STARS

SATELLITE TECHNOLOGY
FOR ADVANCED
RAILWAY SIGNALLING

D5.3 EGNSS Target Performances to meet railway safety requirements

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1 INTRODUCTION

1.1 EXECUTIVE SUMMARY

The purpose of this document is to define the EGNSS performance requirements necessary to achieve ETCS L2 safety requirements and the enhanced high level ERTMS functional architecture suitable for also including EGNSS in ERTMS train positioning function. This task is a follow up on the assessment of EGNSS service performance tackled on Task 5.2 (derived from WP4 findings) and it shall provide the necessary values (i.e. key target performances and safety requirements) to Task 5.4 for defining the service evolution expected for EGNSS considering the railway environment. These key target performances and safety requirements are derived from the functional hazard analysis performed on a selected reference ETCS system architecture which integrates EGNOS services. The output of this document will be used as input for the Shift2Rail (X2Rail-2) project that includes “TD-2.4 fail-safe train positioning (including satellite technology)”.

The main results achieved are:

- Identification and review of the main functional ERTMS requirements that are impacted by the introduction of EGNSS position technology. A detailed description of these requirements are included in Appendix A
- Description of the state of the art of the main current ERTMS positioning solutions and the related performances
- Identification of the challenges of using the EGNSS technology into ERTMS/ETCS
- Overview of the main SBAS functionalities and peculiarities to be taken into account in railway signalling domains
- Identification of possible enhanced ERTMS functional architectures for using EGNSS in ERTMS/ETCS and a comparative analysis of the two identified possible alternative options
- Preliminary hazard analysis of current ERTMS/ETCS
- Apportionment of THRs to elements of new reference architectures

This document is organised as follows:

- section §2 summarises the current ETCS functional requirements on train positioning and the related current solutions;
- section §3 takes a view on the challenges of using GNSS within the ERTMS /ETCS system;
- section §4 describes the existing architectures for both the ERTMS/ETCS system and the SBAS system;
- section §5 mainly presents the proposed references architectures for using GNSS along with EGNOS for the ERTMS/ETCS system and introduces the Virtual Balise Concept;
- the corresponding Hazard Analysis of the particular reference architecture is presented in section §6 and
- subsequently section §7 presents the Tolerable Hazard Rate apportionment;
- finally section §8 closes the document with the summary of conclusions.
- Appendix A: ERTMS/ETCS requirements applicable to the Virtual Balise Concept

1.2 DEFINITIONS AND ACRONYMS

Acronym	Meaning
ATPL	Along Track Protection Level
BTM	Balise Transmission Module
CA	Consortium Agreement
CAPEX	CAPital EXpenditure
CCS	Control Command and Signalling
CTPL	Cross Track Protection Level
CELENEC	European Committee for Electrotechnical Standardisation (Comité Européen de Normalisation Electrotechnique)
CEN	European Committee for Standardisation
COMPASS	Global Navigation Satellite Systems (China)
DFMC	Dual Frequency Multi Constellations
DO178B	Software considerations in Airborne Systems & Equipment Certification
EASA	European Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference (service area of EGNOS)
ECSS	European Cooperation for Space Standardization
EDAS	EGNOS Data Access Service
EGNOS	European Geostationary Navigation Overlay System
ESP	EGNOS Service Provider (generic term)
ESSP	EGNOS Satellite Service Provider (the current EGNOS ESP)
EMC	Electromagnetic Compatibility
EOA	End of Authority
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EVC	European Vital Computer
FDE	Fault-Detection-Exclusion

FSM	Finite State Machine
GA	Grant Agreement
GEO	Geostationary Satellite
GLONASS	GLObal NAvigation Satellite System (Russia)
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
HMI	Hazardous Misleading Information
IODE	Issue of Data Ephemeris
KER	KVB, Ebicab, RSDD
KMC	Key Management Centre
LDS	Satellite based Location Determination System
LEU	Lineside Electronic Unit
LRBG	Last Relevant Balise Group
LRBGONB	Last Relevant Balise Group as reference for ONBoard
LRBGRBC	Last Relevant Balise Group reported from the on-board and used as reference from RBC
MA	Movement Authority
MI	Misleading Information
MOPS	Minimal Operational Performances Specification Document reference DO229
MTBF	Mean Time Between Failures
MTTF	Mean Time To Failure
OBU	On-Board Unit
OPEX	OPerating EXpenditure
OS	Open Service of EGNOS (without guaranteed integrity)
PL	Protection Level
PMO	Project Management Office
PRC	Pseudo Range Correction

PRN	Pseudo-Random Noise (identification of a specific GPS or GEO satellite)
PS	Passive Shunting mode
PVT	Position Velocity Time. Results of user positioning equation
PVT_C	PVT Constrained
PVT_U	PVT Unconstrained
QM	Quality Manager
RAMS	Reliability, Availability, Maintainability, Safety
RBC	Radio Block Centre
RIU	Radio In-fill Unit
SBAS	Satellite Based Augmentation System
SC	Steering Committee (SC)
SH	Shunting
SIL	Safety Integrity Level
SIS	Signal in Space
SL	Sleeping mode
SoL	Safety of Life service of EGNOS (with guaranteed integrity)
SoM	Start Of Mission
SRS	System Requirements Specification
SSP	Static Speed Profile
TALS	Trackside LDS Server
THR	Tolerable Hazard Rate
TMT	Technical Management Team (TMT)
TSI	Technical Specification for Interoperability
TSR	Temporary Speed Restriction
TTA	Time To Alarm
UDRE	User Differential Range Error (over-bound of residual range error once EGNOS corrections are applied)

VB	Virtual Balise
VBR	Virtual Balise Reader
WGS84	World Geodetic System 1984. Reference coordinate system used by GPS & SBAS
WP	Work Package
WPL	Work Package Leader (WP Leader)

2 REQUIREMENTS IN ERTMS/ETCS ON TRAIN POSITIONING

ERTMS/ETCS is a signalling system whose key task is to protect trains from either operating at speed higher than permitted, or against exceeding the limits of their operating authority (location to which the train is permitted to travel). In ERTMS/ETCS this operating authority, provided from the trackside equipment, is called a Movement Authority, which contains a description of the speed profile and the gradient of the track ahead the train, the maximum distance allowed to travel and some optional track characteristics. ERTMS/ETCS is also used to indicate the information needed to operate the train to the driver; it can therefore replace traditional optical signals placed along the track.

Key data to perform these supervision functions are the train speed, the position of the train in reference to speed and distance limitations (including which track the train operates on), as well as infrastructure and signalling data.

2.1 FUNCTIONAL REQUIREMENTS

2.1.1 General description

Like most railway signalling systems ERTMS/ETCS uses a simplified model to describe the track network. The model is essentially a linear model of the track, with parallel tracks lines on multi track lines. The model neither contains any geometry data, such as curve radii, nor absolute location references, such as national or global grid systems.

An example of a track layout is shown in the figure below.

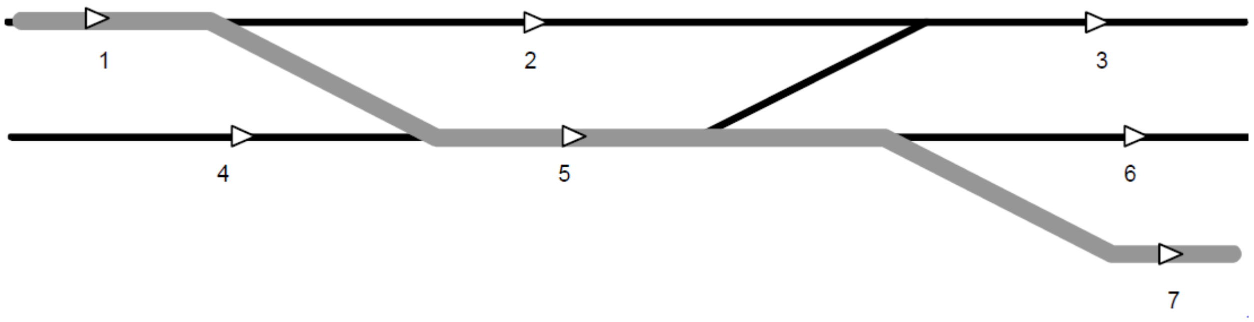


Figure 1: Track model used by ERTMS/ETCS

The track knowledge as known by the train is even more simplified and limited, as only the information about track over which Movement Authority has been issued to the train is transmitted to the train from trackside equipment. In ERTMS/ETCS the train does not possess a track database of the network, over which it operates, in fact track data is only received as needed, and then discarded once the track has been passed.

The following figure shows the track description sent to a train which operates over the route 1 – 5 – 7 as indicated in the figure above.

Figure 2: Track description sent to train in ERTMS/ETCS

In ERTMS/ETCS the position of a train within the track description is always referenced to known positions along the track, which are equipped with transponders. These are called Eurobalises, and have some physical characteristics which support safe positioning ERTMS requirements. Balises are typically used in pairs (called balise group), with the sequence within the group indicating the direction of the track. In ERTMS/ETCS always last read balise group is used as the train position reference, it is then called the Last Relevant Balise Group or LRBG.

The following figure shows how a train determines its position along the track description in reference to a balise group.

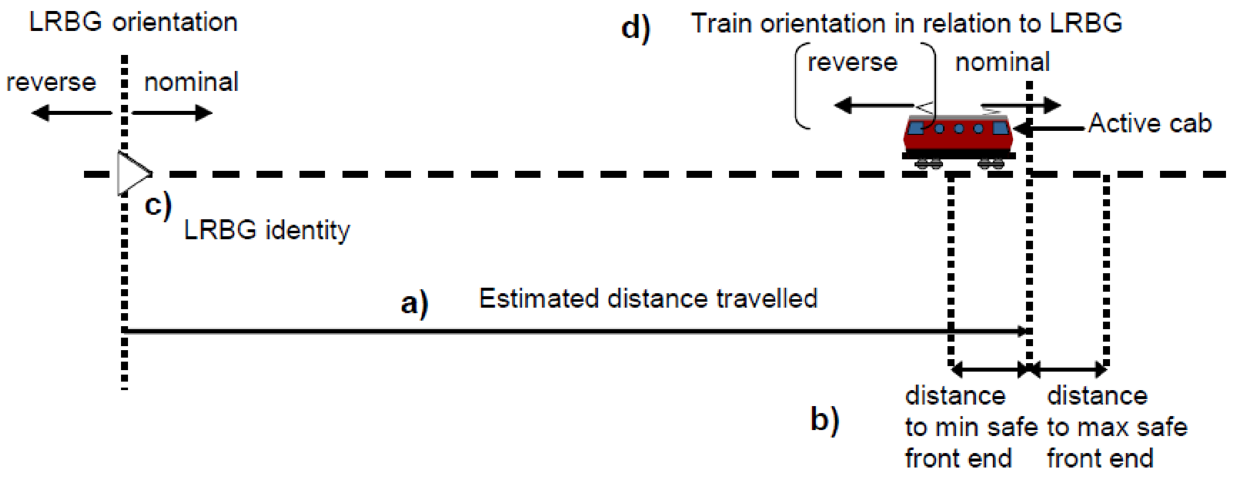


Figure 3: Description of train position in ERTMS/ETCS

2.1.2 Track selectivity

The information that indicates to RBC on which track, among various possible ones in a multi-track line, a train is operating, is probably the most critical element of train positioning. Wrong track determination will very likely lead to a movement authority issued to a wrong train, which could lead to an accident.

Track selectivity is mostly relevant during the train Start of Mission, or after movements under the responsibility of the staff, such as for shunting or during degraded operations. In these cases a safe train position, including track selectivity support, must be available in order to issue a first movement authority.

Once a train moves correctly under a movement authority received from the trackside, track selectivity is less critical as switching between tracks is only possible over routes set by the trackside. The track on which the train operates is therefore known due to the routes set.

2.1.3 Position of train against speed and other infrastructure limitations as well as signal locations

Computation of the correct distance of the train to any location relevant in train supervision mode is also critical, as the calculation of the maximum allowed speed, as well as of braking curves to observe limitations ahead of the train. These critical calculations strictly depend on the exact the train position information availability.

The criticality of supervising the permitted speed and stopping points depends on the characteristics of limitations, respectively the local situation at stopping points.

2.1.4 Train orientation

Train orientation (in which direction a train is pointing in reference to the track) is another critical item of train positioning. Knowledge of train orientation is essential for issuing a movement authority.

2.1.5 Train direction of movement

Direction of train movement is the last element needed to supervise train movement, as a train can move both forward (in reference to the driver's position) and backwards.

2.1.6 Absolute position of Train in reference to a grid model

Contrary to aviation and marine applications, railways have typically no need to know the absolute geographical position of trains in relation to a national or global grid model. All supervision functions are always related to the above described relative track model. This applies also to most other signalling systems in use and their related functions. In fact even the absolute position of the track is not known with any reasonable accuracy in many railway applications.

2.2 CURRENT SOLUTIONS IN ERTMS/ETCS

2.2.1 Track selectivity

In today's ERTMS/ETCS the track on which the train operates is being derived from reading transponders placed in the track. Eurobalises are used as transponders, which have been specifically developed for ERTMS/ETCS. Each balise has a unique identification number, and its position along the track is known to the trackside systems. From reporting that identification number the trackside can therefore determine the track on which the train operates.

Reading a transponder from an adjacent track can be excluded due to the physical characteristics of the balise transmission system. The respective function in the Eurobalise specification is called physical cross talk protection. True cross talk protection does however also require some engineering precautions, such as not placing Eurobalises where cables are buried.

Pre-announcement of balises, performed from the trackside to the train, is also being used for the same purpose, as reading a balise from an adjacent track could be detected if it has not been pre-announced. In ERTMS/ETCS this function is called linking.

2.2.2 Longitudinal position of train along track

In today's ERTMS/ETCS the longitudinal position of the train along the track is being derived from transponders placed in the track (Eurobalises), which are being used as absolute position references, as well as from odometry information generated from a number of distance and speed sensors. Combined with the simplistic description of the track, as shown above, the absolute position of the train in reference to speed restrictions or stopping points can be derived.

A number of errors can result in positioning errors, such as the accuracy of the balise placement, the exact detection of the centre of the balise, and most notably the error resulting from the odometry sensors.

ERTMS/ETCS has a number of mechanisms in place to manage these errors. The following graphic shows how they are being considered.

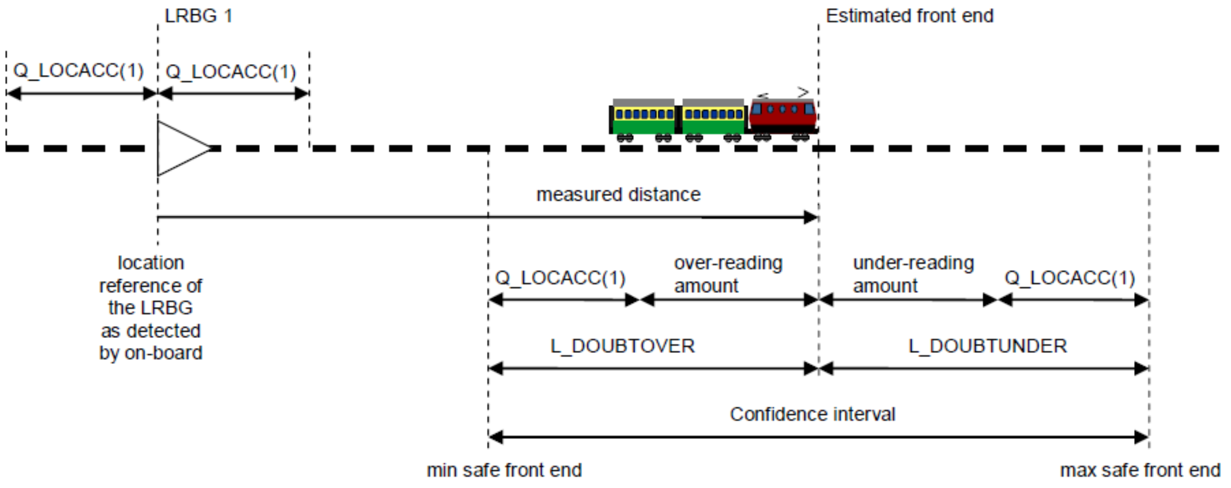
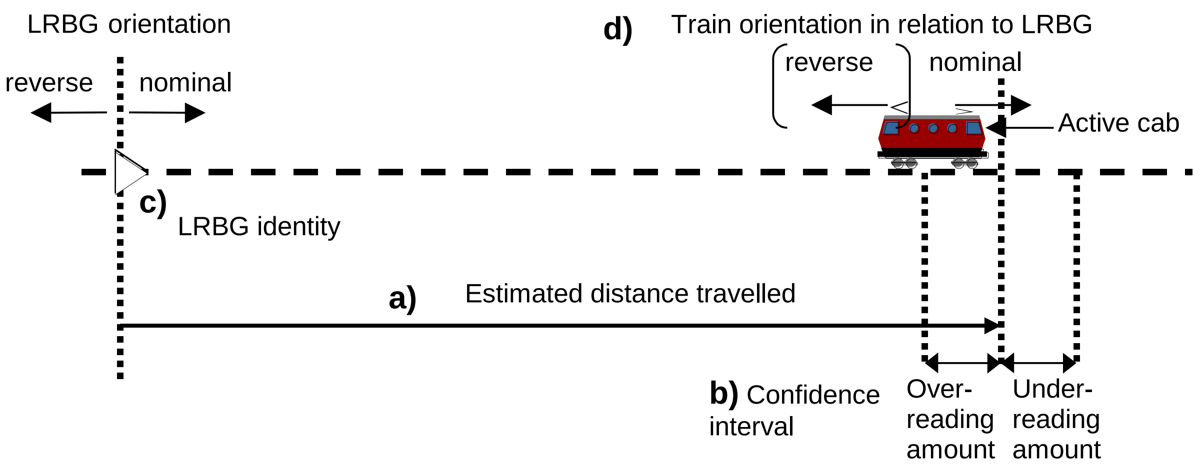


Figure 4: Error handling when calculating train position in ERTMS/ETCS

One of the advantages of the balise based referencing system is that the train position accuracy can be controlled and improved in critical locations by placing additional balises. The nominal error at any location along the track can also be calculated from the distance to the last relevant balise group, as a minimum odometry performance is guaranteed by the odometry system of each ETCS on-board unit.

2.2.3 Train orientation with respect to track

Train orientation in reference to the track is derived from the sequence in which the balises within the last relevant balise group have been read, as well as from the location of the active cab in the train.



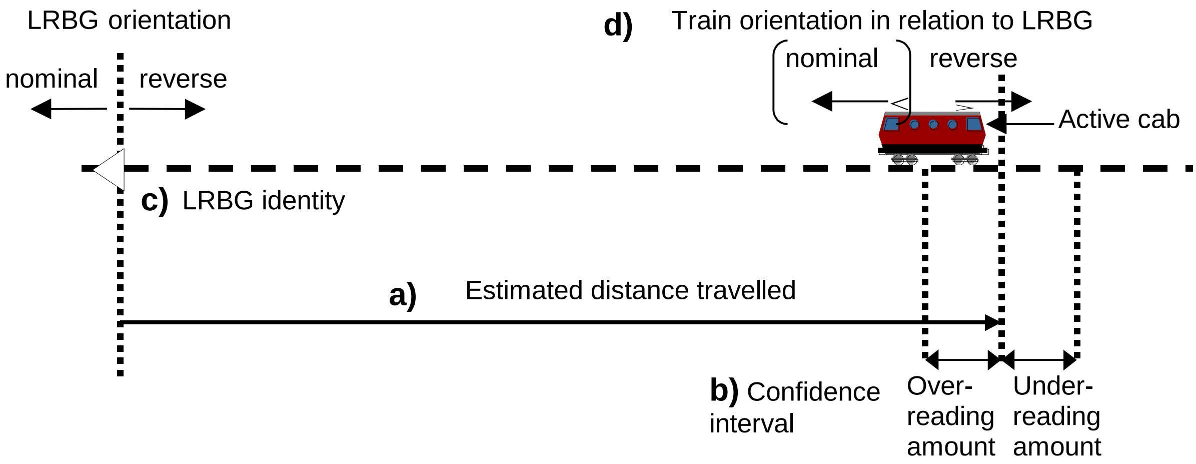


Figure 5: Relation between LRBG and train orientation

2.2.4 Direction of train movement along the track

Train movement in reference to the track is derived from the orientation of the train in reference to the track, and from the odometry information.

2.3 EXISTING PERFORMANCE AND SAFETY REQUIREMENTS

2.3.1 Track selectivity

The tolerable hazard rate for cross-talk has been calculated in Subset-088-3, section 12.5.2.5 to be 1×10^{-9} f/h. This calculation has been done on the basis of a reference application, from which individual projects might deviate. If individual requirements are higher, trackside mitigation measures have to be taken as the above value has been exported to the balise transmission system as interoperability requirement

2.3.2 Longitudinal position of train along track

The tolerable hazard rate for on-board functions has been calculated in Subset-088-3, section 7.3 as 0.67×10^{-9} f/h. This calculation has been derived from the apportionment of the overall safety target to the on-board system, minus the apportionment to the transmission systems.

As described in section 2.2.2 the longitudinal position of the train is calculated from the location of the balise used as reference, the detection accuracy of the balise centre, as well as the odometry information.

For each of these values some errors have to be considered.

- The accuracy requirement, for vital purposes, for detecting the balise centre shall be within ± 1 m, according to 4.2.10.2 in Subset-036.

Note that for non-vital purposes the location accuracy requirement is ± 0.2 m for speeds below 40 km/h, increasing to ± 0.7 m at 500 km/h, both with a confidence interval of 0.998, see Subset-036 and §9.2.1 (Figure 3).

- Odometry performance is specified in Subset-041 and shall be better or equal to ± (5 m + 5%) of the travelled distance, as shown in the drawing below (Note that this is for safety critical applications and includes the ± 1 m for detecting the balise centre):

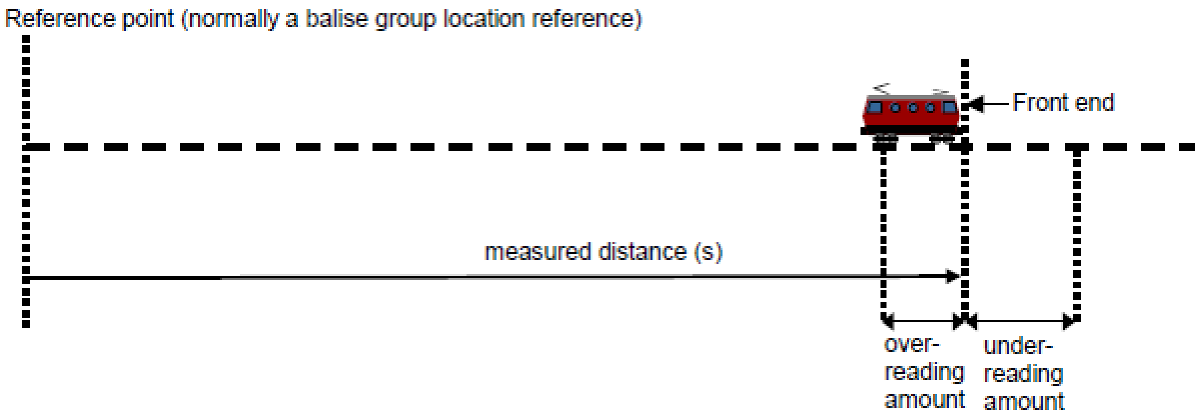


Figure 6: Accuracy of distance measured on-board

Due to the mechanisms described in section 2.2.2 a positioning error is not a safety issue, as margins are added by the supervision functions. These margins can however create performance impact, as trains have to slow down too early where the permitted speed changes to a lower value, or to stop at a distance from the intended stopping point. While the first issue is typically not critical, the second one can create problems in stations where trains have to stop very close to a signal at the end of a platform due to the limited length of the platform and/or track in comparison to the length of the train.

The acceptable longitudinal error will depend largely on the individual application of ERTMS/ETCS. In a number of projects customers require balises to be places at 100 m before critical stopping points, which would generate a position error of ± 5 m + 5% of 100m = ± 10 m. In many applications also ± 20 m might be an acceptable value.

2.3.3 Train orientation with respect to track

No specific performance and safety requirements have been specified for the train orientation, but it can be assumed that they are similar to the track selectivity requirements.

2.3.4 Direction of train movement along the track

No specific performance and safety requirements have been specified for the train direction of movement, but it can be assumed that they are similar to the track selectivity requirements.

2.3.5 Missing a balise

Apart from being used as position reference, balises are also used to transmit safety related and non-safety related data. In some applications it can be critical to miss a balise with safety related data, especially when the balise is not linked (pre-announced). In such cases missing the balise remains undetected.

ERTMS/ETCS currently specifies a failure rate for a balise information point to become undetectable equal to 10^{-9} dangerous failures per hour ([15], §12.5.2.4), while the failure rate of the on-board to be able to detect the transmission of an information point equal to 10^{-7} dangerous failures per hour ([7] §7.3.2).

2.3.6 Erroneous reporting of a balise

According to Subset-036, section 4.4.4 the balise reader should not be erroneously reporting the detection of a balise more than 10^{-3} times/h.

3 CHALLENGES OF USING GNSS IN ERTMS/ETCS

3.1 *AVAILABILITY*

Railway systems typically have to fulfil extremely high availability figures, as any disturbance in operation in many cases not only impacts a single train, but also multiple others due to e.g. a stranded train blocking a line or junction. For that reason most critical signalling systems are built with redundancies.

3.1.1 Availability impacts resulting from MTBF

There are currently no mandatory MTBF requirements for ETCS, but tenders often contain MTBF values in the range of 50’000+ hours for a complete ETCS on-board unit. The Eurobalise reader contributes with only a fraction to that value, so its MTBF must be significantly higher considering that essential parts, such as the antenna under the train, cannot be made redundant.

