Concept for Interference Detection and Analysis on Navigation Satellites

S.Erker, S.Thölert, M.Meurer
German Aerospace Center, DLR

BIOGRAPHY

Stefan Erker received his diploma degree in Information Technology in 2007 from the Technical University of Kaiserslautern. He joined the Institute for Communications and Navigation at the German Aerospace Center (DLR) in September 2007. Now he works on the validation and signal analysis of satellite navigation systems.

Steffen Thoelert received his diploma degree in Electrical Engineering with fields of expertise in high-frequency engineering and communications at the University of Magdeburg in 2002. Since 2002 he is working at the German Aerospace Center (DLR). Currently he works on calibration and signal analysis in the field of satellite navigation systems.

Michael Meurer received the diploma in Electrical Engineering and the Ph.D. degree from the University of Kaiserslautern, Germany. After graduation, he joined the Research Group for Radio Communications at the TU Kaiserslautern, Germany, where he was involved in various projects in the field of communications and navigation. Since 2005 he has been an Associate Professor (PD) at the same university. Additionally, since 2006 Dr. Meurer is with the German Aerospace Centre (DLR), Institute for Communications and Navigation, where he is currently the director of the Department of Navigation.

INTRODUCTION

The modernization of existing satellite navigation systems like GPS, GLONASS and the construction of new systems such as Galileo or COMPASS raises the question for interoperability and interference between these navigation systems. In order to guarantee undisturbed operation with sufficient performance a detailed analysis of the Signals in Space (SIS) is necessary. Next to precise signal quality analysis the detection and characterisation of unwanted emissions by a single satellite is important. These emissions have to be divided into "in band" emissions, whose appearance of course could have a negative impact on the positioning solution for the observed navigation system but also for other coexisting systems using the same band and "out of band" emissions, which would interfer with adjacent services also located at the aeronautical radio navigation bands. These facts demand a detailed verification of the prescriptive limits to ensure unproblematic coexistence of all these services. The determination of the interference source and the classification of these sources during the measurements seem to be the main challenge. So it is necessary to separate interference created by the observed navigation satellite from external interference caused by other L band sources like radars, TV-stations, communication satellites.

Therefore a new method is proposed which uses a calibrated 30 meter high gain antenna for interference analysis of GNSS satellites. This 30 meter high gain antenna which was build up in early seventies at DLR Weilheim ground station for scientific deep space missions was adapted later on for GNSS signal analysis by the Institute of Communications and Navigation of the German Aerospace Center (DLR). In the course of the GIOVE B IOT campaign during spring 2008 a new receiving chain was designed and installed at this high gain antenna. An absolute calibration of the whole system was performed to achieve accurate measurement results. With the use of this instrument and a modified tracking procedure for the observed satellite a detailed separation of different interference types is possible. A performed absolute calibration of the complete measurement equipment also enables a good rating of each individual interferences and possible influences that may affect system interoperability of those satellites.

This paper describes the measurement facility and the used equipment, explains the proposed procedures for interference analyses and their classification in detail and the previous work which was necessary for this paper. At the end first results of these interference measurements are presented using different GNSS and L Band satellites.

MEASUREMENT FACILITY

In the early seventies DLR built up a 30 m dish for the HELIOS-A/B satellite mission at the DLR site Weilheim. This satellite missions were the first US/German interplanetary mission. Launched in 1974 (HELIOS 1, 10 December 1974 - 15 March 1986) and 1976 (HELIOS 2, 15 January 1976 - 8 January 1981), the two German built HELIOS probes approached the sun closer than the inner planet Mercury and closer than any space probe ever. Later the antenna was used to support other scientific space missions like e.g. Giotto, AMPTE and Equator-S as well as for various scientific experiments.

Figure 1: 30m High Gain Antenna at Weilheim

Starting in September 2005 the Institute of Communications and Navigation of the German Aerospace Center (DLR) established an independent monitoring station for the analysis of GNSS signals. The 30m High Gain antenna at Weilheim is the main core element of the DLR verification and analysis facility. This antenna is based on a shaped Cassegrain system with elevation over azimuth mount. It is characterised by a gain value of over 50dB in the L- band and a beamwidth around 0.5°. The absolute position accuracy of this antenna is 0.001° in each direction. The signals are directed from the parabolic main reflector to a hyperbolic sub-reflector with 4 meters in diameter. This sub reflector sends the signals via a waveguide and a second subreflector in a measurement cabin. Were the signals are received by a new developed broadband circular polarized feed.

