Certification of a Galileo Test Range

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1. Introduction

This paper explains the certification of the Galileo Test Environment (GATE) by NavCert GmbH which was successfully completed in 2011 and 2013.

The paper basically consists of two parts. After an explanation of the background of certification detailed in chapters 2 to 4, chapters 5 and 6 explain how the certification of the test-bed was performed and what tests results were achieved. Chapter 7 summarizes the results and gives a brief outlook into the future.

2. The subject of certification, the 'Galileo Test Environment (GATE)'

The successful development of receivers, application technologies and services is a key requirement for the commercial success of the European Satellite Navigation System Galileo. GATE in Berchtesgaden, South of Germany, is the world's first and only real-life test and development environment for GPS/Galileo receiver products and applications, enabling developers to prepare and test their products for Galileo even before the satellite system reaches full operational capability (FOC). GATE closes the gap between laboratory tests with a simulator and the fully operational satellite system. It allows real-life tests of complex receiver products in a virtual satellite environment. GATE can be used since 2008. In 2011 – coinciding with successful certification – GATE was officially opened. GATE was developed under contract of the DLR (German Aerospace Center, Bonn-Oberkassel) with funding by the BMWi (German Federal Ministry of Economics and Technology) and is operated by IFEN GmbH.

The GATE test-bed consists of 8 'virtual satellite' transmit stations installed on mountains surrounding the test area in Berchtesgaden. Each virtual satellite transmits the Galileo signal creating a realistic satellite environment in the test area. The system is complemented by two monitor stations and a processing facility to monitor and control the transmitted signals.

The signals generated by GATE are conform to the Galileo OS SIS ICD (Open Service Signal-in-Space Interface Control Document) signal specification and can be adapted if the signal specification changes. In 'Virtual Satellite Mode' the Galileo satellite constellation is simulated realistically: For an observer in the test area the 'GATE satellites' appear to be moving across the sky due to realistic simulation of the geometry dependent signal Doppler shifts of each satellite. A user is able to test an integrated product in this environment, also with odometer and/or inertial reference system coupled to the receiver, thereby exploring realistic scenarios complete with multi-path and possible interference.

All 4 Galileo IOV (in-orbit validation) satellites can be used in combination with GATE allowing tests of a complete Galileo constellation of up to 12 visible satellites. In addition the control center can inject deliberate failures into the ‘GATE satellites’ to simulate constellation errors, a feature which can be used to analyze the integrity of the user position (RAIM) and the behavior of a receiver in the presence of such errors. As the test-bed is compatible to GPS, interoperability tests employing GPS and Galileo signals are also possible.

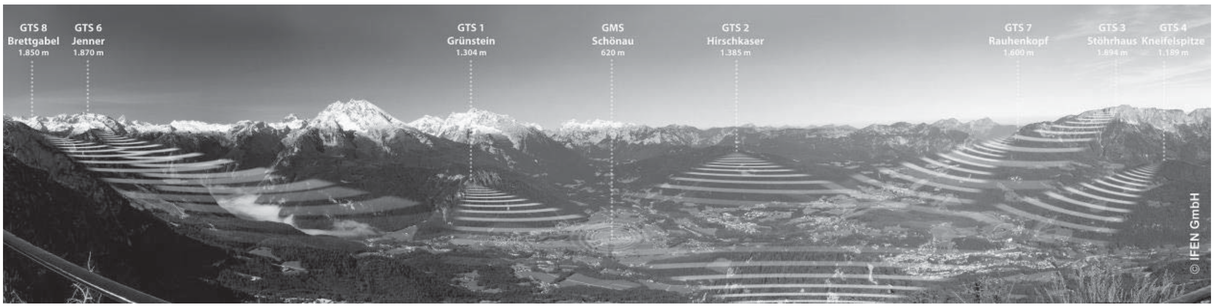

Figure 1. GATE Panorama

It is envisaged that GATE will continue to be used in the future even when the space-based Galileo system is fully operational, to test further generations of Galileo signals on the ground and to the same quality of testing as today.

3. The value of certification of GATE as a Galileo test-bed

GATE is a unique outdoor test environment providing leading edge technology for real-time and real-life testing of complex Galileo receiver products and applications.