The balises themselves have a much higher MTBF, 50+ years can be assumed for a single fixed data balise.

3.1.2 Availability impacts resulting from spurious errors

Apart from the MTBF related availability there is also an availability impact resulting from spurious errors. There is an essential difference here between the Eurobalise system and GNSS, as environmental effects have to be included in the MTBF. For Eurobalises these impacts are negligible, but for GNSS they can probably not be neglected.

3.2 *SAFETY*

ERTMS/ETCS in its entirety has to comply with SIL4 requirement, which has to be proven against applicable standards such as EN50126 etc.

GNSS is currently operated in civil aviation domain for “Safety of Life” (SoL) applications where it is required to comply to its civil aviation applicable safety standard (DO178B) at a “Development Assurance Level” of DAL B (DAL B being the next to higher DAL level for civil aviation domain).

3.3 *LACK OF ABSOLUTE POSITION*

As described in section 2.1.1, ERTMS/ETCS only uses relative positions in relation to balise groups placed in the track. This system has no defined relationship to any absolute coordinate system, whether national or global. The only “absolute” locations in ERTMS/ETCS are the reference balises with their identity, which are identifying an exact location within the track model, including the track in locations with multiple tracks. These “absolute” positions are however not identifying an absolute geographical position.

Between these “absolute” positions only the length of the track is known, regardless of where the track actually lies.

3.4 *DIFFERENT COORDINATE SYSTEMS*

As described above, ERTMS/ETCS only uses relative positions in relation to balise groups placed in the track.

GNSS on the other hand uses a global coordinate system (WGS84). Using GNSS in ERTMS/ETCS therefore requires a translation of data.

To make such a translation possible it is therefore necessary to know the true position of the track in the coordinate system used by GNSS, a requirement that does not exist in the current ERTMS/ETCS.

3.5 OPEN STANDARD / INTEROPERABILITY REQUIREMENT

Key element of ERTMS/ETCS is its open standard specification, which is needed to ensure interoperability between on-board systems and trackside implementations from different suppliers.

The interoperable interface in ERTMS/ETCS is therefore the airgap. All trackside and on-board systems have to show identical behaviour and minimum performance at these interfaces.

Specifying behaviour of the on-board element of the Eurobalise system has been a major challenge, even though the function performed is relatively simple.

3.6 PERFORMANCE IMPACT DUE TO ENVIRONMENTAL IMPACTS

The Eurobalise system has been specified to operate without performance impact within typical worst case environmental conditions. Experience has shown that the environment typically does not exceed these worst case assumptions, meaning there are no environmental effects which dynamically impact the performance of the Eurobalise system.

There are also very few environmental effects impacting the application of the Eurobalise system, which can be considered by applying some very basic engineering rules.

For GNSS the situation is different. There are a number of environmental effects which impact GNSS performance, such as blocking of satellite visibility, reflections creating multipath signals, high RF noise, and malicious attacks. It will be a major challenge to define engineering rules to achieve a predictable minimum performance of GNSS.

3.7 MANAGEMENT OF KNOWN GAPS IN GNSS COVERAGE

Compared to Eurobalises, GNSS will have gaps in coverage, such as e.g. in tunnels or under station roofs. Thanks to the concept of ERTMS/ETCS to generate train position information from “absolute” positions at balises and odometry information between balises it will be possible to bridge gaps in GNSS in the same way.

Typical projects with ERTMS/ETCS Level 2 use a balise group around every 1000 meters on lines, and every few hundred meters in stations. If gaps are short in comparison with these values then they can be managed by the above described mechanism.

If gaps are longer, balises can still be used, as long all ERTMS on-board units retain their balise readers.

The critical aspect will be whether gaps are predictable.

4 EXISTING SYSTEMS

4.1 ERTMS/ETCS

In order to fulfil the scope of requirements for a European interoperable railway signalling system the ERTMS/ETCS system is split into two major sub-systems, the on-board and the wayside sub-systems.

The environment of the ERTMS/ETCS sub-systems is composed of:

a) The train, which will then be considered in the train interface specification;

b) The driver, which will then be considered via the driver interface specification;

c) Other onboard interfaces (see architecture drawing in **Figure 7**),

d) External trackside systems (interlockings, control centres, etc.), for which no interoperability requirement have been established.

The sub-system composition can vary depending on the application level. For the application of EGNSS, in order to take advantage of the ETCS safe communication session, the ERTMS level that used such safe communication sessions are used: ETCS level 2 and ETCS level 3. **Figure 7** depicts the on-board and wayside architecture. It is important to consider that the only purpose of the functional demarcation shown on the on-board is to simplify the visualisation of the interfaces to a particular function. The organisation of functionality is completely up to the supplier of the equipment.

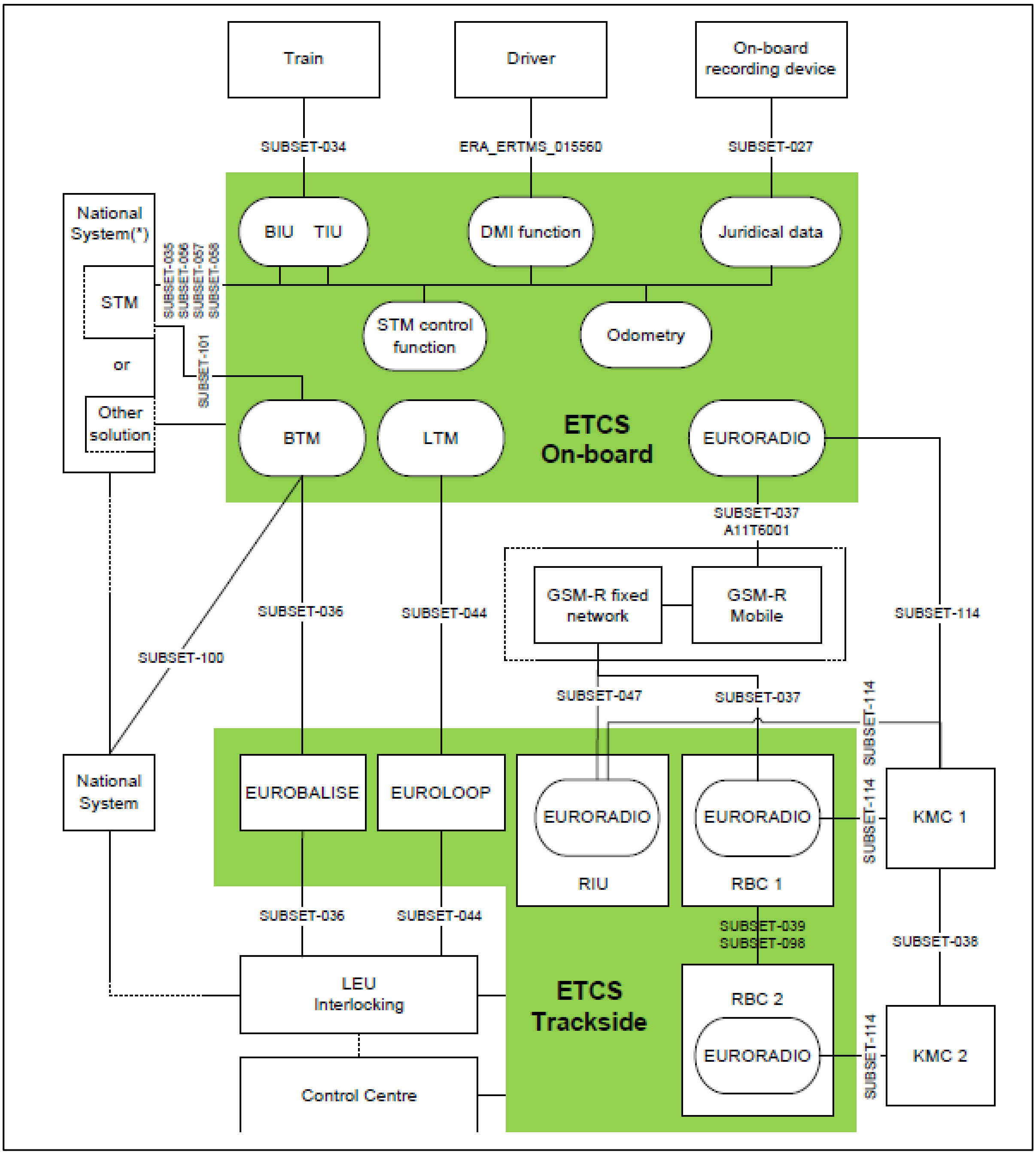


Figure 7: On-board and wayside architecture

4.1.1 Trackside subsystem

a) Balise

b) Lineside electronic unit

c) The radio communication network (GSM-R)

d) The Radio Block Centre (RBC)

e) Euroloop

f) Radio infill unit

g) Key Management Centre (KMC)

Of specific interest when considering EGNSS with ETCS are a) c) and d).

4.1.1.1 Balise

The balise is a transmission device based on the existing Eurobalise specifications that can send telegrams to the on-board sub-system. The balises provides the up-link, i.e. the possibility to send messages from trackside to the on-board sub-system. The balises can provide fixed messages or, when connected to a lineside electronic unit, messages that can be changed.
The balises will be organized in groups, each balise transmitting a telegram and the combination of all telegrams defining the message sent by the balise group.

4.1.1.2 Trackside radio communication network (GSM-R)

The GSM-R radio communication network is used for the bi-directional exchange of messages between the onboard sub-systems and RBC.

4.1.1.3 RBC

The RBC is a computer-based system that elaborates messages to be sent to the train on basis of information received from external trackside systems and on basis of information exchanged with the on-board sub-systems. The main objective of these messages is to provide movement authorities to allow the safe movement of trains on the Railway infrastructure area under the responsibility of the RBC. The interoperability requirements for the RBC are mainly related to the data exchange between the RBC and the on-board sub-system.

4.1.2 On-board subsystem

The ERTMS/ETCS on-board equipment is a computer-based system that supervises the movement of the train to which it belongs, on the basis of information exchanged with the trackside sub-system. The interoperability requirements for the ERTMS/ETCS on-board equipment are related to the functionality and the data exchange between the trackside sub-systems and the on-board sub-system and to the functional data exchange between the on-board sub-system and:
a) the driver;

b) the train;

c) the on-board part of the existing national train control system(s).

4.1.2.1 Onboard radio communication system (GSM-R)

The GSM-R on-board radio system is used for the bi-directional exchange of messages between on-board sub-system and RBC or radio infill unit.

4.1.3 Architecture of the positioning function in ETCS

The following figure shows the current architecture of the positioning function in ETCS:

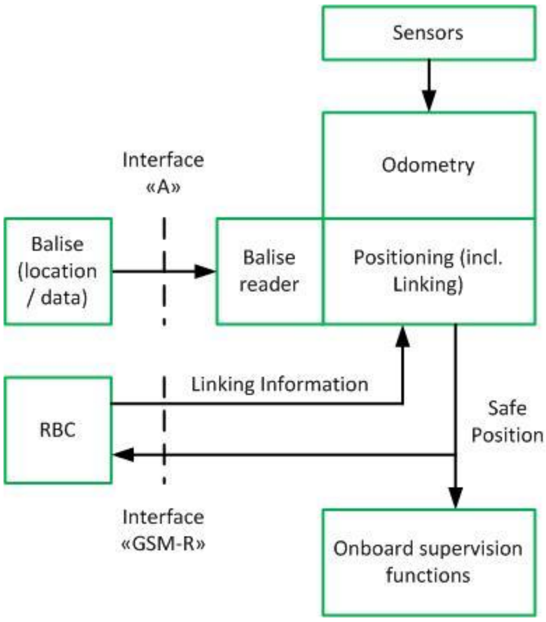


Figure 8: Current ETCS positioning function architecture

The current ETCS positioning function architecture consists of the following functional blocks:

- Sensors: It is currently left to each designer of an ETCS on-board system to select appropriate sensors for odometry. Typical implementations include wheel tachos and Doppler radars, but e.g. accelerometers and inertial platforms are also being used.

- Odometry function: This block generates both speed and distance information from the sensors used. It has to meet minimum performance requirements (accuracy and safety). The odometry function also calculates the confidence interval for position and speed, and uses linking information to re-set the confidence interval when passing balises.

- Balise reader: This function detects balises placed in the track, which are used as absolute location references. It includes technical measures to protect against longitudinal / transversal crosstalk. It also guarantees delivery of balise information in the correct sequence when passing balise groups with more than one balise. It delivers an absolute location reference (meeting minimum performance requirements) and delivers the message stored in a balise group to the on-board system.

- Position/Linking: This function calculates the position of the train based on the Last Relevant Balise Group identity (typically of the last balise group detected), the orientation of that balise group, the direction in which the balise group has been passed and the distance travelled since reading the reference balise of that Last Relevant Balise Group). It also calculates the confidence interval of the train position, based on odometer information (odometry can use a multi-sensor technology). It finally applies linking both for improving positioning accuracy as well as for protection against missing balises. This linking measure is based on pre-knowledge of balise identities and positions along the track, which are supplied by the trackside to the train once a route for the train has been set.

Note that a “position” in ETCS is always in reference to a balise group, whose absolute position is only known by the trackside system.

Note that within ETCS only the airgap between the balise and the balise antenna, as well as the communication via GSM-R, are standardized. The internal structure of the on-board equipment is described on the basis of a general understanding of how positioning works, but actual implementations by different suppliers might vary. The above listed functions are therefore not necessarily separated, but might be integrated into one unit / algorithm.

4.2 SBAS

4.2.1 EGNOS mission overview

"European Geostationary Navigation Overlay Service" (EGNOS) is the European Satellite Based Augmentation System (SBAS) designed to augment the satellite navigation services provided by the American Global Positioning System (GPS) over the European Civil Aviation Conference (ECAC) Region.

EGNOS is designed to be interoperable with other adjacent SBAS like the American WAAS or the Japanese MSAS. EGNOS is designed to be expandable over regions neighbouring ECAC.

As other SBAS, the goal of EGNOS is to "augment" the GPS in order to improve the navigation performances in terms of accuracy and integrity (with the required levels of availability and continuity of service) over the ECAC. These augmentations are provided to user thanks to a GPS-like signal in space broadcast by geostationary satellites and containing GPS, GEO as well as ionospheric differential corrections with the associated Integrity.

EGNOS has been designed as a multimodal system and therefore can be used by aviation, maritime, railway land/mobile users, but till today has been implemented and qualified for aviation domain only.

Aviation EGNOS users must be equipped with a receiver compliant with [MOPS rev.D] (or any anterior MOPS release compatible with it) that will allow them to compute navigation solution (PVT) from the received GPS and EGNOS signals that fulfils aviation users requirements.

Even if the broadcast of EGNOS messages through GEO satellites is a very efficient messages transmission strategy for aviation users, other users may need or desire the use of the EGNOS data, e.g. transmitted by another mean, to overcome challenging reception conditions such as urban canyon. The EGNOS EDAS interface concept has been introduced especially for such a widened user community. It provides raw EGNOS products in real-time through a dedicated EDAS server (Ref “EGNOS Data Access Service (EDAS) Service Definition Document”, issue 2.1 available from ESSP site: https://www.essp-sas.eu/communication/egnos-documentation/).

EGNOS provides today augmentation services based on GPS, getting significantly improved performances in a wide range of navigation applications.

In particular, in addition to an open service (OS) used by many European users communities, such as “precision farming”, EGNOS is providing a safety critical service (SoL) used by civil aviation for en-route as well as for airport approach phases.

In parallel, GNSS constellations and signals are evolving (GLONASS, GPS, GALILEO, COMPASS,), and new services are identified to serve European users communities navigation applications.

EGNOS is evolving and in near future EGNOS V3 will provide service for multi-constellation (GPS, Galileo) and multi-frequency users (L1, L5), improving availability especially in challenging environment and directly providing correction at user level for ionosphere effects.

4.2.2 EGNOS system overview

As schematized in *Figure 9*, EGNOS system is directly decomposed in three segments:

- Ground Segment,
- Space Segment,
- Support Segment.

The preliminary EGNOS release included a fourth segment: the User Segment.

This User Segment was included in EGNOS system because at early development stage, no EGNOS user receiver did exist and it was necessary to develop a representative user receiver to verify the complete EGNOS system behaviour and performances. Now the aviation user receivers are developed and the User Segment is composed of real EGNOS users, using COTS receivers which are no longer designed as part of EGNOS system.

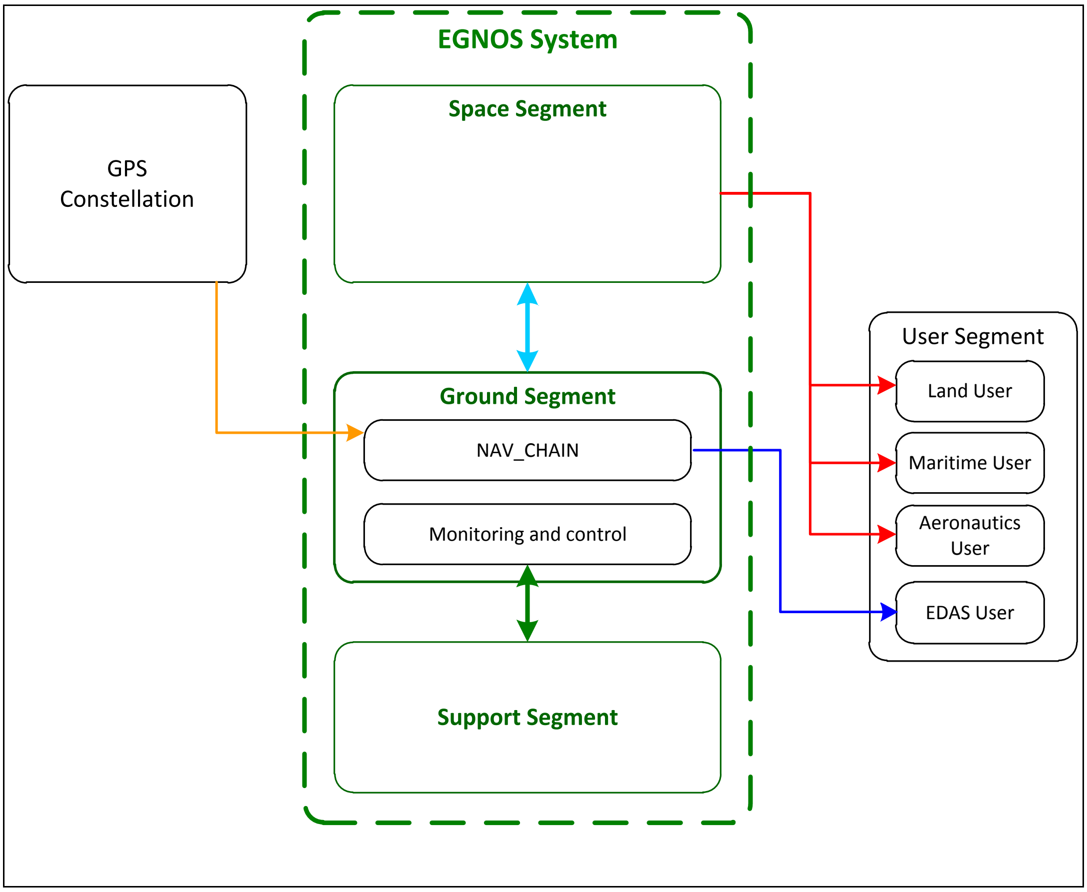


Figure 9: Current system decomposition in segments

Ground Segment:

Ground Segment contains two main chains:

• The Navigation chain is the core element for the EGNOS services SiS delivery (Real time operations). It monitors and augments GPS services (and EGNOS services themselves); in the future EGNOS V3 will also augment Galileo constellation. It can provide an "open service" (OS) through the broadcast of differential corrections as well as a Safety of Life (SoL) service through to the broadcast of integrity information. It makes all these information available to users by broadcasting them through the Space Segment.

• The Monitoring and Control chain allows Ground Segment operators to configure, monitor and control all deployed EGNOS assets. This chain does not directly contribute to Real Time system performance.

Space segment:

This segment is composed of three Navigation payloads embedded on three distinct GEO satellites (two Inmarsat III and IV satellites and one SES ASTRA GEO satellite SES-5). Usually, two of them provide redundant data transmission channel to broadcast toward EGNOS users, the messages containing the differential corrections with the associated integrity information. These messages are conveyed over GPS-like signals (encoded with a specific PRN). The space segment is designed to meet EGNOS SoL Service continuity requirements.

Support segment:

Support Segment goal is to support EGNOS services provider in its task to maintain EGNOS system in operational conditions (e.g. assess operated system performance, manage system configuration, Coordinate Ground Segment Operations including maintenance activities, archive consolidation…).

User Segment:

This segment is composed of all the users of EGNOS system. Although these users could be of many types (land, maritime, aeronautics, laboratories…), they will access EGNOS service thanks to only two different interface types:

- Signal In Space provided by Space Segment (Real Time interface)
- Internet connection relayed by EDAS server (delayed interface)
- EGNOS Service Centre: Provides user support services and products: Helpdesk, Web Portal, customized products, etc.

4.2.3 Considerations regarding EGNOS usage in railway domain

INTERFACE BETWEEN EGNOS AND ERTMS/ETCS

EGNOS provides a Signal In Space (SIS) through the GEO satellites with two functionalities:

- A "Ranging function" by which a user receiver can use the GEO satellite as an additional GPS satellite with its dedicated PRN so that EGNOS users can obtain "pseudoranges" usable in their PVT algorithm. Remark: as of today, this feature is disabled in EGNOS.
- A data transmission channel that transmits the EGNOS generated correction and integrity messages.

The same EGNOS generated correction messages are also available, with some delay, through an internet connection relayed by EDAS. Due to anticipated difficulties to receive GEO satellites signals for ground users in numerous places, the same kind of interface, existing EDAS one or an additional "railway dedicated" one, could be used to distribute EGNOS corrections toward ERTMS/ETCS system. In addition, EGNOS SIS can be jammed therefore preventing the usage of EGNOS system in the area surrounding jammer equipment. Legacy EGNOS SIS does not provide support for authentication. On the other hand, the distribution of EGNOS corrections directly to ERTMS/ETCS transmission means could easily circumvent the above limitations.

DUAL FREQUENCY, MULTI CONSTELLATION USERS

Today, the EGNOS system (also called the legacy EGNOS) provides corrections relative to L1 only GPS signal.

Starting with GPS Block IIF and continued with Block III satellites, all new GPS satellites are capable to broadcast, in addition to legacy L1 signal, new frequencies called L2C and L5. The L5 signal is in particular designed to support dual frequencies safety of life users at least in aviation domain.

As of today (2017), there is already 12 GPS Block IIF in operations, and the first GPS Block III launch date is announced for year 2018. A constellation of at least 24 GPS satellites broadcasting also in L5 signal is anticipated to be available in year 2024 (Ref US document available at “http://www.gps.gov”: “2014 Federal Radionavigation Plan”, section 3.2.8)

WAAS system is presently evolving to be ready to provide, on top of the augmentation to GPS L1 legacy users, a new augmentation service for dual frequency users (L1 & L5) once L5 service will be declared open by US government. It is important to remark that L5 is a protected frequency for aeronautical applications by the ITU.

Initial Galileo open service (Initial OS) has recently been declared, Galileo system being designed as a dual frequency positioning system (L1 & E5a).

Evolutions of EGNOS system are also managed by European Commission so that the future EGNOS V3 will support, on top of the augmentation to GPS L1 legacy users, a new augmentation service for dual frequency multi-constellation (DFMC) users (GPS L1 & L5, Galileo L1 & E5).

The work regarding the standardization of the Minimum Operational Performances Specification (MOPS) for a Dual frequency / multi-constellation (DFMC) user receiver, capable of supporting Safety of Life applications has started several years ago and draft MOPS documents are already circulating within the MOPS subcommittee 159 (SC-159) community.

In view of these planned evolutions, it seems sound for railway domain to address also the (DFMC) Dual Frequency and Multi Constellation case, taking advantage of the increased number of satellites to be more resistant to signal blockage and to no longer make use SBAS ionospheric corrections to remove their associated residual errors but instead to use dual frequency capability to completely remove, at user level, the ionospheric delay incurred by the GPS or Galileo signals.

Anyway, the problem of local errors, signal blockage and signal degradation in challenging environments persists. In fact, local errors due to multipath, or Non Line of Sight (NLOS) and electromagnetic interference cannot be removed by the increased number of satellites or the use of multi-frequency multi-constellation functionality.

<u>USER ENVIRONMENT LOCAL EFFETCS</u>

In aviation domain, the residual errors due to user local effects (troposphere, interference and multipath) are bounded, usually with a value that evolves according to the satellite elevation as seen from user location.

Tropospheric effect is not different in railway domain than in aviation domain but other user environment, especially for interferences and multipath are much more challenging. The bounding formulas used in aviation domain will for sure prove to be not convenient for railway domain and new formulas will need to be defined.

As for aviation domain, the new formulas will likely include the satellite elevation but will complement this parameter with other information such as the signal to noise ratio experienced at user location. It will most certainly be also necessary to detect at user level the conditions where user receiver is exposed to local effects (interference and/or multipath) that are beyond the validity of the defined over-bounding formulas. In such case, the corresponding measurements should be rejected or even the SBAS positioning function declared unavailable at that location.

One of the main goal of the STARS project is, indeed, to measure GNSS services real performances in a variety of user environments in order to propose formulas that can bound and predict user local effects or to identify ways to detect when local environment effects are over the acceptable limit.

USER RECEIVER PERFORMANCES

EGNOS provides through its transmitted SIS, pseudorange correction messages that are applied by a user receiver on pseudoranges measured from the GPS or Galileo signal. Therefore EGNOS performances are not directly measurable at EGNOS SIS level.