One big benefit of this construction is the direct access to the installed feed in the cabin and the possibility to place the complete measurement equipment next to the feed and avoid the use of long connection cables.

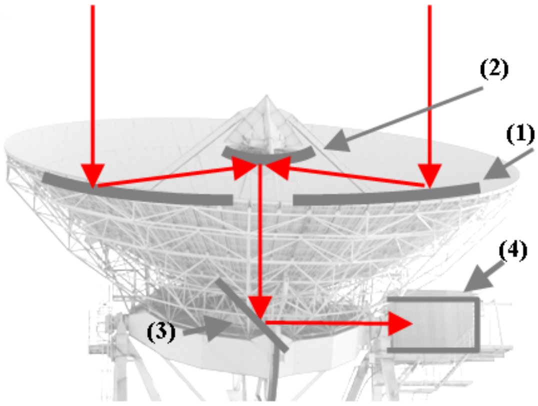

Figure 2 The shaped Cassegrain system:

(1) parabolic reflector of 30 m diameter
(2) hyperbolic sub-reflector with diameter of 4 meter
(3) sub-reflector
(4) Cabin with feeder and measurement equipment

During preparation for the GIOVE B IOT campaign in 2008 a new receiving chain including a new calibration system was installed at the antenna. The combination of this unique instrument with a novel designed online calibration system, a real-time vector signal analyser and signal evaluation facility allows very precise measurements.

The measurement system adapted to the 30 meter antenna includes two Low Noise Amplifiers with a total gain of almost 70dB. Several directional couplers are used for the injection of pilot signals. So it is possible to calibrate the receiving system during operation near real-time.

The setup also has several signal outputs for external equipment like bit grabbers or navigation receivers. By the use of this directional couplers the signal loss and interference by internal reflections is reduced. Another main item of the receiving system are the band pass filters dedicated to the individual Galileo navigation bands. The signals are recorded using a vector signal analyser with at least 80 MHz bandwidth. For signal recording of wideband signals the analyzer is used for down conversion of the signal. A digital oscilloscope connected to the analyzer is able to record with 300MHz signal bandwidth.

The measurement setup consists of two different main parts. The first part is dedicated for the receiving and acquiring of the satellite signals. The second part contains all calibration elements for remote and online calibration of the complete setup.

Due to the distance of the antenna location from the Institute at Oberpfaffenhofen (around 40km) it was necessary to perform all measurements and

calibrations procedures during a measurement campaign via remote control.
This is carried out by an own developed software tool, that is able to control any component of the setup remotely. In addition this software is able to perform a complete autonomous operation of the whole system by a free pre-definable sequence over any period of time.

More detailed information about the 30m antenna and the used measurement setup can be found at [1],[2].

CALIBRATION

The objectives of the DLR monitoring facility are highly accurate SIS measurements to characterise the observed GNSS satellites in detail. To achieve a combined absolute measurement uncertainty significantly less than 1.0 dB it is necessary to completely characterise all elements of the used measurement system and check long term stability of these characterisations. This includes beside all RF components of the receiving system also the high gain antenna itself. Several calibration measurements are performed to characterise the facility setup. A detailed measurement of the system gain and phase is performed using a network analyzer. This network analyser can be calibrated remotely using an electronic calibration kit and can be connected to the receiving system after calibration. Further complementary system calibrations were performed to verify the archived results.

One main part of the calibration is the precise knowledge of the antenna gain and antenna pointing accuracy. Using a 30m antenna these tasks require some effort. For the determination of the exact antenna gain in the used frequency range well known reference sources are needed. That could be natural sources like radio stars or artificial sources like geostationary satellites. For the gain calibration of the 30m antenna at Weilheim mainly Cassiopeia A was used. Cassiopeia A is one of the strongest radio emitters on the northern hemisphere. And well suited for this challenge. More information about the antenna gain calibration performed in Weilheim can be found at [1],[2].

