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GNSS Interference Monitoring System GIMOS

Abstract

This paper describes the GNSS Interference Monitoring System GIMOS, which is operated by the German Air Navigation Services DFS Deutsche Flugsicherung GmbH. This system is used for spectrum measurements, which have to be performed at airports where GPS-based non-precision approach and departure procedures are introduced. Moreover DFS monitors the frequency bands of GPS-L1, GPS L2 as well as GLONASS-L1 to gain statistical information on the interference environment in these frequency bands.

GIMOS has been developed according to the specifications of DFS. It consists of a Digital Signal Processing (DSP) receiver, which determines the spectra of potential interference signals in the GNSS frequency bands by means of a Fast Fourier Transformation (FFT). These spectra are further evaluated to assess the impact on the satellite navigation signals that may be inflicted. Simultaneously a certified GPS receiver is used to look for an impact on the GPS signals. A personal computer is used to control both receivers as well as to store and to evaluate the data. The paper explains the concept of GIMOS and presents the results gained during two years of operation.

Furthermore, the paper briefly describes the concept of a general-purpose Airborne Interference Monitoring System (AIMOS).

The further goal of DFS is to develop AIMOS on the basis of the GIMOS hard- and software. AIMOS shall be used for airborne interference monitoring of GNSS, the GNSS Ground Based Augmentation System GBAS as well as ILS, VOR and DME.

Introduction

Together with the introduction of GPS-based Non-Precision approach procedures, DFS has formulated a requirement for the spectrum monitoring of the GPS L1 frequency band. It demands that a spectrum measurement has to be performed at the site of the commissioning of a new GPS non-precision approach procedure and that periodic inspections are required at this location in regular intervals. For this task GIMOS can be used as a mobile system installed in a van with an additional direction finding capability to locate possible interference sources. Within this activity, DFS anticipates requirements, which are in the definition process by the ICAO Testing of Radio-Navigation Aids Study Group (TRNSG, see ICAO Doc 8071, Ref. 1). Moreover, DFS monitors the frequency bands of GPS L2 (EGNOS will make use of it) as well as GLONASS-L1 to gain statistical information on the interference environment in these frequency bands.

Background

GPS and GLONASS satellites transmit signals that are modulated with pseudo noise codes and data that allows the determination of the satellite position. Within the GPS or GLONASS receiver, the satellite signal is multiplied with a self-generated replica of the pseudo noise code during the correlation process. In this way, the interference signal is converted into artificial noise. The accuracy of the pseudorange measurement and the Bit Error Rate of the transmitted data depend on the ratio of signal power and the sum of the power densities of thermal noise and artificial noise.

From the required pseudorange accuracy and the allowable Bit error rate, the maximum tolerable power of an interference signal can be derived. This was done by RTCA for GPS and GLONASS receivers to be applied in aviation (Ref. 5). The specifications of the so-called interference threshold masks (Fig. 1) were adopted by ICAO in the GNSS SARPs (Ref. 4).

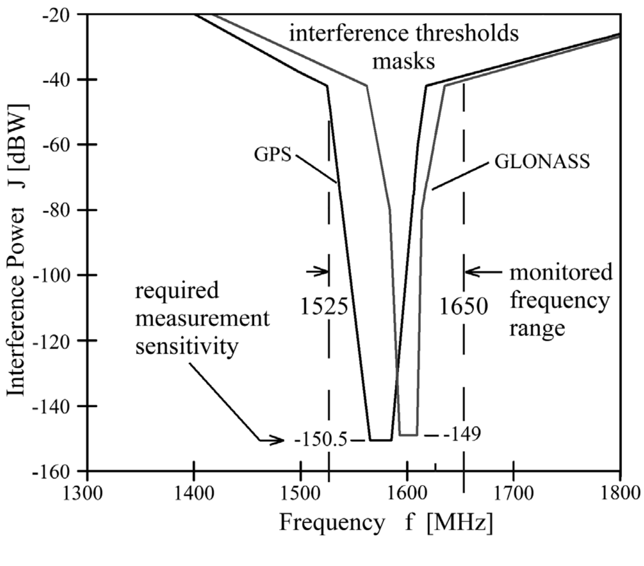

Fig. 1: Interference threshold masks for the GPS L1 and GLONASS L1 bands

The increased noise caused by interference signals is noticeable by a decrease of signal to noise density ratio (S/N_0), which is estimated and output by most GNSS receivers.