There is an absolute need to use a user GNSS receiver to obtain pseudoranges from GPS and Galileo signal, then to apply EGNOS corrections to these measured pseudoranges and ultimately to obtain a 3D position in a reference frame (the so called ellipsoid depends on the GNSS system, e.g. GPS uses a WGS 84) using a “position equation”. In aviation domain, the user “position equation” is constrained by the standard (MOPS appendix E), to be a weighted least-square equation, and EGNOS and RAIMS ensure integrity for user applying this equation.

In this least-square equation for aviation domain, the weight applied to each satellite varies with the satellite elevation as seen from the user location. It is likely that for railway domain, a new formula for weights will be necessary for example using in addition to the elevation, the signal to noise ratio incurred at user receiver location. EGNOS provides also some integrity information (UDRE, Use/Don’t-Use) that are applied by user receiver according to an “integrity equation” (MOPS appendix J). These equations compute a “Protection Level” which can be depicted as cylinder cantered on the computed 3D position, accounting for the horizontal protection level HPL as the radius and the vertical protection level HPL as half of the height. EGNOS guarantees, at the required integrity risk level, that the real position of the aircraft to remains inside this cylinder.

Therefore, there will be a need to standardize the user position equation, time to alarm, as well as the integrity equation for railway domain so that EGNOS system, knowing these equations, can guarantee the integrity of the user position computed through these standard equations.

Vertical position is of course not needed for railway domain, but nevertheless, a 2D “protection level” will need to be defined with its associated equation. This 2D protection level could well be a circle but it could also be separated in “Along track” and “Cross track” protection levels.

CERTIFICATION ASPECTS

In order to offer a SoL service that is certified for use in aviation domain, EGNOS was developed according to safety rules of Space (ECSS) and aviation domain (DO178B). Furthermore EGNOS service operator needed to be recognized as an Air Navigation Service Provider over Europe and certified as such.

Once certified, ESP (EGNOS Service Provider) was in charge to present the EGNOS certification dossier in front of certification authority (EASA). The EGNOS certification dossier is based on EGNOS “Safety Case” that has two main parts:

- Safety case part A evidencing the safety features of EGNOS design and performances
- Safety case part B evidencing the safety features of the way EGNOS is operated by the ESP.

It is anticipated that similar scheme will be used for railway domain certification, including potential mutual recognition for some parts of the safety dossier. The process to be used for exploiting the aeronautical experience and dossier into railway applications must still be defined (e.g. investigation on the cross acceptance method or the pure application of CENELEC).

The certification process is indeed an important point that has to be addressed early enough by Europe, so that additional constraints on safety dossier presentation and content as well as additional constraints on design can be tackled at an early stage of the program to not endanger it.

CONCLUSION

All these constraints / limitations are expressed for aviation domain in the MOPS document.

The same kind of constraints / limitations will need to be expressed for railway domain.

As a consequence of the above discussion

- User positioning equation needs to be specified
- User integrity equation needs to be specified.
- User local environment needs to be characterized.
- Certification process need to be addressed

And in order to request EGNOS performances that are measurable, it is highly desirable that performances required from EGNOS by ERTMS/ETCS are defined at the output of a user receiver presenting what is considered as the Minimum performances needed for railway applications.

It is still to be defined whether the EGNOS performances are defined at pseudorange domain or in 3D position domain.

5 REFERENCE ARCHITECTURE FOR USING GNSS IN ERTMS/ETCS

Concerning the application of GNSS in railway context, many possible architectures have been investigated in other ESA and GSA projects, and can be potentially used in the enhancement of the ERTMS based on the satellite localization. However, in the frame of the STARS project, the SBAS augmentation system shall be explored as described below.

5.1 VIRTUAL BALISE CONCEPT

The main motivation of the introduction of GNSS in ERTMS/ETCS Train Positioning function is economical in order to reduce the cost in terms of CAPEX and OPEX as well as increasing performances and availability, without incurring major impact on the current ETCS implementation.

Using GNSS technology for train positioning in ERTMS/ETCS, based on an approach that minimizes the impact on ERTMS / ETCS, leads to the use of virtual balise concept that allows the replacement of the major part of physical balises with virtual balises.

Backwards compatibility will also be easy to achieve, as long as the Eurobalise readers will be retained.

Other concepts how to integrate GNSS into ETCS might however be investigated, depending on the feasibility of the Virtual Balise concept.

To this end, an additional functional block named "**Virtual Balise Reader (VBR)**" computes continuously position information based on GNSS and compares it with a list of absolute reference positions stored in the on-board track database to detect the "virtual balise" and sends the corresponding virtual balise message to the ETCS kernel, preserving the approach adopted for physical balises.

The objective of the Virtual Balise concept and its implementation is that ERTMS/ETCS kernel does manage virtual balises and / or physical balises in the same manner. The ETCS kernel shall remain responsible for implementing all the ERTMS functions related to balises (e.g. LRBG, Linking, Expectation window,).

5.2 POSSIBLE IMPLEMENTATION OF ARCHITECTURES TO USE GNSS/SBAS IN ERTMS/ETCS BASED ON VIRTUAL BALISE

Based on an approach which acts on minimizing the impact on the two existing main systems ERTMS / ETCS and GNSS augmented with SBAS, the possible architectures to use GNSS technology in ERTMS/ETCS system are limited to the architectures that take into account the particular functionalities and peculiarities in railway environments of both systems [3], for example:

a) The train determines its exact 1D position with respect to a location reference called LRBG
b) The train reports its position to the trackside system in reference to the LRBG
c) The trackside system transmits to the train the MA based on the LRBG
d) The trackside system transmits to the train the info describing the track conditions always taking the LRBG as location reference
e) A GNSS receiver processes GNSS Signal In Space and outputs PVT and pseudorange / carrier phase measurements (together with other performance metrics like estimated standard deviations, carrier to noise ratio, pseudorange residuals)
f) EGNOS transmits augmentation and integrity data which are valid for a GNSS receiver that implements a well-defined position and integrity equation
g) EGNOS signal reception in challenging environments (urban, dense foliage, etc.) is degraded in terms of availability

The afore-mentioned aspects result in the following possible ERTMS/ETCS architectures (see **Figure 10** and **Figure 11**) based on GNSS, considering that both the ETCS on-board and trackside constituents are based on the reference architecture defined in SUBSET-026-2 §2.5.3. These possible architectures have been identified starting from the NGTC analysis and the results of other R&D Projects; further architectures might be identified in future important R&D project such as S2R.

a) Option 1 (**Figure 10**): The VBR consists in four functional blocks; a "**GNSS receiver type I**", a **GNSS Algorithm tailored for railway (named "R-GNSS Algorithm")**, "**Virtual Balise Detector**" and "**Track Database Manager**". The augmentation information can be received by the VBR from three possible channels;
   i) EGNOS SIS from on-board antenna / receiver (as it is, no changes proposed)
   ii) EGNOS augmentation from EDAS through the "**Augmentation dissemination**" (EGNOS augmentation information is received though the Space segment on EGNOS standard ground segment network. The augmentation information is then forwarded to the "Augmentation Dissemination" functional block responsible for forwarding the information to the on-board through the RBC)
   iii) EGNOS augmentation from SBAS enabled GNSS receiver through the "**Augmentation dissemination**" and installed at the RBC constituent (EGNOS augmentation is received from the Space Segment through the "Augmentation Dissemination" functional block which is equipped with a standard receiver. Then this information is forwarded to the on-board through the RBC)

b) Option 2 (**Figure 11**): The VBR consists in four functional blocks; a "**GNSS receiver type II**", a "**Position mapping and monitoring checks**", "**Virtual Balise Detector**" and "**Track Database Manager**". The augmentation information can be obtained by the VBR from three possible channels;
   i) EGNOS SIS from on-board antenna / receiver,
   ii) EGNOS augmentation from EDAS through the "**Augmentation dissemination**"
   iii) EGNOS augmentation from SBAS enabled GNSS receiver through the "**Augmentation dissemination**" installed at the RBC constituent

Note that with regard to the on-board constituent, the VBR architecture options described below are based on the ERTMS/ETCS reference architecture defined in the context of NGTC ([8] section 3.2 Figure 3-1).

<u>The first option:</u>

The VBR consists in four functional blocks;

- "**GNSS receiver type I**",
- "**R-GNSS Algorithm**",
- "**VBD**" and
- "**Track database manager**".

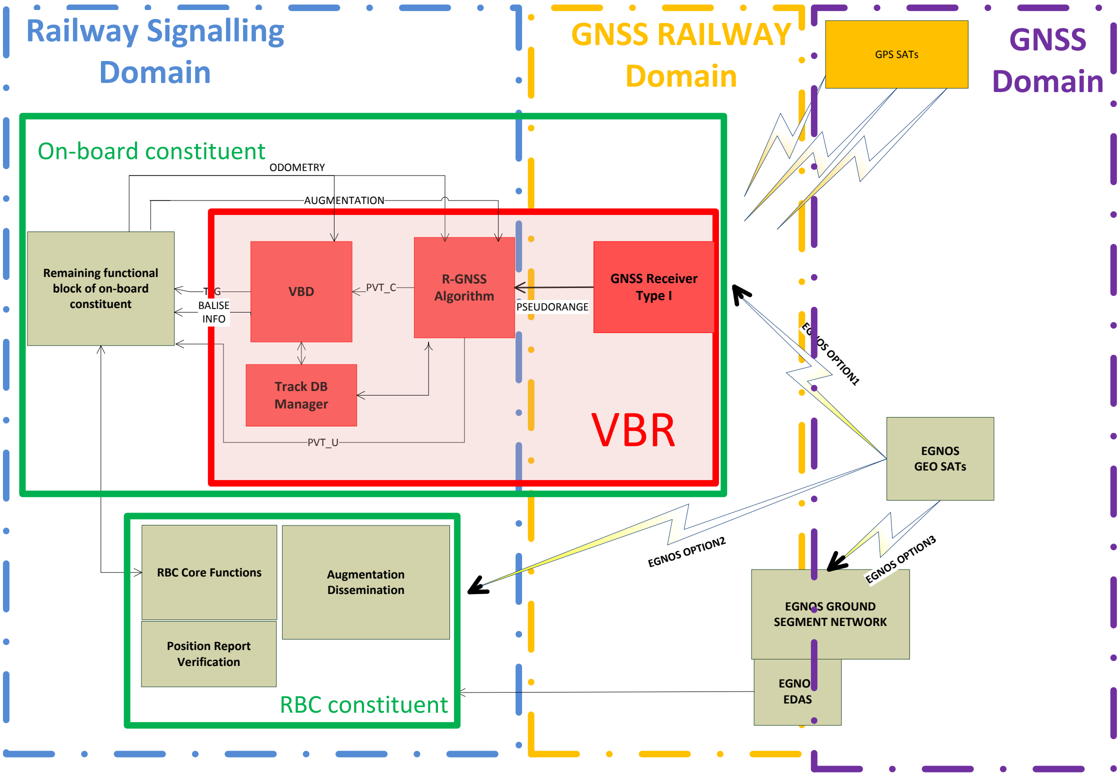


Figure 10: Possible architectures based on option 1 for using GNSS / SBAS in ERTMS / ETCS

The "**GNSS receiver type I**" processes EGNSS SIS and outputs pseudorange/carrier phase measurements and navigation data to the functional block "**R-GNSS Algorithm**". It should also be compliant to the MOPS for the railway environment (still to be defined, it is outside the scope of the STARS project). This functional block does not receive any signalling information (e.g. odometry, track database) or GEO information for the case of augmentation provided via RBC.

The receiver is outputting the pseudorange (and other raw data) that will be used by "**R-GNSS Algorithm**".

The functional block "**R-GNSS Algorithm**" implements GNSS PVT algorithms specific to the railway environment; the output should be the unconstrained PVT[1] (e.g. 3D PVT) as well as constrained 1D position information and relative ATPL and CTPL by making use of the track database information. This functional block must use augmentation information. It also implements fault detection and exclusion algorithms to identify when local effects may lead to unbounded position errors by also using SIL4 odometry information based on the multi-sensors (e.g. IMU) available on the SIL 4 on-board constituent. It should also be compliant to the MOPS for the railway environment (still to be defined, is outside the scope of the STARS project).

The "**VBD**" carries out at least the following functions: ([11] section 3.2):

a. "It uses the constrained PVT and the track database info related to pre-known virtual balise positions in order to declare virtual balise detection.

[1] This type of PVT is required, for example, at Power-On for allowing RBC to locate the train in the limited area under its control: the train is located at Station X instead of Station Y.

b. It also provides the following information to the ETCS on-board kernel when a balise passage occurs:
   i) Time / odometer stamp of the detected virtual balise centre and virtual balise detection accuracy for resetting the confidence interval by the position/linking function (refer to "BALISE INFO" in **Figure 10**); and
   ii) Balise telegram content (user bits) (refer to "TLG" in **Figure 10**)
c. Guarantees delivery of virtual balises in the correct sequence.

The "**Track Database Manager**" is a Module that provides services for reading and updating track database information based on the information received from the wayside. The description of the functional requirements of this Module as well as of the track database format and algorithms are outside the scope of STARS; these details will be part of other future projects such as S2R.

The second option:

The VBR consists in four functional blocks:

- "**GNSS receiver type II**",
- "**Position mapping and monitoring checks**"
- "**VBD**" and
- "**Track Database Manager**".

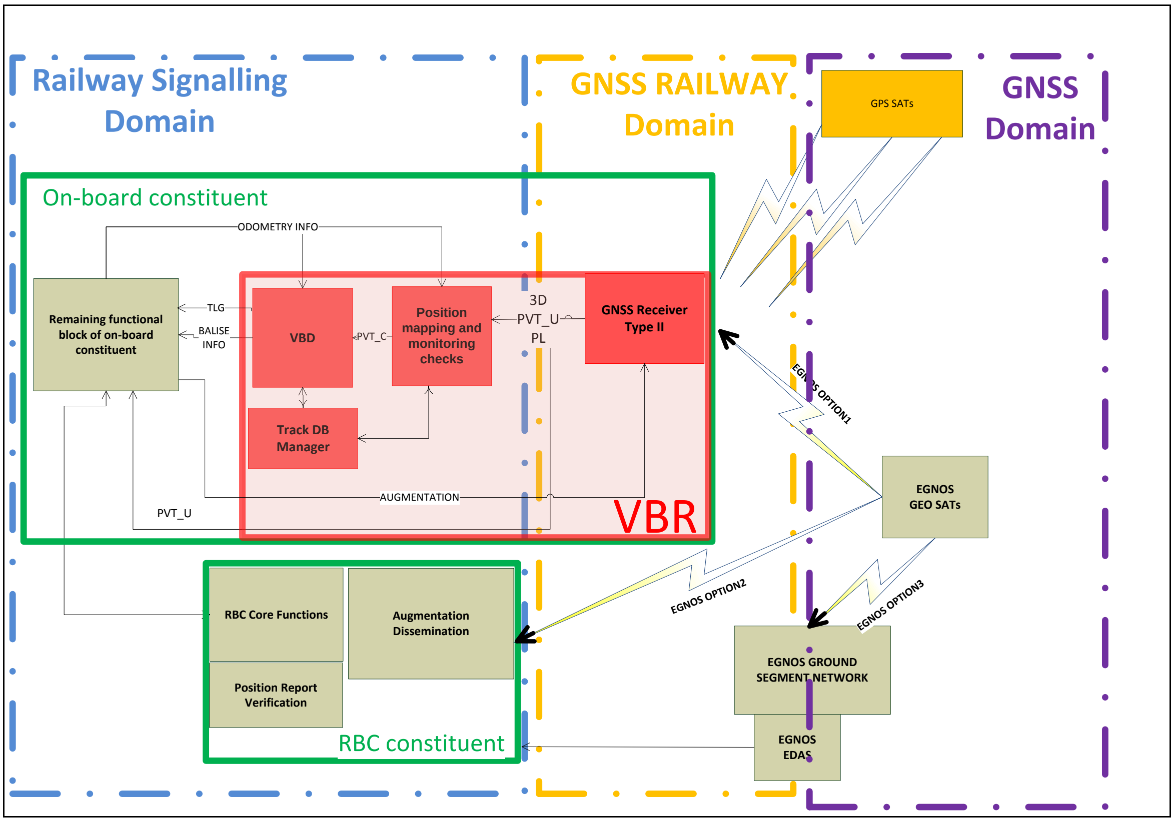


Figure 11: Possible architectures based on option 2 for using GNSS / SBAS in ERTMS / ETCS

The “**GNSS receiver type II**” processes GNSS SIS and outputs unconstrained 3D PVT and the related PL to the functional block “**Position mapping and monitoring checks**”. It should also be compliant to the MOPS for the railway environment (still to be defined, is outside the scope of the STARS project). The “**GNSS receiver type II**” does not receive any signalling information (e.g. odometry, track database); however it does receive GNSS information and augmentation (e.g. augmentation provided via RBC or from on-board GNSS antenna / receiver). The GNSS receiver might incorporate internal hybridization techniques in order to achieve the expected performances.

The “**Position mapping and monitoring checks**” functional block takes care of mapping the unconstrained 3D PVT to a 1D constrained PVT by using track database information in order to feed it to the **VBD**. The algorithm that describes the methodology to map the 3D PVT into 1D PVT and the relative PL into ATPL and CTPL should also be defined in the MOPS for the railway environment. Moreover, this functional block implements fault detection and exclusion RAIMS algorithms to identify when local effects may lead to unbounded position errors.

The “VBD” and “Track Database Manager” are two functional blocks that are identical for the afore-mentioned two reference architectures.

In the context of ERTMS/ETCS railway applications, although the augmentation of GNSS by SBAS is considered in order to increase integrity of the position information coming from GNSS on its own, the achieved integrity level regarding position information delivered by GNSS complemented with SBAS is still not enough for SIL 4 level required by ERTMS/ETCS context ([8], [11]). To this end, **a track-side position report verification** block is included in the ETCS trackside (RBC constituent) in order to verify train position validity with other means thus increasing train position integrity together with availability to satisfy the requirements.

Moreover, given unavailability of EGNOS GEO satellites signal in challenging conditions such as urban environments or some regional areas, an additional functional block named “**Augmentation dissemination**” shall be present at the RBC. In fact, some first measurements relative to availability of EGNOS SIS reception on-board the train, lead to an approach that distributes this information to each train individually over the ETCS radio airgap through the RBC. The augmentation information required by the “Augmentation dissemination” functional block can be obtained either by SBAS enabled GNSS receivers installed at the RBC, or by the SBAS ground centre facility via an EDAS interface compliant with CENELEC standard EN 50159. The augmentation information is transferred to each train by means of EuroRadio communication protocol.

5.3 LOCAL ENVIRONMENTAL CONDITIONS

Local environmental conditions in the railway context are especially challenging and diverse with respect to the civil aviation context where GNSS technology complemented with GBAS or SBAS is applied and widely documented through extensive literature work and certified standards [9]. Dedicated landing spaces are available for aviation making the reception environment favourable in terms of open sky visibility and hardly prone to multipath and interference due to the controllable nature of the environment, whereas railway lines are omnipresent in local and regional lines, in urban and rural context, easily accessible by the public and easily exposed to multipath, intentional and unintentional interference, jamming, spoofing and meaconing.

The augmentation of GNSS by SBAS is considered in order to increase integrity of the position information coming from GNSS on its own, and the accuracy figures. The augmentation information indicates both correction and integrity information that is provided to a GNSS user receiver in order to improve position accuracy and compute a protection level, acting as a bound on the position error. However, due to the nature of the railway environment, this type of augmentation is only effective to limit the impact of global threats or/and global propagation environment such as system threats (GNSS satellites transmitted SIS), and ionospheric or tropospheric effects. On the other hand, unlike in the aviation domain, local environmental conditions in the railway context have a considerable role in GNSS performance degradation in terms of both integrity and availability.

Examples of local feared events that would be taken into account in railways are

- Excessive ionospheric scintillation, see §3.3.2.16 in [10]
- Excessive troposphere, see A4.2.4 in [9]
- Excessive electromagnetic interference from RF sources (unintentional)
- Excessive electromagnetic interference from jamming (intentional)
- Spoofing (intentional)
- Shadowing
- Multipath
- Multipath with Non-line of sight conditions

Moreover, the augmentation system must also implement monitoring techniques to cope with System Feared Events such as

- Loss of signal
- Signal distortion (evil waveform)
- Code-carrier incoherency satellite induced code-carrier divergence
- SIS step error (incl. clock jump)
- SIS ramp error (incl. clock drift)
- Jump in inter-frequency hardware bias
- Drift in inter-frequency hardware bias
- IODE anomaly
- Erroneous ephemeris
- Noisy ephemeris
- Corrupted navigation message

Regarding local environmental conditions in the railway context, as documented in [12] , it has been noted in many projects that EGNOS reception is particularly problematic in challenging, urban-like conditions, making availability of EGNOS SIS to the on-board hardly possible. This specific issue can be avoided by relegating to the RBC the function of receiving EGNOS augmentation information.

On the other hand, due to the core nature of GNSS position information, the same strategy cannot be adopted to improve GNSS SIS reception at the on-board unit. Instead, mitigation and verification strategies are necessary; one of the solutions is to use Multiconstellation.

Characterization of such local feared events will be performed in [13] based on the data collected and processed in WP4 activities.

Mitigations to these system and local feared events will be outlined in [14] after the GNSS SIS Characterization.

5.4 Resulting Architecture

This section presents a high level trade-off analysis of the possible reference architectures outlined in section 5.2 (represented by **Figure 10** and **Figure 11**). In particular, regarding EGNOS augmentation information which can be received by the VBR using the three afore-mentioned means in section 5.2, it is worth saying that:

i) EGNOS SIS from on-board antenna / receiver is subject to continuous interruption of signal reception depending on the local environment conditions (see [12] section 5.3), as well as safety and security issues during the SIS transmission or

ii) EGNOS augmentation from EDAS through an internet connection (EDAS) with the RBC constituent. EDAS interface with RBC will need adaptation in order to meet safety and security needs for the railway domain or
iii) EGNOS augmentation from SBAS enabled GNSS receiver through the "**Augmentation dissemination**", installed at the RBC constituent is subject to safety and security issues during the SIS transmission.

From above we can select the EGNOS Dissemination option as received from "railway EDAS channel" through the "Augmentation dissemination", installed at the RBC constituent. Thus, two architectures are recommended to represent the reference architecture for using GNSS augmented by SBAS in ERTMS / ETCS. The two reference architectures are the following and are based on *Figure 10* and *Figure 11* respectively:

Option 1: The VBR consists in four functional blocks; a "**GNSS receiver type I**", a "**R-GNSS Algorithm**", "**Virtual Balise Detector**" and "**Track database manager**".

Option 2: The VBR consists in four functional blocks; a "**GNSS receiver type II**", a "**Position mapping and monitoring checks**", "**Virtual Balise Detector**" and "**Track database manager**".

In the following, a non-exhaustive description of some properties of both options is reported.

In *Option 1*:

a) The "**R-GNSS Algorithm**" is the functional block specifically designed to take advantage of the track database. This block might be ad hoc designed for railway environment.
b) The "**GNSS receiver type I"** is outputting the pseudorange (and other raw data) that will be used by "R-GNSS Algorithm" tailored for railway.
c) "**R-GNSS Algorithm**" could perform a direct map-matching, based on pseudorange, in the Position domain.
d) Direct computation of ATPL and CTPL is performed from the "**R-GNSS Algorithm**" using PVT algorithm constrained to 1D railway line based on the received augmentation information.
e) Cross checking between ERTMS/ETCS info such as odometry on one hand, and GNSS / SBAS info at pseudorange level on the other, is possible. It is to be evaluated the advantages of such cross checking for mitigating local feared events through RAIM algorithms.
f) Enabling loose coupling of certified sensors already installed on the train (odometry SIL 4) at the position domain level.

In *Option 2*,

a) The output of the "**GNSS receiver type II**" block is the 3D PVT and 2D PL. Please, note that this receiver would be a receiver compliant with the Railway MOPS. The Railway MOPS will be defined in the context of other future R&D Projects such as S2R.
b) The "Position mapping and monitoring checks" functional block, by using the track database and the GNSS 3D PVT, performs the following tasks:
    i) Projecting the unconstrained 3D position onto the 1D railway line to compute the constrained position
    ii) Computing corresponding ATPL and CTPL after projection
    iii) Enabling loose coupling of certified sensors already installed on the train (odometry SIL 4, or other sensors) at the position domain level

c) The EGNOS augmentation information received through the EuroRadio channel must be propagated to "**GNSS receiver type II**"; in this case, the interface with the **GNSS receiver type II** must also take into account this input flow of data. The behaviour of the "**GNSS receiver type II**" in the case of loss of augmentation data must be outlined to allow the implementation of the required defensive technique in the railway domain.

The certification process of the "GNSS receiver type II" in the GNSS domain can be completed based on the railway MOPS without the interaction with the Signalling System (once the Railway MOPS has been defined and assessed for railways applications); therefore, the certification process of the on-board constituent would be less complex than Option 1. However, the certification process in the Railway Domain must still address the computation of the constrained PVT, ATPL and CPTL and defensive techniques based on SIL 4 Odometry. In both cases, the algorithms for computing Constraint PVTs must be described and be part of the Railways MOPS.

In both cases we have taken into account the need of a clear separation between ETCS Railway Domain and GNSS Railway Domain, in order to make the certification process easier.

The functional block VBR should be implemented in a SIL4 platform.

5.5 System Boundaries

It was agreed that, in the context of STARS, the GNSS SIS interoperability interface, from an ETCS point of view, shall be the GNSS SIS airgap and the output of EDAS. The definition of the interfaces inside on-board and RBC constituents is outside the scope of STARS and will be done in other future R&D projects such as S2R.

For the architecture based on option 1, the system boundaries between GNSS railway domain and railway signalling domain is at ""**GNSS receiver type I**"" output through raw data complemented by the part of the tailored algorithm function dealing with position equation and integrity equation .

