

# ETCS

## for Engineers

Ian Mitchell (Editor)

2<sup>nd</sup> edition





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## Preface

### Professor Rod Muttram FREng, FIRSE

I am proud to be the 102<sup>nd</sup> President of the IRSE for the year 2026-2027.

The IRSE is the professional institution for all those engaged in, or associated with, railway signalling and telecommunications, train control, traffic management and the allied professions.

Our recent name change from the Institution of Railway Signal Engineers to the Institution of Railway Signal Engineering reflects the wide range of disciplines now involved in safely and efficiently controlling all forms of guided transportation.

The European Train Control System (ETCS) is typical of the current technology used in the railway industry, depending on many of those disciplines; computer hardware, software, communications, cyber security, operations, human factors, specialised components (and increasingly machine learning) together with deep domain knowledge of how they all fit together to deliver the unique requirements of controlling and regulating trains.

I have been involved with ETCS for many years, as Chairman of The European Rail Research Institute (ERRI) when the initial specifications were drafted there in the early 1990s, and later as a board member of the Association Européenne pour l'Interoperabilité Ferroviaire (AEIF) and of the ERTMS Users Group (the European Rail Traffic Management System of which ETCS is part). My signature is one of those on the original ERTMS/ETCS Class 1 Specifications delivered to the European Commission in April 2000. In the intervening 25 years, ETCS has evolved and matured into a highly reconfigurable train control system including additional features such as Automatic Train Operation (ATO).

Revising this textbook under Ian Mitchell's leadership to reflect those many changes has been both challenging and rewarding, and I hope it will prove helpful to those coming to ETCS for the first time or seeking a deeper understanding of this complex system.



## Editor's Introduction

### Ian Mitchell

The Institution of Railway Signal Engineering (IRSE) has a long tradition of publishing textbooks to support the professional development of railway engineers. As ETCS emerged as an important element of the railway signalling world it was obvious that a textbook covering the topic would be required, and the decision was taken to partner with an established European publisher of railway literature to fulfil the need. The outcome of this initiative was the first edition of this book 'ETCS for Engineers' published in 2010. The title was deliberately chosen to emphasise that the aim is to describe the technical detail of ETCS, and not the commercial and political aspects of its development and deployment on projects.

The editor for the first edition was the late and much respected former IRSE President Peter Stanley. He assembled a remarkable international team of authors, many of whom had been deeply involved in the early development of ETCS. The resulting book took the form of an extended series of essays describing all aspects of the ETCS system as it existed at that time.

When I was asked to lead the initiative to produce a second edition, my initial assumption was that this would simply be an update of the existing text to address the development of ETCS specifications in the intervening years. However, it soon became apparent that this would not be straightforward, as many of the original authors had retired or moved to different roles. There was also a certain element of overlap between their contributions. The decision was taken to undertake a more fundamental revision, and while some of the original text remains, other parts have been re-written from scratch.

High-level information about ETCS is readily available in magazine articles and websites, and the detailed specifications are also publicly available from the European Agency for Railways (ERA). Our aim with this book is to fill the gap between these, explaining the technical detail in a manner that will be understandable to an engineer who is new to ETCS. I hope very much that we will fulfil that need.

After much consideration, we decided to avoid describing specific projects that have deployed ETCS technology. To do justice to the wide range of applications that ETCS makes possible would double the size of the book. Fortunately, our publishers have a parallel project to fill this gap with another book, 'ETCS in Europe', which will describe applications in several European countries.

## Acknowledgements

This new edition has been several years in the making, and I am very fortunate to have been supported throughout by a small working group of IRSE members. **Rod Muttram** and **Tom Godfrey** have written a substantial part of the new text, while **Frans Heijnen** and **Jacques Poré** provided continuity as they had contributed to the first edition.

I would also like to thank IRSE members **Francis How** for proof-reading and **Mark Glover** who produced many of the figures, and **Alexandra Schöner**, our professional editor at Global Rail Academy and Media who has taken the output from engineers and managed the process to make it into a real book.

Whilst this is in no way an official publication, we have had informal support from the ERA and UNISIG and have reproduced some figures from their published standards.