For high accuracy of measurement results also high precision of the antenna pointing is required. To get the accurate pointing correction values a pilot signal of the ESA Artemis satellite was used. The pilot signal had a centre frequency of around 1557.1 MHz and a bandwidth of 10 kHz. The signal was captured with the spectrum analyser. The antenna misalignment was measured for azimuth and elevation direction. The results of these misalignment measurements yield in an offset. The obtained values will be inserted in the antenna steering program unit as fixed offsets, so that a correct pointing will be achieved for the measurement campaigns using the specific measurement setup. The measured elevation offset is between 0.02° and 0.03° for the azimuth direction. The antenna pointing measurements were performed periodical to check the antenna alignment and estimate the error contribution of the used two line elements to the antenna pointing accuracy.

The outputs of these pointing measurements deliver a part of the antenna pattern for azimuth and elevation for the 30m dish (see Figure 3 and Figure 4). This antenna diagram is used later in this paper as a basic key parameter for a sophisticated interference detection and separation.

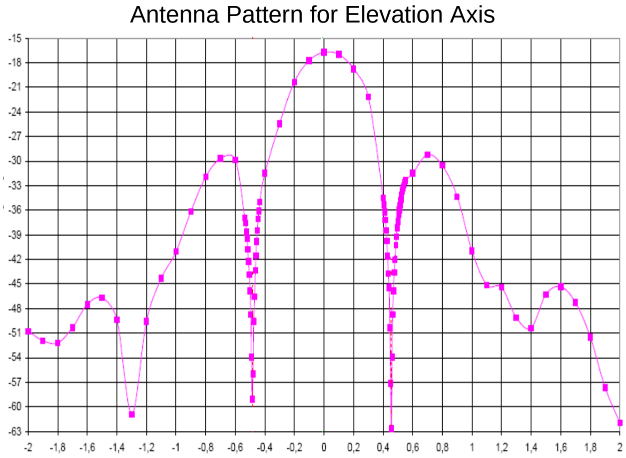

Figure 3 Antenna Pattern for Elevation Axis

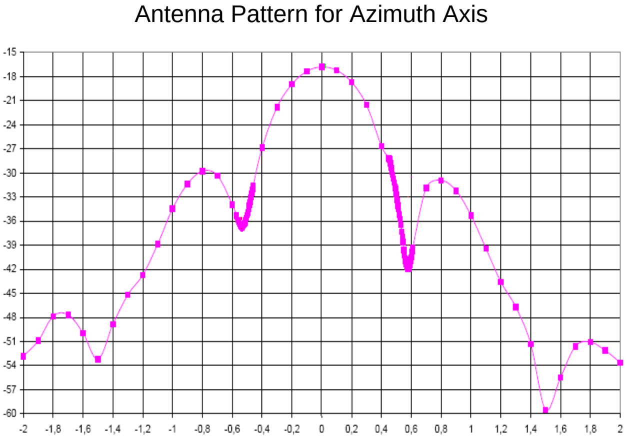

Figure 4 Antenna Pattern for Azimuth Axis

INTERFERECE CLASSIFICATION

The intention of the proposed method is the detailed detection and determination of radiated interference by L-Band satellites. A basic requirement for this task is the classification of different possible interference scenarios that could appear during our measurements. Below a short overview about the different interference classes which are used in this paper is given:

- Out-Of-Band Emissions
- In-Band Emissions
- Intra-System Interference
- Inter-System Interference
- External Interference

Out-Of-Band Emissions

Out-of-Band Emissions describe any type of unwanted and unspecified emission which is caused by the observed satellite outside the specified frequency band limits. These emissions could lead to Inter-System-Interference.

In-Band Emissions

In-Band Emissions names all unwanted and unspecified radiation inside the systems own specified frequency bands. They can cause Intra-System Interference as well as Inter-System Interference.

Intra-System Interference

Intra-System Interference can be caused by interference which is radiated by a single navigation satellite inside the own used signal bands and could therefore result in performance degradation of the satellite or other satellites of the navigation system which of course also operate in the same frequency band (In-Band Emissions).

