The GATE Test Infrastructure and its Use for Galileo Integrity Tests to Support ESA`s European GNSS Evolution Programme

E. Wittmann, T. Zink, G. Heinrichs, *IFEN GmbH, Germany*
D. Lekaim, H. Delfour, D. Joly, *Thales Alenia Space, France*
M. Jeannot, M. Tossaint, *European Space Agency, The Netherlands*

BIOGRAPHIES

Elmar Wittmann received a Dipl.-Ing. degree in Geodesy from the Munich University of Technology in 2000 and then joined the IFEN GmbH where he is working in the Mobile Solutions department as a systems engineer in the field of GPS/Galileo satellite navigation. He is currently the head of GATE (German Galileo Test and Development Environment) customer operations and also responsible for the GATE experimentation activities in the framework of HISTB (High Integrity Safety critical regional augmentation Test-Bed) and MLUTB (Multi-Constellation Regional System Land Users Test-Bed).

Theodor Zink received a Dipl.-Ing. degree in Electrical Engineering from the University of Erlangen-Nuremberg in 1995 and then joined the Institute of Geodesy and Navigation of the University of Federal Armed Forces Munich as a Research Associate, mainly concerned with development and analysis in the field of GNSS integrity. In 2001 he entered IFEN GmbH where he is currently working in the Mobile Solutions department as a systems engineer for software development and system integration, including implementation of GATE upgrade for HISTB.

Guenter Heinrichs received a Dipl.-Ing. degree in Communications Engineering from the University of Applied Science Aachen in 1988, a Dipl.-Ing. degree in Data Processing Engineering and a Dr.-Ing. degree in Electrical Engineering from the University Paderborn in 1991 and 1995, respectively. In 1996 he joined MAN Technologie where he was responsible for system architectures and design, and digital signal and data processing of sat-nav receiver systems. He was Head and R&D manager of MAN Technologie’s satellite navigation department from 1999 to 2002. In 2002 he joined IFEN GmbH where he is currently the head of the customer applications department and business development.

David Lekaim is Project Manager in navigation at Thales Alenia Space (TAS) in Toulouse, where he started his career in 1997. He worked first for telecom satellite programs (WorldStar, EuropeStar, Eurasiasat, Koreasat,…) as Mission Segment responsible. In 2006, he entered the Navigation Business Line in TAS and became project manager for Multi-Constellation Regional System (MRS) studies (ESA and CNES activities). Today, he is currently managing the HISTB Program in TAS.

Hélène Delfour is system engineer in navigation business line at Thales Alenia Space (TAS) in Toulouse, where she started her career in 1998. Involved first in EGNOS V1 project, in charge of system performance analysis, she then moved to Galileo mission segment as responsible of system performance verification and validation. In 2008, she became technical responsible for Multi-Constellation Regional System (MRS) studies (ESA and CNES activities). Today, she is coordinating technical activities for the HISTB Program in TAS.

Damien Joly is an engineer in the navigation system engineering department of THALES ALENIA SPACE (TAS) France. He received in 2004 a M. Sc engineer degree in space system engineering and telecom from TELECOM Paris France. Since then he has been working for TAS in navigation department. First he was involved in activities on EGNOS integrity; then he was working in the Galileo Mission Segment performance allocation management activity. Since 2011, he is responsible of HISTB experimentations in TAS.

Marc Jeannot graduated as an electronics engineer from ENAC (French National School of Civil Aviation) in Toulouse in 1984. After having worked in the field of embedded software development, he entered CNES, the French Space Agency, in 1989. He has been responsible for development of GNSS application projects at national and European levels, and is now member of CNES/ESA EGNOS integrated team at Toulouse, France, in which he is more particularly in charge of Test Beds developments for EGNOS V3 preparation.

Michel Tossaint is a Radio Navigation System Engineer at the European Space Agency (ESTEC, The Netherlands) in the GNSS Evolution Team of the Navigation Directorate. He holds an M.Sc.-degree from the faculty of Aerospace Engineering of Delft University (The Netherlands). His interests are in systems engineering, estimation and precise carrier phase navigation.

ABSTRACT

Over the past years GATE has become well known for being an unequalled Galileo test and development range worldwide. It offers today – several years before the full operability of the Galileo system in space – possibilities for navigation with realistic Galileo signals on three frequencies simultaneously in an outdoor environment.

Thanks to its additional sophisticated features for the intentional generation of "Feared Events" and functional alerts, the test infrastructure allows to perform various individual functional integrity test scenarios. This includes GPS and GATE/Galileo dual-constellation RAIM (Receiver Autonomous Integrity Monitoring) as well as testing of receivers with user integrity advanced concept (ARAIM) functionalities implemented. These test scenarios support the European GNSS Evolution Programme (EGEP), which is an ESA programme to undertake research and development in and verification of technologies relating to regional space-based augmentation systems (SBAS) and global navigation satellite systems (GNSS). The implementation of EGEP is done, amongst others, by EGEP test beds providing operational support to experimentation and demonstration campaigns, like the "High Integrity Safety critical regional augmentation Test-Bed" (HISTB) and the "Multi-Constellation Regional System Land Users Test-Bed" (MLUTB). Distinctive test campaigns for HISTB and MLUTB in GATE are being performed in summer and autumn 2012.

This paper provides an overview of the GATE infrastructure and its segment design, setup, its functionalities as well as the design and implementation of the upgrades done in the framework of HISTB and MLUTB. A description of the test set-up and execution will be given also considering the dedicated test cases that have been identified for the EGEP test campaigns. Furthermore, the paper will present preliminary results of ARAIM user integrity tests as well as dual-frequency / dual-constellation user experiments with SBAS-like augmentation done in-field in the upgraded GATE test range for HISTB. Finally the paper will provide an outlook on the corresponding upcoming integrity experimental activities, including aeronautical tests with a helicopter in the GATE area.

