9.16 is to verify that voltage changes in the external supply do not adversely affect the performance of the vehicle. That is studied from the perspective of the traction system of the train (EN 61377-1, -2 and -3) but, in addition, where applicable, the coordination of protective systems between the traction vehicle and the power supply infrastructure shall be checked in accordance with EN 50388.

The 4 subsections of this 9.16 section specify the test to be applied to the train to comply with:

- Voltage jumps based on EN 50163;
- Interruptions with total time of interruptions from disconnection to reconnection of 10ms to 10s;
- Voltage variations from a full range operation point of view;
- Short circuits with an unlimited time;

None of these supply issues is taking into consideration the transients that affect the signaling systems tackled by this project (in magnitude, frequency and time duration). Therefore, here again, special measuring methods should be proposed and tested for future EMC standards.
11. **EN 50238: RAILWAY APPLICATIONS – COMPATIBILITY BETWEEN ROLLING STOCK AND TRAIN DETECTION SYSTEMS**

In this section the drawbacks, missing information and some improvements to the EN 50238 [9] standard are detailed. Further information will also be provided in section 15, where the EMC issues related to track circuits are linked to the drawbacks of the current approval tests.

### 11.1 Scope

EN 50238 is missing a reference to all the apparatus or equipment that are not directly involved with train detection – equipment of this nature would come under 50121-4 - and there is also no reference to specific differences in power supply systems in the section titled “Characteristics of traction power supplies” An example of a piece of equipment that would not be covered by this is a rail-switch detector.

There is some railway equipment (like detectors and other electronic apparatus) that have the same specifications as the train detection systems, therefore it may be appropriate to mention them in the scope of the different standards regarding train detection systems.

There is some electronic equipment based line-side, like the rail switches detectors that work on DC. This apparatus can be influenced by the low frequency emissions from the rolling stock, signalling systems, etc. and that should be checked. This apparatus should also have passed the immunity requirements from 50121-4.

### 11.2 Neutral sections

The influence of the neutral sections is treated on the document EN 50388, but only for the relation between the rolling stock and the power supply installations. This can influence on the electronic equipment that are installed on the surroundings of the track.

Annex A of the document EN 50238 shows the different scenarios used to determine the susceptibility of train detection systems. Transitions between neutral and powered sections should be described in this section as well as here in EN 50388.

A way to avoid influences on signalling equipment located on the surroundings of neutral sections could be to test not only the behaviour of the train in the neutral section, but also the transition between both sections, studying the peaks that are produced when the train enters and exits on a neutral section and the influences of these maximum peaks on the electronic equipment on the surroundings.

In this section the drawbacks, missing information and some improvements to the EN 50388 [10] standard are detailed.

### 12.1 Application procedure

In the standard EN 50388 there is a diagram describing the process to follow when introducing a new element on the railway network. It is also described the acceptance procedure, compatibility study, tests and tests methodology.

This can be more suitable to be included on the standard EN 50121-1 instead or as well as in the EN 50388, as a standard procedure to follow in case on introducing new electronic equipment on the infrastructure network. This diagram is shown in Figure 2, and it is also present in 50238.

### 12.2 Neutral sections

The document EN 50388 specifies that a train should bring the power consumption to zero when entering the phase separation section (paragraph 5.1; EN 50388). When entering to the powered section again a peak on the voltage can be produced. That can produce electromagnetic emissions that not only will influence the power supply installations but also any other electronic equipment (signalling, telecommunication, detectors, etc.).

A way to avoid influences on signalling equipment located on the surroundings of neutral sections could be to test not only the behaviour of the train in the neutral section, but also the transition between both sections, studying the peaks that are produced when the train enters and exits on a neutral section and the influences of these maximum peaks on the electronic equipment on the surroundings.

Annex A of the document EN 50238 shows the different scenarios used to determine the susceptibility of train detection systems. Transitions between neutral and powered sections should be described in this section as well as here in EN 50388.
13. SAFETY

13.1 Induced Potential (Touch Voltages)

Potential difference can be induced onto un-sheathed or un-shielded cables (either signalling or other cables) co-located with the HV cables. The level of induced currents on these HV cables can range from few tens of Amps to hundreds of Amps under normal running condition. This magnitude is increased several orders when there is a fault short-circuit current flowing in (for a brief period before the circuit is tripped).