Summarizing, the benefits of certification with respect to GATE or test-beds in general are:

- The GATE test-bed targets developers of Galileo receivers and chip-sets. Customers shall be convinced of the benefits of testing their products in the test-bed and not relying on simulator tests alone, and a certified test-bed is an important argument;
- Certification becomes essential when the test-bed is used as a reference for receiver testing for safety-critical applications. In such cases the regulating authority will ask for prove that all devices used for testing – and also the test-bed is to be viewed as such a ‘device’ – are compliant to relevant standards;
- For the users of a test and development environment, e.g. developers of Galileo receiver hardware and software, it is essential that the test-bed is able to reliably reproduce test conditions. For this reason every experiment has to be executed with the respective required quality. Certification will regularly test the quality of operation and thus ensure good quality of all experiments that are conducted within the test-bed.

4 Certification based on standards

All certification is based on standards. For GATE – as a ground-based real-life satellite environment - no dedicated set of standards exists, so a new standard – based on existing, applicable standards – was developed suited to the GATE test-bed in particular. This new ‘house’-standard was developed by NavCert and approved by TÜV-SÜD before it was applied onto the product. The ‘GATE-Standard’ is based on the following standards considered applicable:

4.1. ECSS Standards

GATE is unique in a sense that it establishes a satellite system on the ground. To construct a standard dedicated to GATE as a ground-based outdoor test environment, the new standard was based on the existing standards for space-based systems, which of course could not be applied fully, but were transferred to the ground-based system as reasonable and to the extent possible. The ECSS implements and maintains a common, coherent and user-friendly set of standards for space projects addressing aspects of:

- Project Management
- Engineering
- Product Assurance
- Space Sustainability

As GATE is a space project only in the figurative sense, space sustainability, i.e. the aspects dealing with the sustainable use of space in terms of e.g. frequency band or orbit usage, were obviously not applicable and were neglected. Other aspects however could well be transferred to a ground-based project.

4.2 Galileo OS SIS ICD

The European GNSS (Galileo) Open Service Signal-In-Space Interface Control Document (abbreviated OS SIS ICD) contains all publicly available information about the Galileo signal 'in space'. It is intended as a means to inform the (future) Galileo user community about the Galileo signal structure that will be received and allows manufacturers to construct receivers which are compatible to the Galileo signal.

GATE has been built to replicate the Galileo satellite constellation on the ground. It is therefore conform to the OS SIS ICD to the extent possible, but limitations due to the fact that it is a ground-based system apply such as the necessity to limit the bandwidth of the transmitted signals.

4.3 DIN EN ISO 17025

The 17025 standard contains 'General requirements for the competence of testing and calibration laboratories' and assesses if GATE is operated in accordance with standards and recommended practice as detailed in the ISO standard.

5. How was the certification of the Galileo Test Environment performed?

The certification of the GATE test-bed was performed very comprehensively and in a number of steps covering all aspects that are applicable to demonstrate the performance and usability as 'open-air' test laboratory for Galileo. The steps undertaken to certify GATE are listed in the following:

5.1 Engineering Requirements / Project, Risk, Document, Configuration Management

Certification confirmed that all phases of the GATE project were carried out in accordance with the applicable ECSS space standards as mentioned above. For certification the 'space components' were adequately translated into system components of the GATE system and conformity of the project management structure with the ECSS standards was thoroughly assessed.

5.2 GATE System Requirements

The GATE project documentation comprise of a number of requirement documents for the various subsystems and the test-bed as a whole specifying all aspects of the system. For certification of all system and component requirements especially those requirements were selected, which specifically address the performance of GATE. Those requirements also relate back to the 'GATE Mission Requirements Document' of DLR.

Requirement conformity was assessed through audits and a detailed study of the GATE system and test documentation, followed by dedicated tests within the GATE test-bed. One important system requirement is signal conformity to GATE OS SIS ICD, which was confirmed by signal measurements within the GATE test-bed and at one of the GATE transmit stations.