INTRODUCTION

Although relying on a ground based infrastructure, the certified GATE system is able to transmit the original navigation signals from eight "virtual" Galileo satellites. This also includes the simulation of natural influences like ionosphere or troposphere delays, the adaptation of other signal characteristics as well as signal strength. Furthermore, GATE includes the capability to induce dedicated "Feared Events" and alerts for one or several satellites of the current Galileo constellation simulated.

The aim of HISTB is to run experiments and use cases related to high-integrity aeronautical performance. HISTB is making use of the modernized SPEED (Support Platform for EGNOS Evolutions and Demonstrations) platform enhanced in the frame of the EGEP activity. The GATE infrastructure serves here as a test environment for HISTB for several use cases identified for integrity related aeronautical test scenarios.

In the HISTB context, one main test objective is to assess the augmentation performance improvements for GPS/Galileo dual-frequency / dual-constellation SBAS user processing. For this reason the SPEED platform provides GPS/Galileo augmentation message types (MT) to GATE, including live GPS dual-frequency correction data. GATE is augmenting the Galileo part of the MT SBAS data with real-time calculated GATE correction data. The complete live SBAS data stream is then transmitted as SIS signal to the GATE user via a GATE local GEO-like communication dissemination signal on L1, implemented on two GATE transmitting stations. Test campaigns undertaken for HISTB are performed as static open sky tests at locations with good and un-shadowed visibility of all eight GATE transmitting stations and using real helicopter test flights in the GATE test bed of Berchtesgaden.

A further test scenario of HISTB assesses the detection capabilities of new user integrity concepts like the Advanced Receiver Autonomous Integrity Monitoring (ARAIM) user algorithm under satellite Feared Event (FE) conditions. For this purpose the GATE processing facility, which can be considered as the "heart" of the GATE system, was modified to generate sophisticated clock feared events, allowing to manipulate pseudoranges of the GATE signals transmitted according to realistic error scenarios, like e.g. the specific GPS PRN 30 clock drift event observed in June 2006. Although GATE was not designed to simulate/validate a real integrity environment (system integrity risks, hazardous misleading information HMI etc.) of a satellite navigation system like Galileo, GATE can be used to calculate user integrity performance parameters like horizontal/vertical protection levels for the ARAIM scenarios identified. As GATE is capable to initiate FEs for different fault scenarios like single fault on single frequency (E1 or E5) or multiple faults on dual/multiple frequencies (e.g. E1 and E5), the paper will present preliminary results of the fault detection capabilities of the implemented ARAIM.

GATE TEST RANGE OVERVIEW

The GATE system architecture comprises four segments - Transmit Segment (GATS), Mission Segment (GAMS), Control Segment (GCS) and Support Segment (GSS), as depicted in Figure 1.

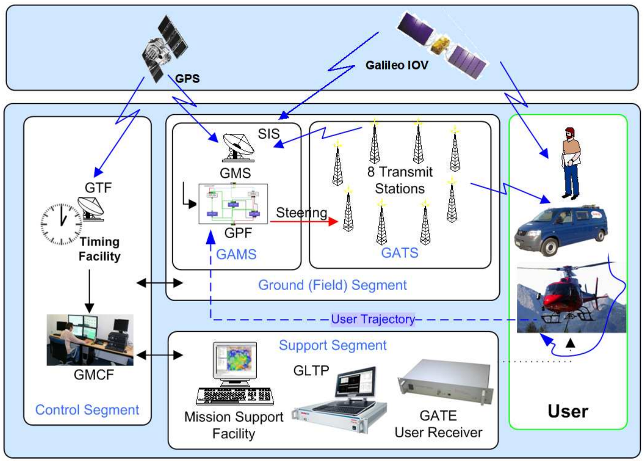

Figure 1: GATE architecture overview

The ground-based transmitters which are part of the GATS emit all frequencies foreseen for Galileo. Therefore they have to be flexible in signal generation and adaptive to changes in signal structure. As GATE is a real-time system it is necessary to feed the navigation message in real-time to the transmitters. They are also equipped with stable atomic clocks. Figure 2 shows the locations of the eight transmit stations.

The GATE Mission Segment monitors the navigation signals by using two GATE Monitoring Stations (GMS), performs the time synchronization of all system clocks and generates navigation messages and steering commands to be sent to the eight transmitters. The tasks denoted above are mainly performed by the two GAMS core elements, the GATE Processing Facility (GPF) and the GATE Monitor Receivers (GMRx), both developed by IFEN GmbH.

The GATE Control Segment includes all the functionality and facilities that are required for the mission control and operation. The main tasks it has to perform are to monitor and to control the entire GATE system, to host and operate the control centre, which serves as operational node of GATE including e.g. the mission planning. Further functionalities of GCS are to host and provide the GATE system time and to archive the GATE mission data.

The main task of the GATE Support Segment is first the appropriate user individual preparation, i.e. simulation and planning of the actual user experiments with dedicated software tools of the GATE Mission Support Facility (GMSF). Second, the GATE User Terminals that are equipped with a combined Galileo/GPS receiver unit as a reference unit for users, are part of this Support Segment.

The GATE test area is located in the region of Berchtesgaden in the very south-eastern part of Bavaria/ Germany. The service area is depicted in the maps shown in Figure 2.