This is the reason why large companies such as Network Rail and London Underground in UK specifies induced voltage limits under normal-running and short-circuit fault conditions. For Network Rail, under normal running condition, the limit is specified as 60V dc RMS. For London Underground, under normal running condition, the normal limit is specified as 25V dc RMS \[11\] whereas for a short-circuit condition, the LU limit is 430V dc RMS. The limit for London Underground is particularly stringent compared to Network Rail due to the fact that London Underground trains operate in a very limited physical space; the electronic/electrical equipment used are much closer to each other, thus increasing the likelihood of electromagnetic interaction between them.

The limits are applied to try and reduce the potential on cables that may be assumed to not have high voltage on them (for example, signal cables) that may be touched by personnel. A situation where this could arise would be a contractor repairing a trackside unit when an unexpected voltage could be induced on the cables or the shields causing a safety hazard. As the coupling into the co-located cables is an EMC issue, some aspects of safety should be included into the EMC railway standards, even if it is just to point users in the direction of the relevant safety standard. These limits are currently absent in the railway-specific EMC standards such as EN50121 series. In the UK such issues are dealt with during the Hazard identification process and subsequent hazard mitigation exercise.

13.2 Human Exposure to EMF

Personnel on a railway environment are exposed to varying degree of electromagnetic fields (EMF). This exposure to EMF could have a serious effect on human health. These electromagnetic fields decay rapidly with distance and the resulting effects tend to be localised, however work carried out trackside is often, by definition, close to the track.

Nevertheless, it is necessary to calculate the separation from these EMF sources so that personnel, especially those working on a railway particularly close to these field sources are safe from any EMF hazards. The delayed EMF Directive (2004/40/EC), due to be implemented or revised by April 2012, will require employers to ensure workplaces met the ICNIRP 1998 occupational limits of 400 Am\(^{-1}\). Workplaces open to the general public (such as stations) must meet the general public limits of 80Am\(^{-1}\). Some companies have their own specific EMF criteria, and test to limits within the carriage of the train. This is an addition that is recommended to add to the EN 50121 set. Work done by the Lloyds register details the potential exposure on various railway systems in the UK, noting that there are some situations where the safe limits set by 2004/40/EC can be exceeded. The railway EMF standard EN50500: 2008 “Measurement procedures of magnetic field levels generated by electronic and electrical apparatus in the railway environment with respect to human exposure” states that tests should be done between DC and 20kHz “because no relevant field strengths are expected above due to the physical nature of EMF-sources in the railway environment”..
14. SPOT SIGNALLING SYSTEM

The deliverable D2.1 (D2.1 – Collection of experiences and establishment of qualitative relationships) of this project summarizes the interferences of each electromagnetic threat in each communication signal. Specifically for the spot communication system, these were the conclusions:

A. Radiation in the 9KHz to 30MHz frequency band
B. Inappropriate antenna positioning
C. Transients due to pantograph arcing or slicing pickup shoe and breaker operation
D. Transients due to return current discontinuities
E. Reflections due to debris
F. CB networks affecting the 27MHz frequency band of the BTM
G. Harmonics of 13.5MHz at manufacturing plants adjacent to the railway

The assessment of each of these points is performed in relationship with the standards related in each case, and just presented in the early section of this document

A. As previously said, only the frequencies above 80MHz have been taken into consideration in the EN50121-3-2 approval test document. This point should be revised as the real electromagnetic environment for the spot signalling systems contains noise and interferences below 80MHz, and more specifically, from 9KHz to 30MHz, which is its band of interest of most of the known spot signalling systems.

B. Closely related to the previous point, the antenna positioning should be considered as a design / integration / validation parameter for the signalling system that uses it. The coupling mechanism and the parameters implied were presented in the case studies in D2.1. And, from the current approval tests and standards, obviously, no specific rules can be stated for the positioning of the antenna. Each design has to tackle the problem internally, but electromagnetic noise simulations could be applied for a correct positioning of this element in its environment, and at least provide some generic directives on that subject.

C. The transients (the voltage peaks with very high amplitude levels and very short time duration that affect a broadband spectrum, as seen in the case studies in D2.1) are an issue that are not considered by the current approval test documents. The transient effects are real and recognized by the documents, but no tests are focused on them and no standard proposes a normalization of its shape. Moreover, the test setup defined for the current approval tests, e.g. EN 50121-3-1, tries to minimize the effects of the transients by placing the radiated emissions measurement set-up in zones free from potential arcing (no sliding zones, far away from the substations, etc.). This is a drawback that should be amended in the revisions of the current approval standards.