Furthermore the increased measurement noise can also cause the sum of squared residuals of the range measurements during position calculation to exceed a given threshold. This is checked by GNSS receivers used in aviation by means of Receiver Autonomous Integrity Monitoring (RAIM).

Basic Concept

The idea behind interference monitoring is, that signals within the frequency bands of GPS and GLONASS are received with an off-the-shelf GPS/GLONASS antenna and their signal properties are evaluated in regular time intervals, e.g. once per second (Ref. 2).

The goal is to assess the impact of occurring signals on the satellite navigation measurements. A DSP receiver is used for the reception and analysis of potential interference signals. It converts down the received signal, performs an analogue–to-digital conversion and calculates the power spectrum by means of a Fast Fourier Transformation.

Parallel to the monitoring of the spectrum, data provided by a GNSS receiver, like signal-to-noise density ratio, pseudoranges and RAIM-status are being monitored. Since to date there are only GPS-L1 receivers available that are certified for airborne applications, for the time being only such a receiver (TSO C129a compliant) is used.

For a first assessment of the potential impact, the measured spectra are compared with interference threshold masks specified by the GNSS SARPs for the frequency bands of GPS-L1, GLONASS-L1 (Fig. 1). Since GPS-L2 will be used by EGNOS, this frequency range will be monitored as well. For this purpose an interference threshold mask for GPS-L2 receivers to be applied by EGNOS, specified by ESA (Ref. 6, Fig. 9) is being applied. If at least one peak of the measured spectrum exceeds the mask, the spectrum is stored into a database together with a time stamp for later evaluation.

Furthermore, a warning is generated and the GPS raw data that has been stored during the some minutes before as well as raw data that are output by the receiver some minutes after this event is copied into the database.

Since, apart from spoofing signals, CW signals are most powerful interference signals; an interference threshold mask for CW signals is only suitable for a first assessment of the potential impact. This is due to the fact, that pulsed or broadband signals can have spectral lines which exceed the CW mask, but nevertheless be harmless. Therefore, the spectrum of every signal exceeding the mask is stored, permitting that the spectrum can be evaluated in more detail during post-processing by signal classification software (further details on post-processing in Ref. 2).

In the case of a signal exceeding the CW threshold, a snap shot of its time domain function (time snap shot) is stored. This enables the determination of the duty cycle and evaluation of the type of modulation during the post-processing of the data.

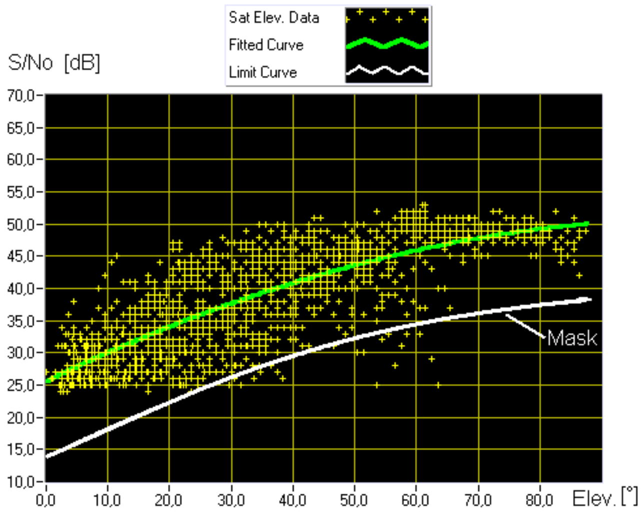

Fig. 2: Threshold mask for the signal to noise density ratio (S/N_0)

A RAIM alarm or an excess degradation of the S/N_0 also triggers the recording of the spectrum of a potential interference signal.

Since S/N_0 depends on the elevation of the received satellite it is difficult to find out whether an unusual degradation takes place. For this purpose the variation of the undisturbed S/N_0 as a function of the elevation is recorded and a polynomial is fitted through the data. This polynomial can be shifted downward by a specific value (e.g. 12 dB) to be used as a mask to detect whether the S/N_0 determined at a given elevation angle is unusually low or not (Fig. 2).