5.3 GATE Performance

As the GATE system is operational and complete since phase SKZ, current certification in phase IRG put a stress on GATE performance and included tests of new capabilities that were introduced into GATE since phase SKZ. Important performance test points were:

- GATE Synchronization to GPS including GGTO (Galileo to GPS Time Offset) through upgrade of GATE receivers and GPF (GATE Processing Facility) to GPS L2C/L2P capability
- Mixed mode capability with GPS and Galileo IOV satellites
- Support of RAIM integrity test scenarios, generation of configurable feared events (Step and Ramp)
- E1 and E5a/b positioning accuracy in all 3 GATE modi (BM, EBM and VSM) ≤10m, also if the receivers move within the GATE area

5.4 Operation of GATE as a 17025 test laboratory

Conformity of the test-bed laboratory to the requirements of ISO 17025 was assessed in two steps:

a) In an audit of the ISO requirements: IFEN as the GATE operator explained how the requirements from ISO 17025 were implemented in the applicant's own quality management system;
b) Study of documentation: The test-bed documentation was analyzed for correct implementation of the requirements from ISO 17025.

5.5 Test Equipment Used

Localization tests in the GATE test-bed were conducted with two state-of-the-art PolaRx 3eG Pro and PolaRx4 PRO Septentrio receivers and compared to the results from the GATE User Receiver (GURx) developed by IFEN. The Septentrio receivers were employed as COTS (Commercial Off-The-Shelf) and GATE independent receivers expected to show similar behavior as when exposed to the future Galileo signal environment.

Signal validation was carried out in cooperation with Fraunhofer Gesellschaft IIS and TeleConsult Austria who employed a state-of-the-art Rohde & Schwarz FSP-13 spectrum analyzer and own sophisticated signal processing equipment especially suited for the task of analyzing the transmitted signal spectrum and contents.

6. Results of the certification

Figure 2. GATE Core Area near Schönau, Berchtesgaden,
as seen from GATE Transmit Station GTS#5 on the Kehlstein mountain

Figure 3. Measurements near the GATE Central Point looking South

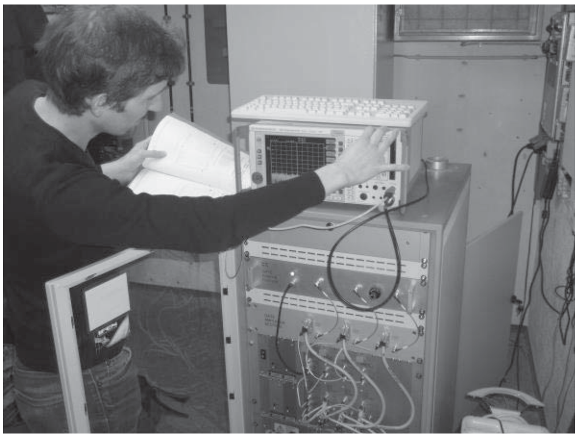

Figure 4. Signal measurements at the GATE Transmit Station #5 'Kehlsteinhaus'