Figure 2: Overview of GATE test area Berchtesgaden

The two monitoring stations and the processing facility are located at the GATE service office which is situated quite in the center of the test area. As can be seen from Figure 3 Berchtesgaden is surrounded by high mountains that are rising up to over 2000 meters (NHN). The installation of the GATE transmitters on well exposed positions allows the emission of navigation signals with average elevation angles between 10 to 15 degrees from a user's point of view, when located within the test area. The test bed is remotely operated from a Control Center which is situated at the premises of the GATE operator IFEN GmbH in Poing near Munich.

Figure 3: View into GATE test area (from GTS 1)

The main characteristics of GATE in terms of capabilities and technical specifications are summarized in Table 1 below.
Note that in order to avoid double PRN assignments of the same PRNs to both GATE pseudolites and Galileo IOV satellites, the PRNs 11 and 12 are not transmitted by the GATE pseudolites.

Table 1: GATE specifications

Area of availability	GATE test area of approx. 65 km² (core area about 25 km²) south-east from Munich
Attainable HDOP & VDOP values	In the core area: HDOP < 2; VDOP 6-20; NB: these values hold for the real physical constellation; in the "Virtual Satellite Mode" the DOPs of the actual Galileo constellation simulated are obtained.
Positioning accuracy	Horizontal (E1, E5a, E5b): 10 m (2 sigma) for HDOP < 2.
Carrier-frequencies	All three carrier frequencies with their bandwidths are emitted in the test area: E1: 1575.420 MHz, bandwidth 40.92 MHz E5: 1191.795 MHz, bandwidth 92.07 MHz E6: 1278.750 MHz, bandwidth 40.92 MHz
Signal compatibility	Compliant to Galileo OS SIS ICD; Compliant to ESA SIS ICD V13 (OS, SoL functionality, C/Nav-0 message for CS, PRS: noise like signal)
Integrity information	SIS integrity flags are emitted. Functional integrity testing is possible by means of appropriate configuration of the integrity flags.
Atmospheric conditions	Signal propagation delays through the ionosphere and the troposphere are realistically emulated.

THE EGEP TEST BEDS 'HISTB' and 'MLUTB'

HISTB

The main objective of HISTB experimentations is to provide technical elements allowing to determine if the EGNOS V3 foreseen new features targeted for aeronautical users are feasible and of interest.

Experiments are thus performed on the following areas, which are currently considered in EGNOS V3 definition:

- Multi Frequency evolution, to offer not only legacy aeronautical service (to mono-frequency SBAS L1 user) but also a dual-frequency L1/L5 augmentation service.
- Multi Constellation evolution, to provide augmentation data not only with respect to GPS constellation but also to Galileo.
- Extension of the service area, in particular to cover Africa.
- Areas of improvement on top of EGNOS V2 system, (functional allocation between ground monitoring stations and central processing facility, MT28 versus MT27, …).

These experiments are based on the SPEED experimentation platform (Support Platform for EGNOS Evolutions & Demonstrations). Briefly, these experiments are split into five different cycles (further details on HISTB experiments and SPEED platform can be found in [1]).

One of this cycle is named 'GATE', because it allows to perform some tests interfacing SPEED Platform with Gate Infrastructure, allowing to perform real-life demonstrations.

MLUTB

The EGEP test bed MLUTB aims to investigate, develop and demonstrate two possible future services, the Proof-Of-Position Service (POPS) and the Emergency Service (ES). POPS is for non-safety-of-life users, e.g. road users in urban or sub-urban environments, which still require some level of integrity, with relaxed integrity risk, relaxed time-to-alarm but possibly reduced horizontal alarm limits. Considering the use of GNSS for POPS there are certain limitations considering especially urban environments. This is mainly caused by reduced visibility and strong local errors, which degrade the potential performance of GNSS based POPS. With future availability of various GNSS constellations (including Galileo) and SBAS systems a significant mitigation of these limitations to GNSS based POPS is expected, regarding the increased number of satellites which will improve visibility and enable the user to eliminate local errors. The MLUTB's aims are to investigate how these improvements can be utilized best and to evaluate the results by a POPS experimentation campaign.

This POPS Experimentation campaign is divided in two phases:

1. End-to-end experimentation campaign with the aim to measure and assess the overall system performance in a variety of scenarios combining different environments and user equipment configurations.
2. Real-life experimentation campaign to measure the overall system performance, evaluate the use of different GIC (Galileo Integrity Channel) dissemination constellations and assess the performance obtained against the results from the end-to-end simulations.

These experiments take place in different test areas aiming to demonstrate the suitability of different integrity concepts. GATE will serve for MLUTB as a POPS test environment for road test scenarios in sub-urban environments with increased levels of multipath and shadowing effects. The MLUTB infrastructure will provide GPS/Galileo integrity/augmentation data to GATE, incorporated into the I/NAV messages of E1 and E5b, which will be transmitted via all eight GATE transmitters into the test area. Using the data recorded by the Ranging Integrity Monitoring Stations (RIMS) the MLU testbed determines the integrity of each GPS satellite creating the GIC data. The corresponding data for the GATE "satellites" are based on simulated values.

