AIS transponder with integrated EGNOS/Galileo receiver and related maritime standardization and certification aspects

     

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Abstract

Within the Austrian national research project EMAG (Feasibility Study for an Experimental Platform for Multi-modal Applications of Galileo), two innovative developments are carried out: (1) the architectural design of a software based Galileo receiver tailored to the requirements of maritime navigation applications, and (2) the development of an AIS (Automatic Identification System) transponder with integrated GPS/EGNOS receiver being capable of providing visual integrity information to the user.

This paper provides an overview of the EMAG project results by describing the benefits of EGNOS and Galileo for maritime navigation applications in detail. First test results regarding functionality and especially accuracy, availability, and integrity of the GPS/EGNOS receiver integrated into the AIS transponder are presented. Available outputs of the standardization process are also mentioned.

Kurzfassung

Innerhalb des nationalen österreichischen Forschungsprojekts EMAG (Feasibility Study for an Experimental Platform for Multi-modal Applications of Galileo) wurden zwei innovative Entwicklungen durchgeführt: (1) das Design eines Software basierten Galileo Empfängers, der auf die Anforderungen maritimer Navigationsanwendungen maßgeschneidert wurde und (2) die Entwicklung eines AIS (Automatic Identification System) Transponders mit integriertem GPS/EGNOS Empfänger, der visuelle Integritätsinformationen für den Nutzer ausgibt.

Dieses Dokument bietet einen Einblick in die EMAG Projektergebnisse, indem die Vorteile von EGNOS und Galileo für maritime Navigationsanwendungen detailliert beschrieben werden. Erste Testergebnisse bezüglich der Funktionalität und speziell der Genauigkeit, Verfügbarkeit und Integrität des in den AIS Transponder integrierten GPS/EGNOS Empfängers werden vorgestellt. Verfügbare Ergebnisse des Standardisierungsprozesses werden ebenfalls behandelt.

1. Introduction

1.1. General

Worldwide open sea and inland waterways are the most widely used method for the transport of goods. A wide variety of vessels move around the world each day. The traffic of goods in, from, and to European ports reaches 40 million containers per year.

The efficiency, safety, and optimization of marine transportation are key issues. Global navigation satellite systems (GNSS) like GPS or the future Galileo [5] [8] [11] are becoming a fundamental tool yielding innovation and progress to this sector. Many other marine activities such as fishing, oceanography, or oil and gas exploitation will also benefit from the availability of Galileo services [1] [2] [3].

Increased accuracy and integrity, certified services, and a higher signal availability introduced by Galileo will be used by leisure boats, commercial vessels and all ships falling under the safety-of-life-at-sea (SOLAS) convention in every phase of marine navigation, i.e., ocean, coastal, port approach, and harbour manoeuvres, and under all weather conditions.

For marine navigation, regulated by the International Maritime Organization (IMO), Galileo will be an additional means of implementing the regulations on automatic identification systems (AIS) and vessel traffic management systems to increase the navigation safety, the collision prevention, and the economic benefit [12] [13].

Many maritime commercial activities are going to use satellite navigation. When fishing, it helps locating traps and nets. Fleet management, cargo monitoring, delivery and loading schedules are optimized. Even the locating of shipping containers can be facilitated, and satellite navigation could be used for automatic piloting or tracing of barges. Within ports, a system for information services tailored to each ship's location is being considered.

Handling of containers is crucial for efficient commercial harbour operations.

Sciro in Italy is involved in developing a system using GNSS that automatically tracks containers inside a terminal. This will reduce container handling time and costs, and increase service levels and terminal productivity.

For inland waterways, accuracy and integrity of navigation data are essential to automate precise manoeuvres in narrow rivers and canals. Better navigation can be a major aid to the increasing capacity in inland waterway networks, which in turn contributes to the modal shift targets EC transport policy [4] [9] [12].

1.2. EMAG project

The content of the EMAG project included technical and economical basic research and analysis regarding the feasibility to develop an experimental platform based on a software receiver for multi-modal maritime applications of Galileo. Thus, the aim was to develop a detailed concept for a future realization [6] [7]. In a next step, the proper development of the experimental platform shall be carried out.