6.1 Localization Accuracy

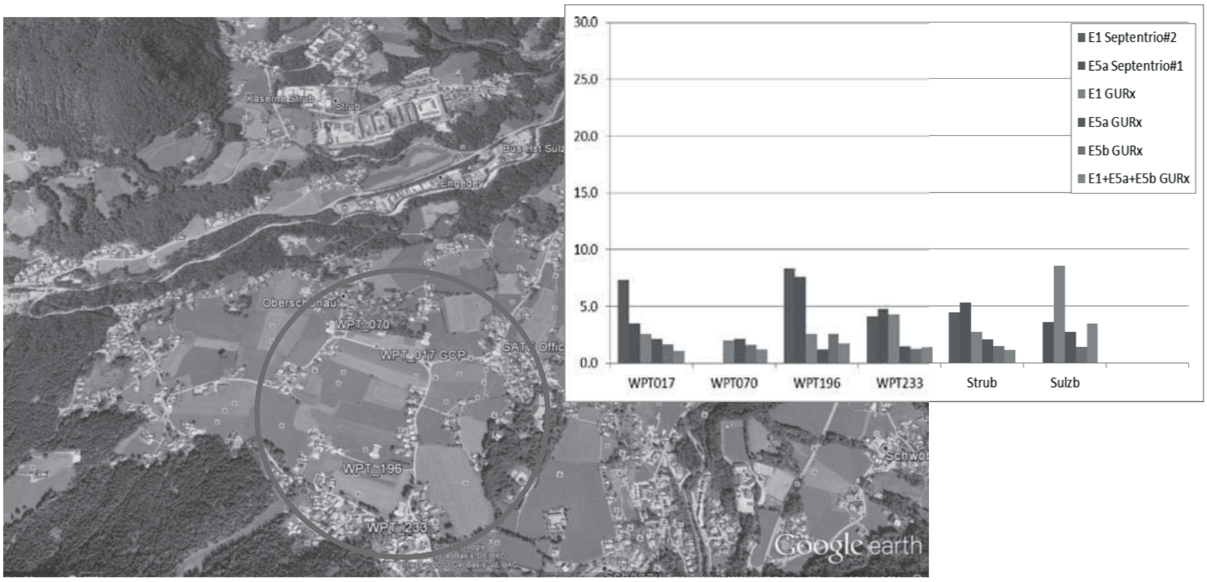

Figure 5. Measurement positions in the GATE core area (red ring) and outside shown in Google Earth and a summary of the localization accuracy of GATE in Virtual Satellite Mode: The graphic shows the localization accuracy in meters that is achieved at various positions in the GATE test-bed when different frequencies and combinations of frequencies are used to establish position fixes

Localization accuracy was assessed on 4 positions in the GATE core area (at GATE central point WPT_017 and on three other positions) and on 2 positions inside the GATE test-bed, but outside the core area where, due to limited visibility of some GATE transmit stations, the accuracy was expected to be slightly worse than in the core area (Strub barracks and Sulzberg bus-stop). All results were as expected and according to the specification:

- All localization accuracies employing frequencies E1 and E5 were better than 10m on all positions inside the GATE test-bed;
- Two GATE independent state-of-the-art Septentrio receivers were able to achieve accurate position fixes in GATE mode VSM, as well as the GURx (GATE User Receiver) which is a Galileo/GPS receiver from IFEN. As expected the localization accuracy when combining the Galileo frequencies for position fixing was better than the accuracy achieved on individual frequencies.

6.2 Mixed Mode Capability

6.2.1 GATE + GPS

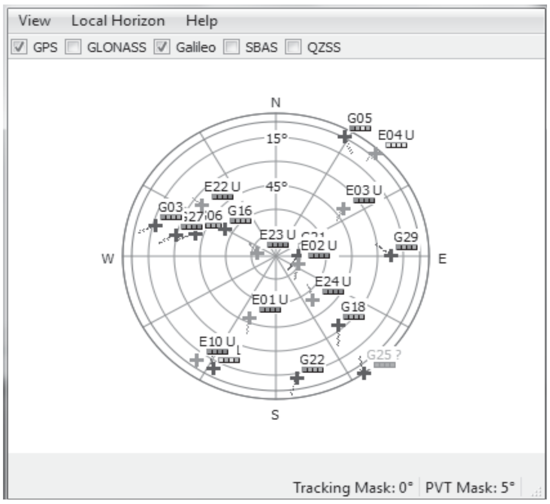

Figure 6. Septentrio Skyplot GATE+GPS

Measurements in mixed GATE+GPS mode were performed with both Septentrio receivers: Septentrio receiver #1 combined GPS with measurements on Galileo frequency E5, Septentrio receiver #2 combined GPS with Galileo measurements on E1. The ‘Skyplot’ screen from the Septentrio software shows the constellation of GPS and GATE-Galileo satellites at the GATE Central Point, position WPT_017.