Inter-System Interference

This type describes the impact of interference on other (GNSS or L Band) satellite systems. This can be caused either by Out-of-Band Emissions - if the interfered systems frequency band is adjacent to the system which is generating the interference - or also by In-Band Emissions – if the interfered system uses the same or a part of the interfering satellite frequency band (e.g. GPS / Galileo L1)

External Interference

This type of interference characterises nearly any other interference that is not radiated by a satellite. There are various sources. The strongest are mainly ground based interferer such as navaids like TARCAN and DME, TV and Mobile Stations or Radars. But also emissions of stars like the sun or the well known radio star Cassiopeia can cause observable influence on the measurements due to the use of a high gain antenna.

MEASUREMENT AND ANALYSIS METHODS

For the interference detection and correct allocation to the sources a combination of different measurement and analysis methods is used.

- Continuous Spectral Measurement
- Low Elevation Scan
- Antenna Offset Tracking

Continuous Spectral Measurement

For a basic determination of Interference during a satellite observation over several hours the recorded data is analysed in the observed frequency bands. The spectrum is displayed over the complete measurement time using a spectrogram. With the help of this presentation it is possible to assess the type of interference and its precise duration. This allows a first separation between other moving satellites that eventually cross the antenna beam during the measurement and external ground based sources that – depending on the actual elevation angle – are located in the near field of the antenna if detected at higher elevation values (see Figure 5 and Figure 6).

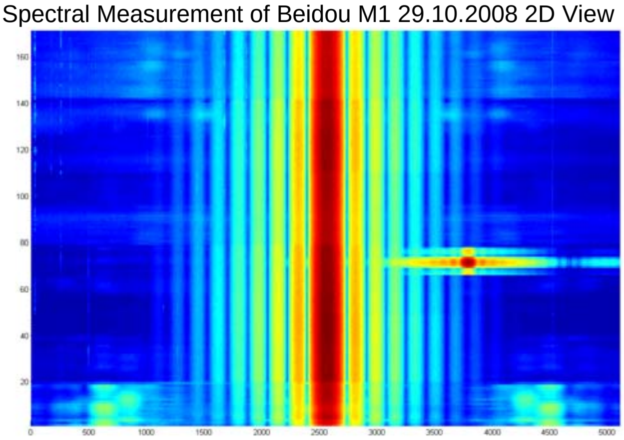

Figure 5 Continuous Spectral Measurement of Beidou M1 2D View with interfering satellite

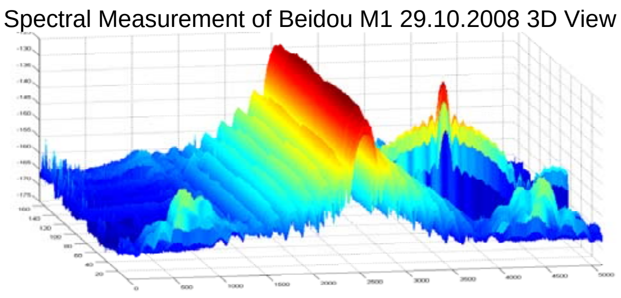

Figure 6 Continuous Spectral Measurement of Beidou M1 3D View with interfering satellite

Low Elevation Scan

At the beginning and end of each complete satellite pass several Low Elevation Scans are performed. The tracking limit of the antenna is set to 3° elevation angle. That means the antenna is moving only the azimuth value if the tracked object is below 3° elevation angle. Using this method it is possible to measure the influence of external ground based interferer. A measurement at low elevation is the worst case scenario for this kind of interference. With the use of this elevation tracking limit it is possible to identify these mainly fixed interfere during the rising of the satellite into the antenna beam or the descending of the satellite out of the antenna beam.

