On the Trail of West – East Signalling Interoperability: A Novel Proposal for an STM and an Interface Proposal for ETCS Onboard Operations on Class B Trackside Signalling Systems

Çağla Kıvılcım Çiftcioğlu[1] and Mehmet Turan Söylemez[2]

[1]İstanbul Technical University, Railway Systems Engineering, İstanbul, Turkey
ciftcioglu21@itu.edu.tr
[1]İstanbul Technical University, Control and Automation Engineering Department, İstanbul, Turkey
soylemezm@itu.edu.tr

Abstract

ERTMS and ALSN signalling systems are two of the major signalling systems that are under operation in the world. With the introduction of technical specifications for interoperability, ERTMS promises increased passenger and freight attractiveness and seamless cross-border operation. The ERTMS specifications recognise ETCS as a Class A train protection system and other signalling systems in Europe as Class B train protection systems. The specifications further define "Specific Transmission Modules" (STMs) that enable trains with ETCS onboard to operate in railway lines that are equipped with Class B train protection systems. Although ALSN is classified as a Class B train protection system, ALSN STM is not defined yet. This paper focuses on proposing a novel ALSN STM that enables trains with ETCS onboard to operate in the countries where ALSN trackside is operational. The proposed STM unit is conceptualised as a system architecture, and a new standardised interface is introduced to enable signalling interoperability between ERTMS and ALSN.

1. Introduction

ERTMS is an international signalling system developed for continuous cross-border train operations across Europe. The ALSN signalling is one of the most operational signalling systems in the world, constituting 10% of the world's railways. ERTMS and ALSN signalling systems are the two systems that are adopted along the international corridors connecting Europe to Asia. This paper aims to propose a method that enables seamless cross-border operation between the countries that have adopted the ERTMS and ALSN signalling. In other words, this paper proposes a novel Specific Transmission Module (STM) that allows the operation of a train with ETCS onboard on the railway line equipped with an ALSN signalling system.

ERTMS to ALSN signalling transition is a must considering all the international railway corridors connecting Europe to Asia. The project named NEAR (Network of European – Asian Rail Research Capacities) is founded by European Union in order to identify all the Trans-Euroasian Railway Networks. As a result of this study, five main routes are identified as Route A, B, C, D and E [18]. The identified routes B and C has more sub-routes. The identified routes and transitioning of the signalling system are shown in Figure 1. All of the identified routes require ERTMS to ALSN or vice versa signalling transitioning.

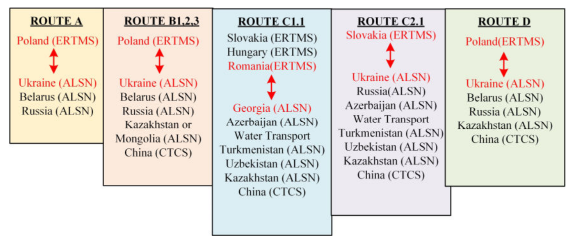

Fig. 1. Routes and Signal transitioning identified by the project NEAR.

ERTMS system has two components: ETCS, the onboard and infrastructure, and GSM-R, a communication system. The main principles of ETCS are to provide all the available functions of train control systems, to ensure cooperation with vehicles and infrastructure, and to ensure traffic management within the requirements and regulations of the relevant Rail Administrations. The specifications define operational levels for ETCS; these are Level 0, 1, 2, 3, and Level STM [1]. The GSM-R radio system, ETCS trackside system, and onboard system have different interfaces for different operational levels. The ETCS onboard has transmission modules to interface with balise and Euroloop. It has an antenna to interface with GSM-R. Each interface has its own specifications: Functional Interface Specifications (FIS), which is for logical interoperability, and Form Fit Function Interface Specification (FFFIS), which is both for logical and physical interoperability.