GIMOS equipment

GIMOS consists of a DSP receiver with a frequency range of 20 MHz to 3 GHz and a GPS L1 receiver (Fig. 3, Fig. 4 and Table 1). The DSP receiver can be connected by means of an antenna switch box to several different antennas. Therefore, GIMOS offers a capability, which is not restricted to GNSS applications only, but may also be applied in other frequency bands (e.g. GPS-L5, VHF and DME). In the default mode the DSP receiver is connected to a combined GPS L1/L2 & GLONASS L1 satellite navigation antenna with a built-in low noise amplifier (LNA). However, it can also be connected to a direction finding antenna. The gain of the LNA and the cable loss are calibrated to be able referenced the measured spectrum to the antenna port (input of the LNA). The use of an off-the-shelf satellite navigation antenna for interference monitoring has the following advantages:

- It has an almost isotropic characteristic in the upper hemisphere, in this way all signals from above the horizon are received.
- Since the interference thresholds for satellite navigation receivers are referenced with respect to the antenna port of

a satellite navigation antenna, it makes sense to compare a measured interference spectrum with the specified interference threshold.

- The same signals are analysed that are also received by a satellite navigation receiver.

An embedded PC (Fig. 3) with a data recording and evaluation software is used for initialisation of the DSP and the GPS receiver, for the generation of alarm messages and for the storage of the measured data into a database. Furthermore the software allows remote control of the system via a network connection. For the mobile use of GIMOS this is done by means of a notebook PC.

The graphic user interface (GUI) software is running on the external PC and allows the display of the spectrum, and the status information of the DSP and the GPS receiver. There are two modes for the control of the DSP receiver:

- In the default mode, pre-configured tasks for the various monitored frequency bands (GPSL1, GPS-L2, GLONASS-L1) are carried out. In this mode parameters like the frequency ranges to be analysed and resolution bandwidth are pre-selected. This allows an easy use of the system during regular measurements.

- The second mode allows a variation of all those parameters that can be selected at a standard spectrum analyser. This mode is to be used either to look for interference sources far apart from the centre frequency of for a precise analysis of an already detected interference signal

Furthermore it is possible to access data from the past measurements that has been stored into a database, located on harddisk and tape. An Uninterruptible Power Supply (UPS) is used to prevent any interruption of the measurements. Furthermore it provides power for about two hours during field measurements with a van. Since the necessary rechargeable batteries are very heavy (Table 1) the system can be used without them, if GIMOS is to be installed in an aircraft.