Finally, I would also like to acknowledge the following original authors of the first edition and others who provided us with input for the new version. I hope they are not too surprised by the level of change from their original contribution and take full responsibility for the end result.

Norbert Apel	Hans-Georg Kast	Patrice Noury
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Ron Bailes	Franciso Lozano	Bernhard Stamm
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Jorge Iglesias	Marcus Montigel	

# Part 1

## Introduction to ETCS

Chapter 1: What is ETCS?

Chapter 2: Governance and Stakeholders

Chapter 3: Evolution of ETCS Specifications

Chapter 4: Game Changers and Developments

Chapter 5: ETCS today – What has been achieved?

The first part of the book provides a brief overview of ETCS, its relationship with wider concepts such as ERTMS and Technical Specifications for Interoperability, and the benefits to railway operations that these initiatives are intended to deliver. The history of ETCS development over more than 30 years is described, with an explanation of the wide range of stakeholders that have been involved in establishing it as a European and World standard. The progressive enhancement of the system to incorporate additional 'game changer' functionality is described, and the realisation of the anticipated benefits is reviewed.

## Chapter 1: What is ETCS?

### 1.1 ETCS and ERTMS

The terms ETCS (European Train Control System) and ERTMS (European Rail Traffic Management System) are often used interchangeably, and the composite term ERTMS/ETCS is also frequently seen. They are, however, not the same:

**ETCS** is a highly configurable suite of mainline railway train control equipment built to a set of specifications managed by the European Union Agency for Railways (ERA). It is available from multiple suppliers, and its role is to:

- Communicate a movement authority from the trackside to the train
- Present movement authority information to the driver in the train cab
- Provide on-board automatic train protection (ATP) functionality to supervise the safe movement of the train

**ERTMS** is the global term for the railway traffic management systems that are being standardised by the European Union. These include ETCS, Railway Mobile Radio (RMR) and Automatic Train Operation (ATO). RMR is the generic term for systems that provide ETCS track-train data transmission and voice communications. It includes GSM-R and FRMCS (Future Railway Mobile Communication System), which is GSM-R's future replacement.

A key feature of all the ERTMS specifications is that they define the track to train interface and functionality in sufficient detail to ensure that equipment from different suppliers will seamlessly exchange and use information.

This textbook focuses on ETCS but also includes information on how ETCS interacts with the other components of ERTMS.

### 1.2 Introduction to ETCS levels

The standardised ETCS on-board equipment allows a train to operate over different levels of ETCS trackside implementation. Originally three main levels were defined, the key difference between them being how the trackside and on-board systems communicated with each other. Level 1 used entirely track-based communication, and levels 2 and 3 used radio communications. The difference between level 2 and 3 was that in level 3 ETCS would provide train integrity proving to allow the elimination of conventional trackside train detection equipment and allow moving block operation.

In the most recent set of specifications (Baseline 4), level 3 was merged with level 2, so that level 2 now covers all radio-based solutions, with various options for train tracking, train integrity and the use, or not, of lineside signals. Level 3 is therefore an obsolete term. However, to aid understanding, particularly with the number of historic references that exist to levels 2 and 3, the three original concepts are still explained below.

### Level 1: Intermittent data transmission using balises (fixed block operation)

**In brief:** ETCS level 1 provides in-cab signalling that is superimposed on conventional lineside signalling to help the driver to drive both safely and efficiently. It also provides automatic train protection functionality.

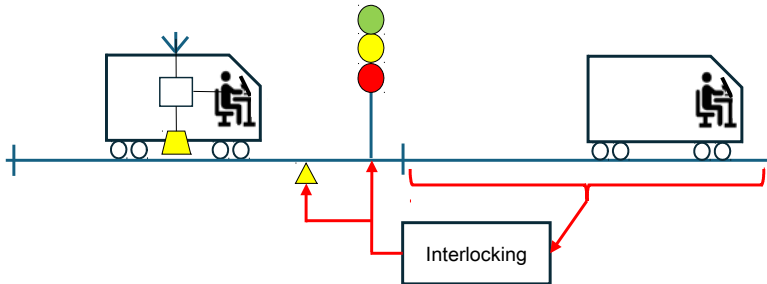


Figure 1-1: ETCS level 1

Communication from track to train is provided by 'controlled Eurobalises' which are placed on the track on the approach to lineside signals. They are connected to the signalling system to gather information on the status of signals, and they communicate the information using localised transmission as the train passes over each one. Balises are 'tele-powered' by a radio frequency signal from the train, so no lineside power supply is required. Cables link the lineside signalling to each balise, which carry the data that is to be transmitted by the balise. Lineside signals are retained although they may be simplified.