ALSN signalling system employs AC-coded track circuits to enable semi-continuous data transmission between the trackside and the onboard as well as to perform track vacancy detection. The movement authority is transmitted to the onboard through rails. ALSN is a cab signalling system. The movement authorities are reflected in the form of ALSN code combinations. Each movement authority is represented with a specific pulse combination. As it is available for three-aspect signalling, there are three ALSN codes: green, yellow, and red-yellow. The green is a 3-pulse long interval sequence. The Yellow is 2-pulse long, and the red-yellow is 1-pulse sequence. These codes are generated via a code generator device [2]. The receiving coils for ALSN onboard pick up the ALSN codes. The signal is processed and shown at the human-machine interface of the ALSN onboard [3].

ERTMS signalling system has specifications that aim to unify railway operations, resulting in interoperability between countries. The efforts of interoperability first started with Directive 96/48/EC "The interoperability of the trans-European high-speed rail system", in 1996. The main purpose of the directive was to increase safety, competitiveness, and track utilisation [4]. In the following years, these efforts became "Technical Specifications for Interoperability" (TSI). EU Commission Regulation Directive 2016/797 defines the latest Technical Specification for Interoperability. The structural and functional requirements of each sub-system are provided under this directive. This study focuses on TSI for "Command Control and Signalling" (CCS) interoperability. The ERTMS is considered as a Class A train protection system. The TSI specification also identifies Class B systems under the documentation named "List of CCS Class B Systems ERA/TD/2011-11"[5]. ALSN signalling system is listed as one of the Class B systems. The specification identifies how to interface and integrate some Class B systems with Class A systems [6]. However, the specifications do not identify or present an STM or an interface to integrate the ALSN signalling system. The majority of international railway corridors connecting Europe to Asia have ERTMS to ALSN signalling transmission. However, no solution has been proposed yet. Even the track gauge incompatibility is resolved between these countries with the track gauge changing facilities (e.g. Turkey – Georgia), which enable vehicles to change track gauge from 1435 mm to 1520 mm without reaching a full stop. However, the signalling interoperability has been completely ignored as of this date. This research recognises this gap and proposes a novel ALSN STM and an interface to enable interoperability for ERTMS systems as Class A and the ALSN system as Class B.

This paper is organised as follows. Section 2 analyses the available research on both signalling systems, and the results are presented as a comparative literature review. In Section 3, the results of the requirement analysis for the proposition of a new STM are shown. A novel ALSN STM, which discusses the conceptual requirements of the system and its interface, is proposed in Section 4. Section 5 provides the conclusions and applicable railway corridors.

2. Review of Literature

A comparative literature review is performed for ERTMS and ALSN signalling systems. The study revealed that the available literature for these two systems is majorly focused on modelling and optimisation. Additionally, ERTMS has STM-related literature proving the availability of efforts for integrating other signalling systems into ERTMS.

The modelling of the ERTMS signalling system is one of the primary focuses of the available literature. The tools employed in modelling ERTMS are UML Class Diagrams, State Charts, System of Systems (SoS), Fault trees, Bayesian Networks, and Petri Nets. The literature on modelling ERTMS aims to overcome the complexity of ERTMS specifications [1], avoid ambiguities of the ERTMS specifications [2], evaluate dependability parameters, and identify failure and repair rates [3]. The modelling efforts in ALSN literature are majorly linked with the proposition of a solution to distortions. ALSN signalling system is attempted to be modelled to eliminate these distortions. ALSN codes are transmitted through rails, and the reliability of the signalling system heavily depends on the correct interpretations of these ALSN codes. The major causes of distortions are traction current, harmonics, changes in the magnetic field, power transmission lines crossing the railways, and height differences in the locomotives' receiving coils [4].

The available research focusing on the optimisation of ERTMS signalling has multiple facets. The targeted optimisation topic varies from block section lengths with a minimum amount of signalling equipment[5], the capacity of the railway network [6], and the availability of the current system with additional communication links [7]. The proposed optimisations on ALSN code immunity focus on developing a method to select the optimum ALSN code carrier frequency [8] and the optimum track section length [9].