D. A similar point to C. As mentioned, Annex B of 50121-3-2 considering transients would help for that problem. The conducted emissions are also a problems for the spot
signalling systems as the radiation from the track affect the very close receiving antenna of this communication system.

E. This point is absolutely dependent on the application and is ruled by the subset of the specific signalling system. For the Eurobalise on-board transmission equipment case, for example, the subset 036 defines all the functions and requirements for its design and the subset 085 sets the applicable eurobalise test procedure. Also defined, among other configurations, are the debris conditions that have to be tested.

F. and G. These two points are closely related because they define the interferences that affect the telepowering signal of the spot signalling system. These are design dependant and in the case of the Eurobalise on-board transmission equipment signalling system, the In-band Susceptibility (subsection 6.7.4, page 140 of Subset036) sets that no harmonized standards exist, meaning each supplier should prove the functionality of their balise system. The exact extract of the in-band susceptibility subsection of the FFFIS for eurobalise is given here and the main ideas that reinforce the thesis of this standard assessment are highlighted. Also the idea of the analysis of the worst case condition, proposed as a main objective of TREND, is here named:

### 6.7.4 In-band Susceptibility

The Eurobalise On-board Transmission Equipment shall be able to operate compliantly with this Norm, when being exposed to the radiated noise of transient burst nature that is typically present in the air-gap during the normal train operation, due to emission from electrical traction drives, cables, and engines.

Shape of such noise bursts, time duration, and frequency distribution are among the most prominent features affecting the susceptibility characteristics of the On-board Transmission Equipment. They are strongly dependent on the type of electrification and of the electrical/electronic devices in actual use.

The noise level in the air-gap zone is generally dependent on the geometry and the position of the possible noise sources (radiating cables, reflecting surfaces, etc.), with respect to the position chosen for the Antenna Unit installation.

No harmonised standards exist to date on this kind of susceptibility issue. Therefore, each supplier of On-board Transmission Equipment shall responsibly define suitable models representing worst case susceptibility conditions and modes (with reference to the recalled ones) that may be possible within the range of application cases of his commercial interest. The definition of the noise environment and the suitability of the elaborated models are a matter of shared responsibility between suppliers of On-board Transmission Equipment, rolling stock devices, and infrastructure devices. Specific compatibility cases may be needed (to be decided on a case by case basis).

The supplier of the On-board Transmission Equipment shall then coherently prove the fulfillment of the functionality and the availability requirements for the On-board Equipment, as defined in this Norm, by adequate simulation of such worst case susceptibility conditions and modes during functional Laboratory Tests.

Paradoxically, the Subset 085- Test specification for Eurobalise FFFIS doesn’t define any electromagnetic characteristic for the test procedure on this signalling system. Moreover, in the introduction of the test of the up-link balise (section 4, page 21), the first table shows the generic conditions that should be applied for the majority of the tests. Note that the last line sets that the EMC noise is negligible.
Consequently, both the FFFIS and its Test specification show that the harmonization duties that were the objective of the SST.2011-25.1 are really needed for this signalling system and should be included as an EMC standard. The objectives proposed by TREND project should close that gap.

Another point that has not yet been considered in the previous list of interferences is the possible resonances of the lines. That effect, dependant on particular characteristics of the infrastructure and the rolling stock, can also be considered a transient effect. Physically, resonances with the feeder line inductance L and capacitance C between feeder line and earth can provoke the harmonic currents (and inevitably the same current on the return circuit) amplification up to 10 times as large as the original [12]. If this resonance occurs for the transient interference frequency, the threat is much higher than expected. This point should be studied and included in the model of WP4.

<table>
<thead>
<tr>
<th>Ambient temperature</th>
<th>25 °C ± 10 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative humidity</td>
<td>25 % to 75 %</td>
</tr>
<tr>
<td>Atmospheric Pressure</td>
<td>86 kPa to 106 kPa</td>
</tr>
<tr>
<td>Debris in the air-gap</td>
<td>None</td>
</tr>
<tr>
<td>Tele-powering mode</td>
<td>CW</td>
</tr>
<tr>
<td>EMC noise within the Up-link frequency band</td>
<td>Negligible</td>
</tr>
</tbody>
</table>
15. TRACK CIRCUITS

The deliverable D2.1 (D2.1 – Collection of experiences and establishment of qualitative relationships) of this project summarizes the interferences of each electromagnetic threat in each communication signal. Specifically for the track circuit, these were the conclusions:

A. Conducted from 20Hz to 20kHz
B. Radiation in 9kHz to 30MHz frequency band
C. Transients due to pantograph arcing or sliding pickup shoe and breaker operations
D. Transients due to locomotives starting at stations
E. Continuous high frequency return currents generated by power systems on-board the rolling stock itself or another in the same section
F. Uncontrolled ground currents due to poor design of power supply return paths or poor maintenance

The analysis of the study cases has found that they were caused not by mistakes on the current standards but by drawbacks and missing facts on them. Therefore it has been analysed from the point of view of the different standards since most of the facts not considered are quite general.