Additionally, a functional demonstrator based on the integration of AIS, GPS, and EGNOS was developed. Therefore, a combined GPS/EGNOS receiver was used and integrated into an AIS transponder of ACR Electronics Europe GmbH (formerly Nauticast Navigationssysteme GmbH). The combined position solutions (GPS+EGNOS) and integrity messages are fed into the transponder in real time. Thus, the transponder is capable to broadcast the position of the ship including a quality indicator (integrity flag) for each position solution to other ships and to the control facilities on shore.

2. Maritime Galileo Receiver Development

The implementation of the so-called experimental receiver platform for maritime applications is driven by the need for a receiver, which provides flexibility and openness to novel algorithms and receiver concepts. A software receiver has been found to be the most adequate solution for the above requirements.

2.1. Architectural Hardware Design

A high-level block diagram of the proposed receiver platform hardware is shown in Figure 1. Three major parts can be identified. The first part comprises all the analog hardware required to preprocess and down-convert the signal received from a GNSS antenna to baseband or to an intermediate frequency. This hardware unit is referred to as analog front end, or radio frequency (RF) front end, respectively.

The second hardware unit comprises the analogue-to-digital converter, reconfigurable digital preprocessing hardware and intermediate memory, which allows for the storage of data at high rates being too high to be transferred to a single processor via a standard bus.

The third module establishes the processing platform for the receiver software. An essential part is the software running on the processing platform.

The chosen architectural concept allows a high degree of flexibility. This is mainly provided by the reconfigurable preprocessing hardware and the receiver software. The proposed platform can be configured to perform more or less the complete digital signal processing by the software. However, the wideband Galileo signals cannot be processed in real time with this approach. For real-time processing, the digital preprocessing hardware can be utilised. On the other hand, for the development of novel concepts and algorithms, a software-based approach is preferred and seems to be the logic consequence. Therefore, this approach has been chosen as driving requirement for the architectural design of the maritime Galileo receiver platform.

2.2. Architectural Firmware Design

Figure 2 shows a high-level context diagram of general GNSS receiver software. The receiver software comprises the following elements:

- The low-level software handling the external interfaces and converting the received data into a defined format, which allows a standardized access to this data.
- The control software establishes the interface to the man-machine interface and allows for the configuration and control of the algorithm software.
- The algorithm software accomplishes the signal processing tasks required to provide the GNSS receiver functionality.
- The algorithm software can be based on a set of predeveloped functions collected in the function library or on dedicated functions. The function library is open to be augmented by

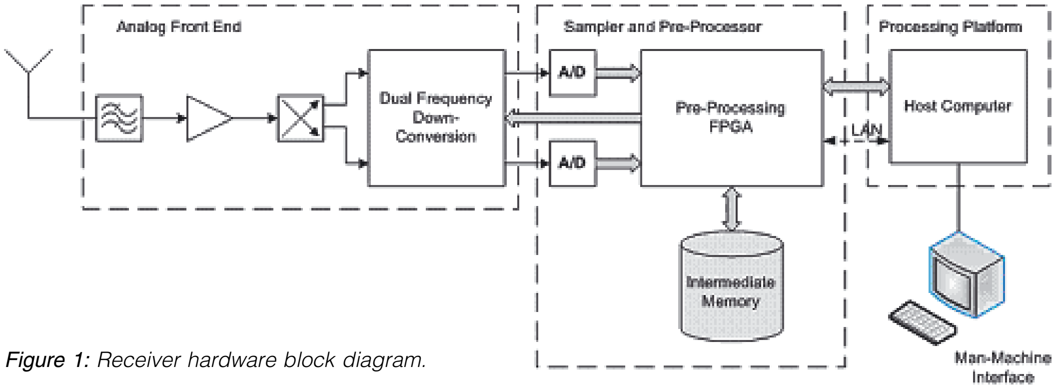

Figure 1: Receiver hardware block diagram.

custom functions. The default functions of the library shall be configurable in order to allow a high degree of flexibility. One specific part of the receiver algorithms is established by the position, velocity, and time (PVT) determination functions.

- For applications without stringent deadline constraints, a conventional operating system is sufficient. For such applications the interactions of the algorithm software with the operating system are more or less transparent for the software developer. In case a real-time operating system is required, the algorithm software has to use services provided by this operating system. A real-time operating system is recommended in case stringent deadlines have to be met.

