GNSS Receiver Testing by Hardware Simulation with Measured Interference Data from Flight Trials

Holmer Denks, Alexander Steingaß, Achim Hornbostel,
German Aerospace Center (DLR)

Vincent Chopard, *Thales Avionics*

BIOGRAPHY

Holmer Denks received his engineer diploma in electrical engineering and communications at the University of Kiel, Germany, in 2002. There he was involved in investigation and simulation of communications systems. In 2002 he joined DLR. Since then he works in the field of satellite navigation. Currently he works on simulations of Galileo signals.

Alexander Steingass received his engineer diploma in electrical engineering and communications at the University Ulm, Germany, in 1996. In 1997 he joined DLR. Since then he works in the field of satellite navigation. He was involved in the early GALILEO signal design and performance analysis. He received his PhD 2002 at the University of Essen/Germany. Since then he was involved in multipath measurements and modelling as well as in interference measurements and modelling.

Achim Hornbostel joined the German Aerospace Center (DLR) in 1989 after he had received his engineer diploma in electrical engineering at the University of Hannover in the same year. In 1995 he received the PhD in electrical engineering from the University of Hannover. In 2000 he became member of staff at the Institute of Communications and Navigation at DLR, where he is now leading a working group for receivers and algorithms since 2005. He was involved in several projects for remote sensing, satellite communications and satellite navigation. His main activities are currently in signal propagation and receiver development.

Vincent Chopard received his engineer diploma in aeronautical engineering from ENSICA (École nationale supérieure d'ingénieurs de constructions aéronautiques) in Toulouse in 2004. He was then involved in avionics system integration and validation. Since 2005 he has joined Thales and then he works on the algorithmic of satellite navigation.

ABSTRACT

The new signals and services provided by future GNSSs like Galileo and modernized GPS will foster the use of satellite navigation for safety of life applications, e. g. for precision landing approaches of higher categories in aviation. These new signals and services require the development of advanced receiver technologies, which make full use of the performance provided by the new signal characteristics. In aviation environments various potential interference sources exist, which can degrade the performance of receivers. In particular, DME/TACAN is one of the main interference sources in the E5 Galileo band in aviation environments. Therefore, besides functional receiver validation under nominal conditions also the behaviour of the receiver under strong interference conditions must be tested.

Software and hardware simulations have shown already that DME interference can reduce the C/N_0 of a receiver by some dB even if pulse blanking is applied in the receiver [1], [2]. However, there is a gap of real measurements for flight conditions. Therefore, a flight measurement campaign was performed within the frame of the “ANASTASIA” project, which was financed by the Sixth Framework Program of the EU. During this campaign terabytes of data have been recorded in the E5 band at different flight levels over the Frankfurt DME hotspot area [5]. These data contain numerous recordings of DME and other interferers. The measurements were made with a skyward looking navigation antenna for the Galileo E5/L1 bands. This antenna belongs to a L1/E5 Galileo mock-up receiver for safety-of-life applications which was also developed within ANASTASIA. The receiver that is compliant with current Galileo MOPS standards has been already tested and validated with the help of simulated Galileo signals which were superposed with synthetic DME data [2]. The Galileo signals were generated at the nominal RF carrier frequencies and power levels by the very powerful Multi-output Advanced Signal Test

Environment for Receivers (MASTER) [3], [4] of the German Aerospace Center (DLR) and fed into the antenna port of the receiver under test. The synthetic DME data were generated with a programmable signal generator according to the test procedures defined in the Galileo MOPS [5] by EUROCAE WG 62.

In this paper a similar approach will be used, but now the synthetic data will be replaced by the recorded data from the flight measurements, which will be again superposed with simulated Galileo signals. The collection of the interference data as well as the test setup will be described and test results will be presented. During the simulations the navigation performance of the receiver under interference conditions will be investigated.

INTRODUCTION

Future GNSS like Galileo and the modernized GPS will make the introduction of satellite navigation into new application areas possible, where conventional GPS cannot be used. These are in particular safety of life applications, e. g. landing approaches of higher categories in aviation. Highly specialized receivers will be developed for these applications, which must fulfill all requirements defined by the responsible authorities and certification bodies and must cope with the specific signal reception conditions in the application environments. These receivers need thoroughly testing under controlled and repeatable conditions.

In aviation environments various potential interference sources exist, which can degrade the performance of on-board receivers as well as the performance of ground based reference receivers which are part of a ground based augmentation system (GBAS). Therefore, besides functional receiver validation under nominal conditions also the behavior of the receiver under strong interference conditions, namely CW interferers, broadband noise as well as pulsed interference from Distance Measurement Equipment (DME) and the military Tactical Air Navigation (TACAN) must be tested. DME/TACAN is one of the main interference sources in the E5 Galileo band in aviation environments. Software and hardware simulations have shown already that DME interference can reduce the C/N_0 of a receiver by some dB even if pulse blanking is applied in the receiver [1], [2].