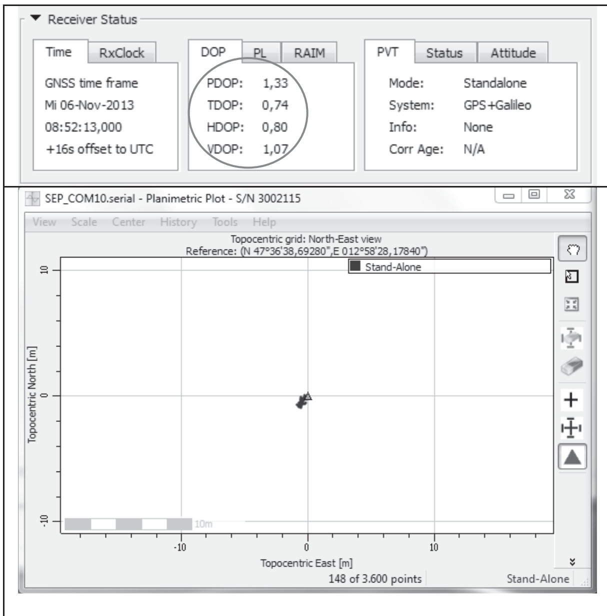

Figure 7. Septentrio#1 localization accuracy on GATE Central Point WPT_017 using Galileo and GPS; excellent DOP values were achieved

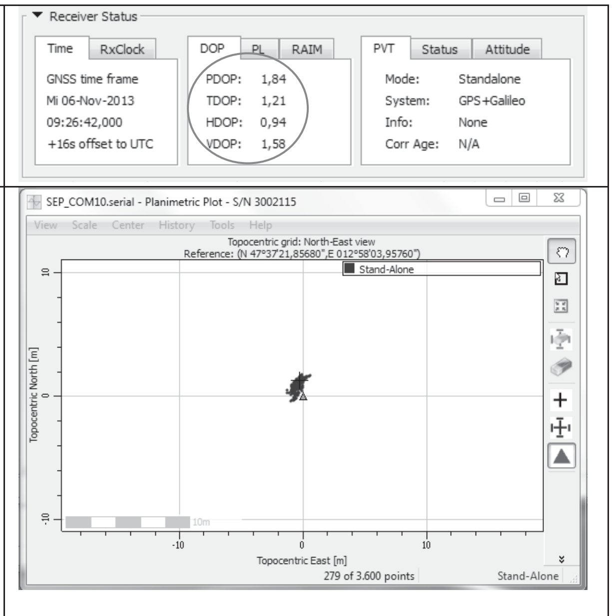

Figure 8. Septentrio#1 localization accuracy outside GATE core area using Galileo and GPS; excellent DOP values were achieved

The tests of mixed mode capability – GATE together with GPS – resulted in successful position fixes fulfilling the interoperability requirements between Gate and GPS. By employing two state-of-the-art off-the-shelf and GATE independent receivers this, including the correct time synchronization between GATE and GPS, was demonstrated impressively.

Both Septentrio receivers were able to calculate position solutions on the test positions in the GATE area with accuracies better than the required 10m. The HDOP values during the test were in general very good. In most cases they were below 2.

6.2.2 GATE + Galileo IOV Satellites

This test was performed on Tuesday 5th November 2013 between 13:25 and 13:40 (UTC) when all four GALILEO IOV satellites where visible in the GATE test area at an elevation greater than 10°.

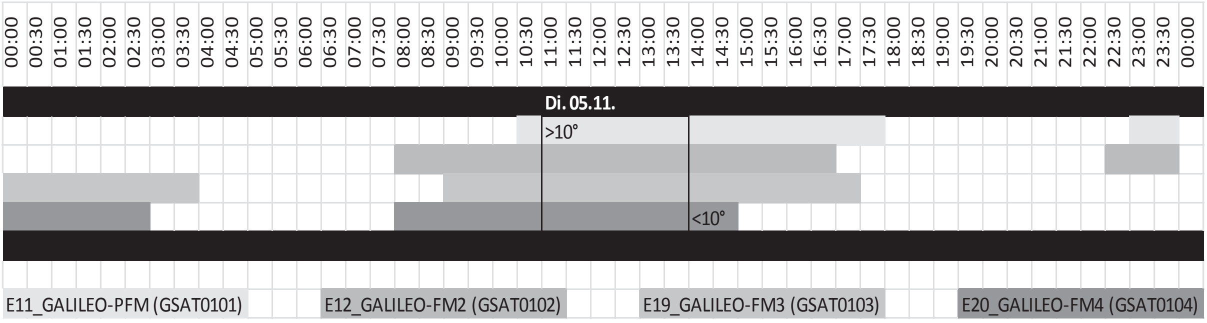

Figure 9. Galileo IOV satellite visibility on Tuesday, 05th November 2013

This test was focused on the ability of GATE to integrate the Galileo IOV satellites into the GATE environment and to test GATE-IOV compatibility. The Septentrio receivers used for testing were again deployed into this environment and their position fixing capability was assessed on again the 6 test positions in the GATE test area.