The receiver firmware covers the low-level software, the control software, and the function library. As the Galileo receiver platform shall establish a platform for the development of maritime Galileo receiver concepts and algorithms, the receiver firmware does not implement a specific functionality, but has to provide the flexibility to define the functionality for the desired application. Thus, the receiver platform has to provide an application programming interface (API). An API defines the access to a set of functions, procedures, variables, and data structures using a library that has been written for that purpose. A programmer implementing a specific application puts the blocks together and can write applications consistent with the operating environment in a straightforward way.

Novel concepts or algorithms require additional functionality, which is not available in the default library. Therefore, the Galileo receiver platform has to allow for augmentation and modification of the library.

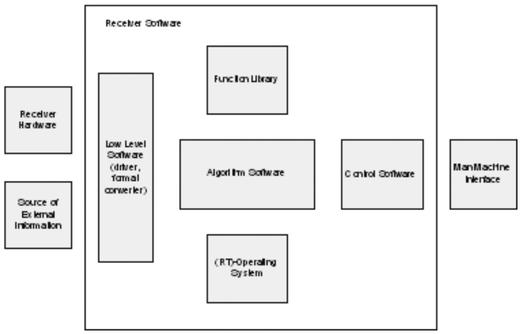

Figure 2: Receiver context software diagram.

2.3. Architectural PVT Software Design

The software design for the processing of Galileo measurements and the integration of GPS/EGNOS and Galileo is based on currently available modules used in TeleConsult Austria's IntNav software. The PVT software is designed for the processing of Galileo raw data and the integration of the raw data gathered from Galileo, GPS, and EGNOS applying different algorithms for PVT computation, including quality data as well. Thus, the following main functionalities of the PVT software are implemented:

- Processing of navigation measurements in real time and in post-processing mode (only for developmental purposes).
- Processing of (currently simulated) Galileo raw measurements.
- Processing the combination of Galileo/GPS/EGNOS measurements.

Figure 3: *EMAG functional demonstrator overview (left: u-blox GPS/EGNOS receiver module; right: NAUTICAST AIS transponder).*

- Output of quality information for the processed position solution.
- Provision of position, velocity, time, and the quality data (integrity) for the application software.

3. EMAG Functional Demonstrator

The functional demonstrator developed and tested within EMAG consists of the AIS transponder NAUTICAST from ACR Electronics Europe GmbH using an integrated low-cost GPS/EGNOS receiver board from u-blox AG as position fixing device (Figure 3).

The transponder communicates with the receiver module via an internal standard serial interface (RS232). Thus, on the one hand the receiver can be configured by the transponder and on the other hand the receiver provides position information and integrity data to the transponder. The transponder is now capable of providing visual warnings to the user if so-called out-of-tolerance conditions appear (the calculated protection level exceeds the defined alarm limit as specified for inland waterway navigation or maritime navigation). Further, the transponder transmits the position of the own ship including the quality information to other ships and to the control facilities on shore.

The test region was selected alongside the river Danube from the lock “Freudenau“ upstream to the bridge “Reichsbrücke“ (green trajectory). The test center was located in the office of ACR Electronics Europe GmbH at Handelskai 388 (red circle in Figure 4).

Figure 4: *Test region along the river Danube in Vienna.*

3.1. Operational Tests

The reference installation of the standard inland AIS transponder “NAUTICAST Inland AIS“ is used to demonstrate the behavior and interoperability between the developed demonstrator and the live AIS acting along the river Danube. Irrespectively of the type of AIS, currently present traffic should be visible beside the developed demonstrator.

One installation is a standard inland AIS transponder “NAUTICAST Inland AIS“ together with a connected inland ECDIS solution in the test center (ACR office). On the screens of this ECDIS solution (Figure 6), the EMAG demonstrator should be visible for tracking and tracing. It is evaluated, whether the pick report could be used for reading out the data transmitted by the demonstrator. Nevertheless, the continuous visibility on the inland ECDIS is the target of this part.