Depending on how it is applied to an existing lineside system, level 1 may reduce track capacity, primarily because if a signal changes to a less restrictive state (aspect), the on-board system will continue to force the driver to drive in accordance with the more restrictive state until it is updated when the train passes over the next balise. This drawback can be mitigated by the provision of additional 'infill' balises on the approach to signals.

Although data transmission in level 1 is intermittent (at each balise), it usually provides continuous supervision of train movement along a route as each balise provides a movement authority up to or beyond the next one. There is, however, an option known as Level 1 Limited Supervision (L1LS) which uses a subset of level 1 functionality to supervise the train movement at specific locations as a replacement for a national train control system that does not provide continuous coverage.

**Level 2: Continuous data transmission using radio (fixed block operation)**

**In brief:** ETCS level 2 provides in-cab signalling and ATP without the need for lineside signals (although they can still be provided). Used in conjunction with conventional track-based train detection equipment (track circuits or axle counters), block sections are still fixed in length, but their lengths are unconstrained by signal sighting or train braking distance considerations. Block lengths can therefore be set to optimise capacity on a route more effectively than is the case with lineside signalling.

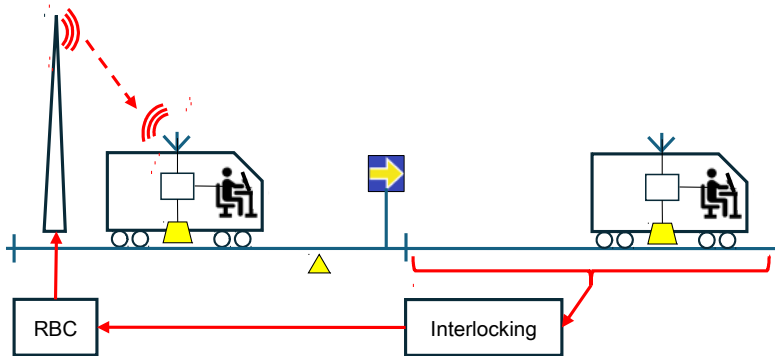


Figure 1-2: ETCS level 2 fixed block

Level 2 is a continuous ATP system where track to train communication is provided by the GSM-R radio system (although some non-European implementations use a different radio bearer, and in future FMRCS will be used). A Radio Block Centre (RBC) translates information from the trackside signalling systems into ETCS movement authorities and manages communications to and from the trains.

Radio bearer systems are inherently non-vital, meaning that the integrity of messages cannot be guaranteed by the bearer system itself. The transmission of messages in level 2 therefore uses a safe transmission protocol known as EuroRadio that virtually eliminates the risk of message corruption.

Train detection in level 2 (fixed block) can be implemented using track circuits or axle counters, and lineside signals can be either retained (for instance to allow unfitted trains to be run during a phase migration to level 2 without lineside signals), or they may be replaced by fixed marker boards which indicate the end of block sections.

Balises are used in level 2, but most are not controlled, meaning that they do not transmit variable data. They are used primarily as reference points for the train to determine its location accurately as it passes over them, enabling the correction of any on-board odometry errors and maintaining positional correlation between the on-board and trackside equipment. These passive (uncontrolled) balises are pre-programmed with the necessary positional and other data and, as with controlled balises, they are tele-powered. However, unlike controlled balises, they need no cabling for data.

## Chapter 13: Automatic Train Operation

### 13.1 Introduction to ATO

In its most basic form, Automatic Train Operation (ATO) is responsible for controlling a train's movement and braking, instead of the driver performing these functions. ATO is designed to ensure consistent and smooth running, and accurate stopping. When connected to the Traffic Management System (TMS), the ATO can receive real time updates and respond accordingly, to take account of the latest prevailing conditions. For example, to increase speed to achieve a revised station arrival time, or slow down to achieve energy savings. ATO can increase line capacity, improve punctuality and reduce energy consumption.