In the project “ANASTASIA”, which was financed by the Sixth Framework Program of the EU, the development of a L1/E5 Galileo receiver for safety-of-life applications had taken place. Now, after the end of the project this receiver serves as test receiver for performance tests For these tests the very powerful Multi-output Advanced Signal Test Environment for Receivers (MASTER) [3], [4] of the German Aerospace Center (DLR) is utilized. MASTER provides simulated Galileo and GPS signals at the nominal RF carrier frequencies and power levels, which are fed into the antenna port of the receiver under test. The combined output signal of the simulator contains the sum of the signals from all or some selected satellites in view for an arbitrary receiver position or track. It is possible to generate up to four different carriers at a time, e.g. GPS L1 and L2 as well as Galileo L1 and E5. All “true data”, i.e. the positions of SVs and receivers, pseudo-ranges, errors and so on provided by the simulator, are logged and are therefore available for the analysis later on.

In this paper we will give an insight in the receiver tests undergone to prove the performance of the ANASTASIA receiver developed with the focus on measured interference. Different interference situations, i.e. the situation at the same position but different altitudes are investigated. The real data recorded during a measurement campaign over the Frankfurt hotspot area [5] at different flight levels is used for this purpose. The DME interference is first stored and preprocessed in baseband as a MATLAB file and than up-converted to RF with help of an AGILENT E8267D programmable signal generator. The test setup and preparations will be described in detail and test results will be presented.

ANASTASIA PROJECT

ANASTASIA (Airborne New and Advanced Satellite techniques and Technologies in A System Integrated Approach) was an integrated project funded by the European Community’s Sixth Framework Programme (DG research); see www.anastasia-fp6.org. The core of ANASTASIA research was to provide on-board Communication, Navigation and Surveillance (CNS) solutions to cope with the expected increase in air traffic by 2020. A receiver mock-up has been designed under the Thales expertise for three Galileo bands (L1, E5a, E5b), which is compliant to the MOPS current standards [5]. A DME measurement campaign was carried out and the receiver was tested up to its limits regarding interferences, multi-paths and low level signals.

INTERFERENCE DATA COLLECTION

Within the project ANASTASIA a measurement campaign was carried out in March 2009 in order to obtain better and realistic data for the interference scenario in the E5 band for aviation. For this purpose flight trials were performed in different altitudes and data were recorded with a Galileo navigation antenna.

Figure 1: DLR's Test aircraft: Dassault Falcon 20 E

Figure 2: ANASTASIA navigation antenna mounted on top of test aircraft

Figure 1 shows the test aircraft, a Dassault Falcon 20E which is owned by DLR. This small jet is able to go to a maximum altitude of 42 000 ft (12800 m). Figure 2 shows the skyward looking ANASTASIA navigation antenna being mounted on top of the test aircraft. However, most but not all of the interferers are radiating from the ground and, therefore, are not in the direct line-of-sight view of the antenna, but obviously nevertheless reach the antenna by propagation along the aircraft body.

Figure 3: Test area "European hotspot" near Frankfurt/Germany

The main area of interest for the measurement campaign in a geographical sense was around Frankfurt/Main, Germany where the European hotspot in respect to DME/TACAN is assumed to be, compare Figure 3. The data used for this investigation belong to the "hotspot" position (used coordinates: 50° 3‘ N, 8° 5' E) at the following altitudes:

- 1473 m (4 800 ft) (FL50)
- 4520 m (14 800 ft) (FL150)
- 8833 m (29 000 ft) (FL 300)
- 11155 m (36 600 ft) (FL 380)

While the snapshots were taken the aircraft had a bank angle of zero degree. This is important because during turns of the aircraft situations have occurred where a sight of line connection between the interferers on ground and the receiving antenna onboard have been established and thus resulting in higher power levels. For all measurements almost the air traffic peak was met.

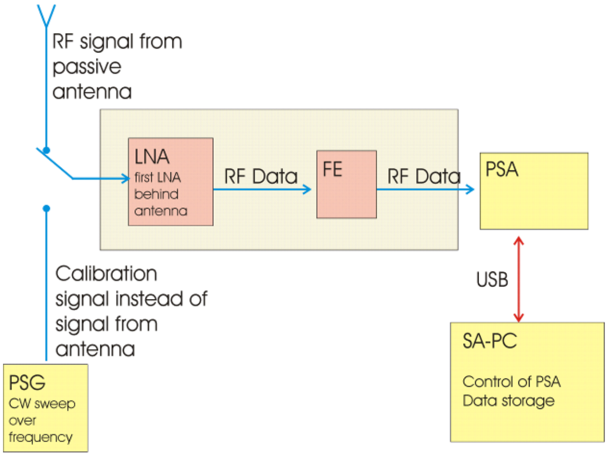

Figure 4: Test setup for data collection

Figure 4 shows the general setup for the measurements during the flight trials: The received signal is first fed into a low noise antenna preamplifier (LNA) and then is entering the RF- frontend (FE), where filtering and additional amplification take place. The total RF-amplification is approximately 45 dB. As the main measurement equipment a vector power spectrum analyzer (Agilent E4443A (PSA)) is used. The PSA executes the down conversion as well as the digitization with a bandwidth of up to 80 MHz. The control of the PSA is done via a PC (SA-PC). On that PC also the data files containing the interference data are stored. For calibration purpose a signal generator (PSG) is connected to the LNA instead of the passive antenna prior to every flight to obtain the characteristics of the measurement setup. These data are also collected by the PSA.