The proposed measures to add on each standard (or modify the current information related) can be summarized as described on the following paragraphs from each standard listed previously on this document:

A. And B.- The frequency limits for EN 50121-2:2006 are set between 9kHz and 1GHz. Apparatus limits go up to 2.5GHz. The standard mentions that sensitive frequencies should be tested, but if these are below 9kHz or over 1GHz then there is no measurement or test method neither given nor inferred. These limits can leave testers in the dark when it comes to testing outside the frequencies, an issue of increasing size as, for example, onboard WIFI among other potentially high emitters working at frequencies in excess of 1GHz. Dependent on equipment being used on-board rolling stock or identified victims in the external environment, testing for emitted frequencies outside of the range specified may be required. However, the standard provides no information on how this might be carried out. In practice, measurements have been conducted to EN 50121-2:2006 with the frequency range extended up to 6GHz using suitable receivers and horn antennas. Therefore, given the frequency limits, suitable measuring methods should be proposed.

The substation emissions are well defined, but there is no mention of the environment in which the substation or the other fixed installations are present, for example trackside or in another particularly harsh EM environment. These limits are applied to “other fixed installations” but no mention of what sort of fixed installation (trackside box, signalling unit or substation) or reference to EN 50121-5:2006 which deals specifically with these power systems. As EN 50121-5:2006 will need to be adhered to in the case of a substation or other fixed installation being present, perhaps just a reference to EN 50121-5:2006 is needed rather than stating the same limits in the two different areas. Nor is there any mention of conducted emissions from substations or directly from trains.

EN 50121-2 can inform on the test that can be performed in order to validate that conducted emissions do not affect the normal behaviour of the systems. The document is focused on the radiated emissions but there is no mention of the possible conducted emissions that can occur and provoke a failure or malfunction of
the different elements on the railway network. Conducted emissions should be tested, especially on the wiring of the different signalling systems onboard and wayside.

C. And D. - Rare voltage peaks, with levels much higher than the average signal amplitudes, do occur in railway systems. Long cables can act as antennas and receive electromagnetic pulses from various sources. Thorough shielding and grounding can minimize the impact or damage done by transient voltage peaks, but transients can still cause interruptions to services, black out video screens, give false alarms for hot bearings etc.

Transients of high magnitudes have been reported, having very long time intervals. Transients may occur once an hour, once a week and in some cases once a month. Therefore special measuring methods should be proposed and tested for future EMC standards.

The location has to be close to the track where the particular antenna shall be placed and also have the right environment to make sure that the levels are correct for the measuring process. The measuring time during a train passage with the antennas 10 from the track is very short. Each passage can only give values for one geographical location and one driving condition. Therefore testing with the antennas by the track is very expensive if many different locations or driving conditions are to be measured.

To make the testing cheaper, and to provide long measuring times, under varying driving conditions and in varying surroundings, it is recommended that EMC standards for trains should be based on using antennas located on the trains, as an alternative to antennas by the track.

E. And F. - Ground currents are caused by transients on the surrounding of the track, affecting the equipment situated on the surroundings. On the Annex C of the document EN 50122-1 a test for the voltage can be found for the case of having a double track section (see Figure 3). This Annex is only informative, not normative. This kind of test would prevent having transients that could provoke malfunction on the equipment on the surroundings. In the document only is made a reference to the double track section scenario, but no to the other scenarios, like the most common single track. The most suitable would be to change the annex to normative in order to avoid transients by ground currents due to lack of isolation, and take in account all the scenarios possible for performing the tests. Another point to mention is that there are not maximum values mentioned, which should be really suitable in order to diagnose malfunction on the earthing that can trigger failures on the equipments or even safety issues.