### 13.2 Evolution

The world's first ATO railway was London Underground's Victoria Line, opened in 1968. Nowadays ATO has become standard on modern metros and people movers. The Communications-Based Train Control (CBTC) standard for transit systems, IEEE 1474.1, describes ATO as optional, but in reality almost all CBTC systems include ATO.

By contrast, mainline railways have only recently started to adopt ATO. This slow uptake of ATO is attributable to various reasons associated with the complexity of railway operations and the mainline environment, but the growing demand for mainline passenger and freight services in many parts of the world is now driving the need for more efficient rail operations, which ATO helps to facilitate.

'ATO over ETCS' is the term used to describe how ATO is interfaced to an ETCS-equipped train. The first mainline passenger railway to operate with ATO over ETCS was London's Thameslink, in 2018. In this case the need for ATO was driven by capacity. The Thameslink railway has a number of different routes that converge through a central core section, requiring a throughput of 24 trains per hour. Studies showed that this could only be reliably achieved by using ATO.

Around the same time as the Thameslink project, the European Research and Development Programme commissioned a task force to develop the ATO over ETCS specifications for incorporation in the TSI CCS. One of the key objectives was to ensure interoperability such that ETCS/ATO-equipped trains could operate over any ETCS/ATO-equipped tracks. To achieve this, ATO over ETCS uses a standardised air gap interface specification for the transmission of data between track and train during each train journey. This includes both dynamic journey data and static topology data, in a manner similar to ETCS. This is in contrast to CBTC systems that tend to use an on-board map to store all static topology data for the network over which the trains operate. The use of an on-board map is well suited to a self-contained metro system, but is not practicable for a large interoperable railway network.

The new ATO over ETCS functionality was tested on two reference test benches, followed by two pilot projects that were completed in 2020. The first pilot project took place in the UK using a passenger train and involving five different suppliers. This pilot used GSM-R packet switched radio (GPRS) for the transmission of ATO messages. The second pilot project took place in Switzerland and used a freight locomotive, along with LTE (4G) radio for transmission of ATO messages.

Following the success of the pilot projects, the ETCS over ATO specifications were finalised and published in the 2023 version of the TSI CCS, together with updates to the ETCS System

Requirements Specification to include the new Automatic Driving (AD) mode of operation (described in chapter 8).

### 13.3 Grades of Automation

The various types of ATO are classified in the Grades of Automation (GoA) standard, IEC 62290-1, first published in 2006, as follows:

- GoA2: Semi-automated train operation (STO)
- GoA3: Driverless train operation (DTO)
- GoA4: Unattended train operation (UTO)

GoA2 (STO) still requires a driver in the cab to watch the track ahead of the train, supervise passenger transfer (at stations), engage/disengage ATO, and manage degraded and emergency situations. With GoA3 (DTO), there is no driver but a member of staff is required to be on the train for operating the doors and handling emergency situations. At GoA4 (UTO), all these tasks are performed by the system or by staff at the control centre, i.e. there is no need for a member of staff on-board to undertake these duties.

Although the initial set of ATO over ETCS specifications contained within the TSI CCS are limited to GoA2 (STO), the European Economic Interest Grouping (EEIG) ERTMS Users Group (EUG) has developed an 'ATO Operational Concept' that includes GoA3 and GoA4 for future standardisation.

### 13.4 Driver Advisory Systems

Driver Advisory Systems (DAS) provide additional information to the driver, to supplement information conveyed by the signalling system. Their purpose is primarily to enable energy savings and capacity improvements.

**Standalone DAS (S-DAS)** was initially developed for heavy haul freight railways in the USA and Australia. In more recent times it has been deployed on passenger railways in Europe. S-DAS typically uses the Global Navigation Satellite System (GNSS) to track the train's position. It then compares the actual time and location of the train versus a journey profile derived from the pre-defined timetable and issues advice to the driver which aims to maintain punctuality and save energy (speed up/slow down/coast). S-DAS energy saving estimates are typically between 5% and 10%.