INTERFERNCE DATA INSPECTION

In Figure 5 to Figure 8 the power spectrum density (PSD) of the datasets chosen for this investigation are shown. The carrier frequency was set to 1188 MHz, i.e. it is slightly below the center frequency of the Galileo E5 band. The marked area is the part of the spectrum which is visible for the test receiver when operating in E5b mode.

Table 1: Number of visible DME/TACAN stations

Altitude	# spikes
1473 m (FL 50)	13
4520 m (FL 150)	28
8833 m (FL 300)	43
11155 m (FL 380)	48

There are two main differences between the datasets that can be observed: First of all the number of spikes differ strongly. The second difference is the noise floor.

Please note the identification of the DME/TACAN stations used to generate Table 1 which states the number of spikes observed in the different flight levels (FL) is done in the spectrum by visual inspection, i.e. if two or more stations use the same frequency they are counted as one station. One and the same frequency is allocated several times, i.e. different DME/TACAN stations use the same frequency but they are separated by a distance which is typically in the order of 300 km. However, in higher altitudes these stations are visible at the same time. The consequence is that the number of identified stations especially for FL 300 and FL 380 is too low.

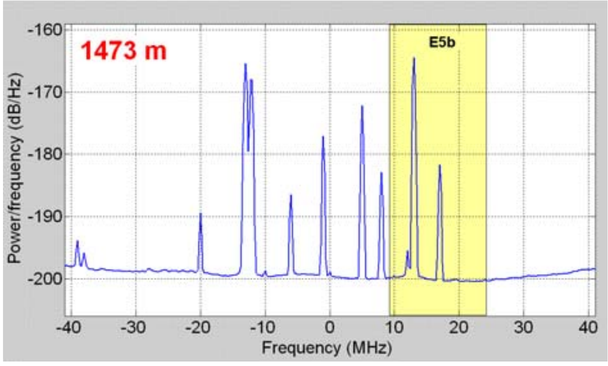

Figure 5: PSD of interference measured at FL 50

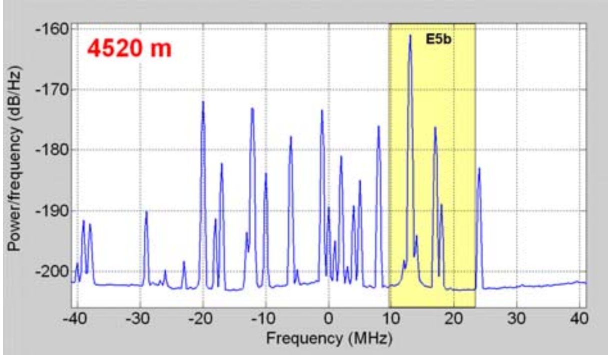

Figure 6: PSD of interference measured at FL 150

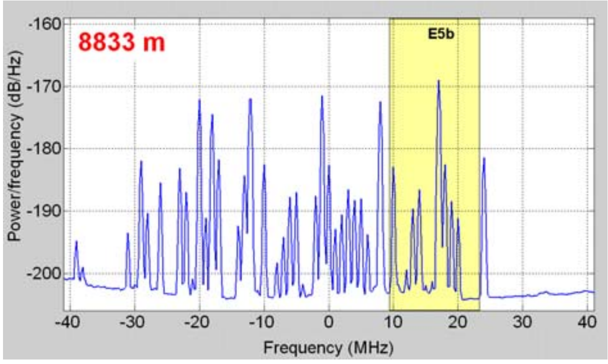

Figure 7: PSD of interference measured at FL 300

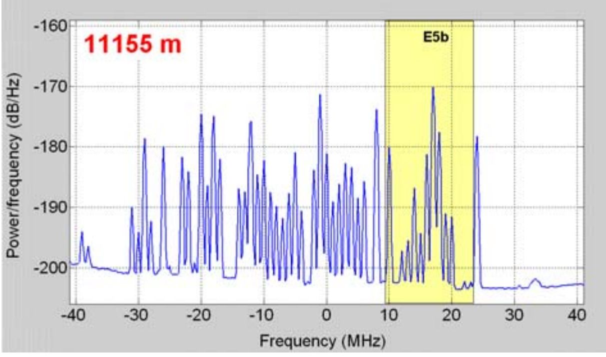

Figure 8: PSD of interference measured at FL 380

When comparing different data sets by inspection of the spectrum one has to have in mind that the interference signals are pulsed. This has a strong influence on the appearance of the spectrum: The signals energy is averaged and one might expect that all visible signals appear at the same time which is not necessarily the case.

Besides the DME/TACAN stations also other interferers are visible within the spectrum; one example is a radar which can be seen in 8833 m as well as in 11155 m height, marked by the red circle in Figure 9. Again, please have the non-stationary character of the signal in mind.