The surroundings of the neutral sections have been reporting some problems. A way to avoid influences on signalling equipment located on the surroundings of neutral sections could be to test not only the behaviour of the train in the neutral section, but also the transition between both sections, studying the peaks that are produced when the train enters and exits on a neutral section and the influences of these maximum peaks on the electronic equipment on the surroundings. Annex A of the document EN 50238 shows the different scenarios used to determine the susceptibility of train detection systems. Transitions between neutral and powered sections should be described in this section as well as here in EN 50388.
16. BROADCASTING SERVICES

16.1 Electromagnetic influences on the broadcasting services

The deliverable D2.1 (D2.1 – Collection of experiences and establishment of qualitative relationships) of this project summarizes the interferences of each electromagnetic threat in each communication signal. Specifically for the Broadcasting Services, these were the conclusions:

A: Radiation in the 30MHz to 530MHz frequency band and the 900MHz and 1.8GHz GSM spectrums
B: Transients due to pantograph arcing or sliding pickup shoe and breaker operations
C: Electrification cables too close to public facilities
D: Transients due to electrical discontinuity of the track
E: Return paths too close to public facilities
F: Uncontrolled ground currents from power infrastructure due to poor design of power supply paths or poor maintenance
G: GSM services allocated in adjacent channels to GSM-R services
H: Overpopulation of GSM handheld equipment in stations & on board
I: BTM 27MHz tone affects CB radios
J: Uncontrolled ground currents from S&T apparatus

Analysis of the case studies has found some gaps in the standards that, if plugged, would reduce or help eliminate some of the points mentioned above.

A: As the broadcasting services predominantly operates in these frequency areas, the current EN50121-2 document tries to deal with the emissions from the whole system that may effect broadcasting services. The radiation in these frequency bands needs to be reduced in order to provide uninterrupted services; this may be implemented by the addition of a lower limit line. A new measurement arrangement may be needed in order to help protect radio services by using a quasi-peak measurement.

B: The transients due to pantograph arcs and other associated sources cannot be reduced without a great amount of effort and cost, so what needs to be done here is to help categorise the transient emissions (particularly for the broadcasting services, radiated transients) in order to make equipment more immune to transients. This needs to be fed into the relevant standard. Measurement techniques currently outlined actively avoid areas where there may be transient emissions from both the track circuits and power systems.

C: The limits for equipment for installations distance closer than 3m are not fully detailed, and EMC management and Hazard Identification should be carried out, neither of which are alluded to in the standards. It may be useful to include a prompt to carry out such studies in situations where the environment is particularly harsh or outside the standard testing procedural guidelines.

D: A similar point to B, but should be preventable by correct maintenance and/or operational procedures.

E: A similar point to C.
F: Again, this is an issue to do mainly with keeping the railway in good condition; intelligent design of power supply system and return paths with EMC in mind will greatly help with this point.

G: This becomes an issue when GSM transmitters are placed close to the line-side, when GSM-R is being used. This may not be a job that needs to be addressed in the EMC standards, as it is more to do with spectrum sharing and use. Guidelines for the design and placement of ESM transmitter masts may be useful to include.

H: This issue is not addressed at all in any current or superseded EN standard to do with railways. There would need to be a study of how the radiated field strength is changed by multiple handheld transmitters, both externally to the train and internally. Similar work has been carried out for aeroplanes and is aspects are present in defence standards. The relatively potentially quite high field strength inside the train carriages invites further investigation.

I: In the UK, the 27MHz bandwidth is an unrestricted band, meaning users are able to transmit at any power irrespective of interference to other systems. This means that nothing can be done about this point, as there are no limits on power.

J: A similar point to F.

16.2 Additional points

16.2.1. Frequency range

The frequency ranges stated throughout the EN50121-x: 2006 series of standards are inadequate for the full protection of broadcasting services. The emissions from the whole train include test limits from 9kHz up to 1GHz, which is not high enough to protect more recently used services which can be seen in Figure 4. The immunity limits stated in Part 4, to provide protection to the signalling and telecommunication systems, are present up to 2.5GHz, which is insufficient to encompass the newer 4G networks at 2.6GHz, but sufficient to encompass the lower GSM and radio frequency bands.

16.2.2. Transient and Continuous Emissions

One of the main outcomes from the 2002 report [13] is the conclusion that the limits present in the EN50121-X: 2000 standard are insufficient to ensure compatibility with existing radio services. Most influences are covered, but the limits are deemed to not be sufficient. Since the introduction of the 2006 version of the EN-50121 series of standards, the emission limits stated in part 2 have not changed.