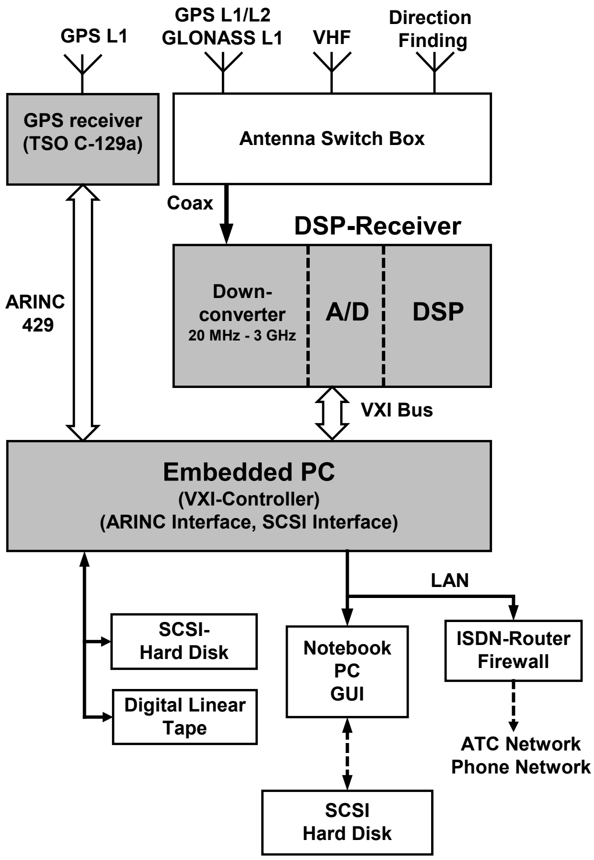

Fig. 3: Block diagram of GIMOS

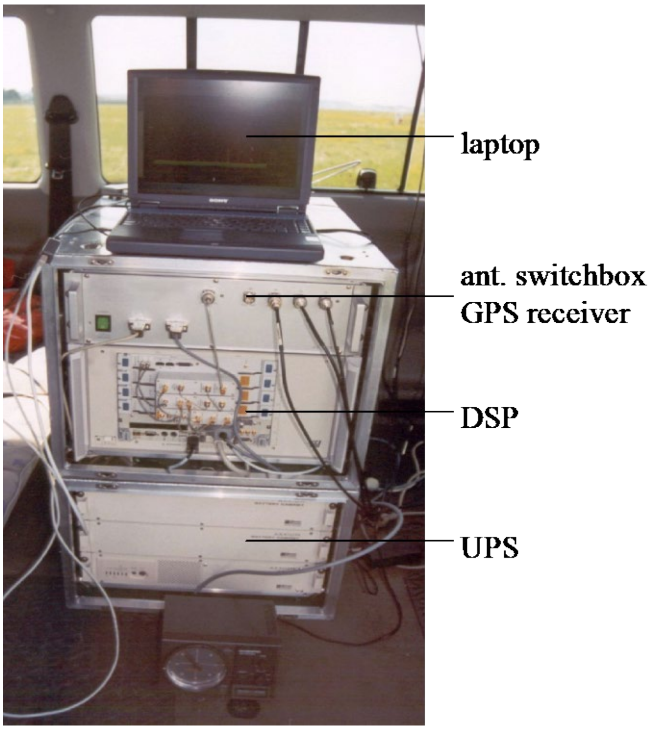

Fig. 4: GIMOS racks

Table 1 gives an overview over the most important properties of the selected DSP receiver and the physical specifications of the whole GIMOS.

Table 1: Specifications

General:	
Frequency range	20 MHz to 3 GHz
IF bandwidth	8 MHz
Gain of LNA	32 dB
Loss of antenna cable	10 dB
Gain of Intermediate amplifier	10 dB
Spectrum monitoring mode:	
Resolution bandwidth:	10.4 kHz
Measurement sensitivity (resol. bandwidth 10.4 kHz)	-154 dBW
Max. sweep rate: (resol. bandwidth 10.4 kHz)	2.8 GHz/s
Monitored frequency bands:	
GPS-L1:	1525 to 1625 MHz
GPS L2:	1175 to 1275 MHz
GLONASS L1:	1550 to 1650 MHz
Time snap shot mode:	
IF bandwidth	200 to 400 kHz
Duration of time snap shot	10 to 200 ms
Physical (whole GIMOS)	
Power consumption	540 W
Size with UPS batteries	19 inch x 14 height units
Size without UPS batteries	19 inch x 10 height units
Weight with UPS batteries	106.5 kg
Weight without UPS batteries	58.5 kg

The interference threshold masks in the ICAO GNSS SARPs specify the inference threshold as a function of the frequency for continuous wave (CW) interference. The GPS-L1 mask (Fig. 1) requires the highest sensitivity of all masks namely -150.5 dBW. Therefore, it is desirable to be able to detect at least interference signals with levels above -150.5 dBW. It turned out that this sensitivity is achievable with a preamplifier gain of approx. 32 dB and a resolution bandwidth of approx. 10 kHz.

Measurements Results

GIMOS is almost permanently installed at Frankfurt airport since two years. It was only removed on occasions, when a site survey had to be performed for commissioning or periodic inspections at other airports for GPS NPA or departure procedures.

To date experience had been gained by measurements at approx 20 different German airports. During this time it never occurred that GPS NPA procedures had to be cancelled.

Interference in the GPS-L1 band:

Occasionally the GPS-L1 interference mask was shortly exceeded by several dBs by some spikes. But such signals never had any impact on the performance of the GPS receiver and never occurred for a time interval of more than one second. During the last two years only one major interference incident occurred: On the 18th of Feb. 2002 a CW signal with a frequency of 1575.07 MHz and a power of -147.33 dBW was detected at Frankfurt airport. The spectrum of this signal exceeded the interference mask and therefore was recorded (Fig. 5).