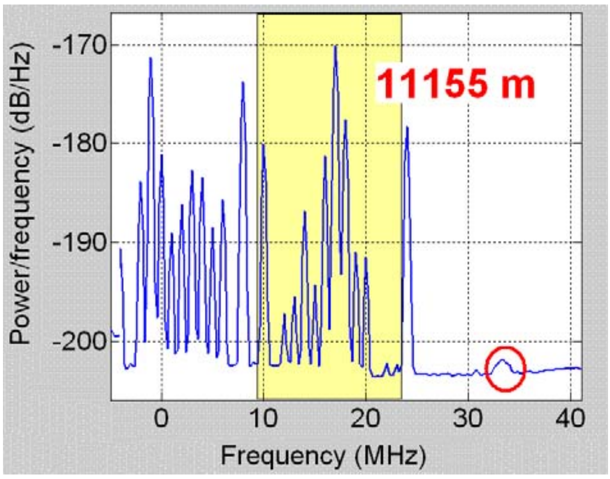

Figure 9: Radar at FL 380

RECEIVER AND MITIGATION TECHNIC

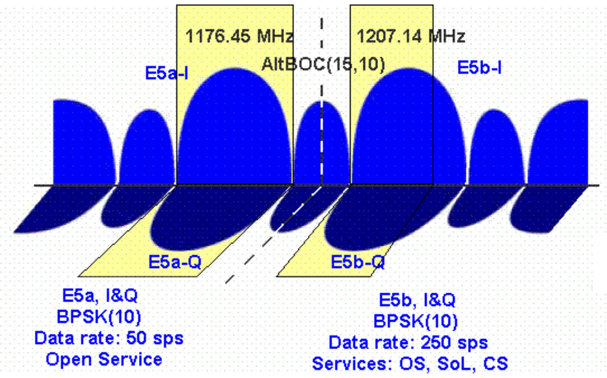

Figure 10: Main characteristics of Galileo E5 band

Due to the fact that still not enough real Galileo signals are available the receiver tests have been performed with the help of DLR's very powerful GNSS hardware simulator "MASTER" which is able to provide the Galileo signals of a whole constellation and thus enabling the receiver to navigate.

The navigation receiver developed in the ANASTASIA project is capable to receive Galileo L1 and E5a or E5b signals, which are all included in the allocated spectrum for Aeronautical Radio Navigation Services (ARNS). The main signal characteristics for the E5 band and the receiving filter bandwidth of the test receiver are depicted in Figure 10.

Figure 11: ANASTASIA Test receiver

The receiver (Figure 11) is consisting of the following units:

- RF-Unit: Here the RF signals coming from the antenna (or a simulator) are separated in the tree different bands with different bandwidth:
    - L1 (8MHz)
    - E5a (20 MHz)
    - E5b (14 MHz)
- The signal is also amplified and filtered in this module. Finally a down conversion to IF takes place here.
- Digital Processing Unit: The input signal is converted to digital domain and the tracking loops are implemented here. The interference mitigation techniques (IMT) are also allocated in this board.
- Receiver Control Unit: Here the Man-Machine-Interface (MMI) is implemented. The user can configure the receiver, e.g. chose frequency band and interference mitigation technique (IMT). This component is also in charge of the position and velocity resolution
- Preamplifier: When the receiver is not operating with an antenna but at a GNSS simulator a preamplifier is required.
- Antenna: The antenna which is designed to receive L1 and E5 consists of two components: The passive antenna and an LNA. For the flight trials the passive antenna has been used whereas the LNA has been substituted by another one.

Regarding the interference mitigation techniques for DME pulses, two of them have been implemented as described in [2]:
The first one, which is temporal blanking, replaces signal samples by zero when the input power exceeds a given threshold. The second one, FDAF (Frequency Domain Adaptive Filtering) with the block diagram given in Figure 12 computes a Fourier transform of the incoming signal on a predefined number of samples, by operating a Fast Fourier Transform (FFT) with a given number of bins, e.g. 64 bins. Each bin's energy is compared to a given threshold and suppressed if it exceeds it. All the bins are then converted back in time samples by an IFFT algorithm. The technique intervenes in the same place as the temporal blanker; the input of the algorithm is therefore a quantized and sampled signal. This technique is used during the simulations described within this paper.

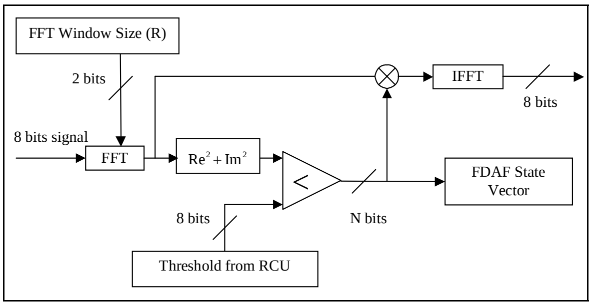

Figure 12: FDAF blanker principle

Note that since the incoming signal is, without disturbances, dominated by thermal noise, the FFT representation of the incoming signal should ideally be flat (white). This assumption allows the determination of a threshold that would represent the usual noise level, with a certain false alarm rate. If any points of the incoming signal's Fourier transform exceed this threshold, they are considered being corrupted by an interferer and set to zero.

The AGC (Automatic Gain Control) has been modified too to be insensitive to the presence of pulsed interference like DME and TACAN.

More details about the receiver can be found in [2] and [9].