The limits given in the EN50121-2 are derived from trackside measurements of emissions from moving trains and as such are a combination of transient and continuous emissions; the transient emissions (for example, due to pantograph bounce) may be significantly larger in amplitude than the continuous emissions. However, EN50121-2 actually means that rolling stock manufacturers can legitimately allow continuous emissions to emanate from rolling stock up to these limits.

If rolling stock does emit continuously at the appropriate limit then the chance of interference to radio services is greatly increased, as shown in the study [14], where interference was predicted 15km away from a 25kV AC railway, on FM radio services, using the limit from EN50121-2. The rolling stock rarely emits continuously at a level that causes severe interference to broadcasting services, as if that were the case then reported interference cases would be much higher. The fact that reported issues are low suggests that the emissions that interfere with broadcasting services are transient in nature. The problem arises if the rolling stock emits continuously below the limit but high enough to interfere with broadcasting services, which with the current limits is possible.
In an attempt to reduce this problem, the 2006 standard introduced a stationary emissions requirement in order to separate the transient and continuous emissions, as the stationary test allows the use of the quasi-peak measurement system, which is much more useful for measuring disturbance to radio systems. However this does not solve the issue of separating the transient and continuous emissions for the moving train test.

**16.2.3. On board systems, RFID, WIFI and GSM**

On board systems operating in the radio frequency region (such as freight RFID and Wifi) come under the heading of ‘intentional transmitters’ and as such are not required to meet emissions limits set out in EN-50121. However, there is no mention within the EN50121 series of standards of the interference effects when using these systems.

Interference from broadcasting services that affect the railway system (i.e. rolling stock immunity) on board the train is severely lacking in the EN-50121 standard set. There is no provision for protection from mobile phones within the passenger compartment other than the assumption (not stated) that any passenger borne equipment would have passed the relevant emission requirements. On board WIFI is not mentioned at all on the European standards, although in some cases the WIFI frequencies are within an OFCOM (Office of communications) designated unrestricted band, meaning there is no limit on emissions in these bands [13]. However, there is still potential to interfere at these unrestricted frequencies and therefore a need for on-board train immunity testing; this is missing from the current standard. There are immunity limits for mobile telephony with regards to interference to signalling and telecommunication systems (in EN50121-4) but not regarding on-board immunity.

The signalling and telecommunication standard (EN-50121-4) is set up to allow immunity testing at mobile telephony frequencies, however the standard only requires testing up to 2.5GHz, which does not encompass the new 4G mobile networks at 2.6GHz or 802.11a at 5.2 GHz. Emission limits from the railway system as a whole (EN-50121-2) are applied from 9kHz to 1GHz, there being no guidelines on limits above 1GHz and therefore potential for interference onto any system that utilises higher frequencies, such as mobile telephony upper bands, 3G and 4G, and both onboard and station based wireless systems. Throughout the EN50121 series of standards, emission limits are defined for lower top frequencies than for immunity levels, except in the case where immunity limits are not present, for example immunity of the whole train.

**16.2.4. Safety Considerations**

Another aspect relating to broadcasting services is the potential interference to safety and emergency services, many of which use radio frequencies to coordinate and organise responses or operations. There is a clause in the EN50121 –x series that states that “sensitive frequencies must be tested”, however there are not different (lower) limits for these sensitive frequencies. There is no mention of safety in any of the parts of the EN50121.

**16.2.5. Relation to current EMC standards**

As the interference to radio services are purely from radiated emissions from the railway environment, there are no other applicable standards available to reduce the interference, and as such the EN-50121-x series needs to have the capacity to reduce interference. Equally, immunity to potential field strengths present within the carriages is currently not included in any part of EN-50121 for the train unit as a whole. EN50121-3-2 applies immunity limits to the apparatus within the rolling stock, referencing the EN 61000 [14] set of standards. To solve these problems, changes to, or updating of, the EN50121-x: 2006 series of standards currently in use is needed. An example of the radio spectrum frequency allocation that can be found it is shown in the next page [15].
Figure 4: UK Radio Spectrum Frequency allocation Chart [15]
17. **GSM-R**

In the deliverable D2.1, it is mentioned that the quality of the GSM-R reception signal on board the train can be affected by the two main interferences sources:

A. The adjacent channels of the GSM-R down link can be affected by other communication services such public GSM public and UMTS (Universal Mobile Telephone System), which employs frequency bands (E-GSM) adjacent to the GSM-R ones and whose antennas are sometimes fixed on the same poles as those for GSM-R.