As stated earlier, there is "Specific Transmission Module" (STM) that enables ETCS onboard to receive movement authority from the legacy (national) signalling system. These signalling systems are limited and not available for the whole list of Class B train protection systems. There are defined interfaces of STM in the ERTMS specifications. These are "K", "G" interfaces. "K" and "G" interfaces are developed for KVB, Ebicab and RSDD (KER) balises. KVB is the French ATP system, Ebicab is Bombardier Transportation's ATP system, and RSDD is the Italian ATP system [10]. Interface "G" supports five different types of balises: A (parallel/grey balise in Sweden and Norway), B (serial balise in Sweden), C (mini balise in Norway), D (Parallel balise in French) and E (serial balise in France) [11]. These are the standardised methods of integrating Class B signalling systems into ERTMS. There are also research efforts that focus on developing STM technologies. Some studies propose a new STM device for the Indusi signalling system that allows trains equipped with ETCS onboard to be operated in the Indusi trackside signalling system [12].

A proposition of ALSN STM is a gateway to seamless rail transportation between the "Commonwealth of Independent States" (CIS) that connects Europe to Far Asia and South Asia. To the best of authors' knowledge, an STM for ALSN has not been proposed yet. Although Latvia, Lithuania, and Estonia are part of the European Union and have the ALSN signalling system as their legacy signalling system, there does not seem to be an existing attempt for an STM by those countries. Although ALSN is identified as a Class B train protection system by the interoperability technical specifications of the European Union and ALSN STM has an identified unique code in ETCS language as "NID_STM / NID_NTC: No. 39"[13], there is no proposed method to enable the interoperability of these two signalling systems.

3. Requirement Analysis

Interoperability is the key to the operational success of railway operations. The success of a railway operation can be measured by its comparative competitiveness to other modes of transport. If a railway network is able to attract passenger or freight movement from an alternative mode of transport, such as airways or roadways, then it is evaluated as competitive. Interoperability plays a crucial role in increasing the competitiveness of the railways since it omits the delays at border crossings due to changes in locomotive or train sets. Signalling is a facet of interoperability, and proposing STMs to enable movement without modifications is an important step toward cross-border operation.

The main assumption of this research is that a train equipped with ETCS onboard operates on a railway line that is equipped with ALSN signalling system. Considering this assumption, the ETCS onboard system is very crucial for this study. The onboard system has the following sub-components: Driver Machine Interface (DMI), European Vital Computer (EVC) Train Interface Unit (TIU), Balise Transmission Module (BTM), Loop Transmission Module (LTM), Euroradio, Odometry, Train Integrity and Specific Transmission Module (STM). The responsibility of BTM is to send a tele-powering signal as a 27MHz Continuous wave signal to activate the balises and to receive the up-link signal generated by balises. The up-link signal received carries the data called “telegram” in the form of a frequency shift keying (FSK) signal. The received signal demodulates in BTM unit to be sent to EVC. As the train passes over a balise, BTM tele-powers the balise, initiating the communication between the balise and BTM. The initiated communication results in the transfer of “Uplink data”. The data processing starts in BTM, where it is demodulated to a digital telegram. BTM shares the digital telegram with European Vital Computer (EVC). In EVC, the received data is processed and displayed to train drivers on DMI. BTM extracts information on geographical position, route-related information, and speed restriction information from the received signal [14]. BTM has an antenna that is located on the bottom of the rolling stock with a metal frame structure. BTM unit has 3 components: BTM Control Unit, FPGA Board, and Analogue Unit[15]. BTM is connected to EVC via an ethernet link. Analogue modules are a BTM antenna, transmission unit, combination filter, and receiver unit.

For the interoperability to be achieved, the railway network and the rolling stock shall give standardised functions, performance, and interfaces. The interfaces identified by the specification are human-machine interface, train-to-track, and track-to-train communication[16]. TSI CCS indicates a very important requirement for ETCS trackside and onboard regarding the level of performance and safety levels. The safety integrity level of these systems shall be SIL4 as defined in the EN 50129 standard. The specification also indicates that the requirement for ETCS onboard is very strict; meanwhile, for ETCS trackside system is defined to be more flexible. TSI CCS indicates that ETCS trackside failures shall lead to a degraded mode of operation rather than safety hazards. The integration ALSN STM, which uses ALSN trackside, shall consider these requirements for performance, functions, and safety. The requirement analysis shows that ETCS onboard shall be employed as a whole, and its integrity shall not be harmed; however, the trackside shall be designed to result in degraded situations rather than safety hazards.