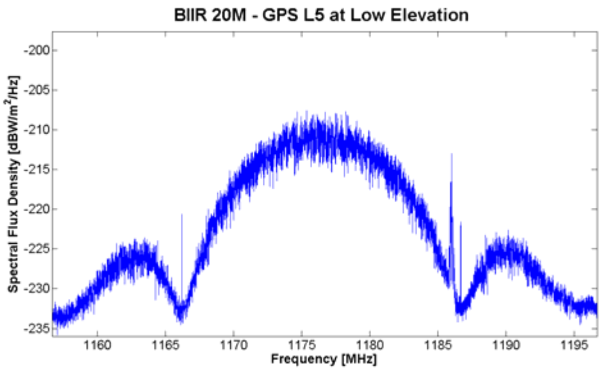

Figure 7 BIIR 20 M´s GPS L5 signal with interferer at low elevation

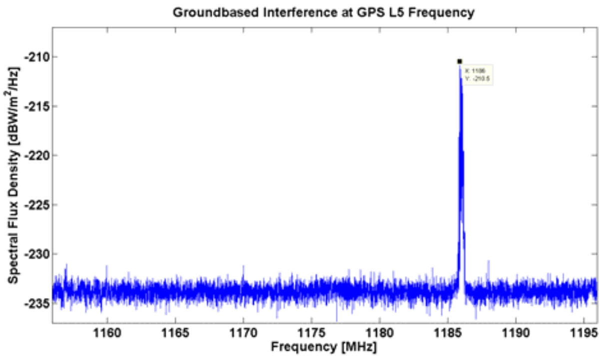

Figure 8 Ground base interferer at L5 band

In Figure 7 we see the new GPS L5 signal transmitted from BIIR 20M with a notable peak around 1186 MHz. This measurement is obtained at low elevation. In Figure 8 we see this interferer without the GPS L5 signal after the satellite disappeared under the horizon.

Antenna Offset Tracking

The Antenna Offset Tracking uses the precise knowledge of the high gain antenna pattern, which was measured during several calibration campaigns for different frequency ranges. With a modified antenna tracking which is adapted to individual pass of the observed satellite a similar effect as described for the low elevation scan is achieved. The antenna tracking performs a set of well defined azimuth and elevation offsets to the original satellite track (see Figure 9 and Figure 10).

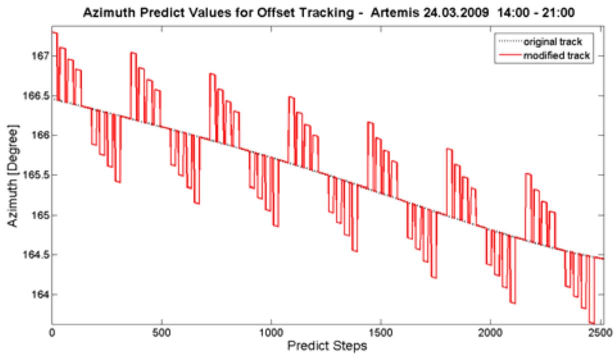

Figure 9 Example for Azimuth Offset Tracking Values

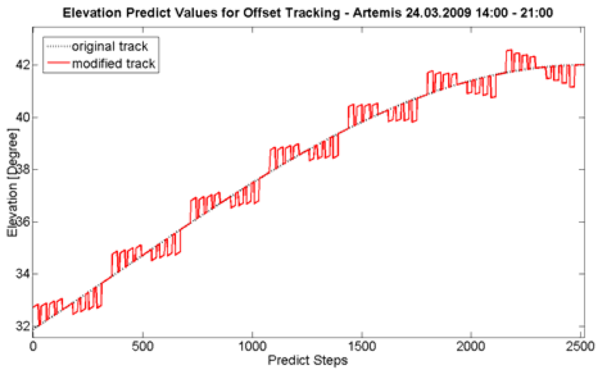

Figure 10 Example for Elevation Offset Tracking Values

These offsets result in a power reduction that directly depends on the selected offset value and the corresponding point of this offset at the antenna pattern. All interference signals which are radiated by the satellite vary with this pattern dependent power value. For this measurement we assume that the radiated interference shows a quite stable power level over time. Quite stable means that the fluctuation of the satellite observed interference is significantly smaller as the power variance caused by the antenna offset tracking.

Interference which is radiated by another L-Band satellite that is accidentally passing the antenna beam should be only visible for a short time and shows a different behaviour in the offset tracking power variance. Possible ground based interference is strongly dependent on the elevation angle. The power level of this kind of interference is much lower at high elevation values. So this issue can be excluded from the analysis by reviewing for example the corresponding spectrogram plot for the complete measurement.