B. The interferences produced by the losses of contact between the catenary and the pantograph, which result in arcing.

In consequence, the control of the EM emissions covering the GSM-R down-link frequency band on board the train have to be controlled to ensure good operation of the GSM-R transmissions.

The source in A does not count as emissions produced by the train. The correct cohabitation between GSM-R and other communication systems such as the public GSM and UMTS can be managed by an adapted use of the channels over the territory. This is more relevant to and works as a result of good organisation of the use of frequency spectrum.

Nevertheless, the source in B is purely radiation coming from the railway equipment and has to be managed by the standards dedicated to railway. Regarding B, two aspects have to be considered:

- controlling the interferences received by the GSM-R antennas, which depends also of the position of the antenna, and
- the control of the immunity of the wireless link and of the on-board GSM-R equipment.

B. Control of the emissions produced by the arcing

Due to their proximity to the catenary and the pantograph, the GSM-R antennas can receive electromagnetic (EM) transient disturbances induced by defects in the sliding contact between the pantograph and the catenary. The losses of contact between the catenary and pantograph provoke the occurrence of broad band transient signals which are conducted in the catenary, the pantograph and in the on board supply voltage line. All these elements can radiate EM interferences in the GSM-R band. Due to the coupling between the antenna and these different radiating elements, interferences are received by the GSM-R antenna. Obviously, the interferences received by the antenna depend on its position on the train but they also depend on the characteristics of the radiating elements (catenary, pantograph...) and the operating conditions (speed, right or curvilinear trajectory...). Since the GSM-R will have to ensure the accurate transmission of voice and data (mainly data signalling), which is essential for safe and secure railways, it is necessary to guarantee immunity against the EM disturbances produced by the railway environment.

Currently, the standards EN 50121 indicate the methodologies and the limits to apply, relating to the EM emissions and immunity of railway equipment, vehicles and infrastructure. The noise levels measured at 10 m (specified in EN50121-2) from the tracks do not indicate the EM disturbances that can exist on board the train, affecting the GSM-R reception. However, the knowledge of these on board disturbances is essential to ensure that the GSM-R systems currently being developed operate correctly in the railway EM environment. It is then necessary to improve the standards with a methodology of measurements of the EM interference on-board trains in order to ensure that the interferences received by the antenna do not affect the capability of the system.
In particular, when the EM noise at the regular location of the GSM-R antennas is known, the immunity of these systems to the railway conditions can be tested in a laboratory; reproducing the observed EM noise.

B. Immunity of the GSM-R signal to the interferences produced by the arcing

On the one hand, standardized immunity tests exist for communication equipment, and are described in commonly applied standards such as the ETSI EN 301 489 series [14]. However these standards, which deal with "electromagnetic compatibility (EMC) for radio equipment and services", are not specific to the railway domain. On the other hand, EN 51121-4 mentions the immunity test of the telecommunication equipment for Railway applications.

However, ETSI EN 301 489 series and EN 50121-4 mainly give general descriptions about the way to perform tests and refer to EN 61000-4 which is not fully applicable to the Railway domain, for configurations and methodologies of test on such radio equipment, but they do not define precise criteria to apply in order to guarantee their immunity to the interferences of exposure. Indeed, if functional criteria are well defined, regarding the impact on the integrity of data, the definition of the immunity criteria is not clear. For example, a way to decide if the Equipment Under Test (EUT) has passed the test is to answer simple questions such as: "does the EUT continue to operate as intended during and/or after the exposure to disturbances?" or "was the communications link lost during the test?", much like the categories employed for apparatus testing. The only not-functional parameter (i.e. with a measurable value) they refer to is the Rxqual. The Rxqual is a quality parameter given by the GSM-R mobile which evaluates the received signal quality before the decoding process and expressed in terms of levels from 0 to 7, each value corresponding to a given BER (Bit Error Rate) interval. A high RXQUAL implies a poor received signal quality. Nevertheless, this parameter is measured by the GSM-R mobile, which does not constitute as measuring apparatus. Such method is then not conforming with EMC standards.

Moreover, in the particular case of the GSM-R system, the immunity criteria for data transmissions should be well defined and evaluated to ensure that this system complies with the reliability required by the railway domain and notably defined via Key Performance Indicators (KPI).