As the ETCS onboard will be utilised, the human-machine interface will be the same in ALSN STM operation. In the zone of ALSN STM operation, the drivers will use DMI. The air-gap interface that is track-to-train communication needs to be defined. The requirement analysis showed that the available interfaces “K” and “G” for STM operation are not relevant. As explained in the literature review section, these are the interfaces designed for STM operation of other signalling systems. For this study, there is a requirement of the proposition of a new interface between ETCS onboard and Class B on-board. The novel ALSN STM is designed to be an external type of interface to protect the standardised interfaces inside the ETCS onboard. This newly proposed interface will be a new standardised air-gap interface.

The trackside system of ALSN shall be analysed to propose the air-gap interface. The responsibility of ALSN trackside is to carry movement authority to the rolling stock with ALSN codes. The transmission medium of these codes is the rails. The most distinctive component of ALSN trackside is the code track transmitter (CTT) that generates Green (G), Yellow (Y), and Red-Yellow (RY) ALSN codes. These codes are sent to the transmitter relay (TR), where amplitude modulation occurs with a separate AC network connection. The generated codes are given to the rails with a code transformer (CT). Whenever a train enters the block section and triggers the track vacancy detection, the ALSN codes transmission window initiates.

There are three types of ALSN codes: Green (G), Yellow (Y), and Red-Yellow (RY). These codes show the signal indication of the signal light that the train is approaching. G indicates green aspect indication, Y is yellow, and RY is red. The code track transmitter receives the signal aspect information and generates a pulse signal with the DC transmitter for the corresponding code. Each signal aspect has a corresponding sequence of rectangular pulses with intervals.

AC transmitter applies amplitude modulation to the generated pulse signal. The AC transmitter transforms the pulse signal S0(t) to modulated signal S1(t). Equation 1 shows the relation between S0(t) and S1(t). FN is the carrier signal frequency of 25 Hz, 50 Hz or 75 Hz.

$$S_1(t) = S_0(t).sin(2\pi F_N t) \quad (1)$$

ALSN onboard has the receiving coils (RCs) connected in series. Receiving coils send the received codes to the amplifier unit of ALSN onboard. The amplifier unit includes a filter, an amplifier, and a pulse relay. These sub-components are responsible for bandpass filtering to the operating frequency range, increasing the signal's amplitude, and demodulating the signal as DC pulses. Next, the processed code enters the major component of ALSN onboard, the Decoder unit. Compliance control compares three cycles of pulse to ensure that the received signal is correct and continues. If the received signal is safe, it is displayed in the locomotive traffic light (LTL), the human-machine interface of the ALSN system [17].

To propose the conceptual architecture of the ALSN STM, the inputs and the outputs of the device shall be defined. Additionally, the required components of ETCS onboard and ALSN trackside need definition as well. The approach that is employed in this paper is based on the approach of TSI. TSI identifies the requirements as “System Requirement Specification (SRS)” and “ form fit functional interface specification (FFFIS)”. The same approach is used to identify the conceptual architecture, system requirements, and interface. The SRS is proposed at a conceptual level, where a block diagram of the proposed novelty is presented. The information on how the data received from ALSN trackside is processed in STM and how the output of the STM is integrated into the ETCS onboard, are included under “Conceptual SRS”. The “Conceptual FFFIS” contains information regarding the new interface between STM and ETCS onboard.

The required components of ETCS onboard are Driver Machine Interface (DMI), Train Interface Unit (TIU), Odometry, European Vital Computer (EVC) and Balise Transmission Module (BTM). The other available sub-systems of ETCS onboard will be available. However, they are not relevant for this study. The proposed ALSN STM module shall also be available on the board. The required components of ALSN trackside are code track transmitter, transmitter relay DC & AC and code transformer. The envisaged ERTMS operational level is Level STM. The Level STM will be operational onboard when the train passes a fixed balise before crossing the border and carries the telegram of “NID_STM / NID_NTC: No. 39” that indicates the train is entering into the ALSN zone.