For the architecture based on option 2, the system boundaries between GNSS railway domain and railway signalling domain is at "GNSS receiver type II" output through unconstrained 3D PVT and PL.

5.6 Performance allocation between ERTMS/ETCS and GNSS based on SBAS

Given the diverse nature of the mission profiles in the railway environment and the possibility that additional mission profiles might be needed for the start of mission and driving under movement authority, a preliminary performance allocation between ERTMS/ETCS and GNSS based on SBAS is carried out in (see [8] section §3.4); this performance allocation has been done with the objective of meeting a SIL4 performance of the "Virtual Balise Function Failure", and therefore a failure rate of 10^{-9} h^{-1} (see§5.4). It is assumed in that instance that the failure rate of GNSS position with augmentation is lower than $5*10^{-6}$ h^{-1} and consequently a requirement on the independent source for the control of safety bound provided by GNSS[2] is to be lower than $2*10^{-4}$ h^{-1} as analysed in the Operational Scenarios Hazard Analysis done in [8] section §2. This quantitative hazard rate has to be fulfilled by the proposed architectures defined in section §5.4 and by the evolutions of GNSS based EGNOS services. These evolutions of GNSS based EGNOS services are required to meet the performance and safety requirements in the railway environment [14].

2 Independent means that the "control of the safety bound" shall be freedom from any mechanism which can affect the correct operation of GNSS signal with augmentation as a result of either systematic or random failure.

In fact, the failure rate of GNSS position with augmentation is the sum of hazards coming from GNSS MI due to unbounded errors caused by system and local feared events. Moreover, the failure rate of GNSS MI due to unbounded errors caused by system feared events is the product of GNSS MI caused by system feared events and the failure of GNSS Diagnostic / Augmentation system coming from EGNOS.

In this respect, a hazard analysis of the current ERTMS/ETCS is presented in section §6.1 and additional hazards coming from GNSS use according to the reference architecture are analysed. It shall then be verified how the augmentation / diagnostic functions implemented by the augmentation system and on-board can limit these hazards and failure rate to satisfy the top gate safety requirements [14].

6 HAZARD ANALYSIS OF REFERENCE ARCHITECTURE

In the following, a brief hazard analysis of the current ERTMS / ETCS is performed based on UNISIG SUBSET-088 v.3.5.0 [15]. In addition, a brief summary of additional hazards is presented due to the introduction of the virtual balise reader in ERTMS / ETCS according to the two reference architectures that are considered in this document.

6.1 HAZARD ANALYSIS OF CURRENT ERTMS/ETCS

The ETCS core hazard ("exceedance of safe speed or distance as advised to ETCS") THR of 2.0*1e-9 / hour is apportioned equally between the following as defined in UNISIG SUBSET-088 v.3.5.0 [15]:

a) On-board functions (trusted parts)

b) Trackside functions (trusted parts)

c) Transmission functions (un-trusted parts)

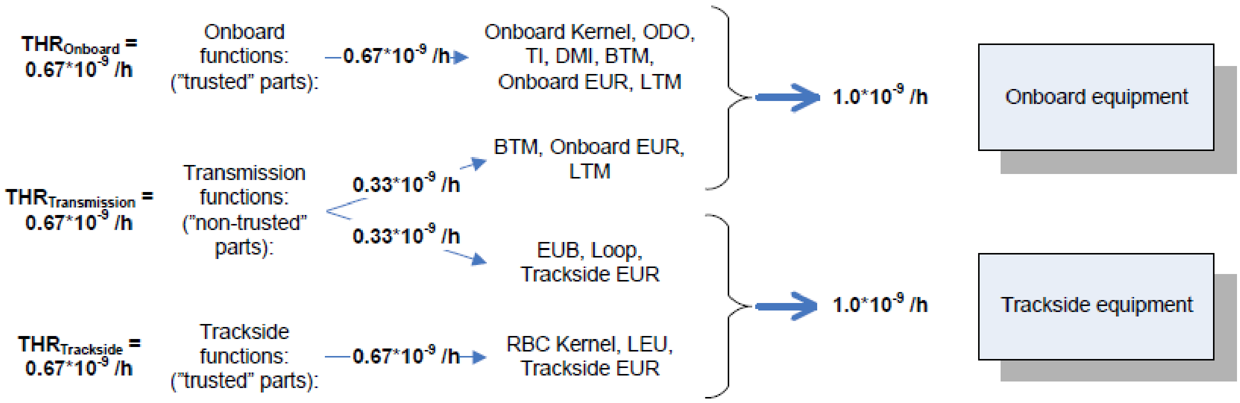


Figure 12: THR apportionment of ETCS equipment (from Subset 088 v3.5 Part 3 [15])

Gate/Event	Description	Apportioned THR	Justification
THR_ONBOARD	On-board functions (trusted parts)	**6.7*1e-10/hour**	Initial allocation of ~1/3 of ETCS core hazard
THR_TRACKSIDE	Trackside functions (trusted parts)	**6.7*1e-10/hour**	Initial allocation of ~1/3 of ETCS core hazard
THR_TRANSMISSION	Transmission functions (non-trusted parts)	**6.7*1e-10/hour**	Initial allocation of ~1/3 of ETCS core hazard

Table 1: Starting point for THR apportionment considering GNSS introduction to ERTMS/ETCS system

Transmission functions as shown in **Figure 12**, can effectively be divided into THR_{RTX} "radio sub-system hazards" and "balise sub-system hazards" THR_{BTX} as noted in [15], where the "balise sub-system hazards" covers around 100% of the hazards related to transmission functions which means **6.6*1e-10/hour** and the "radio sub-system hazards" shall have a negligible effect (around **1.0*1e-11/hour** as specified in §9.2 in [15] and found in [16]).

Under THR_TRANSMISSION, system-level transmission hazards related to “balise sub-system hazards” (later identified by gate THR-BTX) are defined in (§9.3.6 in [15]) to be divided into:

a) TRANS-BALISE 1 – Incorrect balise group message received by on-board Kernel functions as consistent (Corruption)

b) TRANS-BALISE 2 – Balise group not detected by on-board Kernel functions (Deletion)

c) TRANS-BALISE 3 – Inserted balise group message received by on-board Kernel functions as consistent (Insertion / Cross talk)

6.2 Nature of Additional Hazards arising from usage of GNSS according to reference architecture

This section is also based on the NGTC results and summarizes the preliminary results reached in the context of STARS. Further activities will be carried out in other R&D projects such as S2R.

Due to the introduction of virtual balise in the current ERTMS/ETCS, a number of hazards are of a different nature with respect to the use of physical balise detection:

a) The airgap is the GNSS signal in space, with a different propagation environment, signal properties and system hazards (GNSS such as GPS/Galileo and SBAS such as EGNOS including their inherent ground segment components) with respect to BTM airgap.
b) The virtual balise detection mechanism is no longer performed directly but needs a projection on a 1D track line segment.
c) The use of on-board GNSS antenna (s) instead of Eurobalise and BTM antenna (s) implies different signal properties, and local propagation environment including multipath, direct and non-direct line of sight and vulnerability to jamming, interference and spoofing.
d) Linking information and virtual balise information are not independent as they originate from the RBC, removing inherent protections of ETCS [16].
e) Track database process should be suitable for SIL4 system implementation and should take into account the accuracy of the measurements.
f) Response time of ERTMS system less than 1 second and GNSS / SBAS TTA are different requirements and therefore it is necessary to adopt a new mechanism to satisfy the requirements and limitations coming from both systems (check 9.4.1)

7 APPORTIONMENT OF THRS TO ELEMENTS OF NEW REFERENCE ARCHITECTURE

Regarding the ETCS core hazard equal apportionment into on-board functions, trackside functions and transmission functions as described in section §6, the following novelties due to the selection of the two reference architectures based on the virtual balise concept are worth noting:

a) On-board functions
b) Trackside functions
c) Most of the transmission hazards are now the result of "virtual balise sub-system hazards" where the TRANS-BALISE 1 corruption hazards are negligible due to the very high level of protection provided by CRCs and safety coding during both transmission from trackside to on-board and during on-board storage of the balise group message. In fact, telegram content for virtual balises is pre-known.

Based on the study carried out in [11], [16] and [17] in terms of (a) the identified hazard risks due to the introduction of the virtual balise concept, (b) the ERTMS Fault Trees, (c) the ERTMS System Functional Hazard Analysis with the virtual balise sub-system (d) the identified operational scenarios (e) the underlying assumptions regarding THR of GNSS independent diagnostics integrity risk (**3.3*1e-5 /hour** of dangerous failures per hour), and (f) exposure of missions to specific operational scenarios, the preliminary set of requirements regarding THR figures for GNSS integrity risk are summarized in **Table 2** (§8.2 in [16] with details in §7.7 in [16]) given that the integrity concept is related to hazardous misleading information and is defined as in the following. However, it is worth pointing out that further activities will be carry out in other R&D projects such as S2R.

For Staff Responsible (SR) and Movement Authority (MA), the integrity concept is defined as:
a) Along-track position error (ATPE) > Along-track protection level (ATPL)
AND
b) Time To Alarm (TTA) > requirement.

For Start of Mission (SoM), the integrity concept is defined as:
a) Horizontal position error (HPE) > Horizontal protection level (HPL)
AND
b) Time To Alarm (TTA) > requirement.

Availability target figures related to GNSS integrity performance that should eventually be guaranteed by a SBAS considering each railway operational scenario can be derived from the system availability requirement coming from [18] and [19], by making an apportionment according to mission profiles (percentage of time the mission is in a particular operational scenario). These requirements are summarized in terms of:
A_{HW} = 0,999905
$A_{HW\_TrackSide}$ = 0,9999099
$A_{HW\_OnBoard}$ = 0,9999959

In particular, 3% of the 1 hour journey time is in SR mode [15] (§7.2.1.5), and SoM happens at most twice in an hour with a maximum SoM time duration of 4 minutes [15] (§5.2.1.3), therefore 2*4*100/60= 13.333% of the 1 hour journey time can be considered to be in SoM mode. And finally, the result is that the rest of the time which is 83.66% the MA mode is in effect. Multiplying these percentages by the overall system availability requirement A_{HW} yields the availability figures in the following table.

Railway operational scenario	Accuracy	Integrity with TTA requirement	Availability	Continuity
Staff Responsible	+/-20 meters	7.5*1e-6/hour with 10s	2.999715%	NA
Start of Mission	+/-10 meters	1.0*1e-4/hour with 10s	13.332%	NA
Movement Authority	+/-20 meters	7.5*1e-6/hour with 10s	83.659%	NA

Table 2: THR figures for GNSS integrity risk in three railway operational scenarios

It is worth mentioning that summarized THR figures for GNSS integrity risk in **Table 2** originate from the non-trusted parts which are transmission functions assigned mainly to the THR-BTX gate "balise sub-system hazards" (see §6.1).

On the other hand, hazards from the VBR due to failures inside the trusted part of the virtual balise transmission system are an element of the THR-ONBOARD gate which accounts for the on-board functions and as previously reported in section §6, this gate is apportioned a THR of **6.7*1e-10/hour** with a justification coming from a requirement in SUBSET-088 Part 3. For example, the GNSS-VBD hazard coming from the trusted part of the virtual balise transmission system is mentioned in the following tables to consider the architectural elements depicted in the reference architecture options 1 & 2 figures in section §5, however is not accounted in the fault-trees that depict the top hazard gate related to the non-trusted parts of the virtual balise transmission system.

One exception to this has been made regarding hazards from the user GNSS receiver. In fact, even if the user GNSS receiver MI (gate USER-RCVR) is considered in [16] within the trusted parts of the on-board apportionment under VBR hazards, it is included herein under the GNSS integrity risk gate which is a non-trusted part. The reason is that the VBR trusted part is supplier and implementation specific, and therefore impractical to propose fault-trees under that hazard gate. This approach is conservative as the VBR hazards gate shall comprise the USER-RCVR gate as well and will satisfy its assigned THR in any case.

In the following, an initial allocation of these high-level THR figures to elements of the proposed two reference architectures will be presented.

The figures and labels assigned to the hazard gates are based on the reasoning adopted and the fault-trees developed in [11], [16] and [17], however, the novelty resides in a number of steps:

- the identification of the gates as belonging to the functional blocks described in reference architecture options 1 & 2 in section §5,
- the THR allocation to the GNSS receiver type I & II and diagnostic capability according to reference architecture
- an initial allocation of multipath / NLOS and EMI events hazard rates at train antenna
- an initial allocation of FDE diagnostic probability of missed detection

Missing THR figures in [16] that are assigned concrete numbers, and THR figures related to the functional blocks in the reference architecture options 1 & 2 in section §5, have been highlighted in bold in the following tables.

7.1 REFERENCE ARCHITECTURE OPTION 1

Movement Authority (MA) and Staff Responsible (SR)

For a train in mode SR with a valid MA, GNSS integrity risk THR apportionment of **7.5*1e-6** (with **10s TTA**) among the main functional blocks is performed by assigning each identified hazard [16] coming from the **non-trusted** part of the virtual balise transmission system to a functional block based on the described reference architecture option 1 in section §5. The updated fault-tree of gate GNSS-MI relative to the GNSS Integrity risk THR apportionment in SR mode is represented by **Figure 13** where the drawing of hazard gates under USER-MI gate have been omitted for practical reasons in terms of space and avoiding redundancy with respect to the content of [16].

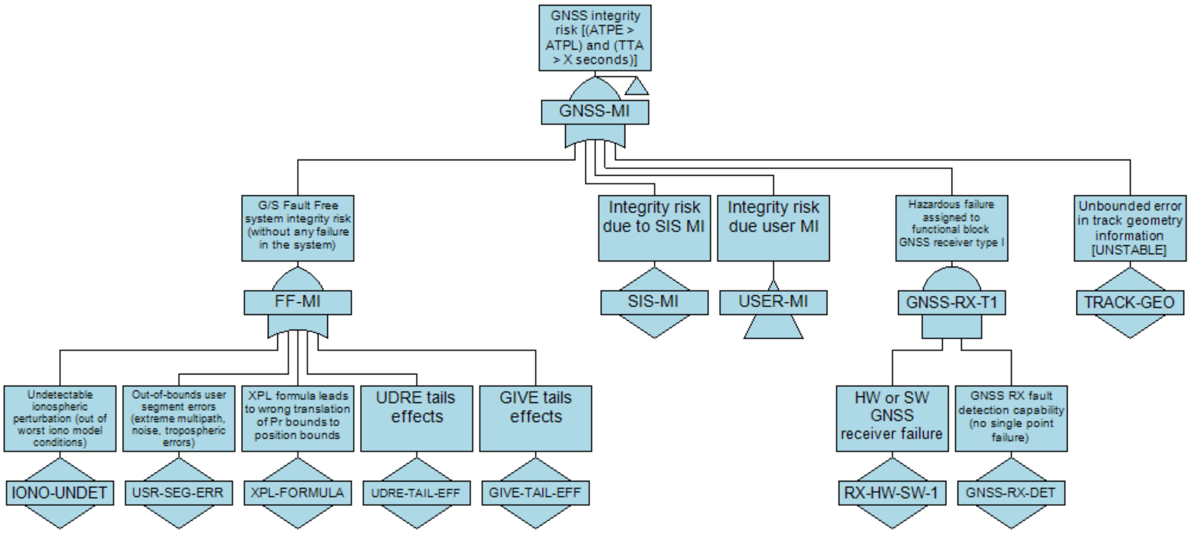


Figure 13: Fault-tree of GNSS integrity risk gate in SR mode and architecture option 1

As a consequence, **Table 3** is filled-in which implies that GNSS MI coming from SIS, user and fault-free MI have to be assessed in terms of EGNOS capability. EGNOS design tailored for the railway environment should consider these values to assess the feasibility of such requirements.

In particular, hazard gates such as IONO-UNDET, USR-SEG-ERR, XPL-FORMULA, UDRE-TAIL-EFF, GIVE-TAIL-EFF, SIS-MI, and USER-MI should be elaborated in terms of constituent lower level hazards and checked if the assigned integrity requirements are feasible together with EGNOS augmentation FDE mechanisms and corresponding performance.

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
GNSS receiver type I	GNSS-RX-T1	Hazardous failure assigned to functional block	+/-20 meters	**THR<2.459 *1e-6 /hour with 10s**	Total THR should amount to **7.5*1e-6 /** hour Total THR amounts to the sum of the lower level gates THR assigned to this functional block. In fact, the hazard gates assigned to the

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
					architectural element GNSS receiver type I, build up a total lower bound of 5.04*1e-6/hour+1e-9/hour
	RX-HW-SW-1	HW or SW GNSS receiver failure (MTBF)	+/-20 meters	**<1e-3/hour**	Implementation dependent
	GNSS-RX-DET	GNSS receiver fault detection capability (no single point failure)	+/-20 meters	**1e-3**	Initial allocation given that detection of HW or SW failure is fairly easy. In fact, this detection capability is relative to hazardous failures that lead to easily identifiable largely inconsistent results. On the other hand, hazardous failures due to GNSS RX type I HW or SW that lead to credible GNSS performance are diagnosed by the USER-MI gate including the relative diagnostics. The detection performance is expressed in terms of missed detection probability
R-GNSS Algorithm		Hazardous failure assigned to functional block	+/-20 meters	**5.04*1e-6 /hour with 10s**	Total THR amounts to the sum of the lower level THRs assigned to this functional block. It is this block that can provide among other functionalities, GNSS independent diagnostics (**3.3*1e-5** as mentioned in beginning of section §7)
	IONO-UNDET	Undetectable ionospheric perturbation (out	+/-20 meters	4.8*1e-7 /hour with	1/5 of apportioned THR associated to FF-MI and Initial

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
		of worst iono model conditions)		10s	allocation of ~1/3 of GNSS-MI to FF-MI (2.4*1e-6/hour) [16]
	USR-SEG-ERR	Out-of-bounds user segment errors (extreme multipath, noise, tropospheric errors)	+/-20 meters	4.8*1e-7 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	XPL-FORMULA	XPL formula leads to wrong translation of Pr bounds to position bounds	+/-20 meters	4.8*1e-7 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	UDRE-TAIL-EFF	UDRE tails effects	+/-20 meters	4.8*1e-7 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	GIVE-TAIL-EFF	GIVE tails effects	+/-20 meters	4.8*1e-7 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	SIS-MI	Integrity risk due to SIS MI	+/-20 meters	2.4*1e-6 /hour with 10s	Initial allocation of ~1/3 of GNSS-MI to SIS-MI [16]
	USER-MI	**Integrity risk due to user MI**	+/-20 meters	**2.4*1e-7 /hour** with 10s	Expected integrity risk due to the sum of the lower level THRs Z1 AND Z2
	USER-MPATH	Multipath and NLOS at train antenna	+/-20 meters	**1.2*1e-3 /hour**	Initial allocation to be checked by actual field data
	MPATH-DIAG	Diagnostic (FDE / mitigation) and local feared event detection with other on-board constituent sensors	+/-20 meters	**1.0e-4**	Hazard detection performance in terms of probability of missed detection
	USER-FE-MPATH	Multipath at train antenna not bounded by σ_multipath	+/-20 meters	**Z1 = 1.2*1e-7 /hour with 10s**	Initial allocation of ~1/2 of USER-MI Z1 AND Z2 should add up to parent gate USER-MI
	USER-EMI	Interference near train	+/-20 meters	**1.2*1e-3 /hour**	Initial allocation to be checked by

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
					actual field data
	EMI-DIAG	Diagnostic (FDE / mitigation) and local feared event detection with other on-board constituent sensors	+/-20 meters	**1.0e-4**	Hazard detection performance in terms of probability of missed detection
	USER-FE-NOISE	PR noise due to interference near train not bounded by σ_noise	+/-20 meters	**Z2 =1.2*1e-7 /hour with 10s**	Initial allocation of ~1/2 of USER-MI Z1 AND Z2 should add up to parent gate USER-MI
Virtual Balise Detector	GNSS-VBD	Hazardous failure assigned to functional block	+/-20 meters	1.0*1e-9 / hour	VBD is a function that is still to be described and shared, however since it is a function implemented on a SIL 4 platform, it should also be SIL4
Track Database Manager	TRACK-GEO	Hazardous failure assigned to functional block due to unbounded error in track geometry information	+/-20 meters	1.0*1e-9 / hour	Initial SIL4 allocation but use of track geometry is still to be defined [16]

Table 3: THR apportionment among elements of reference architecture based on Option 1 for requirements due to MA and SR operational scenarios

Start of Mission (SoM)

In SoM, GNSS integrity risk THR apportionment of **1.0*1e-4** (with **10s TTA**) among the main functional blocks is performed by assigning each identified hazard [16] coming from the non-trusted part of the virtual balise transmission system to a functional block based on the described reference architecture option 1 in section §5. The updated fault-tree relative to gate GNSS-2-MI relative to the GNSS Integrity risk THR apportionment in SoM mode is considered for 2-dimensional horizontal positioning, so that there is no hazard coming from the use of track geometry information and is represented by Figure 14 where the drawing of hazard gates under USER-MI gate have been omitted for practical reasons in terms of space and avoiding redundancy with respect to the content of [16].

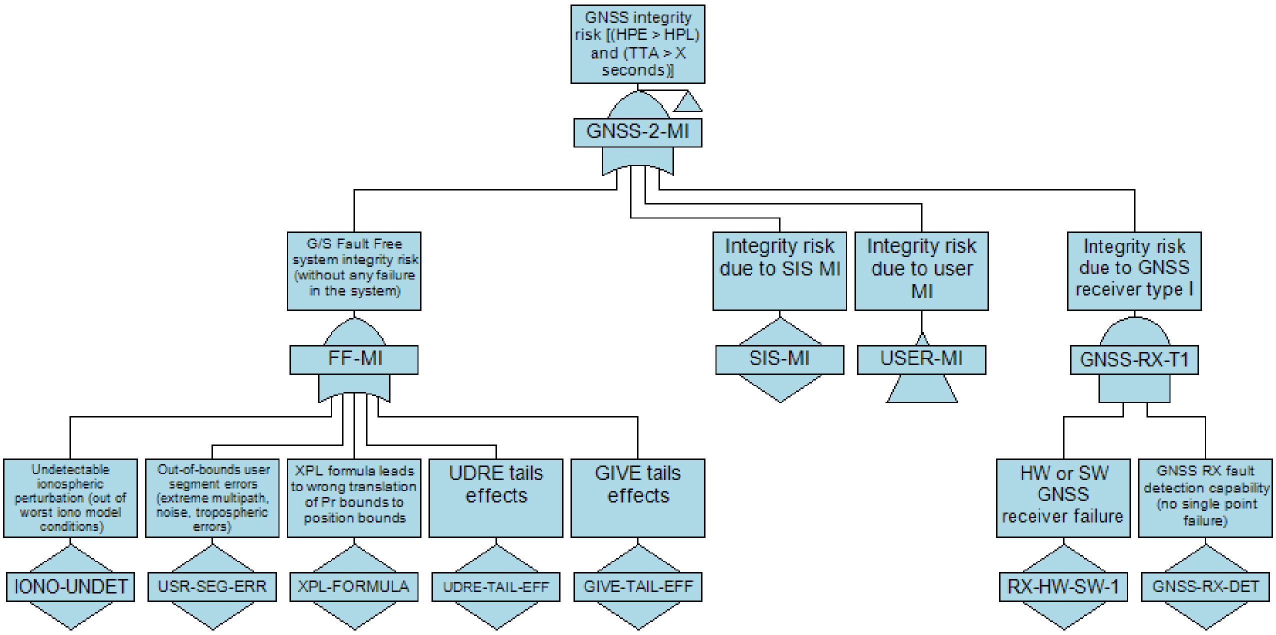


Figure 14: Fault-tree of GNSS integrity risk gate in SoM mode and architecture option 1

As a consequence, **Table 4** is filled-in which implies that GNSS MI coming from SIS, user and fault-free MI have to be assessed in terms of EGNOS capability. EGNOS design tailored for the railway environment should consider these values to assess the feasibility of such requirements.

In particular, hazard gates such as IONO-UNDET, USR-SEG-ERR, XPL-FORMULA, UDRE-TAIL-EFF, GIVE-TAIL-EFF, SIS-MI, and USER-MI should be elaborated in terms of constituent lower level hazards and checked if the assigned integrity requirements are feasible together with EGNOS augmentation FDE mechanisms and corresponding performance.