SIMULATION HARDWARE SETUP

The general idea for the receiver test with interference in the laboratory is to overlay the (synthetic) GNSS signal with the recorded and replayed interference data like shown in Figure 13.

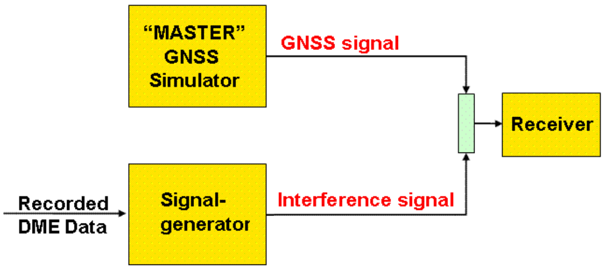

Figure 13: General idea for hardware simulation

A more detailed schematic overview of the system is given in Figure 14.

The core of MASTER consists of two modified GSS7790 multi-output full constellation simulators built by Spirent Communications Ltd. which provide besides GPS all Galileo (E1, E5, E6) satellite signals as digital baseband signals. MASTER is controlled by Spirent's SimGEN^{TM} SW running on a control PC. SimGEN^{TM} enables the user to define a simulation environment including parameters such as orbit parameters of the GNSS used, clock errors, iono- and tropospheric effects, antenna pattern, multipath and user trajectories. It is also used to define the satellite in view (SV) signal and its components as navigation data, pilot/data channel and modulation scheme according to the desired frequency band.

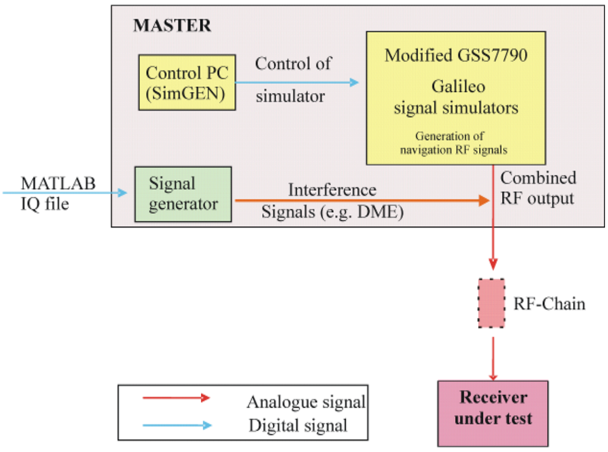

Figure 14: Schematic overview of test setup.

All signals are provided on a combined RF output of the simulator [3], [4] at a nominal power level of about -130 dBm with a dynamic range of ±20 dB. The GNSS signal is then going through a so called RF-chain. The RF –chain is used to get the appropriate C/N_0 while not using a higher GNSS signal level then given by the Galileo ICD.

Finally the GNSS signal is superposed with the interference signal which comes from the signal generator (an Agilent E8267D). The combined signal can be fed directly into the RF input port of a single antenna GNSS receiver.

ADJUSTMENT OF POWER AND NOISE LEVELS

Since the noise, the interferences and the signal powers are specified at the output port of an active antenna an RF chain has to be implemented to provide the same RF level and noise floor as the active antenna. For instance, in the MOPS procedures by EUROCAE a standard pre-amplifier with a worst-case noise figure of 4dB and a gain between 26.5 and 32.5 dB and cable losses of –3 to –13 dB are specified [5].

The equivalent noise temperature required for the test is determined by its components:

- Intersystem interference (GNSS noise) I_{GNSS} = -187.0 dBm/Hz (= k_B * T_{GNSS} => T_{GNSS} = 14.5K), where k_B=1.381*10^{-23} is the Boltzmann constant
- Sky noise: T_{sky} = 100K
- Noise figure F_{SPA} of a standard pre-amplifier ($T_{SPA} = (F_{SPA} - 1)*T_0$)
- Cable loss L_{cable} => $T_{\text{cable}} = (L_{cable} – 1) * T/ G_{\text{SPA}}$ where G_{SPA} is the gain of the standard pre-amplifier and T the physical temperature of the cable.

The total noise temperature to be simulated is then

$$T_{req} = T_{GNSS} + T_{sky} + T_{SPA} + T_{cable} \qquad (1)$$

The basic test configuration with RF chain is shown in Figure 15. We need then to configure the RF test chain between the simulator and the receiver in order to fit with the required performances of the standard chain. We use a first attenuator A_1 between the Signal Simulator (S) and the test preamplifier (PA) in order to tune the equivalent temperature of the total chain. We use a second attenuator A_2 after the test preamplifier (PA) to tune the gain of the overall RF test chain. This second attenuator has practically a negligible impact on the noise figure, because its influence is reduced by the gain of the preamplifier.