**Connected DAS (C-DAS)** is additionally interfaced to the traffic management system (TMS) and is able to receive and act upon real-time timetable changes that occur during the day. For example, C-DAS might issue advice to trains to aid a prompt recovery from disruptions, or slow a train in order to avoid it being stopped at a junction because of another late-running train. C-DAS energy savings estimates are typically > 10%, and there may be capacity improvements through reduced junction occupation times.

The ATO over ETCS specifications make provision for C-DAS functionality, but provide flexibility in implementation so that a railway can decide to apply C-DAS but not ATO. The main advantages of this approach are that the C-DAS indications can be integrated into the ETCS DMI (saving physical space) and the train speed/position data is derived from the ETCS avoiding any dependency on GNSS (which will not work in tunnels and may be unreliable in urban environments and in cuttings).

### 13.5 Architecture and interfaces

ATO over ETCS introduces two new subsystems: ATO on-board (ATO-OB) and ATO trackside (ATO-TS), as shown in figure 13-1. Suppliers can decide whether or not to integrate these new subsystems within their existing products. For example, the ATO-TS can be implemented as an application that runs on the TMS platform. The functionality and interfaces are defined in the following specifications:

- SUBSET-125 is the System Requirements Specification for ATO over ETCS. This describes the ATO functions, driver machine interface, operational states and interfaces.
- SUBSET-126, 130, 139 are detailed Application Layer Interface Specifications between the ATO-OB and the ATO-TS, ETCS on-board and Rolling Stock respectively.
- SUBSET-143, 147, 148 are the corresponding Communication Layer Interface Specifications. Note that the ATO Radio (described in SUBSET-148) can use either GSM-R (Packet Switch), or FRMCS, or a public mobile network operator (MNO).

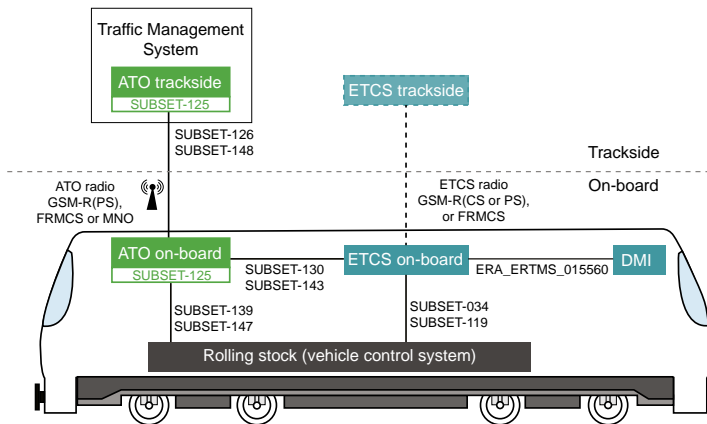


Figure 13-1: ATO architecture and interfaces

The ETCS DMI interface specification, ERA\_ERTMS\_15560, is shown in figure 13-1 because there are new features that affect the driver, such as ATO data entry windows, ATO symbols (for example, the ATO engage, overshoot/undershoot, door controls/statuses, skip stopping point) and DAS indications (for example, target advice speed, coasting advice).

When running under ATO (ETCS on-board in AD mode), audible overspeed and warning alerts on the DMI are suppressed to allow the ATO to drive close to the ETCS braking curves without causing concern to the driver. For more information about the DMI in AD mode, see chapter 8.

### 13.6 ATO data flows

The ATO-OB receives a ‘journey profile’ from the ATO-TS, containing dynamic information about a specific train journey. This includes the times at which the train should arrive and depart specific locations, and intermediate ‘timing points’, as defined by the TMS.

The ATO-OB also receives ‘segment profiles’ (typically there are multiple segment profiles associated with one journey profile). These segment profiles contain static information such as

## Chapter 21: Driver Machine Interface

### 21.1 Introduction

The driver machine interface (DMI) in the train cab is one of the most distinctive and visible features of ETCS. The DMI format was the result of an ergonomics study undertaken by the UIC in the early 1990s, with the concept being validated in a cab simulator using train drivers from several countries.

Both the train and the driver are the responsibility of the Railway Undertaking (RU), and therefore the DMI did not require to be standardised to achieve technical interoperability. Nevertheless, the specification for the DMI has been made mandatory, so that drivers operating different trains and working for different RUs always interact with a consistent DMI regardless of which supplier's products are fitted. This facilitates cross-acceptance of equipment and reduces the potential for human errors and the driver training requirement.