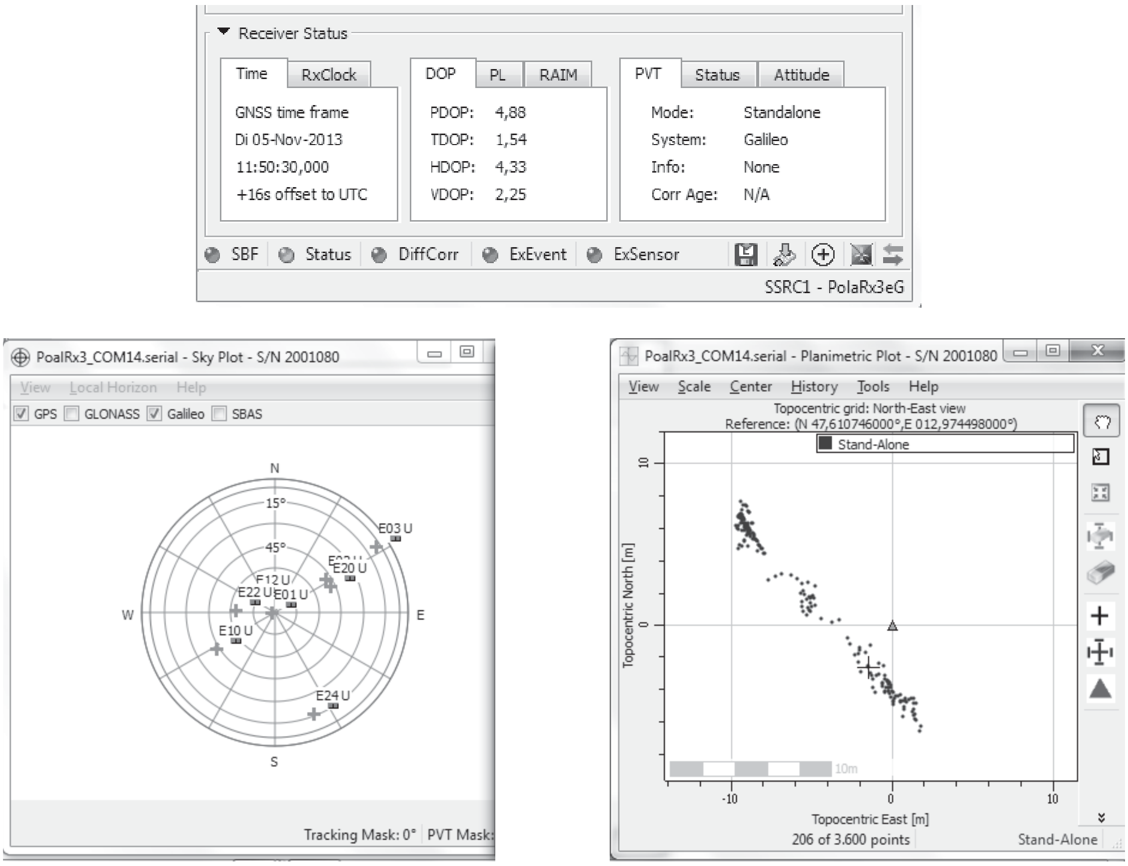

Figure 10. Screenshot Septentrio SBF Analyzer Software on 5th Nov 2013, tracking IOV Satellites #E12 (E12_Galileo-FM2 GSAT0102) and #E20 (E20_Galileo-FM4 GSAT0104) and GATE satellites E03 and E10

Figure 11. Position fixed at GATE Central Point and results exported to Google Earth: The yellow pins marks the reference position on WPT_017 GATE Central Point; the blue trace shows all positions measured between START and END of a 3 minutes measurement; deviations were observed to lie within a 5m radius

Two Galileo IOV satellites were used in combination with two GATE (virtual) 'satellites' to establish position fixes at various positions in the GATE test-bed area in stand-alone Galileo mode. The Septentrio receivers were configured to form a position solution on the basis of two GATE (virtual) and two IOV satellites, ignoring the remaining GATE 'satellites' and forcing them to calculate a combined GATE-IOV solution.