The Attingimus AIS test device is a worldwide approved device for measuring the date flow in and out of an AIS transponder. Most of the developed features are seen in particular on that device because of it’s capability to decode the binary data stream of the VDL (VHF Data Link).

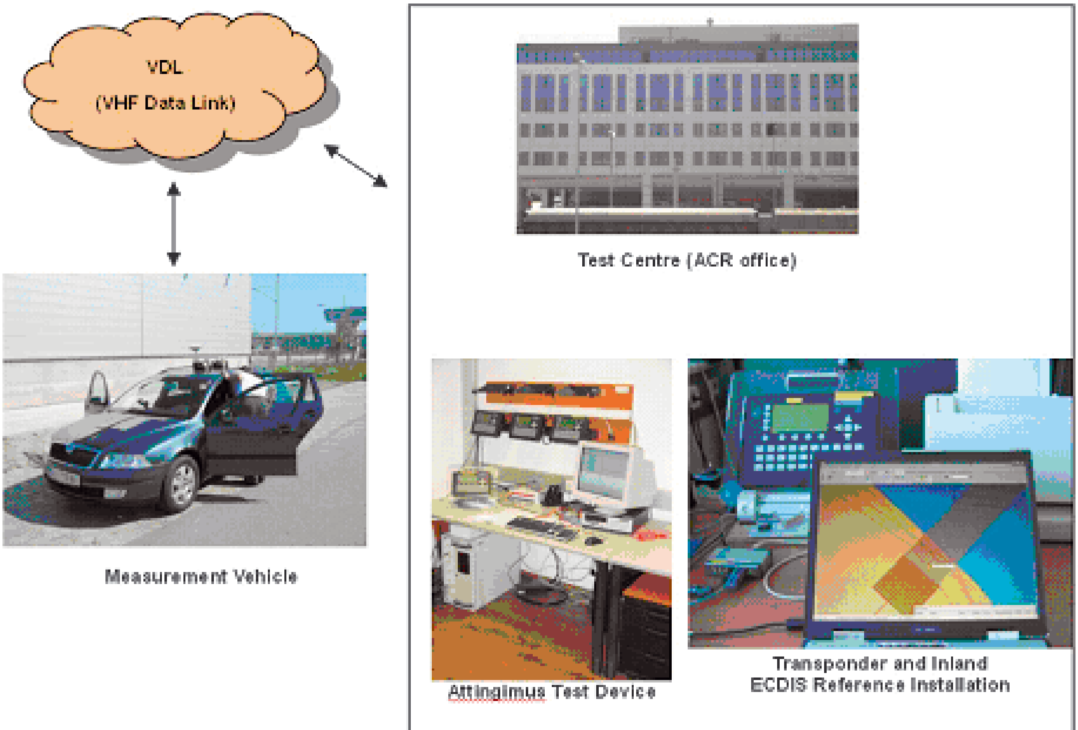

Figure 5: Operational test setup overview.

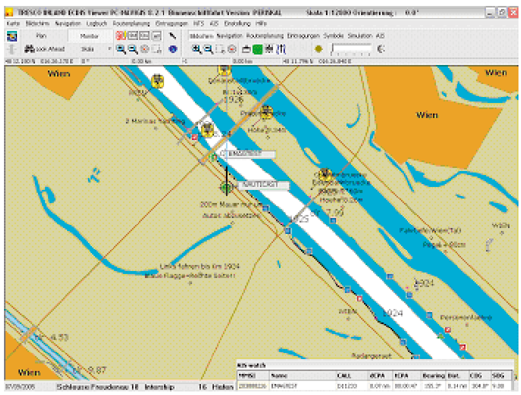

Figure 6: Visualisation on the presentation interface during the test measurements.

The demonstration with the above setup (Figure 5) showed an operational sample of a future implementation and its requirements. Based on these results (and the essential functional requirements of future EGNOS/Galileo input and output receiver performance characteristics) the inland AIS transponder families (as well as the high seas) electronic positioning fixing device performance could be substantially improved.