The GIOVE CW EIRP measurements which are performed during the In-Orbit-Test of the GIOVE satellites and on re characterisation campaigns make the detection of In-Band Interference possible. For the L1 Offset Carrier CW two pilot signals located on the BOC(15,2.5) main lobe frequencies are transmitted by the satellite (see Figure 11).

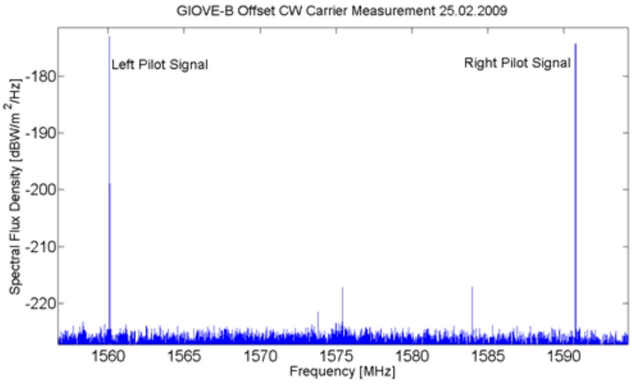

Figure 11 GIOVE-B Offset Carrier CW Measurement 25.02.2009

An Offset-Tracking was performed during this satellite pass. Figure 12 shows the power behaviour of both pilot signals during the Offset-Tracking. It can be seen that the pilots change with the same ratio at the different offset values. Using this technique interfering signals from the satellite can be detected. They should show a similar behaviour with respect to their power level.

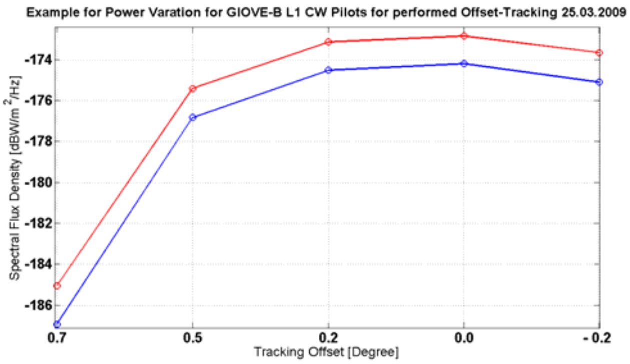

Figure 12 Power Variation of GIOVE Offset Carrier Pilots caused by Offset Tracking

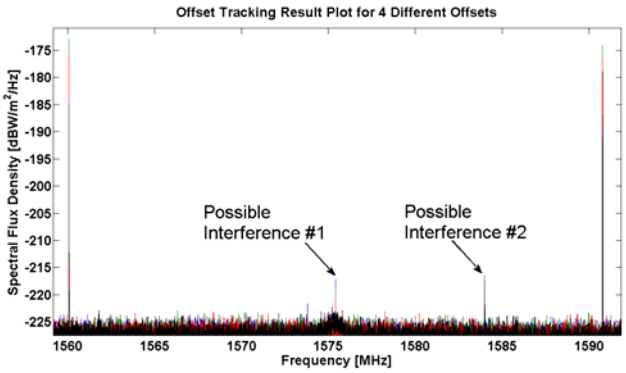

Figure 13 Offset Tracking result overview

Figure 13 presents the result of one Offset Tracking. Four different data sets with different offset values are compared. To possible In-Band interferer are marked in this overview spectrum. In Figure 14 the Left Pilot Peak is plotted for all offset values. The different power levels caused by the offset tracking are visible.

Figure 15 shows an detailed plot for the possible interference #1. In the Figure we see that the power level of this peak shows similar power behaviour as the pilot peak at Figure 14. So this peak could be an interference caused by the satellite itself. The peak frequency of this peak is identically to the Galileo L1 center frequency. So this peak seems to be an unsuppressed residual of the L1 carrier.