The results of mixed mode capability tests were very positive and the compatibility between IOV and GATE (virtual) satellites could successfully be demonstrated. On all test positions in the GATE area the receivers were able to calculate reliable 2D position fixes. On frequencies E1 and E5a and employing only two satellites of each type, localization accuracies better than 10 meters were achieved. The low DOP values arise from using only 4 satellites for position fixing.

6.3 Signal Validation

Next to actually using the GATE signals to establish position fixes in the test-bed, which already proved compatibility to the Galileo signal specification, the signals themselves were assessed and analyzed in detail. Comprehensive measurements of the carrier frequencies, the transmitted spectrum and RF (Radio-Frequency) power distribution, of Code Carrier and Code Data Coherency and of the signal contents such as the NAV message structures were conducted in cooperation with signal experts from Fraunhofer IIG and Teleconsult Austria.

For a thorough assessment of the signals, undistorted by transmission and influences by multi-path and weather down in the valley, the signals were tapped directly at a GATE Transmit Station (GTS) on a mountain. For accessibility reasons GTS#5 on the Kehlstein mountain was selected as it can be reached by a road and is open to late in the year.

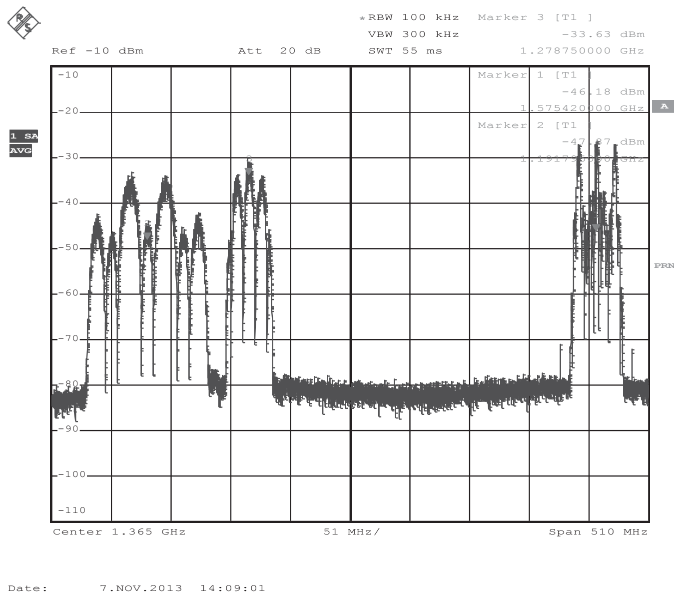

Figure 12. Measured GATE signal spectrum including E5, E6 and E1 (Spectrum Analyser)

The picture above shows the signal spectrum as recorded at the Kehlstein GSG (GATE Signal Generator) showing the complete GATE/Galileo signal in the L-Band.

6.4 Test of Integrity Alert & Feared Event Generation Functionality

GATE possesses the ability to generate deliberate failure modes so that the behavior of receivers in the presence of such failures can be assessed in the test-bed. GATE allows simulating two failure modes which can be injected into individual GATE 'satellite' messages:

- SISMA (Signal-In-Space Monitoring Accuracy) Integrity Alerts, which on the Galileo system is broadcast to the users through the integrity message
- Feared Events: To support user RAIM integrity test scenarios, GATE is able to generate configurable feared events (failure types: Ramp with ascending slope, constant error, descending slope).

It was verified that all integrity flags and SISMA values entered during the test were correctly received and immediately displayed on the test receivers. Tests and subsequent analysis of results showed that the integrity alert feature as implemented in GATE functioned as intended.

A 'Feared Event' is a disturbance of the signal transmitted by one (or more) satellites which leads to the degradation of the position solution computed on a user receiver. The functionality of GATE to generate Feared Events in terms of clock jumps and drifts (Steps and Ramps) on one or more frequencies was tested by selecting different PRNs and setting the Feared Event on them. The PRNs were selected randomly. The tests with the off-the-shelf Septentrio Galileo receiver showed that GATE correctly implements the Feared Event functionality and is able to generate this error as intended.