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
GNSS receiver type I	GNSS-RX-T1	Hazardous failure assigned to functional block	+/-10 meters	**THR<3.07* 1e-5 /hour with 10s**	Total THR should amount to **1.0*1e-4 /** hour therefore (**1.0*1e-4 - 6.93*1e-5 = 3.07*1e-5**)
	RX-HW-SW-1	HW or SW GNSS receiver failure (MTBF)	+/-10 meters	**<1e-3/hour**	Implementation dependent
	GNSS-RX-DET	GNSS receiver fault detection capability (no single point failure)	+/-10 meters	**1e-3**	Initial allocation given that detection of HW or SW failure is fairly easy given that hazardous failures of this type that lead to credible GNSS performance are covered by the USER-MI gate. The detection

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
					performance is expressed in terms of missed detection probability
R-GNSS Algorithm		Hazardous failure assigned to functional block	+/-10 meters	**6.93*1e-5 /hour with 10s**	Total THR amounts to the sum of the lower level THRs assigned to this functional block. It is this block that can provide, among other functionalities, GNSS independent diagnostics (**3.3*1e-5** as mentioned in beginning of section §7)
	IONO-UNDET	Undetectable ionospheric perturbation (out of worst iono model conditions)	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI and Initial allocation of ~1/3 of GNSS-2-MI to FF-MI (3.3*1e-5 from [16])
	USR-SEG-ERR	Out-of-bounds user segment errors (extreme multipath, noise, tropospheric errors)	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	XPL-FORMULA	XPL formula leads to wrong translation of Pr bounds to position bounds	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	UDRE-TAIL-EFF	UDRE tails effects	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	GIVE-TAIL-EFF	GIVE tails effects	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	SIS-MI	Integrity risk due to SIS MI	+/-10 meters	3.3*1e-5 /hour with 10s	Initial allocation of ~1/3 of GNSS-2-MI to SIS-MI [16]
	USER-MI	**Integrity risk due to user MI**	+/-10 meters	3.3*1e-6 /hour with 10s	Expected integrity risk due to the sum of the lower level

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
					THRs Z1 AND Z2
	USER-MPATH	Multipath and NLOS at train antenna	+/-10 meters	**1.65*1e-2 /hour**	Initial allocation of ~1/2 of USER-MI to be checked by actual field data
	MPATH-DIAG	Diagnostic (FDE / mitigation) and local feared event detection with other on-board constituent sensors	+/-10 meters	**1.0e-4**	Hazard detection performance in terms of probability of missed detection
	USER-FE-MPATH	Multipath at train antenna not bounded by σ_multipath	+/-10 meters	**Z1 = 1.65*1e-6 /hour with 10s**	Z1 AND Z2 should add up to parent gate USER-MI
	USER-EMI	Interference near train	+/-10 meters	**1.65*1e-2 /hour**	Initial allocation of ~1/2 of USER-MI to be checked by actual field data
	EMI-DIAG	Diagnostic (FDE / mitigation) and local feared event detection with other on-board constituent sensors	+/-10 meters	**1.0e-4**	Hazard detection performance in terms of probability of missed detection
	USER-FE-NOISE	PR noise due to interference near train not bounded by σ_noise	+/-10 meters	**Z2 =1.65*1e-6 /hour with 10s**	Z1 AND Z2 should add up to parent gate USER-MI
Virtual Balise Detector	GNSS-VBD	Hazardous failure assigned to functional block	+/-10 meters	1.0*1e-9 / hour	VBD is a function that is still to be described and shared, however since it is a function implemented on a SIL 4 platform, it should also be SIL4
Track Database Manager	TRACK-GEO	Hazardous failure assigned to functional block due to unbounded error	+/-10 meters	1.0*1e-9 / hour	Initial SIL4 allocation but use of track geometry is still to be defined [16]

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
		in track geometry information			

Table 4: THR apportionment among elements of reference architecture based on Option 1 for requirements due to SoM operational scenario

7.2 REFERENCE ARCHITECTURE OPTION 2

Movement Authority (MA) and Staff Responsible (SR)

In MA and SR, GNSS integrity risk THR apportionment of **7.5*1e-6** (with **10s TTA**) among the main functional blocks is performed by assigning each identified hazard [16] coming from the **non-trusted** part of the virtual balise transmission system to a functional block based on the described reference architecture option 2 in section §5. The updated fault-tree of gate GNSS-MI relative to the GNSS Integrity risk THR apportionment in SR mode is represented by **Figure 15** where the drawing of hazard gates under USER-MI gate have been omitted for practical reasons in terms of space and avoiding redundancy with respect to the content of [16].

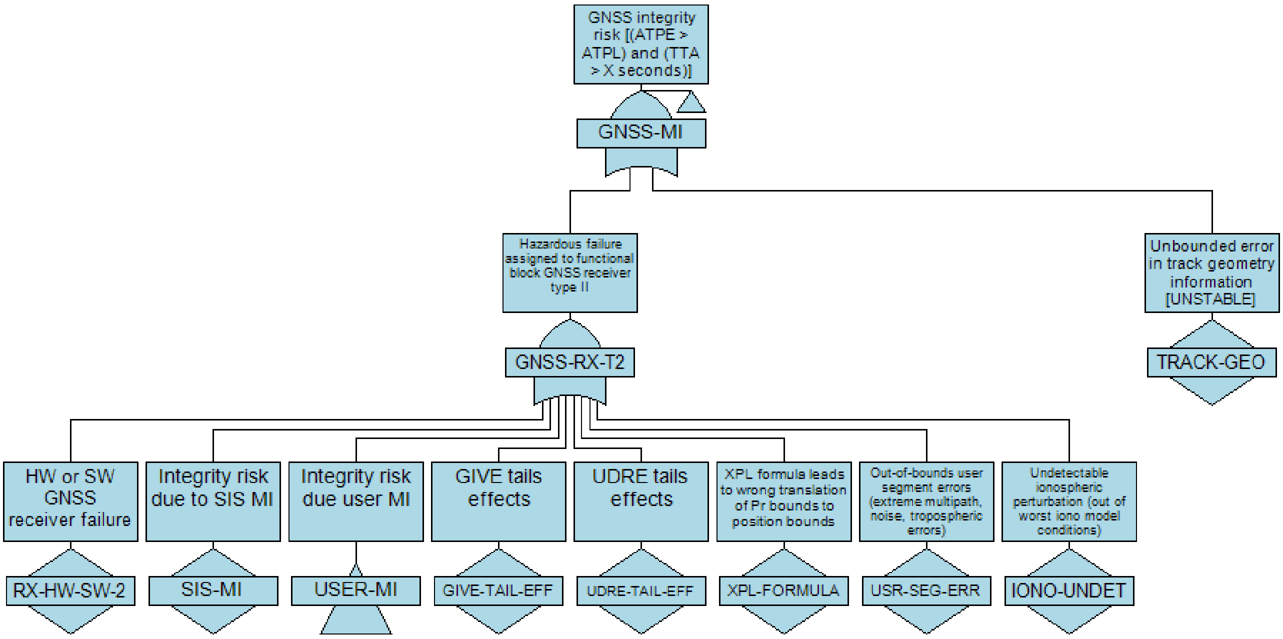


Figure 15: Fault-tree of GNSS integrity risk gate in SR mode and architecture option 2

As a consequence, **Table 5** is filled-in which implies that GNSS MI coming from SIS, user and fault-free MI have to be assessed in terms of EGNOS capability. EGNOS design tailored for the railway environment should consider these values to assess the feasibility of such requirements.

In particular, hazard gates such as IONO-UNDET, USR-SEG-ERR, XPL-FORMULA, UDRE-TAIL-EFF, GIVE-TAIL-EFF, SIS-MI, and USER-MI should be elaborated in terms of constituent lower level hazards and checked if the assigned integrity requirements are feasible together with EGNOS augmentation FDE mechanisms and corresponding performance.

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
GNSS receiver type II	GNSS-RX-T2	Hazardous failure assigned to functional block	+/-20 meters	**7.201*1e-6/hour <THR<7.5*1e-6 /hour with 10s**	Total THR should amount to **7.5*1e-6 /** hour Total THR amounts to the sum of the lower level gates THR assigned to this functional block. In fact, the hazard gates assigned to the architectural element GNSS receiver type II, build up a total lower bound of 7.2*1e-6/hour+1e-9/hour
	RX-HW-SW-2	HW or SW GNSS receiver failure (MTBF)	+/-20 meters	**<(2.99e-7) /hour**	Total THR should amount to **7.5*1e-6 /** hour, therefore RX-HW-SW-2 THR is equal to (7.5-7.201)*1e-6/hour. The RX-HW-SW-2 integrity risk should be lower than 2.99e-7/hour in order to yield a total number that is not higher than 7.5e-6 /hour
	IONO-UNDET	Undetectable ionospheric perturbation (out of worst iono model conditions)	+/-20 meters	4.8*1e-7 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	USR-SEG-ERR	Out-of-bounds user segment errors (extreme multipath, noise, tropospheric errors)	+/-20 meters	4.8*1e-7 /hour with 10s	1/5 of apportioned THR associated to FF-MI and Initial allocation of ~1/3 of GNSS-MI to FF-MI
	XPL-FORMULA	XPL formula leads to wrong translation of Pr bounds to position bounds	+/-20 meters	4.8*1e-7 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	UDRE-TAIL-EFF	UDRE tails effects	+/-20 meters	4.8*1e-7 /hour with 10s	1/5 of apportioned THR associated to FF-MI

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
	GIVE-TAIL-EFF	GIVE tails effects	+/-20 meters	4.8*1e-7 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	SIS-MI	Integrity risk due to SIS MI	+/-20 meters	Y = 2.4*1e-6 /hour with 10s	Initial allocation of ~1/3 of GNSS-MI to SIS-MI [16]
	USER-MI	**Integrity risk due to user MI**	+/-20 meters	2.4*1e-6 /hour with 10s	Expected integrity risk due to the sum of the lower level THRs Z1 AND Z2
	USER-MPATH	Multipath and NLOS at train antenna	+/-20 meters	**1.2*1e-3 /hour**	Initial allocation to be checked by actual field data
	MPATH-DIAG	Diagnostic (FDE / mitigation) and local feared event detection based on GNSS information only	+/-20 meters	**1.0e-3**	Hazard detection performance in terms of probability of missed detection
	USER-FE-MPATH	Multipath at train antenna not bounded by σ_multipath	+/-20 meters	**Z1 = 1.2*1e-6 /hour with 10s**	Initial allocation of ~1/2 of USER-MI Z1 AND Z2 should add up to parent gate USER-MI
	USER-EMI	Interference near train	+/-20 meters	**1.2*1e-3 /hour**	Initial allocation to be checked by actual field data
	EMI-DIAG	Diagnostic (FDE / mitigation) and local feared event detection based on GNSS information only	+/-20 meters	**1.0e-3**	Hazard detection performance in terms of probability of missed detection
	USER-FE-NOISE	PR noise due to interference near train not bounded by σ_noise	+/-20 meters	**Z2 =1.2*1e-6 /hour with 10s**	Initial allocation of ~1/2 of USER-MI Z1 AND Z2 should add up to parent gate USER-MI
Position mapping and monitoring checks	POS-MAP	Hazards due to projection of 3D position to 1D position	+/-20 meters	**1e-9/hour**	It is part of SIL 4 platform, and could provide GNSS independent diagnostics (**3.3*1e-5** as mentioned in beginning of section

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
					§7)
Virtual Balise Detector	GNSS-VBD	Hazardous failure assigned to functional block	+/-20 meters	1.0*1e-9 / hour	VBD is a function that is still to be described and shared, however since it is a function implemented on a SIL 4 platform, it should also be SIL4
Track Database Manager	TRACK-GEO	Hazardous failure assigned to functional block due to unbounded error in track geometry information	+/-20 meters	1.0*1e-9 / hour	Initial SIL4 allocation but use of track geometry is still to be defined

Table 5: THR apportionment among elements of reference architecture based on Option 2 for requirements due to MA and SR operational scenarios

Start of Mission (SoM)

In SoM, GNSS integrity risk THR apportionment of **1.0*1e-4** (with **10s TTA**) among the main functional blocks is performed by assigning each identified hazard [16] coming from the **non-trusted** part of the virtual balise transmission system to a functional block based on the described reference architecture option 2 in section §5. The updated fault-tree relative to gate GNSS-2-MI relative to the GNSS Integrity risk THR apportionment in SoM mode is represented **Figure 16** where the drawing of hazard gates under USER-MI gate have been omitted for practical reasons in terms of space and avoiding redundancy with respect to the content of [16].

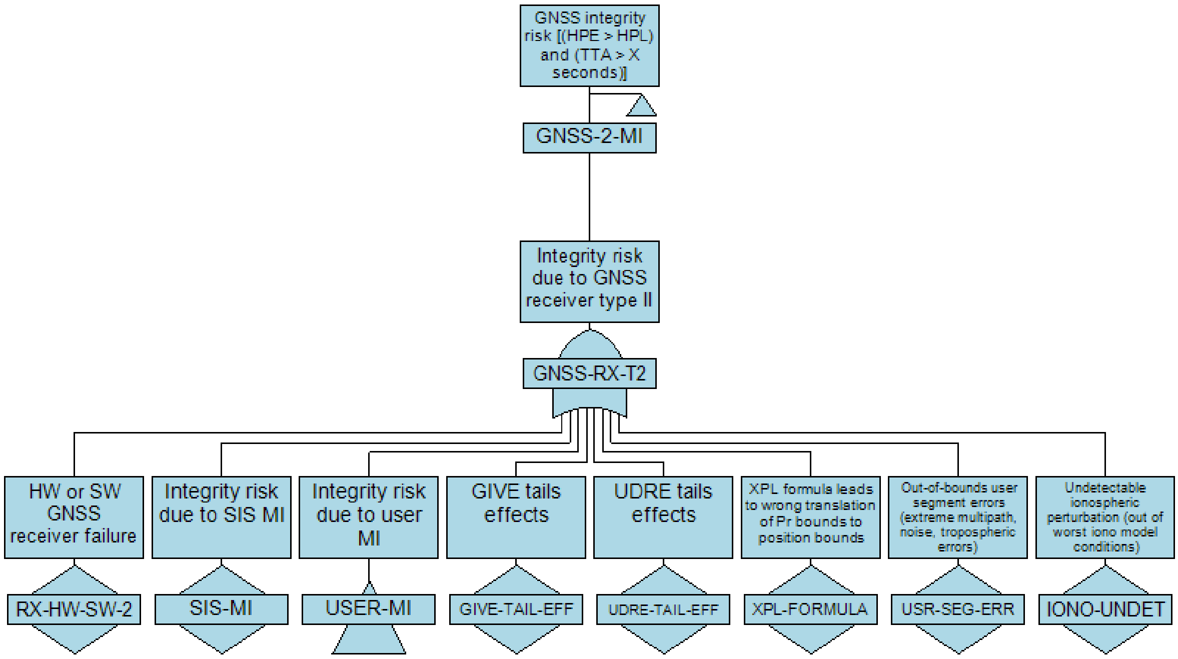


Figure 16: Fault-tree of GNSS integrity risk gate in SoM mode and architecture option 2

As a consequence,

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
GNSS receiver type II	GNSS-RX-T2	Hazardous failure assigned to functional block	+/-10 meters	**9.9*1e-5<THR<1.0*1e-4 /hour with 10s**	Total THR should amount to **1.0*1e-4 /** hour Total THR amounts to the sum of the lower level THRs assigned to this functional block
	RX-HW-SW-2	HW or SW GNSS receiver failure (MTBF)	+/-10 meters	**<1e-6 /hour**	Total THR should amount to **1.0*1e-4 /** hour and therefore RX-HW-SW-2 THR is equal to (1-0.99)*1e-4/hour
	IONO-UNDET	Undetectable ionospheric perturbation (out of worst iono model conditions)	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI and Initial allocation of ~1/3 of GNSS-2-MI to FF-MI (3.3*1e-5 from [16])
	USR-SEG-ERR	Out-of-bounds user segment errors (extreme	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
		multipath, noise, tropospheric errors)			
	XPL-FORMULA	XPL formula leads to wrong translation of Pr bounds to position bounds	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	UDRE-TAIL-EFF	UDRE tails effects	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	GIVE-TAIL-EFF	GIVE tails effects	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	SIS-MI	Integrity risk due to SIS MI	+/-10 meters	3.3*1e-5 /hour with 10s	Initial allocation of ~1/3 of GNSS-2-MI to SIS-MI [16]
	USER-MI	**Integrity risk due to user MI**	+/-10 meters	3.3*1e-5 /hour with 10s	Expected integrity risk due to the sum of the lower level THRs Z1 AND Z2
	USER-MPATH	Multipath and NLOS at train antenna	+/-10 meters	**1.65*1e-2 /hour**	Initial allocation to be checked by actual field data
	MPATH-DIAG	Diagnostic (FDE / mitigation) and local feared event detection based on GNSS information only	+/-10 meters	**1.0e-3**	Hazard detection performance in terms of probability of missed detection
	USER-FE-MPATH	Multipath at train antenna not bounded by σ_multipath	+/-10 meters	**Z1 = 1.65*1e-5 /hour with 10s**	Initial allocation of ~1/2 of USER-MI Z1 AND Z2 should add up to parent gate USER-MI
	USER-EMI	Interference near train	+/-10 meters	**1.65*1e-2 /hour**	Initial allocation to be checked by actual field data
	EMI-DIAG	Diagnostic (FDE / mitigation) and local feared event detection based on GNSS information only	+/-10 meters	**1.0e-3**	Hazard detection performance in terms of probability of missed detection
	USER-FE-	PR noise due to	+/-10	**Z2 =1.65*1e-5**	Initial allocation of

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
	NOISE	interference near train not bounded by σ_noise	meters	**/hour with 10s**	~1/2 of USER-MI Z1 AND Z2 should add up to parent gate USER-MI
Position mapping and monitoring checks	POS-MAP	Hazards due to projection of 3D position to 1D position	+/-10 meters	**1e-9/hour**	It is part of SIL 4 platform, and could provide GNSS independent diagnostics (**3.3*1e-5** /hour as mentioned in beginning of section §7)
Virtual Balise Detector	GNSS-VBD	Hazardous failure assigned to functional block	+/-10 meters	1.0*1e-9 / hour	VBD is a function that is still to be described and shared, however since it is a function implemented on a SIL 4 platform, it should also be SIL4
Track Database Manager	TRACK-GEO	Hazardous failure assigned to functional block due to unbounded error in track geometry information	+/-10 meters	1.0*1e-9 / hour	Initial SIL4 allocation but use of track geometry is still to be defined

Table 6 is filled-in which implies that GNSS MI coming from SIS, user and fault-free MI have to be assessed in terms of EGNOS capability. EGNOS design tailored for the railway environment should consider these values to assess the feasibility of such requirements.

In particular, hazard gates such as IONO-UNDET, USR-SEG-ERR, XPL-FORMULA, UDRE-TAIL-EFF, GIVE-TAIL-EFF, SIS-MI, and USER-MI should be elaborated in terms of constituent lower level hazards and checked if the assigned integrity requirements are feasible together with EGNOS augmentation FDE mechanisms and corresponding performance.

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
GNSS receiver type II	GNSS-RX-T2	Hazardous failure assigned to functional block	+/-10 meters	**9.9*1e-5<THR<1.0*1e-4 /hour with 10s**	Total THR should amount to **1.0*1e-4 /** hour Total THR amounts to the sum of the lower level THRs assigned to this

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
					functional block
	RX-HW-SW-2	HW or SW GNSS receiver failure (MTBF)	+/-10 meters	**<1e-6 /hour**	Total THR should amount to **1.0*1e-4 /** hour and therefore RX-HW-SW-2 THR is equal to (1-0.99)*1e-4/hour
	IONO-UNDET	Undetectable ionospheric perturbation (out of worst iono model conditions)	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI and Initial allocation of ~1/3 of GNSS-2-MI to FF-MI (3.3*1e-5 from [16])
	USR-SEG-ERR	Out-of-bounds user segment errors (extreme multipath, noise, tropospheric errors)	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	XPL-FORMULA	XPL formula leads to wrong translation of Pr bounds to position bounds	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	UDRE-TAIL-EFF	UDRE tails effects	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	GIVE-TAIL-EFF	GIVE tails effects	+/-10 meters	6.66*1e-6 /hour with 10s	1/5 of apportioned THR associated to FF-MI
	SIS-MI	Integrity risk due to SIS MI	+/-10 meters	3.3*1e-5 /hour with 10s	Initial allocation of ~1/3 of GNSS-2-MI to SIS-MI [16]
	USER-MI	**Integrity risk due to user MI**	+/-10 meters	3.3*1e-5 /hour with 10s	Expected integrity risk due to the sum of the lower level THRs Z1 AND Z2
	USER-MPATH	Multipath and NLOS at train antenna	+/-10 meters	**1.65*1e-2 /hour**	Initial allocation to be checked by actual field data
	MPATH-DIAG	Diagnostic (FDE / mitigation) and local feared event detection based on GNSS	+/-10 meters	**1.0e-3**	Hazard detection performance in terms of probability of missed detection

Architectural Element	Hazard Gate / Event	Description of events	Accuracy	Integrity with TTA	Justification
		information only			
	USER-FE-MPATH	Multipath at train antenna not bounded by σ_multipath	+/-10 meters	**Z1 = 1.65*1e-5 /hour with 10s**	Initial allocation of ~1/2 of USER-MI Z1 AND Z2 should add up to parent gate USER-MI
	USER-EMI	Interference near train	+/-10 meters	**1.65*1e-2 /hour**	Initial allocation to be checked by actual field data
	EMI-DIAG	Diagnostic (FDE / mitigation) and local feared event detection based on GNSS information only	+/-10 meters	**1.0e-3**	Hazard detection performance in terms of probability of missed detection
	USER-FE-NOISE	PR noise due to interference near train not bounded by σ_noise	+/-10 meters	**Z2 =1.65*1e-5 /hour with 10s**	Initial allocation of ~1/2 of USER-MI Z1 AND Z2 should add up to parent gate USER-MI
Position mapping and monitoring checks	POS-MAP	Hazards due to projection of 3D position to 1D position	+/-10 meters	**1e-9/hour**	It is part of SIL 4 platform, and could provide GNSS independent diagnostics (**3.3*1e-5** /hour as mentioned in beginning of section §7)
Virtual Balise Detector	GNSS-VBD	Hazardous failure assigned to functional block	+/-10 meters	1.0*1e-9 / hour	VBD is a function that is still to be described and shared, however since it is a function implemented on a SIL 4 platform, it should also be SIL4
Track Database Manager	TRACK-GEO	Hazardous failure assigned to functional block due to unbounded error in track geometry information	+/-10 meters	1.0*1e-9 / hour	Initial SIL4 allocation but use of track geometry is still to be defined

Table 6: THR apportionment among elements of reference architecture based on Option 2 for requirements due to SoM operational scenario

8 CONCLUSIONS

The main functional and not functional ERTMS/ETCS requirements that might be affected by the introduction the Virtual Balise concept have been summarized. In particular, some related performance and safety requirements have been outlined. These requirements have been used for identifying possible alternative enhanced ERTMS functional architecture suitable for supporting the ETRTMS train localization function also based on GNSS.

A preliminary architecture trade off analysis has been carried out with the objective of identifying the pros and cons of these architectures with also the objective of providing input requirements to the WP5 tasks related to EGNOS.

Possible system boundaries of the identified functional architectures between the Railway Signalling Domain and the GNSS Railway Domain have been identified.

In addition, the preliminary THR functional apportionment between architectural elements as a function of the identified architecture options has been carried out based on the study in NGTC WP7 which was defined to be an input to Task 5.3.

This deliverable has thus reached the objective to define target performances for EGNOS to meet railway safety requirements in the context of the STARS project. These target performances will have to be examined in terms of feasibility and the results will be achieved in Task 5.4 through D5.4.

Further analysis will be carried out in other future R&D projects such as S2R for completing the analysis and proposing solutions suitable for the ERTMS standard evolution.

9 APPENDIX A: ERTMS/ETCS REQUIREMENTS APPLICABLE TO THE VIRTUAL BALISE CONCEPT

This Annex is informative only. It reports all the ERTMS requirements directly affected by the introduction of the virtual balise concept or to be taken into account for the application of the virtual balise concept.

Note that these requirements have been extracted from [3], [4], [5] and [6] maintaining the original ERTMS numbering scheme (for paragraphs, figures and tables).

This document only provides the additional requirements or outlines the applicability of some ERTMS requirements to virtual balise. Thus, it is a **complementary** document with respect to the standard ERTMS requirements. An ERTMS application must apply all the applicable ERTMS requirements and related Subsets.

9.1 SUBSET-026 SYSTEM REQUIREMENTS SPECIFICATION APPLICABLE TO THE VIRTUAL BALISE CONCEPT

This subsection reports SUBSET026 System Requirements [3] applicable to the Virtual Balise Concept.

9.1.1 System structure (SUBSET-026 §2.4)

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

2.4.1.1 Due to the nature of the required functions, the ERTMS/ETCS system will have to be partly on the trackside and partly on-board the trains.

2.4.1.2 This defines two sub-systems, the on-board sub-system and the trackside sub-system.

2.4.1.3 The environment of ERTMS/ETCS system is composed of:

a) the train, which will then be considered in the train interface specification;

b) the driver, which will then be considered via the driver interface specification;

c) other on-board interfaces (see architecture drawing in 2.5.3),

d) external trackside systems (interlockings, control centres, etc.), for which no interoperability requirement will be established.

Note for Virtual Balises:

in order to use GNSS technology to provide Virtual Balises, the GNSS Signal In Space (SIS) shall be part of the environment of ERTMS/ETCS system.

9.1.2 Sub-systems (SUBSET-026 §2.5)

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

2.5.1 Trackside subsystem

2.5.1.1 Depending of the application level (see further sections), the trackside sub-system can be composed of:

a) balise
b) lineside electronic unit
c) the radio communication network (GSM-R)
d) the Radio Block Centre (RBC)
e) Euroloop
f) Radio infill unit
g) Key Management Centre (KMC)

Note for Virtual Balises:

in order to allow safe use of GNSS technology to provide Virtual Balises, the GNSS Augmentation Sub-system shall be interfaced with the RBC.

2.5.1.2 Balise

2.5.1.2.1 The balise is a transmission device that can send telegrams to the on-board sub-system.

2.5.1.2.2 The balise is based on the existing Eurobalise specifications. These documents are included in the frame of the ERTMS/ETCS specifications.

2.5.1.2.3 The balises provides the up-link, i. e. the possibility to send messages from trackside to the on-board sub-system.

2.5.1.2.4 The balises can provide fixed messages or, when connected to a lineside electronic unit, messages that can be changed.

Note for Virtual Balises:

Virtual Balises can only provide fixed messages.

2.5.1.2.5 The balises will be organised in groups, each balise transmitting a telegram and the combination of all telegrams defining the message sent by the balise group.

2.5.1.4 Trackside radio communication network (GSM-R)

2.5.1.4.1 The GSM-R radio communication network is used for the bi-directional exchange of messages between on-board sub-systems and RBC or radio infill units.

Note for Virtual Balises:

In order to allow safe use of GNSS technology to provide Virtual Balises, the radio communication network will be used also to provide augmentation information.