The purpose of the DMI is to allow the driver to:

- enter data about the train into the system and validate it at start of mission;
- display all the information that the signalling system provides for safe and efficient driving of the train;
- allow for driver acknowledgement of information display when required.



Figure 21-1: Typical DMI installation in cab, Class 102 train, Madrid (Siemens)

The DMI hardware is a colour display screen with driver input facilities, normally positioned directly in front of the driver in the train cab. The specification allows for two versions, depending on the technology used for driver input. It can be either a 'touch screen' where the driver interacts by directly touching areas of the screen that are configured to act as buttons, or one with separate hardware buttons alongside the screen, with the function of each button being indicated by an adjacent 'soft key' on the screen. The DMI also incorporates an audio output to alert the driver to situations where some action may be required.

## 21.2 Screen layout

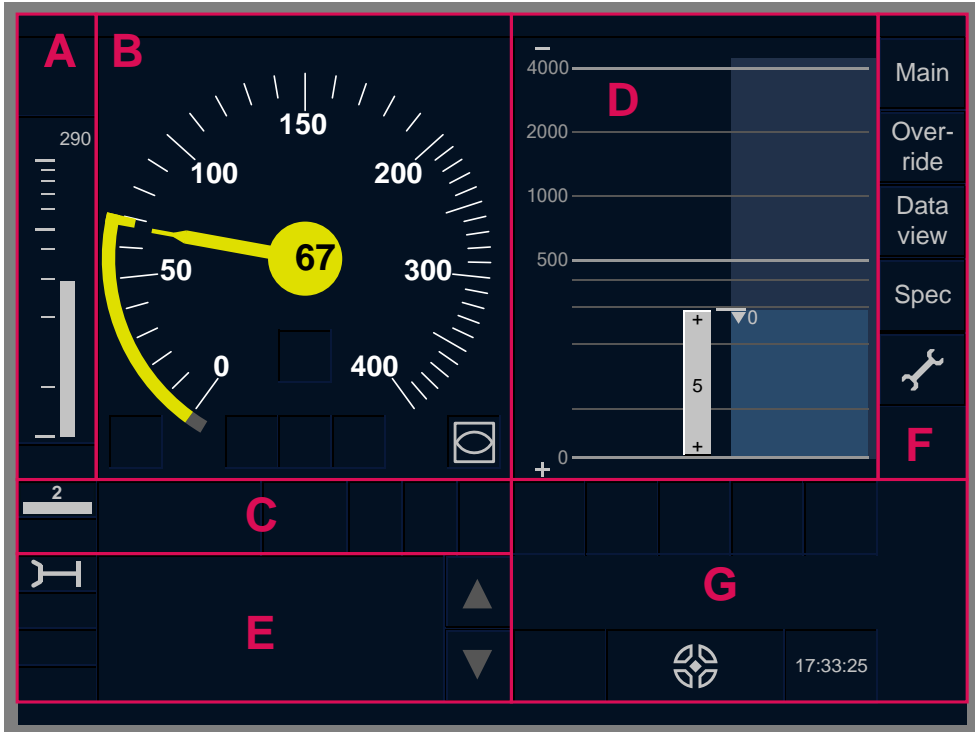


Figure 21-2: ETCS DMI screen areas – touch screen version

The DMI specification sets out in detail how the screen is to be divided into areas and sub-areas for the display of symbols, numbers and text. There are seven main areas, with the following functions:

**A – Brake details area**

This is a strip to the left of the main speedometer which shows information to assist the driver in braking to a new target speed or limit of authority, showing:

- distance to target (a vertical bar and number of metres)
- time to change in ETCS supervision status (a square that increases in size)
- low adhesion symbol

**B – Speed control area**

This is the main circular speedometer display, showing:

- current speed of the train (position of pointer and the number in the centre)
- permissible speed (a 'hook' on the speedometer dial)
- target speed (change in colour on the speedometer dial)
- release speed (change in colour on the speedometer dial)
- ETCS mode
- current orders and announcements of track conditions