HISTB & MLUTB TEST BED COMPONENTS FOR GATE EXPERIMENTATION

GATE Infrastructure Upgrade

The following adaptations and functional extensions of GATE had to be implemented in order to meet the needs of HISTB experimentation:

GATE Local GEO dissemination means on L1:

The GATE Local Means is responsible for generating an RF signal into the testbed, which has the same specification as the EGNOS SIS. For this reason, the hardware of two GATE pseudolites has been prepared to transmit a second L1 signal, in addition to the Galileo E1 signal. An SBAS enabled receiver like the GATE Test User Receiver TUR (see corresponding section below) can track this GEO-like signal in the same way as the real EGNOS SIS. The TUR receives EGNOS corrections, even if no EGNOS satellite is in view as soon as one of the pseudolites transmitting the GATE GEO-like signal is in view. The signal content can either be configured to be compatible to standard EGNOS SIS or it can be filled by the SPEED/H-NK PF (Navigation Kernel of the Processing Facility – See [1] for further details) and further augmented by the GATE processing facility with respect to GATE relevant data. The PRN of the GEO-like signal can be configured enabling the TUR to distinguish between real EGNOS and HISTB data. Currently the unallocated PRN 123 and 125 are used for experimentation. It has to be noted that the GATE GEO-like signal is only a communication signal and cannot be used for ranging purposes.

GATE SISNeT User Application Software (UAS):

The data for the GEO-like signals which are transmitted by the GATE pseudolites will be received from outside of the GATE system and complemented with GATE specific content, if required. The GATE UAS is the element, which receives data from outside, converts it and forwards it to an internal interface. Dependent on the use case, the data is received from the ESA SISNeT Data Server or from the HISTB/SPEED Data Server.

Extended GATE navigation message update intervals:

The default GATE navigation message update interval of 1-2 minutes was increased to 15 minutes in order to behave more representatively to the real Galileo satellite navigation system. This adaptation of the navigation message update interval was made to slightly increase GATE pseudo-range errors over time. Therefore it enables the generation of realistic fast corrections for the GATE pseudolites in the frame of the experiments performed within the HISTB mission.

GATE message augmentation:

In order to correct the GATE pseudolite errors at user level, the GPF generates pseudo-range fast corrections. These errors (in particular clock errors) are mainly caused by the intentionally increased GATE navigation message update interval of 15 minutes. For each GATE pseudolite the GPF generates dual-frequency (E1/E5a) pseudo-range fast corrections, which are computed by means of real GATE SIS observations. The GPF encodes them into the corresponding dummy augmentation message fields of the fast corrections message types provided by SPEED. The integrity data (UDREIs) contained in the EGNOS like message types is provided on a functional basis for the GATE pseudolites. I.e. they are configurable within the GPF or by the operator, and encoded into fast corrections and integrity information message types provided by SPEED. The completed messages are subsequently transmitted to the user in the field.

Flexible generation of multiple "Feared Events":

In order to appropriately test and verify ARAIM based integrity scenarios, GATE was upgraded with more sophisticated Feared Event (FE) generation functionalities. Those FE are realized on operator command or by a pre-defined test plan script as transmitter clock drifts/jumps, including the execution of several consecutive FEs. Thus, arbitrary clock FE error functions which are non-linear over time can be linearly approximated by successively scheduling appropriate FE commands as depicted in Figure 4 below.

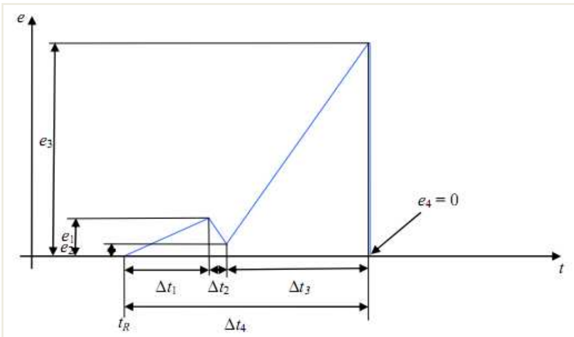

Figure 4: Example of GATE "Feared Event" scheme

GATE Test User Receiver

For HISTB-GATE experimentation a dedicated GATE Test User Receiver (TUR) is used, which is a multi-frequency/ multi-constellation GNSS receiver, capable of MOPS D EGNOS user processing and with dual-frequency SBAS (L1/L5 or L1/L2) and ARAIM functionality. The receiver and the associated processing software were developed by IFEN GmbH in the frame of the ESA RIMS-NG project. The processing and visualization software is based on IFEN's GSPF (GNSS Simulation and Processing Facility) framework. ESA is the owner of the receiver and made it available to the HISTB project for the duration of GATE experimentation. The ARAIM functionality of the GATE TUR provides the user position and velocity solution, its integrity in terms of protection levels and its availability in terms of comparison between protection levels vs. alert limits. This ARAIM functionality corresponds to the algorithm described in GNSS Evolutionary Architecture Study (GEAS) Phase II Report [2]. In addition, this functionality applies to bi-frequency and multi-constellation GPS and Galileo pre-processed pseudoranges, which are in particular corrected for ionospheric and tropospheric errors.