3.2. Navigation Performance Tests

The overall test system consists of a GPS reference station (L1/L2 GPS receiver) and the mobile equipment used in a demonstration vehicle. The mobile equipment consists of the AIS transponder with integrated u-blox GPS/ EGNOS receiver module – the EMAG functional demonstrator, another GPS receiver (L1/L2 GPS receiver) including antenna (for comparison purposes), an antenna splitter, a notebook for data recording, the power supply, and the necessary cablings. The demo tests were carried out with a car, simulating the trajectory of a vessel, on the Treppelweg.

The analyses and interpretation of the navigation performance are split into three parts. The first part deals with the positioning performance of the GPS/EGNOS receiver compared to a reference trajectory. In the second part, an availability analysis of the receiver with special focus on the EGNOS signal is carried out. In the last part, the computed protection level (integrity information) is verified.

For a significant analysis, the GPS/EGNOS trajectory output by the transponder-internal u-blox receiver is compared with the computed trajectory of the second receiver. The reference trajectory is measured with a dual-frequency geodetic GPS receiver (Ashtech Z-Xtreme) and is computed by kinematic baseline determination in post-processing mode [10].

In Figure 7, the differences (Y = longitude, X = latitude in meters) between the computed reference trajectory and the trajectory of the transponder-internal GPS/EGNOS receiver are visualised.

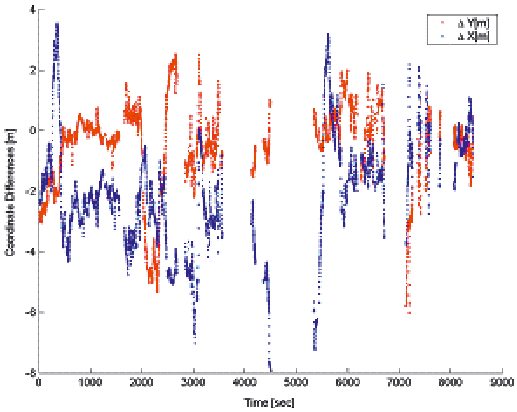

Figure 7: Absolute positioning accuracy of the functional demonstrator.

In a next step, the availability of the EGNOS signal was validated. The percentage of the EGNOS signal availability for the transponder internal receiver amounts 93.1%. Due to various high buildings along the south-west shore of the river Danube, this is a very positive result.

The protection level calculation is presented in Table 1. It indicates the amount of generated visible user warnings in situations, where the calculated protection level exceeds the defined alarm limit as specified by IMO regulations for inland waterway navigation.

The demo tests showed clearly that the low-cost u-blox receiver provides sufficient absolute accuracy (usually better than ±5 m) for the use in inland waterway navigation during normal conditions (no extensive satellite signal shadings). During conditions with various satellite signal shadings occurring (e.g., under bridges, etc.), the absolute accuracy is worse than ±5 m, e.g., due to bad satellite geometry. Furthermore, the EGNOS signal is sometimes shaded because of high buildings, vegetation, and bridges. It can be assumed that the EGNOS signal availability is much better directly on the river Danube. Nevertheless, due to the low elevation of the EGNOS satellites, signal shadings will occur sometimes.

Suggestions to improve the situation significantly are alternatives to the direct EGNOS signal reception:

- a terrestrial network transmitting the EGNOS corrections (e.g., as described in the ESA project GALEWAT – Galileo and EGNOS for Waterway Transport);
- a direct internet communication link to the EGNOS data messages provided by ESA (SiSNet or, in future, EDS – EGNOS Data Server).

It is worth to mention that the suggestions only include infrastructure improvements to provide better EGNOS signal availability. The tests showed clearly that the u-blox receiver provides sufficient absolute accuracy and EGNOS signal availability during normal conditions.

4. General EGNOS and Galileo Differentiators and Benefits

Satellite navigation applications are currently based on GPS performances, and great technological effort is spent to integrate satellite-derived information with a number of other techniques in order to achieve better positioning accuracy with improved reliability. This scenario will significantly change in the very near future. Still in 2007, EGNOS, the European regional augmentation of GPS, starts to fully provide its services. Later, the global satellite navigation infrastructure will dramatically increase with the advent of Galileo, with full operational capability (FOC) probably around 2010/11. The availability of two or more GNSS (also a renaissance of the Russian GLONASS is to be expected soon), which will significantly increase the total number of available satellites, will enhance the quality of the services - and the number of potential users and applications will rise.