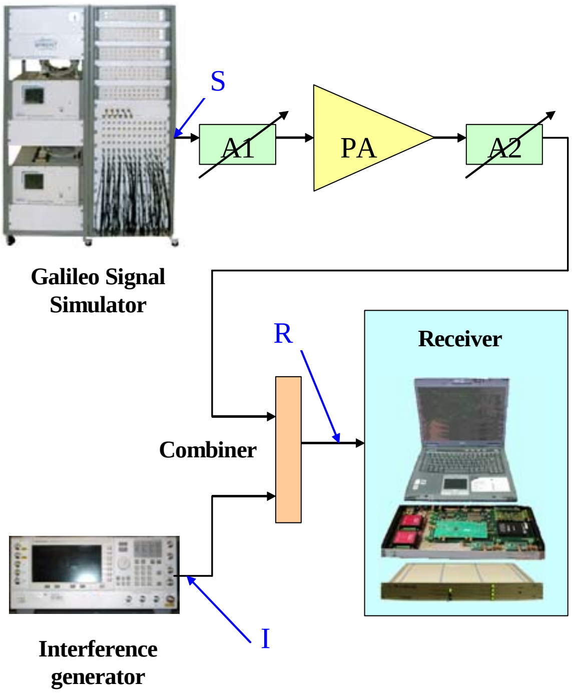

Figure 15: Setup with RF chain

The equivalent noise temperature in the reference plane of the Galileo simulator output (point S in Figure 15) is:

$$T_{noise} = T_{sim} + (A^*_1 - 1) \cdot T_0 + (F_{PA} - 1) \cdot T_0 \cdot A^*_1 + (A^*_2 - 1) \cdot T_0 \cdot A^*_1 G_{PA}^{-1} \qquad (2)$$

Where T_{sim} is the noise temperature of the Galileo simulator, A_1^* and A_2^* are the attenuations of the attenuators A_1 and A_2 including all cable losses and combiner loss, G_{PA} is the gain of the preamplifier, F_{PA} is the noise figure of the preamplifier and $T_0 \sim 290K$ is the physical temperature of the attenuators.

The parameters of the RF-chain must be set in such a way, that the simulated equivalent noise temperature T_{noise} is equal to the required total noise temperature T_{req} of (1) and that the total gain of the RF chain $G = G_{PA} - A^*_1 - A^*_2$ is equal to $G = G_{SPA} - L_{cable}$. With these two conditions the required values for A^*_1 and A^*_2 can be determined from (2). The settings of the attenuators A_1 and A_2 are then determined by subtraction of cable losses and combiner losses from the calculated values for A^*_1 and A^*_2.

The interference signals are generated by the programmable signal generator and integrated in the chain by a splitter just before the receiver input. The idea is to avoid any filtering of the interference signal by the test preamplifier. However, the power of the signal generator must be increased in order to take into account the gain of the RF-chain.

During the simulations the satellite power was set to the minimum Galileo E5 power of -122 dB. Taking into account 0.7 dB modulation loss [5] the corresponding power of the E5b component is -125.7 dBm. The settings of the attenuators A1 and A2 were set in such way, that the C/N_0 measured by the receiver was 40.5 dB. This value corresponds to the C/N_0 given in Annex D of [5]. The measured effective gain of the whole RF-chain was 13.5 dB. The calculated noise temperature at the antenna output (i.e. at point S in Figure 15) was 650K which corresponds to a noise power density of -170.5 dBm/Hz. This scenario is close to the worse case scenario in [5].

NOISE CORRECTION

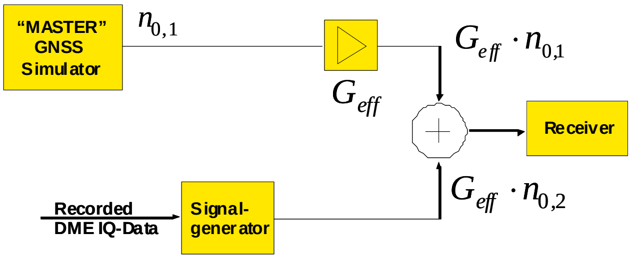

Figure 16: Simplified scheme for calculation of total noise of combined signal

Because the GNSS signal and interference signal are added the noise floor of the combined signal is increased by the noise coming form the interference branch. The power spectra in Figures 5 to 8 show that their noise floor is only a little below the calculated noise level of the GNSS signal of -200.5 dBW/Hz. Therefore, the C/N_0 degradation by the noise contribution of the replayed DME signals is not negligible. The power spectra show also that the noise floor is not equal for the measurements in the different heights due to different settings of the measurement equipment, i.e. the impact of this noise on the C/N_0 of the combined signal is different. Because we want to investigate the C/N_0 degradation only by the DMEs, the measured C/N_0 in the presence of interference has to corrected for the noise contribution of the replayed DME signals.

In order to calculate the C/N_0 degradation just by the noise coming from the interference generator we use the simplified scheme of the measurement setup shown in Figure 16. The noise power density $n_{0,1}$ at the GNSS simulator output corresponding to the equivalent noise temperature calculated in (2) is amplified by the effective gain of the whole RF chain. The power of the interference signal generator is adjusted so that the power of the DME signal is also amplified by G_{eff}. Thus, also the noise of the recorded DME signal $n_{0,2}$ is amplified by G_{eff}. The C/N_0 degradation in dB by $n_{0,2}$ compared to the case with $n_{0,1}$ only is then:

$$\Delta\frac{C}{N_0} = -10\log\left(\frac{n_{0,1}+n_{0,2}}{n_{0,1}}\right) \tag{3}$$