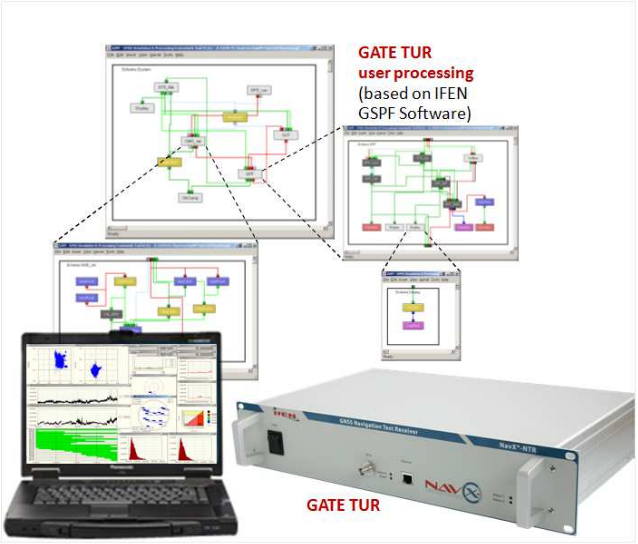

Figure 5: GATE Test User Receiver & Software

HISTB architecture for GATE experiments

Figure 6 represents the overall architecture for the Gate experiments.
GPS data are collected in real-time from the SPEED RIMS Data Server (S-RDS, see [1]) located in Torrejon. These data are then processed in real time by the SPEED Processing Facility (PF) algorithms (located in Toulouse), in order to compute GPS augmentation messages.
These messages are then broadcasted to the Gate facilities, through the Speed SISNET and SPEED Data Dissemination Server (S-DDS, see [1]) located in ESTEC.

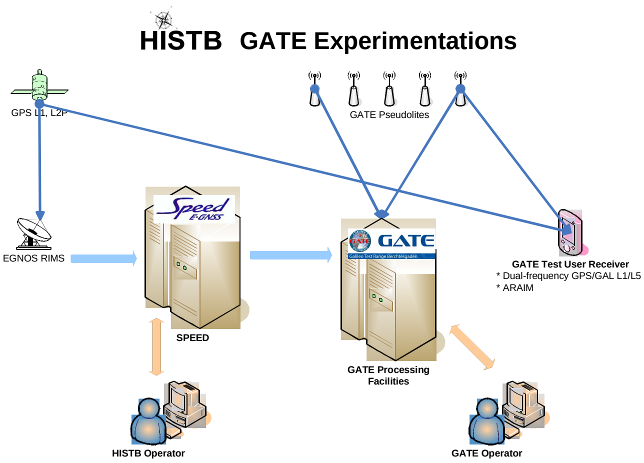

Figure 6: HISTB architecture for GATE experiments

GATE upgrade for MLUTB

For the periodical provision of the experimental GPS/Galileo integrity/augmentation data from MLUTB to GATE the GATE infrastructure was upgraded with a dedicated communication link. This is based on a secure FTP server allowing for the upload of the GATE pseudolite files, which contain the ERIS-like data, by the corresponding MLUTB secure FTP client application. These data are then decoded by the GPF and incorporated into the I/NAV data stream to be transmitted from the GATE stations. For the GATE experimentations in the frame of the MLUTB mission, non-visibility of one or several pseudolites is likely to happen, at least for some parts of the rural/suburban test routes. Therefore, a double frequency I/NAV ERIS data channel is used for the GATE experimentations so that two GATE pseudolites simultaneously transmit the same SBAS corrections, i.e. the same ERIS-like data. Due to this redundancy, the non-visibility to a GATE pseudolite can be compensated by the visibility to the corresponding GATE pseudolite, which transmits the same SBAS corrections. Since GATE comprises eight GATE pseudolites, only four GATE pseudolite files are transferred from MLUTB to GATE. With each GATE pseudolite transmitting the SBAS corrections of 20 GPS/GNSS satellites, corrections for a total number of 80 satellites can be transmitted. The assignments of the GATE pseudolite files to the transmitters are configurable in GATE.

GATE INTEGRITY TEST SCENARIOS

The HISTB-GATE field experimentation considers three specific use cases. Apart from use case “Performance improvements with additional satellites”, which is covering tests of general user performance improvements by combination of GPS & GATE measurements including transmission of operational EGNOS SISNeT data via GATE transmitters, the following two dedicated test scenarios related to user integrity research were defined:

“Early test of GPS & Galileo augmentation”:
The main objective of this scenario is to perform an early testing of the dual-frequency/dual-constellation GPS and Galileo augmentation functionality. The tests performed apply GPS/Galileo dual-frequency SBAS user processing and aim to demonstrate the performance improvement brought by a multi-constellation augmentation feature. Two dedicated use cases are covered, i.e. a static terrestrial scenario with the TUR located in the field under open-sky conditions and a dynamic aeronautical scenario with the TUR mounted in a helicopter.
Provision of GPS/Galileo correction data is established through a communication link to SPEED. Galileo E1/E5a augmentation data is based on GATE clock corrections, GPS augmentation data is calculated on real/live GPS L1/L2P signals from SPEED & HISTB Navigation Kernel Processing Facility. Dual-frequency is implemented according to the SBAS L1/L5 ICD document. However, as currently only few GPS L5 satellites are available, L5 is emulated for HISTB experimentation by the frequency L2P.

In the frame of this test scenario also a number of Feared Events (FE) are generated together with alerts that are provided with the integrity

"User integrity advanced concepts experimentation":
The tests that are performed for this use case serve for assessments of new integrity concepts with injection of abnormal errors/anomalies on the pseudolite signals and experiment of new integrity concepts (ARAIM) in bi-frequency and multi-constellation GPS and GATE/Galileo. The tests analyse various Feared Events scenarios done in order to assess the detection capabilities of ARAIM user algorithm with the TUR and to evaluate how safely and autonomously ARAIM protects user for integrity purpose. Again a static use case in the field as well as a dynamic aeronautical application with a helicopter are covered by this scenario. Four different FE schemes were defined including emulation of clock jump and clock drift events respectively, also taking into account real GPS FEs observed in the past that can be widely reproduced by the new GATE functionality. Numerous single and multiple FE (i.e. for several GATE "satellites" at a time) are generated on E1 and/or E5 frequency during the test sessions, typically lasting six to eight hours each. In order to assess the impact of satellite geometry the FEs are produced for a satellite with particularly high elevation as well as for one with particularly low elevation alternately. The dedicated FEs that were defined for the tests are summarized in the table below:

Table 2: Overview of GATE Feared Events emulated

FE ID	Description	Total duration	Max. error
FE-01	Clock drift event (based on real GPS event observed)	6780 s	6356 m
FE-02	Clock drift event (based on real GPS event observed)	102 s	60 m
FE-03-A FE-03-B FE-03-C	Clock drift events with zero initial and final error	330 s	900 m 180 m 18 m
FE-04	Clock jump event	60 s	10 m

GALILEO PROOF-OF-POSITIONING SERVICE TEST SCENARIO

According to the objectives of the MLUTB experimentation the test drives in the GATE area are performed for two specific use cases: The first one focuses on a "rural environment" with open sky visibility over most parts of the test route and no or only moderate local multipath from the surroundings. The other one aims at testing under "sub-urban environment" conditions with signal shading by surrounding buildings along the streets as well as significant local signal multipath effects. The tests in GATE will be performed at different times of the day during a two-weeks measuring campaign.
MLUTB provides its own POPS user receiver (POPS UR) for the MLU performance tests in GATE. All the measurements are recorded together with the onboard reference receiver solutions ("true reference"). The analysis and evaluation of the results is done in post-processing by the respective partners in the MLUTB project.

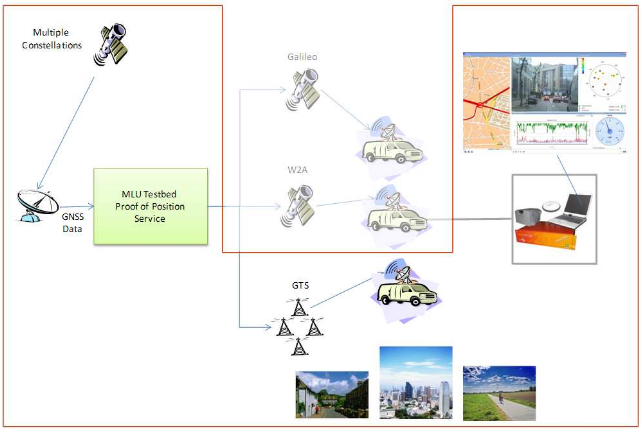

Figure 7: MLUTB-GATE experimentation overview

GATE INTEGRITY EXPERIMENTATION

In the framework of the HISTB-GATE field operation a complete set of all the SIS measurements required to cover each scenario defined above is logged with the GATE-TUR software. Afterwards the analysis of the various constellation "subsets", i.e. different GNSS constellations and frequencies, is done successively in post-processing mode with the TUR software using the binary log data as input files. For the real-time demonstration and the recording of the measurements, the TUR and the standard GATE user terminal - including the precise GPS-RTK/IMU reference position unit and a UMTS communication link - are mounted in the measuring vehicle (see Figure 8). The static field tests are performed at an appropriate "open-sky" location quite in the centre of the test area with good visibility of all signal transmit stations.

Figure 8: GATE measuring vehicle & test equipment

For the aeronautical dynamic experimentation the TUR and GATE user terminal equipment are assembled in a compact rack and mounted in a helicopter as depicted in Figure 9. The test flights are performed in the framework of a measuring campaign of several days.

Figure 9: Helicopter and equipment for flight tests

A two-phase approach has been defined for the HISTB-GATE experiments execution: A “dry-run” phase serves for the verification of the test-setup and the general feasibility of the scenarios planned. It is followed by the final experimentation phase with extensive test activities including several repetitions of the respective test case. The post-processed results of the data recorded during this final phase will be the main basis for the subsequent evaluation and assessment.

Preliminary Results of GATE Integrity Testing for HISTB

At the time of writing this paper the final HISTB-GATE experimentation activities in the field are ongoing. In the following some preliminary sample results from the first static tests executed shall be presented to give a first idea of the further experimentation outcomes.

“Early test of GPS & Galileo augmentation” - Experimentation:

Figure 10 gives an example of a combined dual-frequency/ dual-constellation processing of GPS and GATE measurements including the SPEED corrections that were received via the SBAS channel of the GATE signal transmitter GTS#8, which corresponds to the SBAS PRN 125.

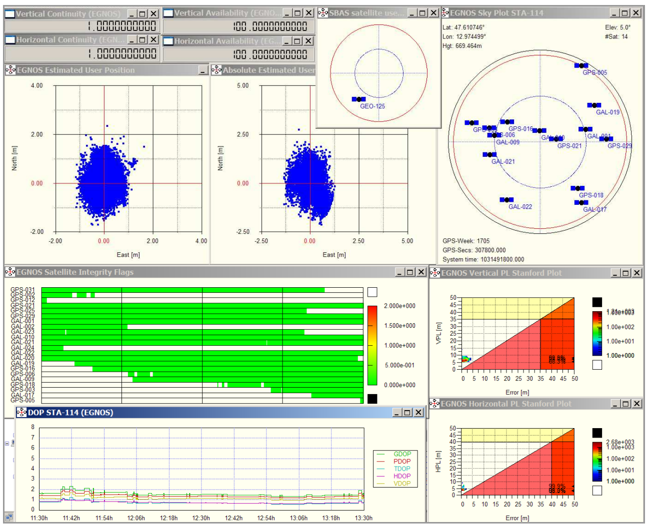

Figure 10: Example of GPS L1/L2 & GATE E1/E5a positioning with/without SPEED SBAS

A comparison of the position error (3D) obtained for the uncorrected solution and the corresponding solution with SPEED SBAS corrections for GPS L1/L2 and GATE E1/E5a applied is given in the Figure 11. It can be seen from this sample that the augmented position solutions actually outperform the ones without SBAS corrections most of the time.