	Transponder internal GPS/EGNOS receiver
Nr. of trajectory points recorded	8774
Nr. of alerts generated	1355
Percentage of exceeded alarm limit (visible user warning generated on the display of the AIS transponder)	15,4%

Table 1: Protection level summary.

Galileo's specific characteristics will bring significant enhancements. Primarily for urban areas, indoor applications, and inland waterway navigation, the design of Galileo signals will improve the availability of the service (broadcast of data-less ranging channels, in addition to the classical pseudorandom ranging codes). Additionally, the high-end professional market will also benefit from Galileo's signal characteristics [9]. Three-carrier phase measurements will be essential for the development of specific three-carrier ambiguity resolution (TCAR) algorithms, leading to centimeter accuracy over large regions.

Simulations demonstrate that availability of positioning services in urban areas or valleys (like the Danube valley in Austria) with "canyons" (satellite visibility obstruction by topography, vegetations, high buildings and skyscrapers) is increased significantly using a combination of Galileo and GPS.

Galileo is and will remain under civil control and has been designed under civil requirements. It is operated in a transparent way, allowing for full service certification.

The need for service guarantee for safety-of-life and commercial applications has been taken into account in the design of the systems. Legal implications of service level commitment are driving the Galileo system implementation. Accountability on requirements regarding service provision has led to clear traceability requirements on detailed system performance history (already implemented in EGNOS). This approach significantly improves the safety of the navigation system, facilitates the detection and investigation of any malfunctioning and allows recording of service-level performance in case of claims. In this context, the integrity information plays an important role.

Law enforcement in the road and maritime domains, road charging and tolling, safety-of-life navigation in all modes of transport will soon rely on dedicated infrastructures with reliability and guarantee characteristics that are simply not available with current systems.

5. Conclusion

The conclusion is split into the development of the experimental maritime Galileo receiver platform and the EMAG functional demonstrator (AIS transponder with integrated GPS/EGNOS receiver board).

5.1. Experimental Galileo Receiver Platform

Within the EMAG project, the first step for the development of an experimental maritime Galileo receiver platform has been carried out. The structures of the hardware, firmware, and software for the receiver are defined and developed. In a planned follow-on project, further development steps (prototyping of hardware components and programming of the software) shall be carried out.

The implementation of an experimental receiver platform is driven by the need for such a receiver, which provides flexibility and openness to novel algorithms and receiver concepts. A software receiver has been found as most adequate solution for these requirements.

5.2. Demonstration System

The operational and navigation performance tests pointed out clearly that the navigation performance of the AIS transponder could be improved significantly by the integration of EGNOS into the system concept. By applying the EGNOS corrections to the GPS position solution, an absolute positioning accuracy of better than ±5 m is achieved during normal operation conditions. This fact is very essential for the compliance of the requirement regarding an absolute positioning accuracy of better than ±5 m as stated in the inland ECDIS standard for operations in the so-called "navigation mode". Further, the user gets visual information via the AIS transponder display if the system provides "safe navigation conditions" (the continuously computed protection level is better than the defined horizontal alarm limit of 25 m as specified for inland waterway navigation.

The main outcome of the demonstration tests points out clearly that the AIS transponder with integrated GPS/EGNOS receiver provides improved positioning and navigation performance and can be extended by the integration of Galileo to further improve the system performance significantly.

Acronyms and Abbreviations

AIS	Automatic Identification System
API	Application Programming Interface
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EC	European Commission
ECDIS	Electronic Chart Display and Information System
EDS	EGNOS data server
EGNOS	European Geostationary Navigation Overlay Service
EMAG	Feasibility Study for an Experimental Platform for Multi-modal Applications of Galileo

ESA	European Space Agency
FOC	Full Operational Capability
GALEWAT	Galileo and EGNOS for Waterway Transport
GATE	Galileo Test Environment
GNSS	Global Navigation Satellite System
GPS	Global Positioning System (U.S.)
IMO	International Maritime Organisation
PVT	Position, Velocity, Time
RF	Radio Frequency
SOLAS	Safety Of Life At Sea
TCAR	Three-Carrier Ambiguity Resolution
VDL	VHF Data Link
VHF	Very High Frequency

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