Table 2 shows the average noise levels in the E5b band of the DME measurements at different heights, which are extracted from Figures 6 to 9, and the resulting degradations $\Delta C/N_0$. When interference is switched on, these values have to be subtracted from C/N_0 values measured (estimated) by the receiver

Table 2 Noise level and C/N_0 degradation

Altitude	**Noise level**	**$\Delta C/N_0$**
1473 m FL (50)	-200.3 dBW/Hz	3.1 dB
4520 m FL(150)	-203.0 dBW/Hz	1.9 dB
8833 m (FL 300)	-203.8 dBW/Hz	1.7 dB
11155 m (FL 380)	-203.1 dBW/Hz	1.9 dB

It shall be underlined that the removing of the $\Delta C/N_0$ degradation was done offline after the measurement, i.e. the FDAF algorithm had to work with the uncorrected (higher) noise floor. Therefore the blanking was less efficient because the DME signals power in comparison with the noise power was lowered at the receiver entry.

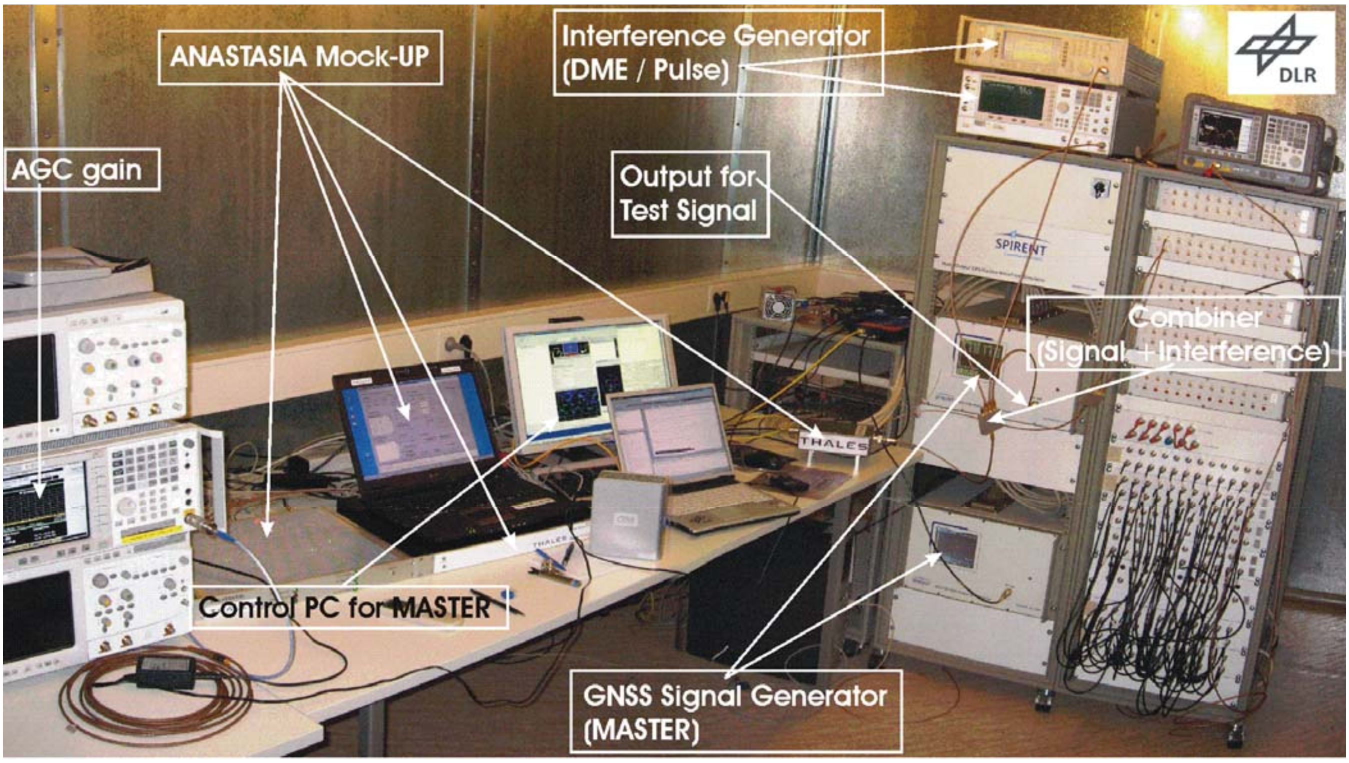

Figure 17: Test setup in laboratory

SIMULATION RESULTS

Figure 18 shows the simulation results. On the x-axis the altitudes corresponding to the flight levels at which the interference data has been collected are put on. On the y-axis the degradation of the C/N_0 due to the presence of the interference data is shown. The dashed curves present the case that no noise correction has been made: The blue ones are without any mitigation and the red ones are with FDAF. The solid curves are with noise correction calculated as described above.