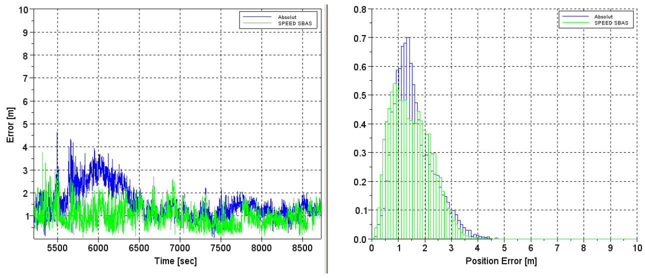

Figure 11: Comparison of position errors with (green) and without (blue) SPEED SBAS corrections applied

Another experiment for this use case includes the generation of GATE Feared Events (combined clock drift ramps as depicted in Figure 4) as well as the corresponding alerts with MT6 (Message Type 6) for the affected PRNs that are provided with the SPEED SBAS stream transmitted by two GATE stations. The following figures show a visualization of the results with various FEs detected with the MT6 alert received in time according to LPV200 specification, i.e. within 6 seconds after FE generation.

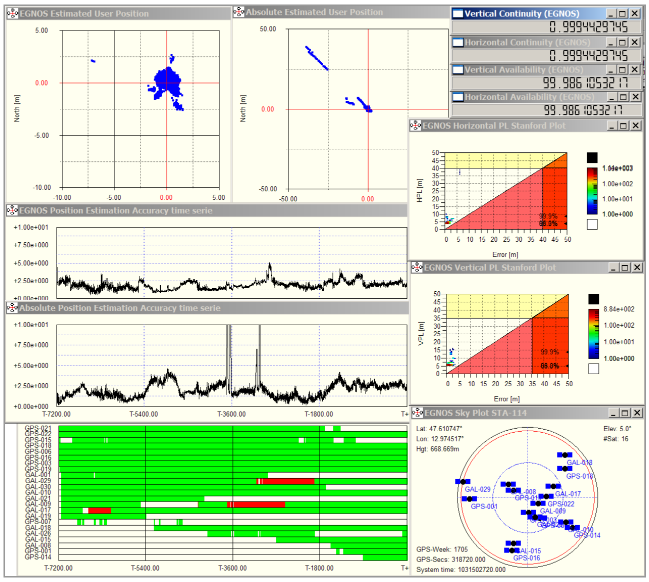

Figure 12: Example of GPS L1/L2 & GATE E1/E5a positioning with/without SPEED SBAS, GATE FEs

The first of the three FEs depicted (Galileo PRN 17) was already detected by the pre-processing. Therefore the affected signal was excluded from the position calculation independent from the alert generated. The two other FEs caused significant degradations in the position solutions without SBAS (see lower “position estimation accuracy” timeline, Figure 12) while the corresponding SBAS based solutions above do not show any impairments thanks to the timely availability of the MT 6 alert for the signals affected, as indicated by the red flags for the Galileo PRNs 9 and 29 respectively. Note that the vertical and horizontal availability and continuity values of 99.99 % in this screenshot are due to the limited availability of measurements at the very beginning of the processing period.

Finally, a TUR SW screenshot of a first helicopter test flight performed during the dry-run phase is presented in Figure 13. It shows the GPS/GATE dual-frequency/dual-constellation position results with SPEED corrections applied, together with some information on the satellites used as well as the resulting vertical and horizontal protection levels that are below 10 m each.

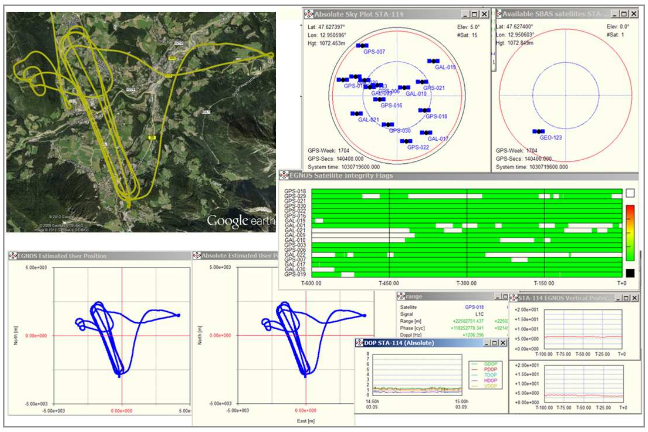

Figure 13: Example of dynamic (flight) GPS L1/L2 & GATE E1/E5a positioning with/without SPEED SBAS

"User integrity advanced concepts experimentation":

The preliminary results for this test case are presented in the following. They shall give a first impression of the performance of the ARAIM algorithm for dual-frequency/ dual-constellation processing implemented in the GATE-TUR as described above. The main focus of this scenario is on the detection capability of various FEs and the corresponding integrity performance values obtained.

In Figure 14 the sequence of FEs generated during an experiment of several hours is visualized. It shows the integrity table of the TUR SW indicating each detected/ excluded FE with a red flag as well as the impact of the erroneous signals on the position accuracy in case of no ARAIM applied. In contrast the corresponding accuracy timeline for the position solutions (3D) based on ARAIM processing is given in Figure 15 together with the vertical protection level plot. It can be seen from these graphs and the additional integrity information in Figure 16 respectively, that the ARAIM based solutions were fully available within the specified alert limits thanks to the successful detection and exclusion of the FEs.