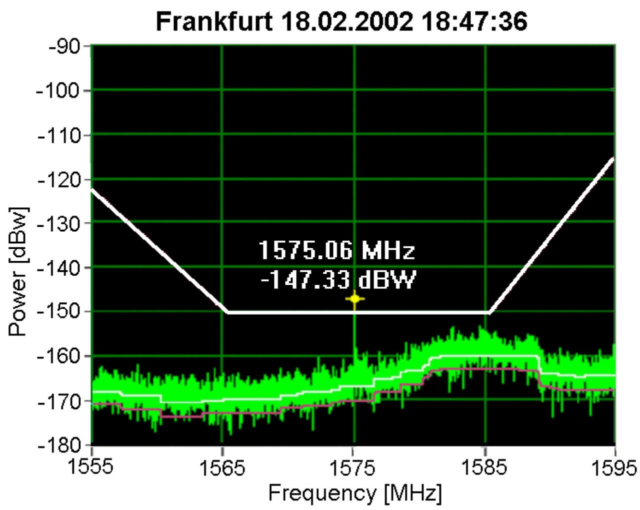

Fig. 5: Interference signal near GPS-L1

The signal caused a severe degradation of the S/N0 of all satellite signals received by the GPS receiver of GIMOS (Rockwell Collins GPS 4000A, see Fig. 6).

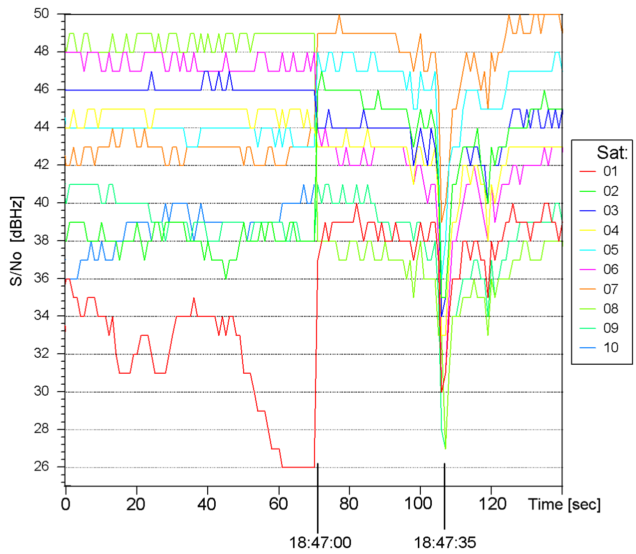

Fig. 6: Impact of interference on the S/N$_0$ of signals received by a Rockwell Collins GPS 4000A aviation receiver

Fortunately this TSO C129a compliant receiver did not lose track of satellites. Yet two other GPS receivers, namely an Ashtech GG-Sensor and Ashtech Z-Senor (both not TSO C129a compliant, and usually rather applied for surveying purposes) lost track of all satellites during the occurrence of the interference, which lasted less than one minute. This can be recognised in Fig. 7 as a reduction of the S/N0 until 0 dBHz.

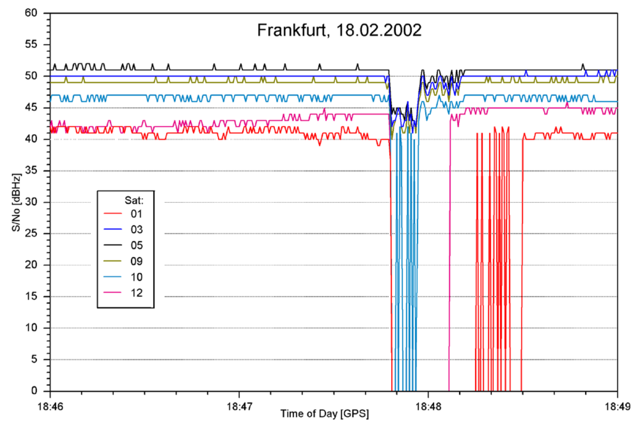

Fig. 7: S/N$_0$ degradation of signals received by an Ashtech Z-Sensor receiver in Frankfurt

To investigate, how big the coverage area of the interference source was, data provided by the differential GPS network SAPOS, which provides data for geodesy and surveying, was analysed. It turned out that in an area with a diameter of a least 150 km, geodetic GPS receivers lost track of satellites during the occurrence of the interference signal.

Fig. 8 shows a plot of the code-phase measurement of a GPS receiver, which was located in the German town of Kassel approx. 150 km north-east of Frankfurt.