2.5.1.5 RBC

2.5.1.5.1 The RBC is a computer-based system that elaborates messages to be sent to the train on basis of information received from external trackside systems and on basis of information exchanged with the on-board sub-systems.

2.5.1.5.2 The main objective of these messages is to provide movement authorities to allow the safe movement of trains on the Railway infrastructure area under the responsibility of the RBC.

2.5.1.5.3 The interoperability requirements for the RBC are mainly related to the data exchange between the RBC and the on-board sub-system.

Note for Virtual Balises:

In order to allow safe use of GNSS technology to provide Virtual Balises, the RBC shall also provide augmentation information to the on-board sub-system.

2.5.2 On-board sub-system

2.5.2.1 Depending of the application level (see further sections), the on-board sub-system can be composed of:

a) the ERTMS/ETCS on-board equipment;

b) the on-board part of the GSM-R radio system;

2.5.2.2 ERTMS/ETCS on-board equipment

2.5.2.2.1 The ERTMS/ETCS on-board equipment is a computer-based system that supervises the movement of the train to which it belongs, on basis of information exchanged with the trackside sub-system.

2.5.2.2.2 The interoperability requirements for the ERTMS/ETCS on-board equipment are related to the functionality and the data exchange between the trackside sub-systems and the on-board sub-system and to the functional data exchange between the on-board sub-system and:

a) the driver;

b) the train;

c) the onboard part of the existing national train control system(s).

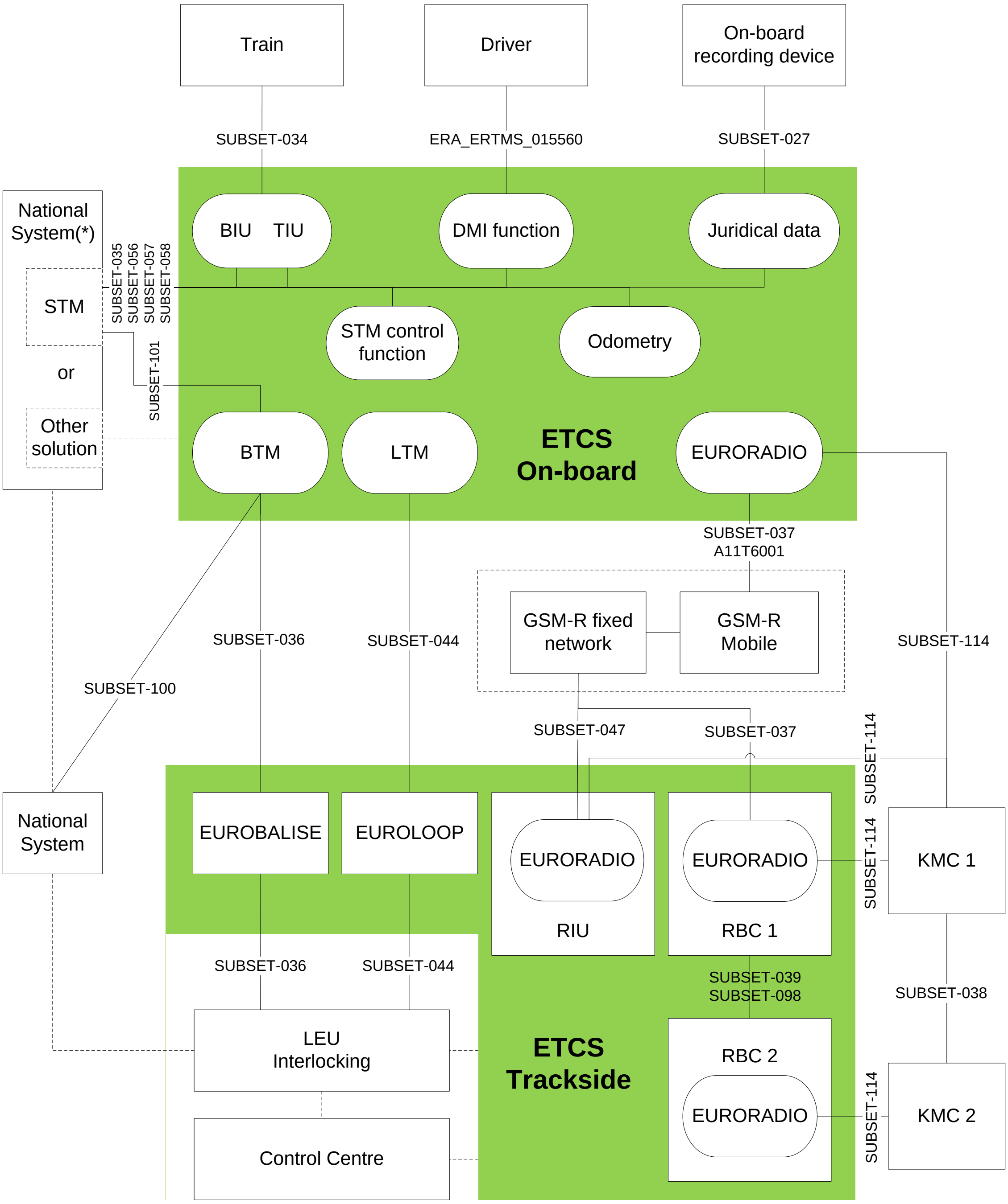
2.5.2.3 Onboard radio communication system (GSM-R)

2.5.2.3.1 The GSM-R on-board radio system is used for the bi-directional exchange of messages between on-board sub-system and RBC or radio infill unit.

Note for Virtual Balises:

In order to allow safe use of GNSS technology to provide Virtual Balises, the radio communication network will be used also to communicate augmentation information.

2.5.3 ERTMS/ETCS reference architecture



(*) Depending on its functionality and the desired configuration, the national system can be addressed either via an STM using the standard interface or via another national solution

Figure 1: ERTMS/ETCS system and its interfaces

2.5.3.1 Note: the entities inside the ERTMS/ETCS on-board equipment box are shown only to highlight the scope of the interfaces that are specified in the TSI CCS annex A.

Note for Virtual Balises:

In order to minimize impact on the ERTMS/ETCS system, the Virtual Balise Reader shall mimic as far as possible the BTM entity. In order to allow interoperability for safe use of GNSS technology to provide Virtual Balises, the following interfaces shall be defined:

- ***the GNSS Interface between the On-Board Sub-system and the Space Segment (SUBSET to be defined);***
- ***the Signalling Augmentation Interface among Radio Block Center and the On-Board Sub-System (SUBSET to be defined);***
- ***the Augmentation Interface among the Radio Block Center and the GNSS Augmentation Sub-system (SUBSET to be defined).***

9.1.3 Balise configuration and linking (SUBSET-026 §3.4)

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

3.4.1 Balise Configurations – Balise Group Definition

3.4.1.1 A balise group shall consist of between one and eight balises.

3.4.1.2 In every balise shall at least be stored:

a) The internal number (from 1 to 8) of the balise

b) The number of balises inside the group

c) The balise group identity.

3.4.1.3 The internal number of the balise describes the relative position of the balise in the group.

3.4.2 Balise Co-ordinate System

3.4.2.1.1 Every balise group has its own co-ordinate system.

3.4.2.1.2 The orientation of the co-ordinate system of a balise group (i.e., nominal or reverse direction) is identified as balise group orientation.

3.4.2.2 Balise groups composed of two or more balises

3.4.2.2.1 The origin of the co-ordinate system for each balise group shall be given by the balise number 1 (called location reference) in the balise group.

3.4.2.2.2 The nominal direction of each balise group is defined by increasing internal balise numbers.

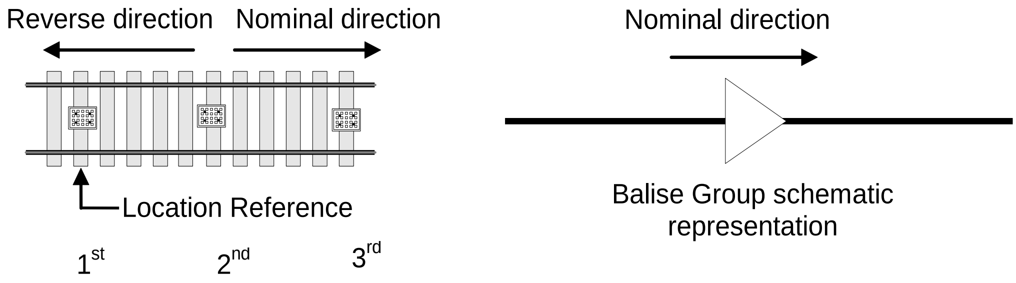


Figure 1: Orientation of the balise group

3.4.2.3 Balise groups composed of a single balise

3.4.2.3.1 Note: Balise groups consisting of only one single balise are referred to as "single balise groups" in the following.

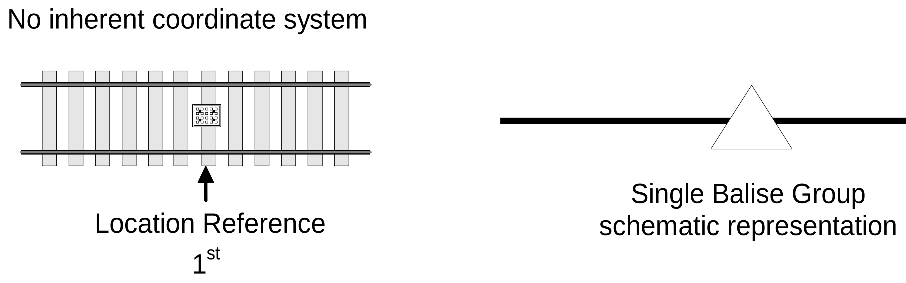


Figure 1a: Single balise group

3.4.2.3.3 Level 2/3:

3.4.2.3.3.1 If the ERTMS/ETCS on-board equipment cannot evaluate the orientation of the last balise group detected, being a single balise group, i.e. no linking information is available to identify the orientation of the co-ordinate system of this single balise group, the ERTMS/ETCS on-board equipment shall report its position by means of a position report based on two balise groups reporting the train position in reference to the LRBG and the “previous LRBG”, if any.

3.4.2.3.3.1.1 Note: Receiving this type of position report advises the RBC of the need to assign a co-ordinate system to this single balise group.

3.4.2.3.3.2 When a single balise group is detected and the previous LRBG is known, the position report based on two balise groups shall use as direction reference a move from the “previous

LRBG" towards this single balise group (being the new LRBG): directional information in the position report pointing in the same direction as the direction reference shall be reported as "nominal", otherwise as "reverse".

3.4.2.3.3.6 The assignment of a co-ordinate system received from the RBC shall identify the balise group for which the assignment is given, and assign a balise group orientation "nominal" or "reverse" to this balise group

3.4.2.3.3.6.1 Note: From the sequence of reported balise groups, the RBC can derive the balise group orientation with which the balise group was passed.

3.4.2.3.3.7 For single balise groups reported as LRBG and stored according to 3.6.2.2.2c, awaiting an assignment of a co-ordinate system, the ERTMS/ETCS on-board equipment shall be able to discriminate if a single balise has been reported more than once and with different "previous LRBGs" to the RBC.

3.4.2.3.3.7.1 Note: For a single balise group reported as LRBG awaiting the assignment of a co-ordinate system also the rules for LRBGs reported to the RBC (see 3.6.2.2.2) apply.

3.4.2.3.3.8 A co-ordinate system assignment received from trackside shall be rejected by the ERTMS/ETCS on-board equipment if the referred LRBG is memorised (see 3.6.2.2.2c) to have been reported more than once and with different "previous LRBGs".

3.4.2.3.3.8.1 Note: If a single balise group is memorised, according to 3.6.2.2.2c, more than once, and with different "previous LRBGs", the assignment of the co-ordinate system is ambiguous.

3.4.2.4 Balise groups composed of one pair of duplicated balises

3.4.2.4.1 A group of two balises duplicating each other shall be treated as a single balise group in case where only one balise is correctly read.

3.4.3 Balise Information Types and Usage

3.4.3.2 A balise may contain directional information, i.e. valid either for nominal or for reverse direction, or may contain information valid for both directions.

3.4.4 Linking

3.4.4.1 Introduction

3.4.4.1.1 Aim of linking:

- To determine whether a balise group has been missed or not found within the expectation window (see section 3.4.4.4) and take the appropriate action.
- To assign a co-ordinate system to balise groups consisting of a single balise.
- To correct the confidence interval due to odometer inaccuracy (see section 3.6.4).

3.4.4.1.2 A balise group is linked when its linking information (see section 3.4.4.2) is known in advance.

3.4.4.2 Content of linking information

3.4.4.2.1 Linking information shall be composed of:

a) The identity of the linked balise group.

b) Where the location reference of the group has to be found.

c) The accuracy of this location.

Note: If the reference balise is duplicated, it is the trackside responsibility to define the location accuracy to cover at least the location of the two duplicated balises.

d) The direction with which the linked balise group will be passed over (nominal or reverse).

e) The reaction required if a data consistency problem occurs with the expected balise group.

3.4.4.2.1.1 "Linking information is used" shall be interpreted as when balise groups are announced and the minimum safe antenna position has not yet passed the expectation window of the furthest announced balise group.

3.4.4.2.3 For each linked balise group, the trackside shall select one of the following reactions to be used in case of data inconsistencies:

a) Train trip (Trip mode, see Chapter 4)

b) Command service brake

c) No reaction

For further details see section 3.16.2.

3.4.4.3 Unlinked Balise Groups

3.4.4.3.1 A balise group, which contains information that must be considered even when the balise group is not announced by linking, is called an unlinked balise group.

3.4.4.3.2 Unlinked balise groups shall consist at minimum of two balises.

3.4.4.3.3 Unlinked balise groups shall always contain the unlinked balise group qualifier.

3.4.4.4 Rules related to linking

3.4.4.4.1 When no linking information is used on-board, all balise groups shall be taken into account.

3.4.4.4.2 When linking information is used on-board, only balise groups marked as linked and included in the linking information and balise groups marked as unlinked shall be taken into account.

3.4.4.4.3 The on-board equipment shall accept a balise group marked as linked and included in the linking information (i.e. the balise giving the location reference) from

- when the max safe front end of the train has passed the first possible location of the balise group

until

- the min safe front end of the train has passed the last possible location of the balise group taking the offset between the front of the train and the balise antenna into account.

3.4.4.4.3.1 Note: The first possible location and the last possible location of the balise group are defined by the linking distance and the location accuracy.

3.4.4.4.3.2 Note: The interval between the outer limits to accept the balise group defines the expectation window.

9.1.4 Management of Radio Communication (SUBSET-026 §3.5)

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

3.5.3 Establishing a communication session

3.5.3.16

Option	Balise data content	Train reaction
1	Order to contact RBC Special value for RBC ID: Contact last known RBC RBC Phone number irrelevant	Contact last known RBC (order is ignored in case no RBC ID/ phone number is stored on-board)
2	Order to contact RBC RBC ID Special value for RBC phone number: use on-board stored short number	Contact given RBC by using RBC ID and the on-board short number. Note: If the short number does not direct to the RBC with the given RBC ID, the connection will be terminated (EURORADIO functionality).
3	Order to contact RBC RBC ID + RBC phone number	Contact given RBC by using RBC ID and the RBC phone number

9.1.5 Location Principles, Train Position and Train Orientation (SUBSET-026 §3.6)

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

3.6.1 General

3.6.1.1 It shall be possible to identify:

a) Data that refers only to a given location, referred to as Location data (e.g. level transition orders, linking)

b) Data that remains valid for a certain distance, referred to as Profile data (e.g. SSP, gradient).

3.6.1.2 Note: Determination of the Train Position is always longitudinal along the route, even though the route might be set through a complex track layout.

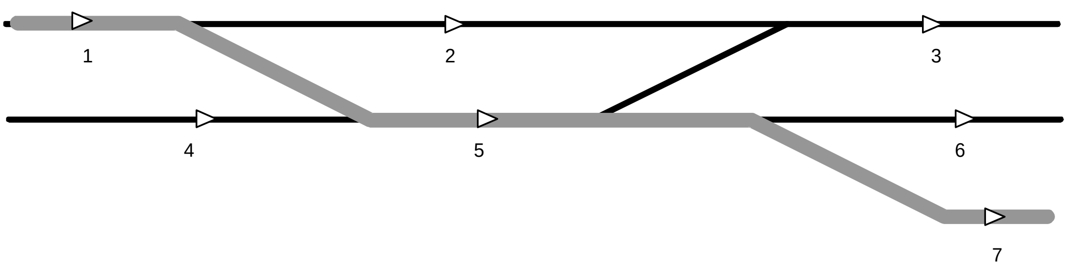


Figure 6: Actual route of the train

Figure 7: Route known by the train

3.6.1.3 The Train Position information defines the position of the train front in relation to a balise group, which is called LRBG (the Last Relevant Balise Group). It includes:

- The estimated train front end position, defined by the estimated distance between the LRBG and the front end of the train
- The train position confidence interval (see 3.6.4)
- Directional train position information in reference to the balise group orientation (see 3.4.2, also Figure 14) of the LRBG, regarding:

- the position of the train front end (nominal or reverse side of the LRBG)
- the train orientation
- the train running direction

In case of an LRBG being a single balise group with no co-ordinate system assigned, directional information is defined in reference to the pair of LRBG and "previous LRBG", see 3.4.2.3.3.

- A list of LRBGs, which may alternatively be used by trackside for referencing location dependent information (see 3.6.2.2.2 c)).

3.6.1.4 Balise groups, which are marked as unlinked, shall never be used as LRBG.

3.6.1.4.1 Justification: The location of an unlinked balise group, or the balise group itself, may not be known to the RBC.

3.6.1.5 If there is an active cab, this one defines the orientation of the train, i.e. the side of the active cab shall be considered as the front of the train. If no cab is active, the train orientation shall be as when a cab was last active.

3.6.1.6 The "train orientation relative to LRBG" is defined as the train orientation related to the orientation of the LRBG, see Figure 14. It can be either "nominal" or "reverse".

3.6.1.6.1 Note: The train orientation cannot be affected by the direction controller position.

3.6.2 Location of Data Transmitted to the On-Board Equipment

3.6.2.1 Data Transmitted by Balises

3.6.2.1.1 All location and profile data transmitted by a balise shall refer to the location reference and orientation of the balise group to which the balise belongs.

3.6.2.1.2 Exception: Regarding infill information see section 3.6.2.3.1.

3.6.2.2 Data Transmitted by Radio from RBC

3.6.2.2.1 All location and profile data transmitted from the RBC shall refer to the location reference and orientation of the LRBG given in the same message.

3.6.2.2.2 For the LRBG the following requirements have to be met:

a) The on-board equipment shall use the last balise group passed as a reference when reporting its position to the RBC (in the following termed as LRBGONB) only in the following two cases:

- balise groups marked as linked and contained in the previously received linking information, if linking information is used on-board

  or

- the last balise group not marked as unlinked, if no linking was used when this balise group was passed

b) The RBC shall use the last relevant balise group which was reported by the on-board equipment as a reference (in the following termed as LRBGRBC). At a certain moment LRBGRBC and LRBGONB can be different.

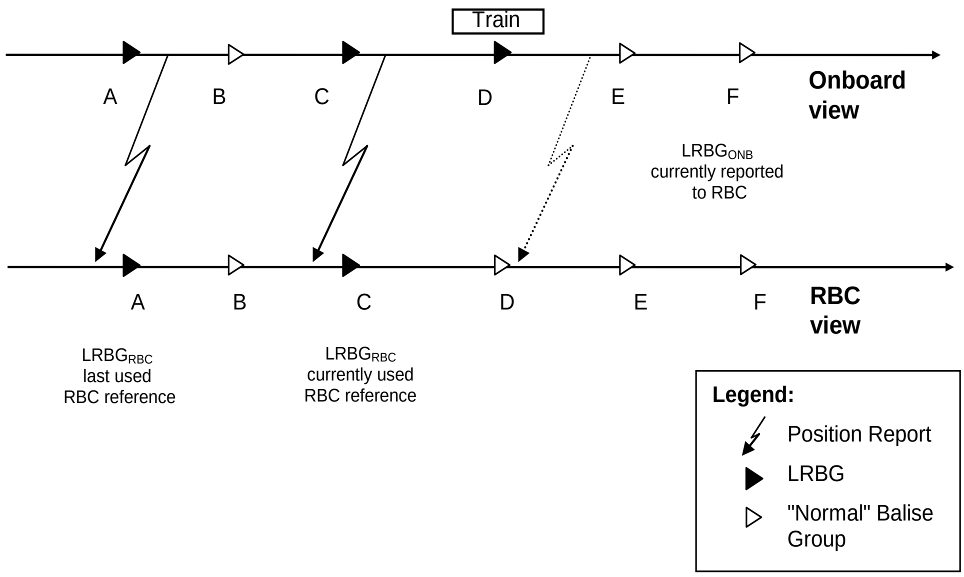
c) The on-board equipment shall be able to accept information referring to one of at least eight LRBGONB last reported to the RBC.

3.6.2.2.2.1 Exception to a): When on-board position is unknown or when position data has been deleted during SoM procedure, the on-board equipment shall use an LRBG identifier set to "unknown" until the onboard has validated its position again by passing a balise group.

3.6.2.2.2.2 Exception to b): When the RBC has received from the onboard an unknown position, or an invalid position which it is not able to confirm during SoM procedure, the RBC shall use an LRBG identifier set to "unknown" until it receives a position report from the onboard having validated its position by passing a balise group.

3.6.2.2.2.3 Regarding c): From the time it has reported an unknown position, or an invalid position during SoM procedure, to the time it has received from the RBC a message with an LRBG not set to “unknown”, the on-board equipment shall also be able to accept messages from the RBC containing LRBG “unknown”.

3.6.2.2.3 Example: The following figure illustrates the on-board and RBC views of LRBGs:



Balise groups A, C have been reported to the RBC and can be used by the RBC as LRBG

Balise groups D - F : are known thanks to previously received linking information and can be used in the future as onboard reference

Figure 8: On-board and RBC views of LRBG when train is reporting new LRBGONB "D"

3.6.3 Validity direction of transmitted Information

3.6.3.1 General

3.6.3.1.3 When receiving information from any transmission medium, the ERTMS/ETCS on-board equipment shall only take into account information valid for its orientation. Other information shall be ignored. Exception: for SL, PS and SH engines, balise group crossing direction shall be considered.

3.6.3.1.3.1 If the train position is unknown, data received from any transmission medium valid for one direction only (nominal or reverse) shall be rejected by the onboard equipment. Data valid for both directions shall be evaluated (see section 4.8).

3.6.3.1.4 If no co-ordinate system has been assigned to a single balise group, data transmitted by trackside, which refers to that balise group requiring the co-ordinate system to be known (i.e. all data which are only valid for one direction (nominal or reverse)) shall be rejected by the ERTMS/ETCS on-board equipment. Data valid for both directions shall be evaluated (see section 4.8).

3.6.3.1.4.1 Exception: if not rejected due to balise group message consistency check (see 3.16.2.4.4.1 and 3.16.2.5.1.1), data to be forwarded to a National System (see section 3.15.6) shall be accepted. Justification: the co-ordinate system of the balise group might be known to the National System by other means inherent to the National System itself.

3.6.4 Train Position Confidence Interval and Relocation

3.6.4.1 All location related information transmitted from trackside equipment shall be used by the on-board equipment taking into account the confidence interval to the train position, if required for safe operation.

3.6.4.2 The confidence interval to the train position shall refer to the distance to the LRBG and shall take into account

a) On-board over-reading amount and under-reading amount (odometer accuracy plus the error in detection of the balise group location reference)

b) The location accuracy of the LRBG.

3.6.4.2.1 Distance information received from trackside shall be evaluated on-board as nominal information (without taking into account any tolerances).

3.6.4.2.2 Note: The confidence interval increases in relation to the distance travelled from the LRBG depending on the accuracy of odometer equipment until it is reset when another balise group becomes the LRBG.

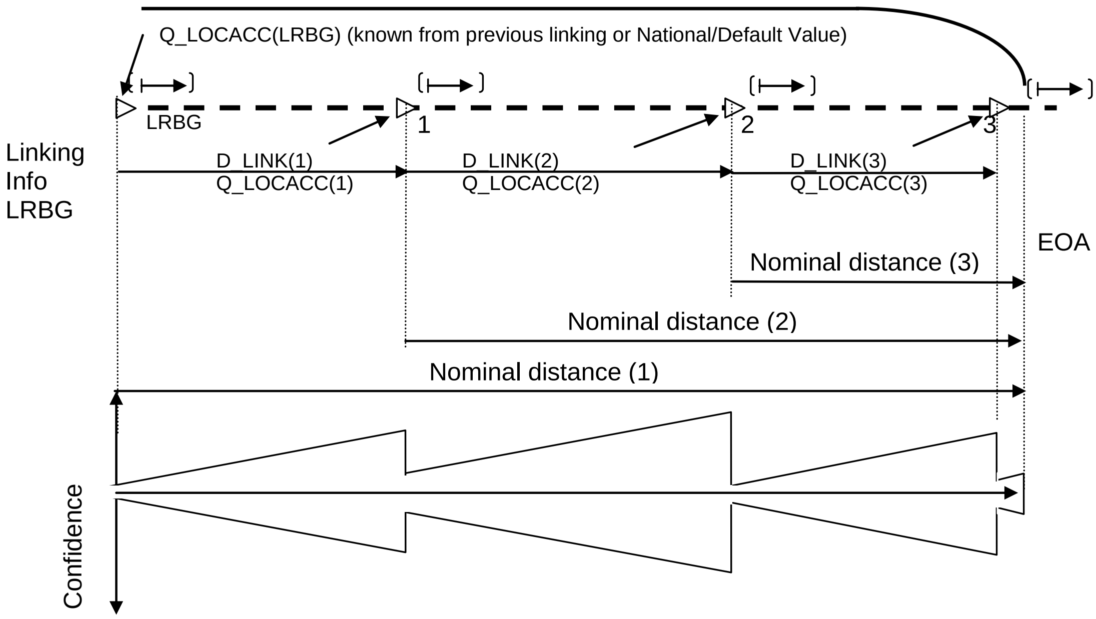
3.6.4.2.3 The value of the Location Accuracy shall be determined by Linking information if available, if not, by the corresponding National Value, or the corresponding Default Value if the National Value is not applicable.