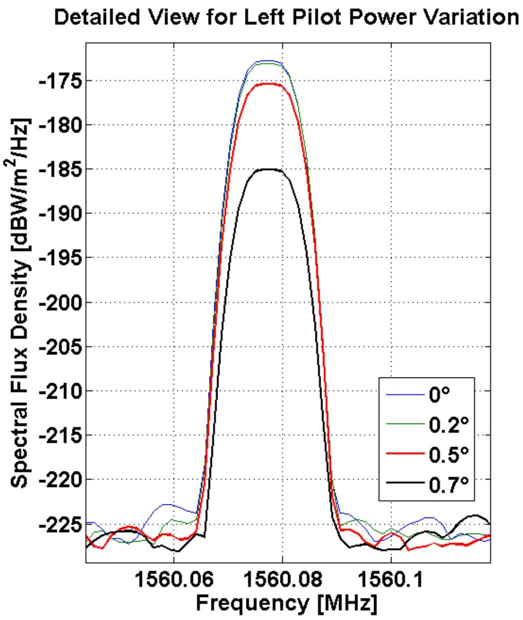

Figure 14 Offset Tracking Result for Left Pilot Peak

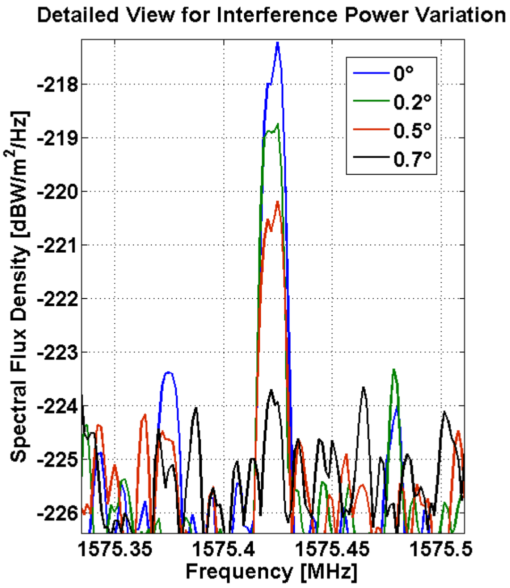

Figure 15 Possible interference #1 seems to be GIOVE-B L1 carrier residual

The second possible interference (see Figure 16) peak does not significantly change its power level during the offset tracking, so this interference seems to be not from GIOVE-B.

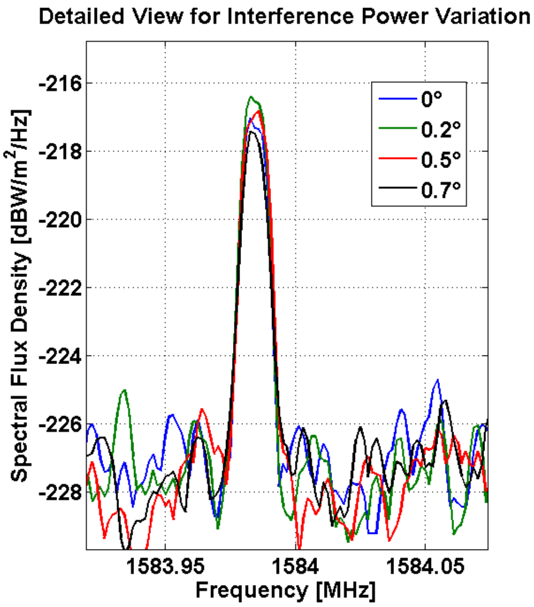

Figure 16 Possible interference #2 seems to be external interference

CONCLUSIONS

This paper gives a short overview of DLR GNSS monitoring facility and introduces three different methods for interference detection during Signal in Space measurements

The different methods enable a precise determination of the interference source which allows analysing possible interference radiated from navigation satellites. First results are shown in the end of this paper.

ACKNOWLEDGEMENTS

The authors look like to thank GSOC for using this great antenna and the colleagues at the DLR location near Weilheim for the operational and maintenance service.

REFERENCES

[1] S.Thölert, S.Erker, M.Cuntz, M.Meurer, U.Grunert, J.Furthner, *'GNSS Signal Verification: Spectral and Temporal Analysis of GIOVE B and BEIDOU Signals'*, NAVITEC-2008, Noordwijk

[2] S.Thölert, S.Erker, M.Meurer, *'GNSS Signal Verification with a High Gain Antenna - Calibration Strategies and High Quality Signal Assessment'*, ION-ITM-2009, Anaheim, California