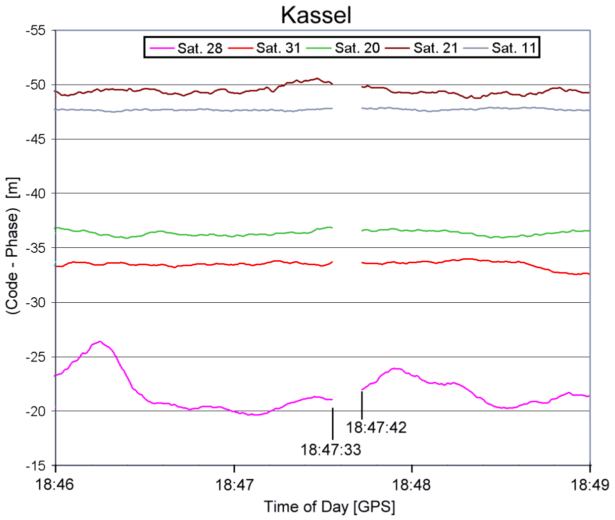

Fig. 8: Impact of interference on the (Code minus Phase) measurements

It can be seen that while the interference signal was detected in Frankfurt at this location the GPS receiver lost track of all satellites.

Interference in the GPS-L2 band:

Most of the electromagnetic interference to satellite navigation in Germany affect the GPS-L2 signal and are caused by emissions of Radio amateur stations. These stations are part of a European network of relay stations for the transmission of digital data (digital repeaters = Digipeaters). In Germany of approx. 250 Digipeaters operate between 1240 and 1250 MHz.

The Fig. 9 shows a typical spectrum of such a signal. It is possible to recognise two peaks between 1240 and 1241 MHz exceeding the interference threshold masks which has been specified for EGNOS receivers. Therefore the location where this measurement was taken would not be suitable for an EGNOS Ranging and Integrity Monitoring Station (RIMS). Such signals occur at a lot of locations throughout Germany and other European countries (e.g. Switzerland and the Netherlands).

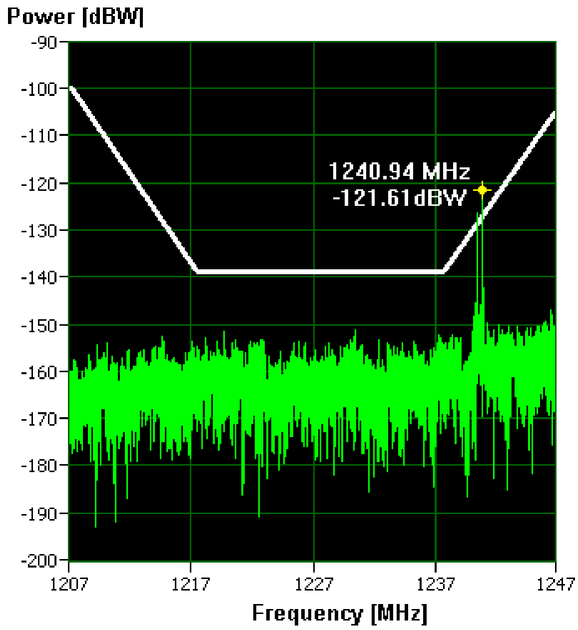

Fig. 9: Interference signal near GPS-L2

Apart from the depiction of single spectra the software of GIMOS allows the display of received power versus frequency and time (spectrogram). Fig. 10 shows a zoomed view of a spectrogram, which shows the signals of various Digipeater channels.

It is possible to recognise that two channels are permanently active (two continuous vertical lines), while two others are scarcely used (two dark dots each).