3.6.4.3 When another balise group becomes the LRBG or when evaluating (see section 4.8) location related trackside information, which is referred to a previously received balise group different from the LRBG, all the location related information shall be relocated by subtracting from the distances that are counted from the reference balise group of the location related information:

a) the distance between the reference balise group of the location related information and the LRBG, retrieved from linking information if it is available and it includes both the reference balise group and the LRBG, OR

b) in all other cases, the estimated travelled distance between the reference balise group of the location related information and the LRBG.

3.6.4.3.1 Justification: it is always the trackside responsibility to provide linking in due course, knowing this rule; if the location related information is to be used in situations where linking is not provided (e.g. TSR transmitted by balise group marked as unlinked), the trackside can include provisions, if deemed necessary, when engineering the distance information.

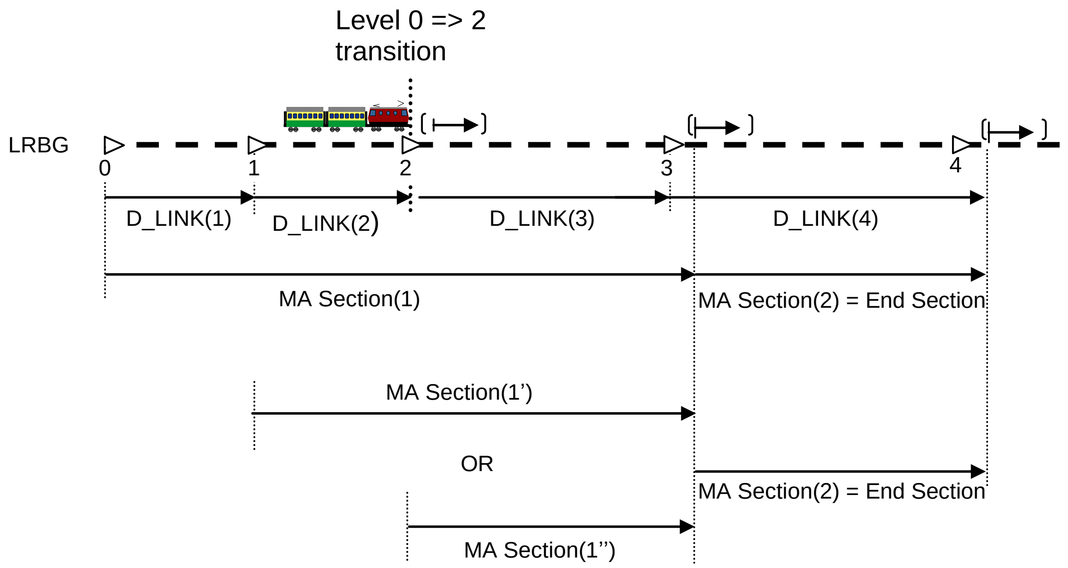


Confidence Interval = Function [Q_LOCACC; Odometer Error]

When the ERTMS/ETCS on-board has read the balise group 1

- the Confidence Interval is reset taking into account the location accuracy of balise group 1, and on-board tolerances when determining the reference location of the balise group,
- the nominal distance to EOA is relocated by subtracting D_LINK (1) from nominal distance (1), resulting in nominal distance (2). (Nominal distance (1) may be the distance to EOA received in the MA or the result of a previous relocation.)

Figure 13a: Reset of confidence interval and relocation, on change of LRBG



When the on-board performs the transition to level 2, the MA stored on-board (referred to balise group 0) is relocated prior to its evaluation:

- If balise group 1 is still the LRBG, the first MA Section distance is relocated by subtracting D_LINK (1) from MA Section (1), resulting in MA section (1')
- If balise group 2 is already the LRBG, the first MA Section distance is relocated by subtracting (D_LINK (1) + D_LINK (2)) from MA Section (1), resulting in MA section (1")
- MA Section (2) distance remains unchanged

Figure 13b: Relocation of trackside information referred to previously passed balise group, different from the current LRBG

3.6.4.4 The train front end position shall be identified in the following way

a) The estimated front end position.

b) The max(imum) safe front end position, differing from the estimated position by the under-reading amount in the distance measured from the LRBG plus the location accuracy of the LRBG.

I.e. in relation to the orientation of the train this position is in advance of the estimated position.

c) The min(imum) safe front end position, differing from the estimated position by the over-reading amount in the distance measured from the LRBG plus the location accuracy of the LRBG.

I.e. in relation to the orientation of the train this position is in rear of the estimated position.

3.6.4.4.1 Note: The rear end position is referenced in the same way. However min safe rear end is only safe if sent together with train integrity information.

Note for Virtual Balises:

When the LRBG is a Virtual Balise, the max(imum) and min(imum) safe front/rear end position must be computed also taking into account the dynamic contribution of the location accuracy that can be guaranteed by using the GNSS technology.

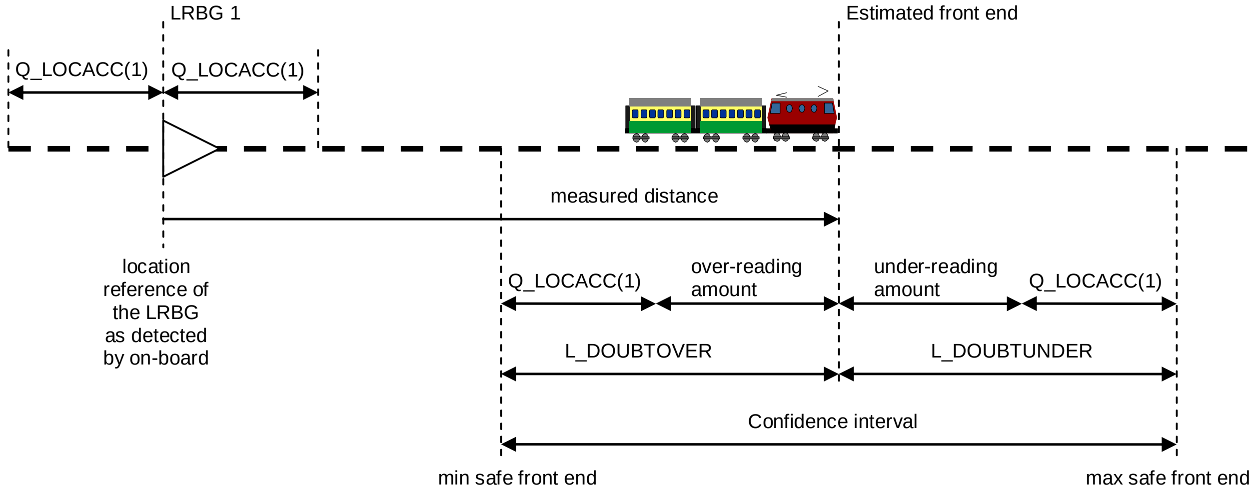


Figure 13c: Train confidence interval and train front end position

3.6.4.6 The estimated front end shall be used when supervising location information, unless stated otherwise.

<u>3.6.4.7 Supervision of location related information transmitted by a balise group marked as unlinked and referred to this balise group:</u>

3.6.4.7.1 By exception to clause 3.6.1.3, the train position is referred to this balise group marked as unlinked. The ERTMS/ETCS on-board equipment shall temporarily apply by analogy clauses 3.6.4.2, 3.6.4.2.1, 3.6.4.2.3 and 3.6.4.4 to determine an additional confidence interval, until a further received balise group becomes the LRBG or the location related information is deleted on-board.

3.6.4.7.2 If another balise group marked as unlinked is received before the additional confidence interval is deleted:

a) the additional confidence interval shall be reset in relation to this new balise group marked as unlinked

b) the location related information referred to the previous balise group marked as unlinked shall be relocated by subtracting the estimated travelled distance between both balise groups from the distances that are counted from this previous balise group marked as unlinked.

3.6.6 Geographical position reporting

3.6.6.1 The ERTMS/ETCS on-board equipment shall display, only on driver request, the geographical position of the estimated front end of the train in relation to the track kilometre. The display of the geographical position shall also be stopped on driver request.

3.6.6.2 The resolution of the position indication shall be 1 metre (sufficient to allow the driver to report the train position when communicating with the signalman).

3.6.6.3 When receiving new geographical position information (from radio or from balise group), the ERTMS/ETCS on-board equipment shall replace the currently stored geographical position information (if any) by this new received one, continuing the on-going geographical position calculation until at least one of the condition of 3.6.6.9 applies.

3.6.6.4 Geographical position information shall always use a balise group as geographical position reference balise group and if needed an offset from that balise group. A geographical position reference balise group shall be either:

a) part of the last reported balise groups memorised on-board, in case the information is received from radio, OR

b) the balise group transmitting the information, in case the information is received from balise group, OR

c) any balise group not yet passed at the time of reception of the information.

3.6.6.4.1 In case the information is received by radio and at least one of the announced geographical position reference balise group(s) is part of the last reported balise groups memorised on-board, the on-board equipment shall use the data related to the most recently reported balise group.

3.6.6.4.2 From the currently stored geographical position information, the track kilometre reference given for a geographical reference location shall become applicable if the train has detected the related geographical reference balise group and has travelled the offset distance from this reference balise group.

3.6.6.4.3 The announced and not applicable geographical references shall be deleted on-board if the train changes orientation.

3.6.6.5 The distance travelled from the geographical reference location shall be taken into account when calculating the geographical position.

3.6.6.6 In cases where the track kilometre is not incremental (jumps, changes in counting direction, scaling error) the reported position might be wrong between the point of irregularity and the next new reference.

3.6.6.7 In cases where single balise groups are used as a reference for geographical position information and where no linking information is available (and therefore no orientation can be assigned to the balise group), the on-board equipment shall ignore the geographical position information related to these single balise groups.

3.6.6.9 The on-board equipment shall continue calculating the position from a track kilometre reference (i.e. this track kilometre reference shall remain applicable) until:

a) a new track kilometre reference becomes applicable, OR

b) it is told not to do so, OR

c) the calculated geographical position becomes negative, OR

d) no more geographical position information is available (e.g., deleted according to conditions in SRS chapter 4)

3.6.6.9.1 Once a track kilometre reference is no longer applicable, it shall be deleted.

3.6.6.10 The following data shall be included in a message for geographical position (for every track kilometre reference):

- Identity of the geographical position reference balise group
- Distance from geographical position reference balise group to the track kilometre reference (offset)
- Value of the track kilometre reference
- Counting direction of the track kilometre in relation to the geographical position reference balise group orientation.

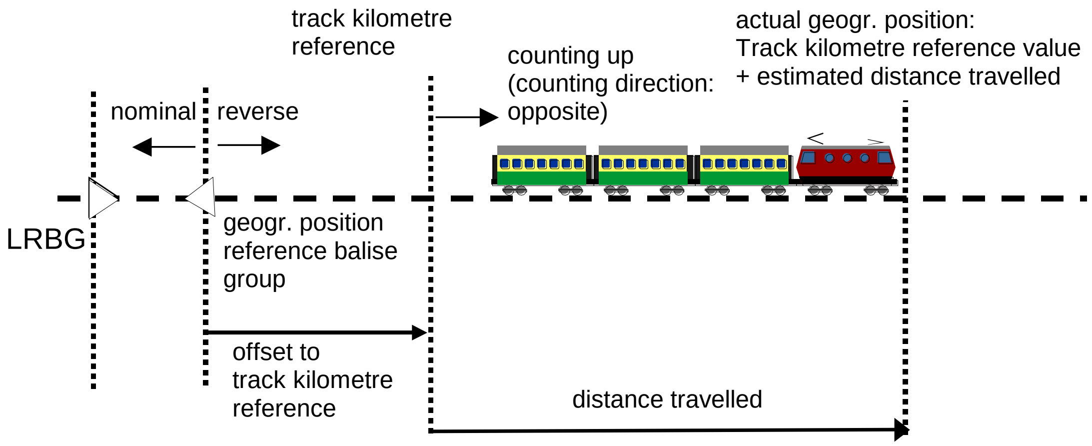


Figure 16: Geographical position example

9.1.6 <u>Data Consistency (SUBSET-026 §3.16)</u>

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

3.16.2 Balises

3.16.2.1 Definitions

3.16.2.1.1 The information that is sent from a balise is called a balise telegram.

3.16.2.1.2 The whole set of information (balise telegram or telegrams) coming from a balise group is called a balise group message.

3.16.2.1.2.1 Note: In case of a balise group containing a single balise, telegram and message coincide.

3.16.2.1.3 A balise within a balise group shall be regarded as missed if

a) No balise is found within the maximum distance between balises from the previous balise in the group.

or

b) A following balise within the group has been passed.

3.16.2.2 General

3.16.2.2.1 If the on-board is not able to recognise whether a balise group is linked or unlinked (if none of the balises in the balise group can be read correctly), it shall consider it as unlinked.

3.16.2.3 Linking Consistency

3.16.2.3.1 If linking information is used the on-board shall react according to the linking reaction information in the following cases:

a) If the location reference of the expected balise group is found in rear of the expectation window

b) If the location reference of the expected balise group is not found inside the expectation window (i.e. the end of the expectation window has been reached without having found the expected balise group)

c) If inside the expectation window of the expected balise group another announced balise group, expected later, is found.

3.16.2.3.1.1 The ERTMS/ETCS on-board equipment shall ignore (i.e. it will not consider as LRBG) a balise group found with its location reference outside its expectation window.

3.16.2.3.2 The on-board shall reject the message from the expected group and trip the train if the balise group is passed in the unexpected direction.

3.16.2.3.2.1 Exception: When the expected balise group is referred in the linking information with a balise group with ID “unknown”, 3.4.4.4.2.1 shall apply.

3.16.2.3.3 If the location reference balise of the group is duplicated and the on-board is only able to correctly evaluate the duplicating one, the duplicating one shall be used as location reference instead.

3.16.2.3.4 If the balise duplicating the location reference balise is used as location reference for the group, and is found within the expectation window, no linking reaction shall be applied.

3.16.2.4 Balise Group Message Consistency

3.16.2.4.1 If linking information is used, the on-board shall reject the message from a linked balise group found in the expected location and react according to the linking reaction in the following cases:

a) A balise is missed inside the group.

b) A balise is detected but no telegram is decoded (e.g. wrong CRC,...).

c) Variables in the balise group message have invalid values.

d) Message counters do not match (see 3.16.2.4.7)

3.16.2.4.2 Exception: Concerning a) and b) above, the ERTMS/ETCS on-board equipment shall not reject the message and shall not apply the linking reaction if the balise not found, or not decoded, is duplicated within the balise group and the duplicating one is correctly read.

3.16.2.4.3 If linking information is used, the on-board shall reject the message from a balise group marked as linked but not included in the linking information. No reaction shall be applied, even if errors in the reading of the balise group occur.

3.16.2.4.4 If no linking information is used, the on-board shall reject the message from a balise group marked as linked and command application of the service brake in the following cases:

a) A balise is missed inside the group.

b) A balise is detected, but no telegram is decoded (e.g. wrong CRC).

c) Variables in the balise group message have invalid values.

d) Message counters do not match (see 3.16.2.4.7)

3.16.2.4.4.1 Exceptions: Concerning a) and b) of clause 3.16.2.4.4, the ERTMS/ETCS on-board equipment:

a) shall not reject the message and shall not command application of the service brake if the balise not found, or not decoded, is duplicated within the balise group, the duplicating one is correctly read and contains:

- directional information while the orientation of the balise group can still be evaluated, or

- only information valid for both directions, or
- neither directional information nor information valid for both directions, or
- only data to be used by applications outside ERTMS/ETCS, or
- only data to be used by applications outside ERTMS/ETCS together with other information valid for both directions.

b) shall not command application of the service brake if the telegram correctly read from another balise of the group contains the information “Inhibition of balise group message consistency reaction”.

3.16.2.4.4.2 Concerning clause 3.16.2.4.4, if the service brake is applied, the location based information stored on-board shall be shortened to the current position when the train has reached standstill. Refer to appendix A.3.4 for the exhaustive list of information, which shall be shortened.

3.16.2.4.4.3 Concerning clause 3.16.2.4.4, if the service brake is applied, the driver shall be informed that this is due to a balise group message consistency problem.

3.16.2.4.5 A message counter shall be attached to each balise telegram indicating which balise group message the telegram fits to.

3.16.2.4.6 Instead of a message counter corresponding to a given balise group message, it shall be possible to identify a telegram as always fitting all possible messages of the group.

3.16.2.4.6.1 It shall also be possible to identify a telegram as never fitting any message of the group.

3.16.2.4.7 Comparing message counters of the received telegrams of a balise group message, excluding the ones complying with 3.16.2.4.6, if their values are not all identical, or at least one of them complies with 3.16.2.4.6.1, this shall be considered as a message consistency error. The balise group can, however, be used for location information.

3.16.2.4.7.1 In case of single balise group, if the message counter of the received telegram complies with 3.16.2.4.6.1, this shall also be considered as a message consistency error.

3.16.2.4.8 It shall be possible to indicate failures in the system underlying the balise/loop/RIU (e.g. the Lineside Electronic Unit, LEU) by sending a balise telegram, a loop message or a RIU message including the information "default balise/loop/RIU information".

3.16.2.4.8.1 If one (and only one) out of a pair of duplicated balise telegrams received by the on-board includes the information “default balise information”, the on-board shall ignore any other information included in this telegram and shall consider information from the telegram not containing “default balise information".

3.16.2.4.8.2 When duplicated balises are both found and decoded correctly, and both, or none of them, contain "default balise information", the ERTMS/ETCS on-board equipment shall compose the message using the telegram from the last received balise out of the pair.

3.16.2.4.9 If a message has been received containing the information "default balise information", the driver shall be informed.

3.16.2.5 Unlinked Balise Group Message Consistency

3.16.2.5.1 An on-board equipment shall reject the message received from a balise group marked as unlinked and command application of the service brake in the following cases:

a) A balise is missed inside the unlinked balise group.

b) A balise is detected, but no telegram is decoded (e.g. wrong CRC).

c) Variables in the balise group message have invalid values.

d) Message counters do not match (see 3.16.2.4.7)

3.16.2.5.1.1 Exceptions: Concerning a) and b) of clause 3.16.2.5.1, the ERTMS/ETCS on-board equipment:

a) shall not reject the message and shall not command application of the service brake if the balise not found, or not decoded, is duplicated within the balise group, the duplicating one is correctly read and contains:

- directional information while the orientation of the balise group can still be evaluated, or
- only information valid for both directions, or
- neither directional information nor information valid for both directions, or
- only data to be used by applications outside ERTMS/ETCS, or
- only data to be used by applications outside ERTMS/ETCS together with other information valid for both directions.

b) shall not command application of the service brake if the telegram correctly read from another balise of the group contains the information “Inhibition of balise group message consistency reaction”.

3.16.2.5.2 Concerning clause 3.16.2.5.1, if the service brake is applied, the location based information stored on-board shall be shortened to the current position when the train has reached standstill. Refer to appendix A.3.4 for the exhaustive list of information, which shall be shortened.

3.16.2.5.3 Concerning clause 3.16.2.5.1, if the service brake is applied, the driver shall be informed that this is due to a balise group message consistency problem.

3.16.2.6 Linking Reactions

3.16.2.6.1 When the linking reaction leads to train trip or a service brake application, the driver shall be informed that the intervention is due to data consistency problem with the expected balise group.

3.16.2.6.2 If the service brake is initiated due to the linking reaction, the location based information stored on-board shall be shortened to the current position when the train has reached standstill. Refer to appendix A.3.4 for the exhaustive list of information, which shall be shortened.

3.16.2.7 RAMS related supervision functions

3.16.2.7.1 Mitigation of balise reception degradation

3.16.2.7.1.1 If 2 consecutive linked balise groups announced by linking are not detected and the end of the expectation window of the second balise group has been passed, the ERTMS/ETCS on-board shall command the service brake and the driver shall be informed. At standstill, the location based information stored on-board shall be shortened to the current position. Refer to appendix A.3.4 for the exhaustive list of information, which shall be shortened.

9.2 SUBSET-036 FFFIS FOR EUROBALISE APPLICABLE TO THE VIRTUAL BALISE CONCEPT

This subsection reports SUBSET036 FFFIS for Eurobalise [4] applicable to the Virtual Balise Concept.

9.2.1 Spot Transmission System (SUBSET-036 §4)

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

4.1 Architectural Layouts

4.1.1 Introduction

The Eurobalise Transmission System is a safe spot transmission based system conveying safety related information between the wayside infrastructure and the train.

The Eurobalise Transmission System is a spot transmission system, where transmission is implemented by Balises.

Note for Virtual Balises:

through the Virtual Balise concept, GNSS technology is used to implement a safe spot transmission, even if virtual balises are not physically installed in the wayside infrastructure.

Information transmitted from an Up-link Balise to the On-board Transmission Equipment is fixed or variable depending upon the application (Up-link data transmission).

Note for Virtual Balises:

Information transmitted from a virtual balise is fixed.

Spot transmission is when a transmission path exists between the wayside equipment and the On-board Transmission Equipment at discrete locations. The information is provided to/from the train only as the Antenna Unit passes or stands over the corresponding Balise. The length of track on which the information is passed and received is limited to approximately one meter per Balise.

Note for Virtual Balises:

The track area on which a virtual balise can be received is typically wider than one meter (based on the performance obtainable with GNSS technology, preliminary value is 20 m).

The Eurobalise Transmission System is intended for use in all of the levels of applications defined within the ERTMS/ETCS (called Level 0, Level 1, Level 2, Level 3, and Level NTC respectively).

Note for Virtual Balises:

Virtual balises are intended for use only in Level 2 and Level 3.

4.1.4 Basic Functions

The Eurobalise Transmission System comprises the following basic functions:

On-board Transmission Equipment functionality:

- Generation of Tele-powering signal
- Assurance of Tele-powering signal level and Balise detectability
- Detection of Up-link Balises
- Up-link signal filtering and demodulation
- Physical Cross-talk protection
- Physical prevention of transmission of Side lobes, and/or management of Side lobe effects in data and in location
- Immunity to environmental noise
- Checking of Up-link incoming data with respect to Coding Requirements
- Detection of telegram type and decoding
- Extraction of user data
- Telegram Filtering
- Management of Up-link telegram switching within a Balise passage
- Time and odometer stamping of output data
- Support for Balise Localisation (for vital and non-vital purposes)
- Time and odometer data management
- Detection of Bit Errors
- Start-up tests

Note for Virtual Balises:

Only following functionalities are relevant for Virtual Balise Reader:

- ***Detection of Virtual Balises***
- ***Virtual Cross-talk protection***
- ***Prevention of accuracy effects in data and in location***
- ***Immunity to environmental noise***
- ***Extraction of user data***
- ***Time and odometer stamping of output data***
- ***Support for Balise Localisation (for vital and non-vital purposes)***
- ***Time and odometer data management***
- ***Start-up tests***

4.1.5 Management of Faults and Failures

If the On-board Transmission Equipment is not able to detect Balises, it shall report this to the ERTMS/ETCS Kernel.

4.2 Functional Requirements

4.2.4 Location Reference

4.2.4.1 Balise Centre Detection

The BTM function shall provide data that enables evaluation of the instant and/or location when the Antenna Unit reference mark crosses over the Balise reference mark, by analysing either the properties of the received Up-link signal, or data, or both.

Note for Virtual Balises:

Similarly, Virtual Balise reader shall provide data that enables evaluation of the instant and/or location when the Virtual Antenna reference mark crosses over the nominal position of the Virtual Balise in accordance with the track description, by means of the GNSS technology.

The position of the Virtual Antenna of a Virtual Balise Reader is an ideal position below the train where a BTM Antenna would detect ideal physical balises placed in accordance with the track description.

4.2.4.2 Time and Odometer stamping of the detected Balise Centre

The Eurobalise Transmission System shall provide data that enables evaluation of the location reference point for the Balise[3], in time or position, depending on the quality of the time and odometer information that is available during each Balise passage. The information shall be made available to the ERTMS/ETCS Kernel. The instant in time or position on which the location reference is based shall originate from the ERTMS/ETCS Kernel.

4.2.4.3 Train Direction Detection

Information about Balise sequences shall be passed on to the ERTMS/ETCS Kernel. The Eurobalise Transmission System shall provide information that enables the ERTMS/ETCS Kernel to evaluate the direction of the train on the basis of the reported sequence of passed Balises.

4.2.5 Cross-talk Protection

[3] The location reference point for the Balise corresponds to the Balise reference mark.

4.2.5.1 Intrinsic Cross-talk Protection

The Eurobalise Transmission System shall not allow a valid telegram to be passed through, from a Balise located in a cross-talk protected zone, to the On-board ERTMS/ETCS Kernel, as defined in this specification.

The Eurobalise Transmission System shall ensure protection against cross-talk based on signal levels when all constraints regarding the installation requirements are considered. Additional cross-talk protection[4] is achieved by performing the ERTMS/ETCS level functions defined in UNISIG SUBSET-026.

Note for Virtual Balises:

Subset-036 considers cross-talk causes based on Eurobalise technology (e.g., metallic objects), and provide conformity and installation requirements to deal with these causes. Similarly, causes of degradation of GNSS technology performances shall be considered and properly managed for Virtual Balises.

Longitudinal cross-talk is mainly related to reliability cross-talk. It is a safety-related aspect that the On-board constituent is enabled to correctly determine the order (e.g., sequence in time and/or position) of the passed Balises, and that erroneous positioning shall not occur.

4.2.9 Timing and Distance Requirements

The maximum time delay between a bit on Interface 'C1' at the Balise end of the interface and the corresponding bit on Interface 'A1' shall be 10 μs.