Finally, we have to highlight that all the tests defined in EN 61000-4 series are more adapted to test the “electronic” part of the systems and not the impact of the EM disturbances on the wireless transmitted signal. Moreover, among the different EM test signals applied in the EN 61000-4 series, none corresponds to the type of interference (frequency and time characteristics) produced by the sliding contact catenary-pantograph interface.

In conclusion, EN 50121-3-1 should contain a section dedicated to the emissions on board in order to warrant the good operation of the telecommunication and signalling equipment and EN 50121-4 should contain a section dedicated to the immunity of the GSM-R (equipment and wireless link) based on well-defined immunity criteria which complies with the Key Performance Indicators.
18. CONCLUSION

18.1 Drawbacks of EMC Standards

The flexibility of the EN50121-X: 2006 series of standards could be seen as an advantage, as it is easier to obtain the conditions according to the standard for the tests to be done. However, it is not given that new vehicles tested according to EN 50121 will not have EMC problems when introduced onto existing networks. On the other hand, it is currently possible, due to the requirements of this standard that some equipment (or element of the new rolling stock) is over-engineered unnecessarily, in order to fulfil the requirements of the standard.

It may be necessary to define a unique test site, test procedure and limits for the different types of rolling stock and different infrastructure arrangements, taking also into consideration national rules and differences. This would be best served by an overarching standard coupled with more specific country standards, as is currently the case. The drawbacks to all standards mentioned in this report would need to be addressed, however. The objective must be, as it is with other product families, that two laboratories “A” and “B” could test to different parts of the EN 50121 standard at separate times and separate locations and obtain the same result. However the uncertainties in testing, particularly the on-site testing of the train as a whole, may make this difficult. As regards to on-site testing, more of an effort is needed in order to separate transient and continuous emissions; also the emission limits perhaps need re-visiting.

There should be some attempts to make the standards more future-proof, as a small change in this stage of development is much less costly than at a later date. An example of this would be the frequency range: the extra effort involved in increasing the range for emission measurements to 4 or 5GHz (in order to catch future higher frequency technologies) instead of 2.6GHz (which would encompass all current technology) is small.

Particular attention should be paid to the situation where new rolling stock is introduced to an older network, as this is extremely common. In this there should be provision for the more up to date signalling system and telecommunication designs such as digital broadcasting. Safety should also be referenced but kept as a separate standard, and an additional test of the fields inside the train should be investigated.

18.2 Points that will inform further work

This section will identify the specific conclusions from this document that will help the TREND project in future work packages involving modelling and measurement campaigns. This bullet list highlights the issues with the standards that can be addressed in future work.

1. On board emissions testing: this is an issue highlighted by case studies in Deliverable D2 and also identified by inspection of the standards in this Deliverable D3. An addition to EN50121-3-1 involving on-board emissions would be very useful to help EMC of GSM and GSM-R and also to help inform medical and EMF standards.

2. Categorising and measuring transient emissions: both conducted and radiated transient EM energy is not accounted for in any of these EMC standards. Additions to the various standards need to be investigated in order to help reduce transient production and boost immunity to transients.

3. Neutral sections: these have been identified as one of the areas that are not treated correctly by the current EMC standards, along with other infrastructure design aspects that can cause issues. This is based on experience from Deliverable D2 in the track circuit section (TC1).
4. Radiated emissions limits: identified by case studies in Deliverable D2 (BS1 and BS2) and by examining the standards and reported in this D3, the emission limits stated in EN50121-X can be interpreted as being too high, allowing interference on radio services at large distances.

5. Frequency Limits: the frequency range specified in the tests to be carried out in the EN50121-2 is insufficient at both the upper and lower ends.

6. Conducted emissions: mainly from substations or induced by passing trains, the categorisation and measurement of these should be included in EN50121-2.

7. Overhead line resonances: these are also not covered but would be useful to categorise in a measurement campaign.

8. Capacity to handle future issues: one of the drawbacks identified in this report is that there is little to aid in the testing of up to date systems (e.g. immunity of the GSM-R system). This should be investigated in order to allow the standards to be as up to date as possible.

As a result of addressing the points in both sections of this conclusion, once a train has been assessed and passed the EMC tests, different costumers, independent of the country, should all accept that the tested item would be tested to a level to ensure compatibility with their railway.
REFERENCES


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[9] EN50238 Railway applications – Compatibility between Rolling Stock and train detection systems

[10] EN50388 Railway applications – Power supply and rolling stock


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