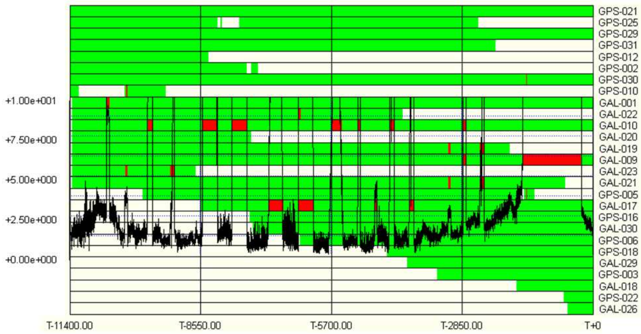

Figure 14: GATE FEs detected and GATE-TUR position errors [m], without ARAIM applied

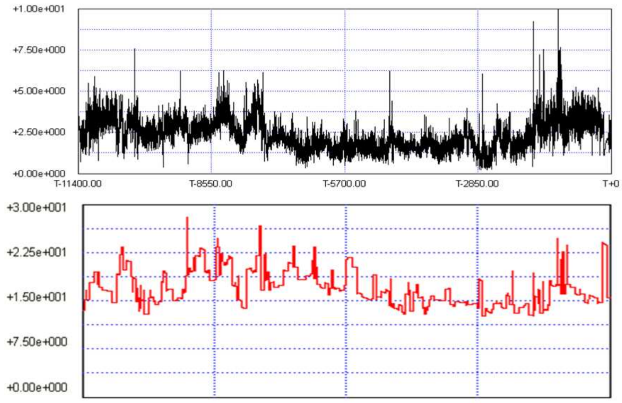

Figure 15: Corresponding GATE-TUR position errors (top) and VPL (bottom), with ARAIM applied

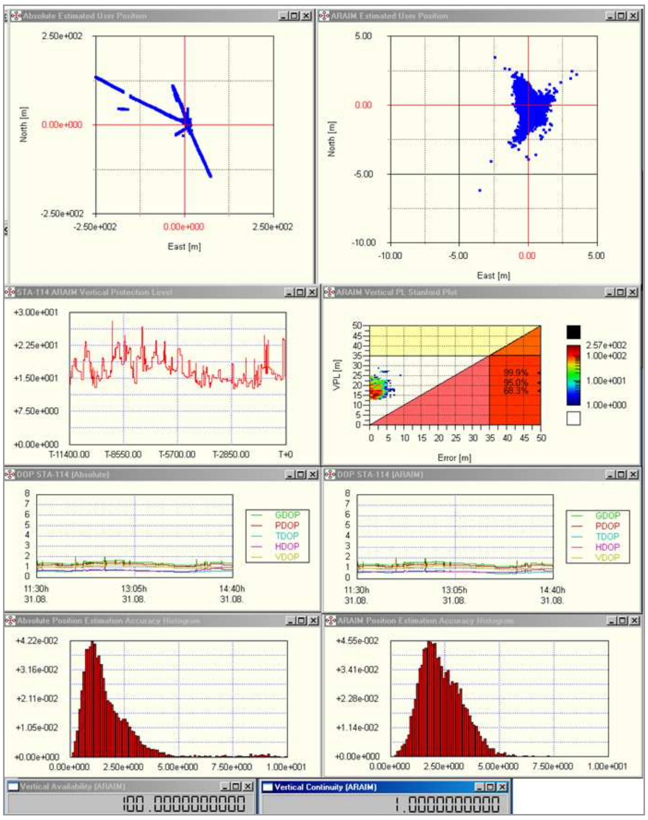

Figure 16: Example of GPS L1/L2 & GATE E1/E5a positioning without/with ARAIM applied, GATE FEs

The related GUI of the TUR software in Figure 16 above provides some further information including position scatter plots, VPL and Stanford diagram, DOP values and position accuracy (3D) histograms for both solutions are finally depicted in . The impact of the pseudorange drifts during the several FEs generated can be clearly seen from the position drift in the 2D scatter plot.

SUMMARY AND OUTLOOK

The paper presented an overview of the GATE upgrade activities that were performed for the usage of the test range in the framework of ESA's EGEP test beds HISTB and MLUTB. Furthermore the related test scenarios and experiments were introduced. At the time of writing this paper the final experimentation phase is being conducted which was started in the beginning of September after the successful completion of several "Dry-Run" tests. Apart from these static, ground-based, test activities on the ground the execution of aeronautical experiments with the GATE Test User Receiver mounted on a helicopter will take place in the area of Berchtesgaden. The finalization of the HISTB-GATE field experimentation campaign is anticipated for the end of October 2012.

First preliminary results of the field tests were presented for dual-frequency/dual-constellation positioning with GPS and GATE using SBAS data provided by the SPEED platform. Furthermore the paper showed some first outcomes of "user integrity advanced concepts" experimentation with intentional Feared Events generated for GATE signals that were successfully detected and excluded for dual-frequency/dual-constellation positioning applying the ARAIM algorithm implemented in the GATE TUR according to [2].

Subsequent to the completion of the HISTB-GATE test activities the test campaign for the MLUTB GATE experimentation will be started in the Berchtesgaden area.

Further information about GATE can be found on the official homepage www.gate-testbed.com.

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REFERENCES

[1] High Integrity System Test Bed (HISTB) - The laboratory for EGNOS evolutions, H. Delfour et al., ION GNSS 2012 proceedings.

[2] Phase II of the GNSS Evolutionary Architecture Study, February 2010