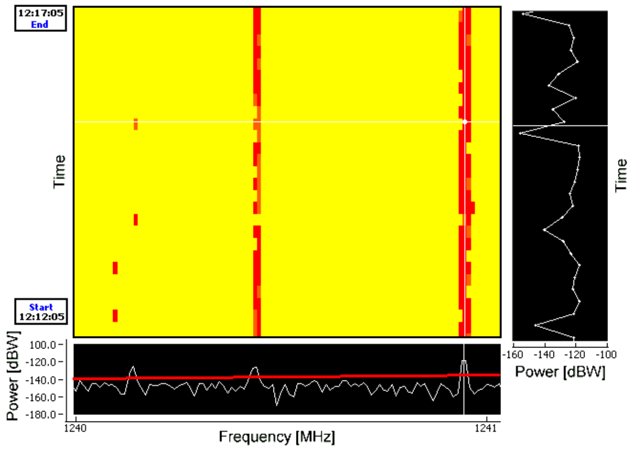

Fig. 10: Spectrogram view

Further Developments - AIMOS

The further goal of DFS is to develop AIMOS on the basis of the GIMOS hard- and software. AIMOS shall be used for airborne interference monitoring of GPS, the GPS Ground Based Augmentation System GBAS as well as ILS, VOR and DME. AIMOS shall be used in the future for the following systems:

- GPS-L1 (during flight inspection of GPS-based NPA procedures)
- VHF data link of the GPS Ground Based Augmentation System GBAS
- ILS Localizer and Glide path
- VOR
- DME

Unlike as in the case of GPS and GLONASS, the signals of terrestrial navigation systems are not buried in the noise floor. Therefore interference signals can be hidden behind the navigation signals. One possibility to overcome this problem is to switch off the desired signal during interference monitoring. But since it is desirable to minimize cost and effort, the goal is to find ways to perform interference monitoring with switched-on navigation signals nonetheless.

The basic concept for interference monitoring of the various systems is as follows:

GBAS data link:

Centre frequency range 108.025 to 117.950 MHz. Monitoring of the VHF frequency during unused time slots of the TDMA signal. Registration of the down converted and digitised time-domain signal with a bandwidth of 100 kHz.

ILS and VOR:

Centre frequency ranges for ILS localiser 108.1 to 111.95 MHz, for ILS glide path 329.15 to 335.0 MHz and for VOR, 108 to 117.95 MHz. Continuous registration of the down converted and digitised time-domain signal with a bandwidth of 100 kHz in the case of ILS and 300 kHz in the case of VOR. During flight, an FFT for a first assessment of interference environment is performed. An analysis of the registered data by means of a parameterised Digital Fourier Transformation (DFT) is carried out during post-processing. This special transformation allows analysis of the impact of interference signals and multipath reception (Ref. 7).

DME:

Centre frequency range 962 to 1213 MHz. Continuous registration of the down converted, rectified and digitised signal (video signal) with a bandwidth of 1 MHz. During post-processing correlation of potential interrogation and response signals to detect whether a signal is a valid DME signal or interference signal (Ref. 7).

Summary and outlook

A GNSS interference monitoring system (GIMOS) had been developed according to the specifications of DFS to fulfil the requirements laid down by ICAO. Since approx. two years it had been applied to perform interference monitoring in the frequency bands of GPS-L1, GPS-L2 and GLONASS-L1. It consists of a Digital Signal

Processing receiver, a GPS receiver and a personal computer.

It monitors the spectra of potential interference signals as well as the raw data provided by the GPS receiver.

This system is mainly used to gain long-term statistical information on the interference environment in the GNSS frequency bands at German airports.

Furthermore DFS demands that a spectrum measurement has to be performed at the site of the commissioning of new GPS non-precision approach and departure procedures and that periodic inspections are carried out at these locations in annual intervals.

Apart from one event, when in the area of Frankfurt for less than one minute occurred interference to GPS L1 by a signal with a frequency of 1575.07 MHz no severe interference was detected during the last two years that affected the GPS L1 signal. The source of the recent interference event in Frankfurt could not be yet determined. To determine the affected area, the use of data provided by a DGPS network proved to be useful. The coverage in this case had at least a diameter of 150 km.

The only interference that is determined almost regularly is interference to the GPS-L2 frequency band. It is mainly caused by so-called Digipeaters operated by radio amateurs. For aviation this fact is only relevant as far as the establishment of a Ranging and Integrity Monitoring Station (RIMS) for EGNOS could be hindered by such interference signals.

The further goal of DFS is to collaborated companies Flight Calibration Services (FCS), Skyguide and Austrocontrol to develop an Airborne Interference Monitoring System (AIMOS). AIMOS shall be used for airborne interference monitoring of GNSS, the GNSS Ground Based Augmentation System GBAS as well as ILS, VOR and DME.

Acknowledgements

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