The time delay between the end of transmission of the current Balise (that is 1.3 m after the centre point of the current Balise) in a cluster of Balises, and the availability of data for the ERTMS/ETCS Kernel (location reference information and the data from this current Balise) shall be less than Tn. The requirement is in general applicable in terms of constraints on distances between Balise Groups.

[4] The Balises are in general configured in (linked or unlinked) Balise Groups with more than one Balise, or as single Balises with information linked to other Balises or sources of data. Verification of the group configuration data and of the linking information, performed by the ERTMS/ETCS system level functions, constitutes an additional protection against cross-talk.

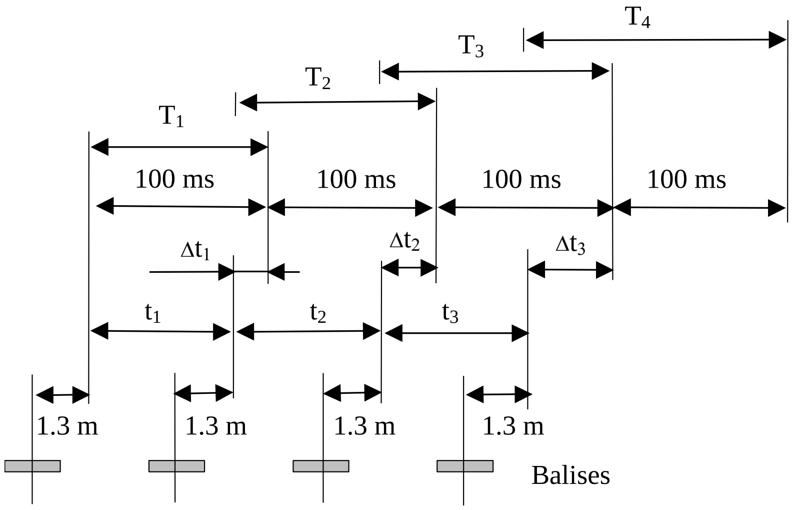


Figure 2: Example of a passage of a cluster of four Balises

$T_n = 100 + \Delta t_{n-1}$ ms, where $\Delta t_0 = 0$ and $t_0 = 0$

$$\Delta t_{n-1} = \begin{cases} 0 & \text{if } t_{n-1} \geq 100 + \Delta t_{n-2} \text{ ms} \\ 100 + \Delta t_{n-2} - t_{n-1} \text{ ms} & \text{otherwise} \end{cases}$$

T_n = Maximum delay from 1.3 m after the centre of the Balise until the Up-link data is available at the ERTMS/ETCS Kernel.

n = The number of the Balise in the cluster, $n \in [1 \, through \, 8]$. When $\Delta t_{n-1} = 0$, then $n \to 1$, i.e., then n corresponds to the first Balise in the next cluster.

Δt_n = The time that the data is FIFO queued.

t_n = The elapsed time when the train moves from 1.3 m after the centre of Balise n to 1.3 m after the centre of Balise n+1.

Note for Virtual Balises:

Previous requirement is applicable to physical balises. In order to allow the ERTMS/ETCS Kernel to manage virtual and physical balises in the same way, the same requirements shall be applied, considering:

- ***the nominal position of the Virtual Balise in accordance with the track description instead of the centre of the physical balises;***
- ***the Virtual Antenna (an ideal position below the train where a BTM Antenna would detect ideal physical balises placed in accordance with the track description) instead of the BTM Antenna.***

The distance between two clusters of Balises [5] shall be at least d_c.

$$d_c = T_N \bullet v_{line} \ \text{[m]}$$

d_c = The distance between two clusters of Balises, i.e., from 1.3 m after the last Balise in the first cluster to 1.3 m before the first Balise in the second cluster.

v_{line} = The Maximum Permitted Speed in m/ms.

N = The last Balise in a cluster of Balises. If $\Delta t_{n-1} = 0 \Rightarrow n = N \Rightarrow T_n = T_N$, $N \le 8$.

Note for Virtual Balises:

Previous requirement is applicable to physical balises. In order to allow the ERTMS/ETCS Kernel to manage virtual and physical balises in the same way, the same requirements shall be applied.

4.2.10 Location Reference Accuracy

4.2.10.1 General

The Eurobalise Transmission System shall evaluate the location for the Balise, using the available time and odometer information, and make this information available to the ERTMS/ETCS Kernel. This delivered information includes the error in the time and odometer information, which is not considered in the following.

4.2.10.2 Accuracy for vital purposes

The location accuracy shall be within ±1 m for each Balise, when a Balise has been passed.

When applicable, the location accuracy in the preliminary location reference, delivered after the reporting period defined in sub-clause 6.2.2.5 on page 112 during the Balise passage, shall be within ±1 m.[6]

4.2.10.3 Accuracy for non-vital purposes

The location accuracy shall fulfil the following Figure 3 with a confidence interval of 0.998 after the Balise passage.

Figure 3 below specifies the error |Lerr| as function of the speed. |Lerr| is the maximum error in measured Balise position relative to the physical centre of the Balise. The error in the external odometer references is not included.[7]

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5 Additional distance may be required by the ERTMS/ETCS Kernel. The distance, d_c, is only related to the Eurobalise Transmission System needs.

6 Each manufacturer shall specify the needed performance related to the received odometer and time information to meet this requirement.

7 Preferably, the vertical component of the Up-link magnetic field is used for this purpose. Therefore particular demands on conformity and stability apply for this signal both in static and dynamic conditions.

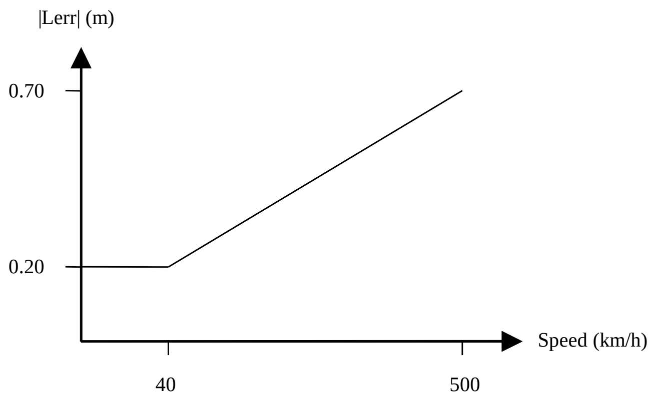


Figure 3: Error in position of the Balise centre relative to the odometer value

The figure above may be expressed as[8]:

$$\left|L_{err}\right| = \begin{cases} 0.20\,m & 0\,km/h < v < 40\,km/h \\ 1.1\cdot 10^{-3} \bullet v + 0.15\,m & 40\,km/h \leq v \leq 500\,km/h \end{cases}$$

Note for Virtual Balises:

Previous requirements can be obtained with physical balises. For Virtual Balises, accuracy is based on the performance obtainable with GNSS technology (preliminary value is 20 m).

4.4 RAMS Requirements

4.4.1 General

Within this sub-clause (4.4), the term "Transmission System" is used as a short form for "Balise Location and Transmission System".

Note for Virtual Balises:

For Virtual Balises, the entire LDS system shall be considered as "Virtual Balise Location and Transmission System".

A RAMS Program (RAM Program and Safety Plan) shall address issues related to RAMS management, reliability, availability, maintainability, and safety, in accordance with the applicable definitions of EN 50126.

In general, the minimum operational lifetime should be 20 years. In particular the minimum operational lifetime for the fixed data Balise should be 30 years.

[8] Each manufacturer shall specify the needed performance related to the received odometer and time information to meet this requirement.

4.4.2 Top level functionality

Table 3 below defines the top-level functionality of the constituents of the Transmission System in terms of basic functions.

No.	Function Description	Related hazards
F1	Balise Detection	H1, H2, H3
F2	Transmit protected data from wayside devices to the intended train devices	H4, H5, H6, H9
F3	Provide data used for localisation of the train	H7
F4	Allow understanding of the travelling direction of the train	H8

Table 3: List of basic functions

4.4.3 Reliability

The MTTF (Mean Time To Failure) for a given constituent of the Transmission System might fluctuate with the time. The reliability targets concern the mean MTTF value over the operational lifetime.

The constituents of the Transmission System shall operate so as to ensure that reliability cross-talk from, and to, adjacent tracks does not adversely affect the overall reliability. Reliability cross-talk is defined as the disturbing effect on the correct transmission of data, such that correct transmission is unattainable.

Note for Virtual Balises:

For Virtual Balises, causes that affect GNSS technology shall be considered.

4.4.4 Availability

The Balise Detect function implicitly measures the air-gap noise levels, and effectively constitutes an EMC level supervision. When the EMC level is above a level that ensures the required Balise transmission performance, then the On-board Transmission Equipment may perform Balise Detect. Thus, this implicitly includes EMC supervision, and triggers a vital fallback function (i.e., the Balise Detect functionality). The false alarm rate for the Balise Detect functionality is affecting the availability that must comply with the overall system level requirements.

The following specific availability targets should be fulfilled:

- A mean figure of 10^6 Balise passages with error free telegrams delivered by the On-board Transmission Equipment to the ERTMS/ETCS Kernel should be ensured. This applies within the entire specified range of environmental conditions and train speeds.
- The On-board Transmission Equipment should not erroneously report to the ERTMS/ETCS Kernel that it has detected a Balise more often than 10-3 times per hour.[9]

[9] This can occur without faults in the equipment (e.g., due to disturbance).

Note for Virtual Balises:

Previous requirements apply to physical balises, that can also be used to provide signaling related information that can lead to hazardous situation if missed. In case Virtual Balises are used only for localization and to provide non safety related telegrams, EMC supervision should not trigger a vital fallback function, as far as it does not lead to hazardous scenario (see following section on Safety).

4.4.6 Safety

4.4.6.1 General

For the constituents of the Transmission System, a Safety Plan shall be agreed. It shall be implemented, reviewed, and maintained throughout the lifecycle of the system. The following issues shall be considered:

- Identification of the safety related functions for the system, and definition of the corresponding integrity levels.
- Applicable analysis methods.
- Identification and analysis of all possible hazards.
- Assessment of risks.
- Criteria for risk mitigation and tolerability.
- Safety verification, validation, and assessment.

All work pertaining to Safety shall comply with the standards:

- EN 50126
- EN 50128
- EN 50129

4.4.6 Safety related functionality

4.4.6.1 Introduction

The functionality defined by Table 3 is categorised safety related.

Note for Virtual Balises:

Not all these functionalities are safety related for Virtual Balises, as described in the notes provided in the following sections.

4.4.6.2.2. Balise Detection

The ability to detect Balises is considered safety-critical, and constitutes a fall-back functionality in case the transmitted telegram cannot be read by the On-board Transmission Equipment. The detection function is given as an indication to the ERTMS/ETCS Kernel.

Information about wayside failures shall be passed on to the ERTMS/ETCS Kernel. This includes transmitting a Balise Detect without an accompanying valid telegram.

Note for Virtual Balises:

As described above for EMC supervision, previous requirements apply to physical balises, that can also be used to provide signaling related information that can lead to hazardous situation if missed. In case Virtual Balises are used only for localization and to provide non safety related telegrams, the ability to detect Virtual Balises can be considered non safety-critical.

4.4.6.2.3 Transmission of protected data

Data and telegram structures shall be protected against possible noise effects in the air-gap and noise induced hazards in the receiving and transmitting equipment, by telegram coding algorithms.

Note for Virtual Balises:

Data and telegram structures for Virtual Balises are supposed to be not affected by noise.

4.4.6.2.4 Localisation

The Onboard Transmission Equipment shall be able to provide information suitable for detecting and evaluating the location reference of the Balise, and make this information available to the ERTMS/ETCS Kernel. The safety of this function is based on the passage of at least two Balises.

The localisation accuracy shall be as specified in sub-clause 4.2.10.2, when a Balise has been passed.

4.4.6.2.5 Travelling direction

The constituents of the Transmission System shall allow evaluation of the travel direction at each Balise Group. It is not allowed to mix the order of the Balises due to longitudinal cross-talk. The safety of this function is based on the passage at least two Balises that are linked to each other.

Information about Balise sequences shall be passed on to the ERTMS/ETCS Kernel. It shall be correlated in such a way that the ERTMS/ETCS Kernel can identify that certain information is transmitted from a certain Balise.

The ERTMS/ETCS Kernel will determine the train’s travel direction, by the sequence of the reported Balises.

The ERTMS/ETCS Kernel will be able to determine the train's direction of travel from received telegrams, from at least two linked consecutive Balises (e.g., two single Balises, or the Balises within a Balise Group with multiple Balises).

4.4.6.3 Top-level Hazards

The top-level hazards are defined in Table 4, together with their possible sources of the hazards10 and the related functionality of Table 3 in sub-clause 4.4.2. Non-considered exceptional conditions outside the specification are not explicitly mentioned herein.

No.	Hazard Description	Related function	Origin of failure
H1	A Balise is not detected	F1	Balise Air-gap On-board Transmission Equipment
H2	The On-board Transmission Equipment erroneously reports that it has detected a Balise	F1	Air-gap On-board Transmission Equipment
H3	The On-board Transmission Equipment erroneously reports detection of a Eurobalise in presence of a KER Balise	F1	Air-gap On-board Transmission Equipment
H4	Transmission of an erroneous telegram interpretable as correct	F2	Balise On-board Transmission Equipment LEU Air-gap Interface 'C' Programming
H5	Loss of the telegram, from a certain Balise, intended for full performance	F2	Balise On-board Transmission Equipment LEU Air-gap Interface 'C' Programming
H6	No transmission of Default Telegram in case of wayside failures	F2	Balise LEU Interface 'C' Programming Air-gap On-board Transmission Equipment
H7	Erroneous localisation of a Balise with reception of valid telegram [11]	F3	Balise Air-gap On-board Transmission Equipment
H8	The order of reported Balises, with reception of valid telegram, is erroneous	F4	Balise Air-gap On-board Transmission Equipment
H9	Erroneous reporting of a Balise in a different track, with reception of valid telegram	F2	Balise Air-gap On-board Transmission Equipment

Table 4: List of top-level hazards

[10] "Balise" includes e.g., the related installation rules for cables etc.

[11] Longitudinal cross-talk is an example of a wayside source for this. On-board Transmission Equipment failure in position and/or time reference of a Balise passage is an example of an on-board source.

Note for Virtual Balises: Only following hazards are relevant for Virtual Balises:

- ***H1 – A Balise is not detected***
- ***H2 – The On-board Transmission Equipment erroneously reports that it has detected a Balise***
- ***H7 – Erroneous localisation of a Balise with reception of valid telegram***
- ***H8 – The order of reported Balises, with reception of valid telegram, is erroneous***
- ***H9 – Erroneous reporting of a Balise in a different track, with reception of valid telegram***

In case Virtual Balises are used only for localization and to provide non safety related telegrams, hazard H1 can be disregarded.

Possible sources for these hazards shall be reconsidered for virtual balises, based on characteristics of GNSS technology.

4.6 Electrical Requirements

4.6.1 On-board Equipment

The On-board Transmission Equipment should be powered from an On-board battery power supply.

The power supply should comply with clause 3 of EN 50155.

9.3 SUBSET-040 ERTMS/ETCS- DIMENSIONING AND ENGINEERING RULES APPLICABLE TO THE VIRTUAL BALISE CONCEPT

This subsection reports SUBSET040 ERTMS/ETCS- Dimensioning and Engineering rules [5] applicable to the Virtual Balise Concept.

9.3.1 Installation Rules (SUBSET-040 §4.1)

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

4.1.1.1 General installation rules for balises

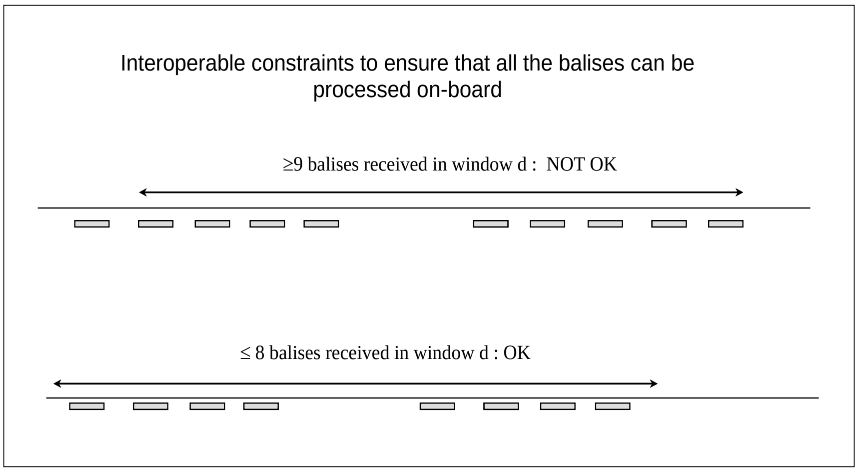
Rule	Reminder: the rules of the references below must be respected.
Reference	SUBSET-036 ❑ Section 4.2.5: Cross-talk protection ❑ Section 5.2 : Balise air gap interface ❑ Section 5.6.2 : Installation requirements for balises ❑ Section 5.6.3: Distance between balises ❑ Section 5.7: Environmental Conditions
Justification	The rules of the reference above are required in order to guarantee interoperability from a transmission point of view.

Note: Only the reminder "Section 5.6.3: Distance between balises" mentioned in [5] § 4.1.1.1 is directly applicable to Virtual Balises.

4.1.1.2 Maximum distance between balises within a group – to determine that no further balise is expected within a group (potentially missing balise).

Rule	The maximum distance between two consecutive balises within the same group shall be 12 m from reference mark to reference mark.
Reference	
Justification	The distance must be as short as possible in order to determine potential loss of balises as soon as possible, but must respect the longest minimum distance according to rule referenced in 0 herein.

4.1.1.6 Number of balises that can be processed per unit of time

Rule	Let “d” be the distance run by a train at the maximum speed of the line during 0.8 s. In this distance “d”, the number of encountered balises shall not exceed 8. Note: The maximum speed of the line is the nominal line speed value (engineered SSP). Tolerances due to inaccuracy of speed measurements and speed margins before brake intervention are not to be taken into account for engineering.
Reference	Limitations of SUBSET-036 - section 4.2.9 must be considered
Justification	The rule is linked to processing of balise information on-board
Remark	Figure 

9.3.2 <u>Telegram and messages (SUBSET-040 §4.2)</u>

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

4.2.1.1 Length of balise telegrams (300 km/h, 500 km/h)

Rule	Reminder: the rules of the references below must be respected.
Reference	SUBSET-036 section 5.2.2.3.
Justification	The rules are required in order to guarantee interoperability from a transmission point of view.

4.2.4.1 Packet 145 (Inhibition of balise group, message consistency reaction)

Rule	For all balise groups: it shall be forbidden to transmit the packet 145 if the balise group message contains, for the same validity direction as packet 145, safety related data that, if missed, could lead to the ETCS core hazard.
Reference	SUBSET-026, section 3.16.2.4.4.1 b), 3.16.2.5.1.1 b), 7.4.2.37.2
Justification	According to SUBSET-091 table 14.1.1.2 footer 14, the message consistency check is a protective feature, which has already been credited when deriving the safety targets for the hazards BTM-H1, BTM-H4, EUB-H1, EUB-H4.

4.2.4.2 Sharing of identifiers within different transmission systems

Rule	Reminder: the rules of the reference below must be respected
Reference	SUBSET-026, section 3.18.4.4
Justification	

4.2.4.3 List of balises for SH Area

Rule	It shall be forbidden to send the packet 49 (list of Balises for SH Area) in a message which does not contain the packet 80 (Mode Profile) with the variable M_MAMODE = “Shunting”. Exception: the rule does not apply for the radio message “SH authorised” since its list of optional packets includes the packets 3, 44 and 49 only.
Reference	SUBSET-026, section 4.4.8.1.1 b), 8.4.4.4.1
Justification	The on-board must always link a list of balises for SH area to either one given mode profile “Shunting” or to one SH authorisation from the RBC.

9.4 SUBSET-041 PERFORMANCE REQUIREMENTS FOR INTEROPERABILITY APPLICABLE TO THE VIRTUAL BALISE CONCEPT

This subsection reports SUBSET041 requirements [6] applicable to the Virtual Balise Concept.

9.4.1 Response Times (SUBSET-041 §5.2)

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

5.2.1.2 Delay between receiving of a balise message and initiating a communication session establishment

Description	**delay between receiving of a balise message and initiating a communication session establishment**
Start Event	The reference mark of the on-board antenna leaving the “side lobe zone” of the last balise in the group (1.3 m from the reference mark of the balise)
Stop Event	Beginning of sending of the connection request to the GSM-R mobile Euroradio interface
Value	< 1.5 sec
Notes	It is assumed that the establishment of the communication session is required by the message contained in the balise group.

5.2.1.3 Delay between receiving of a balise message and reporting the resulting change of status on-board (e.g., update of EOA, level transition, mode change)

Description	**delay between receiving of a balise message and reporting the resulting change of status on-board**
Start Event	The reference mark of the on-board antenna leaving the “side lobe zone” of the last balise in the group (1.3 m from the reference mark of the balise)
Stop Event	Indication to the driver
Value	< 1.5 sec

Description	**delay between receiving of a balise message and reporting the resulting change of status on-board**
Notes	It is assumed that the change of status is required by the message contained in the balise group. The value indicated in this case includes additional delay for the display of the information.

Note for Virtual Balises:

Previous definition of start event is applicable only to physical balises. For virtual balises the following start event can be considered:

When the estimated nominal position of the Virtual Antenna associated with the Virtual Balise Reader is greater than the nominal position of the last Virtual Balise in accordance with the track description.

The position of the Virtual Antenna of a Virtual Balise Reader is an ideal position below the train where a BTM Antenna would detect ideal physical balises placed in accordance with the track description.

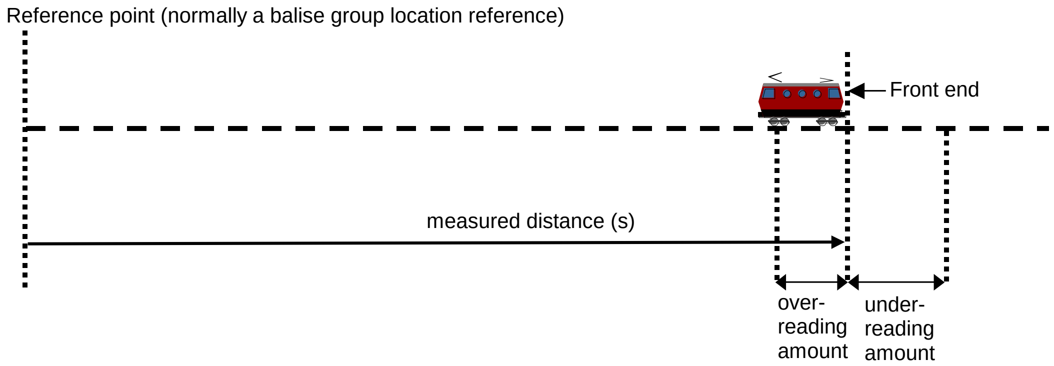
9.4.2 Accuracy (SUBSET-041 §5.3)

Following requirements, figures and tables are reported with their original numbering in order to facilitate referencing ERTMS documents.

Note that subsections not containing explicit notes concerning Virtual Balises are entirely applicable to the Virtual Balise concept.

5.3.1.1

Accuracy of distances measured on-board

Description	Accuracy of distances measured on-board
Start Event	not applicable
Stop Event	not applicable
Value	for every measured distance s the accuracy shall be better or equal to ± (5m + 5% s), i.e. the over reading amount and the under reading amount shall be equal to or lower than (5m + 5% s). 
Notes	This performance requirement includes the error for the detection of a balise location, as defined in the Eurobalise specifications. Also in case of malfunctioning the on-board equipment shall evaluate a safe confidence interval.

Note for Virtual Balises:

When the location is based on a Virtual Balise:

- ***the default error for the “detection” of a virtual balise shall be included, based on the performance obtainable with GNSS technology (preliminary value is 20 m, so the fixed accuracy of 5 m is generally applicable only to physical balises);***
- ***previous requirement does not include dynamically estimated error for the detection of a virtual balise location.***

10 References

[1] STARS Grant Agreement, Annex I - “Innovation Action”, 25th of November 2015.

[2] STARS Consortium Agreement of 6th November 2015.

[3] UNISIG, SUBSET-026 v3.3.0, “ERTMS/ETCS System Requirements Specification”

[4] UNISIG, SUBSET-036 v.3.0.0, “FFFIS for Eurobalise”

[5] UNISIG SUBSET-040 v.3.2.0 “ERTMS/ETCS- Dimensioning and Engineering rules”

[6] UNISIG, SUBSET-041 v.3.1.0, “Performance Requirements for Interoperability”

[7] UNISIG, SUBSET-091 v.3.2.0, “Safety Requirements for the Technical Interoperability of ETCS in Levels 1 & 2”

[8] NGTC D7.7 Results of the Safety Analysis ETCS Application Level 2 – Virtual Balise Detection using GNSS v.01 12/10/2016.

[9] MOPS RTCA-DO 229

[10] MOPS RTCA-DO 245A

[11] NGTC D7.7 Results of the Safety Analysis Appendix C - ETCS Application Level 2 – Virtual Balise Detection using GNSS – Principles, Procedures and Positioning System Performance Requirements v.08 12/10/2016

[12] STARS D5.1

[13] STARS D5.2

[14] STARS D5.4

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[17] NGTC D7.7 Results of the Safety Analysis Appendix E - ETCS Application Level 2 – Virtual Balise Detection using GNSS – Safety Analysis Part 1, Preliminary Functional Analysis v.05 12/10/2016

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[19] ERTMS/ETCS RAMS Requirements Specification – chapter 2 RAM, Reference EEIG: 96S126