4. Proposing the ALSN STM Unit

4.1. Conceptual System Requirement Specifications

Under the scope of conceptual system requirement specifications (SRS), the input–output, data processing, and conceptual architecture of the ALSN STM are presented.

The input-output dynamics of the ALSN STM are based on the idea that the output of the Class B train protection system is going to be employed as the input of the STM unit. The output of the unit is going to be the input of the ETCS trackside system. According to this approach, the input of the ALSN STM is the AC-modulated DC impulse signals, as identified in Equation (1). These signals are the ALSN signals. The output of the ALSN STM is envisaged to be digital telegrams. Under normal conditions, the telegrams are generated in balises. However, for this case, the received information from trackside is going to be processed to become a digital telegram. This eliminates the transmission over an air gap and the requirement of “frequency shift keyed signals” (FSK).

As identified earlier, the proposed STM is an external type that does not require direct connection to ETCS onboard Profibus. The output of the ALSN STM is designed to be fed into the FPGA board of BTM as a digital telegram. This method only bypasses the analogue modules of the BTM.

The conceptual architecture of ALSN STM is explained with the steps of the data processing. First of all, to receive the input from the ALSN trackside, the ALSN STM shall be equipped with the receiving coils. The received signals from the tracks are to be filtered from harmonics and distortions. For this purpose, a bandpass filter that is operational at the carrier frequency of ALSN signal is required. Due to external factors, ALSN signals can be attenuated. Therefore, to avoid this problem, there shall be an amplifier. The amplified signal shall enter into a pulse relay to be demodulated as rectangular pulse signals to represent the movement authority. The process of demodulation is designed to be performed by “Digital Pulse Converter”.

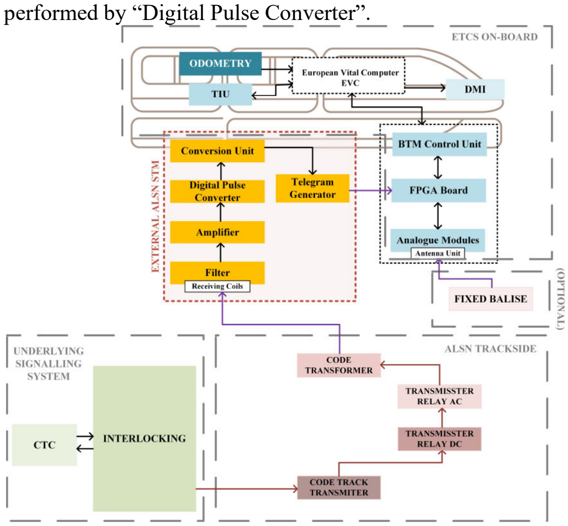

Fig. 2. The Conceptual Architecture of the Level STM operation with ALSN STM

As explained in earlier sections, there are a limited number of ALSN codes; green, yellow, and yellow-red. As the transmission in the ALSN trackside is semi-continuous, the ALSN STM will receive the ALSN code multiple times. The Digital Pulse Converter is designed to perform the demodulation for three cycles and compare the results. If the results are the same for the three cycles of demodulation, the received code is deemed useable and is sent to the “Conversion Unit” (CU). The CU also performs the act of selecting the correct telegram against the received ALSN code. The digital telegram packets and their corresponding ALSN code shall be available as a library. The degraded mode of operation, such as not receiving the same ALSN code for three cycles, shall also be considered in the matching library of ALSN codes and digital telegram. Performing a detailed matching with ALSN codes and degraded mode of operation requires additional research. The matched digital telegram shall be selected, and the telegram generator unit of the ALSN STM shall transmit the digital telegram as the output to the FPGA board of BTM.

The subcomponents of ALSN STM are receiving coils, a filter, an amplifier, a digital pulse converter, and a conversion unit. Except for the conversion unit, the other components are the already available components of ALSN onboard equipment. The novel sub-component is the “Conversion Unit”. Figure 2 shows the conceptual architecture of the Level STM operation with the newly proposed “External ALSN STM”. The CTC and interlocking are shown with tones of green, as these two components are required for all systems. The ALSN trackside and its sub-components are shown in tones of red. The ERTMS onboard is shown in tones of blue. The orange sub-components form the ALSN STM unit. The output of the ALSN STM is directly integrated into the FPGA board.