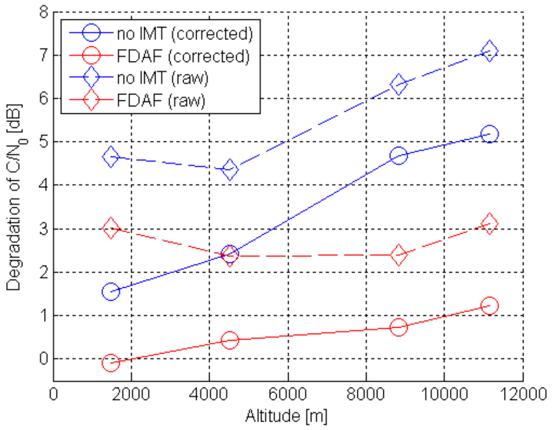

Figure 18: Degradation of C/N_0 by DME interference with and without noise correction

One can state clearly that the degradation of the C/N_0 with and without mitigation grows with the altitude. This is as expected because at higher altitudes the percentage of the spectrum which is affected by DME/TACAN is much higher. One can also state that FDAF is very effective for all altitudes. The more interference is present the larger is the reduction of the degradation: For example, in case of the corrected values one gets an enhancement of 1.65 dB for FL 50 whereas for FL 380 the enhancement is 3.95 dB. In case of the uncorrected values the enhancement due to FDAF is the same.

For comparison also simulations with synthetic DME data according to the DME test file specified in [5] have been performed. The observed C/N_0 degradations were much higher than the results obtained with the measured DME data: Without FDAF the degradation was 18.1 dB and with FDAF 5.3 dB. One reason for the higher values might be that in the synthetic DME data file all DMEs transmit with their highest possible pulse rate, which is not the case in the measured data.

The noise reduction causes a drop of the curves which of course depends on the data used for the investigation. The strongest effect is visible for the first test (FL 50, 1473 m). This is due to the special properties of that data set. As already stated above when presenting the data sets, the noise floor of this set is higher than the noise floor from the other sets. This is due to the special conditions when collecting these data: Much higher interference power values where expected and therefore the measurement equipment has been set to a lower sensitivity in order to protect it against over range which would have destroyed the whole measurement. The penalty has been the higher noise floor.

The corrected value with FDAF in Figure 18 at altitude 1473 m is already slightly negative. This is due to two possible reasons: First, the C/N_0 values and degradations are averaged values for all satellites in view. Second, the accuracy of reading the noise level from Figure 5 is limited. Therefore, the effect of how the noise floor has been determined was investigated. Two different methods have been used (compare Figure 19): The average noise level within the E5b band as listed in Table 2 (possibility 1) or the absolute minimum within this band (possibility 2).

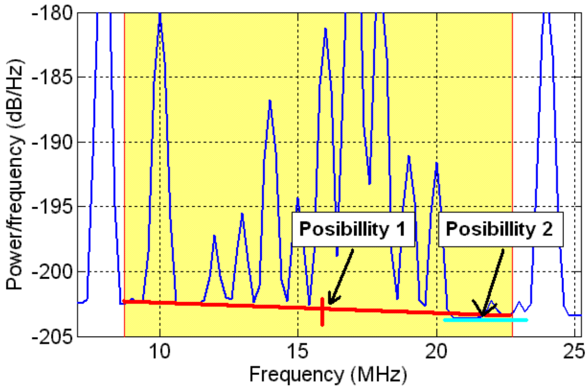

Figure 19: Determination of noise floor

Figure 20 shows the effect of the different noise floor determination: The curves of the C/N_0 degradation are slightly shifted. Note, fore the results presented above the average noise floor has been used.

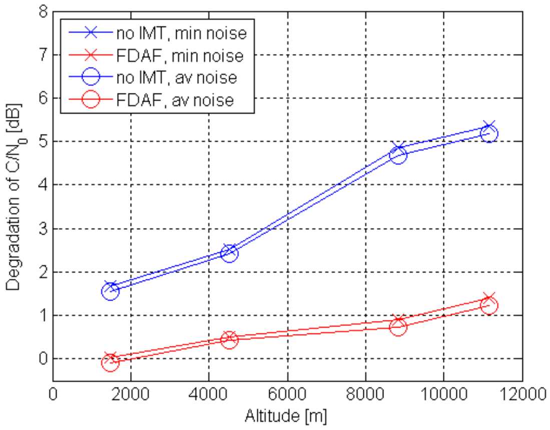

Figure 20: Effect of noise floor determination

The total degradation of the C/N_0 which remains when FDAF is used is for all cases (with noise reduction) below 1.3 dB. With other words a safety-of -life receiver will probably work well under these conditions when FDAF is implemented.

SUMMARY AND CONCLUSIONS

The interference data collection as well as the setup for the hardware simulation has been presented. This includes the description of how the replay of the interference data has been made. Then the used datasets for different flight levels have been presented and a comparison has been made. After presenting the receiver including its interference mitigation technique, the general hardware simulation setup has been detailed. It was shown that the noise floor in the recorded DME data has to be considered und should be corrected for.

Finally, the test results where presented: The C/N_0 degradation grows with the altitude because of the higher percentage of the signal spectrum affected by DME/TACAN. However, the simulation results show also that FDAF is able to reduce the degradation due to interference dramatically. Thus, safety of life receiver requirements can probably be met.

The C/N_0 degradation by the measured DME data used in this paper is significantly lower than simulation results with the synthetic DME test file which is specified in [5].

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