An additional proposition of this level operation is fixed balise application. According to the available specifications, for level STM, fixed balise is only envisaged on the point of level transition. However, as the ETCS onboard will have odometry, the accrued error shall be rectified at constant distances. Fixed balise application is recommended and optional. The initial investment rate of fixed balise is very low considering that it does not require a very complex integration to interlocking.

4.2. Conceptual Form Fit Functional Interface Specification (FFFIS)

As defined under the section of requirement analysis, the conceptual FFFIS defines a new interface and the communication requirements between ALSN STM and ETCS onboard. The communication requirements between ALSN STM and ETCS onboard are identified. The NID number of the operation in ETCS onboard will be NID_STM:39. The ALSN STM shall use the same common time information as ETCS onboard. When the transition code is received, the only active STM shall be ALSN STM in the ETCS onboard. The main decision maker shall be ETCS onboard, and the failures of ALSN STM shall be actively checked by the onboard. The ALSN STM shall be isolated from the ETCS onboard Profibus. According to the specification, if a system has a connection between a system, it cannot have a lower safety integrity level. So that, ALSN STM shall also be SIL 4 certified. The only functional interface will be between the STM and BTM.

The existing defined interfaces of ERTMS signalling systems are “A”, “C”, “S”, “G” and “K” interfaces. “K” and “G” interfaces are analysed earlier and defined as the STM interfaces by the specification. The “A” interface is the air-gap interface between BTM and the balise. The “C” interface represents the interface/ connection between Balise and Lineside Electronic Unit (LEU). The “S” interface is the connection between LEU and interlocking. The available interfaces do not enable integration of the newly proposed STM. A new unidirectional interface from ALSN STM to BTM is envisaged as the interface “E”. Figure 3 shows all the defined interfaces in blue and the newly proposed interface in red. This new interface is very similar to ERTMS’s track-to-train communication. Train-to-track communication is not required here as a rolling stock entering the track section triggers the ALSN track generator to generate ALSN codes. There will be no handshake for this type of communication; this type of transmission method is semi-continuous.

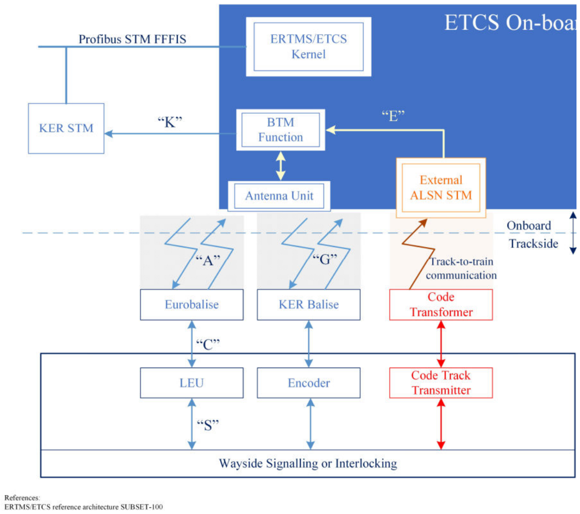

Fig. 3. Defined interfaces shown in blue, newly proposed interface "E" is shown red.

5. Conclusion

This study presented a comparative literature review for ERTMS and ALSN signalling systems, as well as a novel proposition for a new ALSN STM that will allow trains with ERTMS onboard equipment to operate in regions where ALSN is used. The reviewed literature showed that the comparative discussions can be grouped as modelling and optimisation. Additionally, ERTMS has available research and specifications for STM that enable trains with onboard to operate in other Class B signalling systems.

A simple analysis shows that due to incompatibilities and lack of ALSN STM, the cross-border operations along the European – Asian Railway networks experience hardships, delays and financial losses. With the newly proposed ALSN STM, the competitiveness of rail transport can be increased along these international railway networks. The full effects in terms of cross-border operations, financial losses, and the potential increase in passenger and freight transportation might be the subject of future studies. A more comprehensive study that include fallback scenarios is also considered as part of the future work.

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