Airborne measurements of DME interferers at the European hotspot

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BIOGRAPHY

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. His newest interference work is presented in this paper.

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.

Achim Hornbostel received his engineer diploma and Ph.D. in electrical engineering from the University of Hannover in 1989 and 1995. He joined the German Aerospace Centre (DLR) in 1989, where he became member of staff at the Institute of Communications and Navigation in 2000 and is leading a research group on 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. He is member of VDE/ITG and ION.

INTRODUCTION

It's no militarian secret that originally GPS was designed for military usage only. By the years this changed when its ability for civil navigational purposes became evident – and used. Especially in aeronautical applications it is a valuable system to improve the effective usage of the airspace and of air traffic safety. But although the accuracy has been improved a lot in the last decades in the aeronautical world there is still a remaining problem: The integrity of the system to put it simply is not good enough.

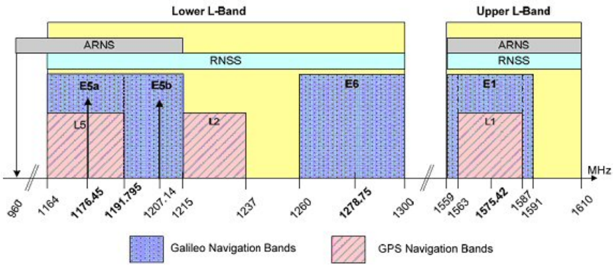

Figure 1 GALILEO frequency plan [3]

This gap is closed for non precision or CAT I like approaches by the usage of WAAS. Still the integrity limitations outlaws high precision approaches with low or without visibility. The GALILEO system wants to provide a solution for this problem by offering a "Safety of Life" (SoL) service which intends to alert the user within 6s of a faulty system status.

To realise this service the E5 Band (1164-1214MHz) has been issued. One strong argument for the usage of this band has been that it has already been awarded an ITU frequency protection for aeronautical applications. But in the past up to today this band has been used for the distance measuring equipment DME. A solution is needed to harmonize those two applications. Luckily DME is transmitting very short pulses (3.6µs). Unfortunately the transmission power reaches values up to 2 kW. Having in mind that a navigation satellite transmits 50W typically and taking further into account the difference in distance (an aircraft can be as close as 0.1km to the DME station but is about 24000 km away from the satellite) it becomes clear that a satellite signal reception is impossible while a DME station is transmitting its pulse.

To prevent the GALILEO receiver from being disturbed usually the "pulse blanking technique" is used. With this technique the receiver input is switched off when a pulse is detected. Due to the short pulse duration the decrease of the navigation accuracy is only small. But when the pulse rate increases because several DME stations are received simultaneously and during high traffic load the receiver is struggling with the satellite signal which is in this case interrupted often.

MOTIVATION

To push new receiver designs EUROCAE has developed a case of artificial DME interference at the assumed hot spot over Frankfurt (Germany) and incorporated this in its Minimum Operational Performance Standards (MOPS) [1]. The handicap of this artificial situation is the lack of measurement data for this scenario. It seems that a "worst case" scenario has been enrolled here. Neither the real power levels of DME interference caught by a skywards looking antenna nor the real number of pulses per second are exactly known. Although the range of DME to be received with a DME receiver is widely known its range of interfering a satellite navigation system is not known properly.

GALILEO FREQUENCY BANDS FOR AVIATION

Figure 1 shows the allocated frequency bands for Galileo and GPS. The Galileo SoL service is in the E5b and L1 band and the Open Service (OS) in the E5a and L1 band. E5a and L1 are shared with GPS L5 and L1. E5a, E5b and L1 are included in the allocated spectrum for Aeronautical Radio Navigation Services (ARNS) and allow safety-critical operations for civil aviation users.

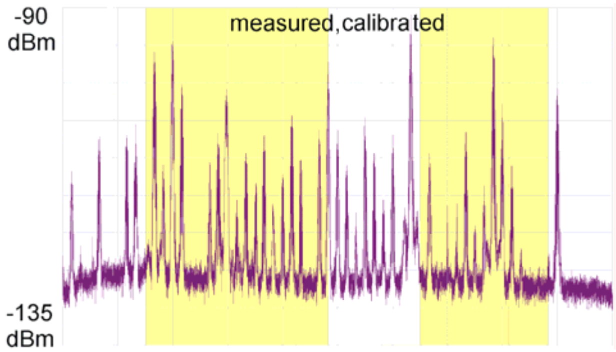

Figure 2 Measured DME spectrum; center frequency 1188 MHz, span 60 MHz.

Figure 2 shows a snapshot of the measured DME spectrum taken over RUDUS at flight level 380. The data are calibrated, i.e. they are corrected for the frequency dependent LNA and frontend gain of the measurement equipment. The Galileo E5a and E5b Bands including the recommended RF-filter bandwidths for a Galileo aviation receiver [1] are marked by the yellow boxes. DME interference is present in both bands.

DME Principles

DME navigation has been issued more than 50 years ago. The basic working principle is that an interrogator located in an aircraft is sending an interrogation signal down to earth. Depending on the DME mode, the DME ground station is responding on a frequency +63 or -63 MHZ from the interrogation frequency. The aircraft receives this pulse and can determine the distance from the delay between interrogation and reception where the DME station introduces a known delay between reception and transmission. The interrogation signal as well as the reply signal consists of two Gaussian pulses. The distance between the pulses is dependent on the mode of the DME. The bandwidth of each DME channel is 1 MHz. While airborne interrogators use usually 300W for transmission, the DME ground station responds with up to 2kW.

Figure 3 Typical DME station combined wit a VOR (Photo by Yaoleilei).

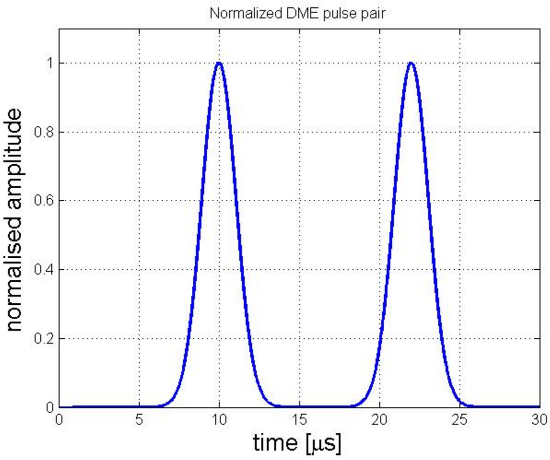

Figure 4 DME pulse pair in mode X.

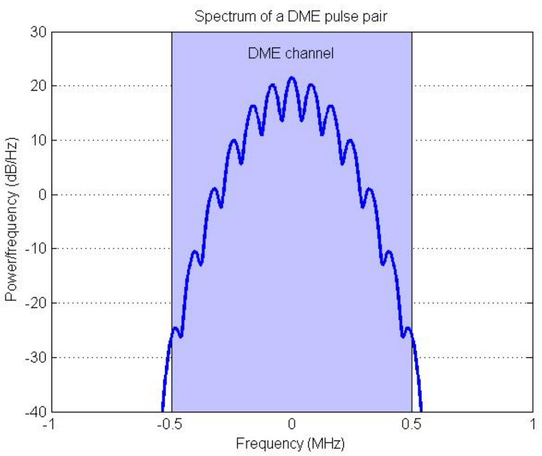

Figure 5 Spectrum of a DME pulse pair.

Beside the DME a military version of this principle exists: The TACAN system. From an interference point of view the difference is not large. It's mainly a variation in pulse rates.

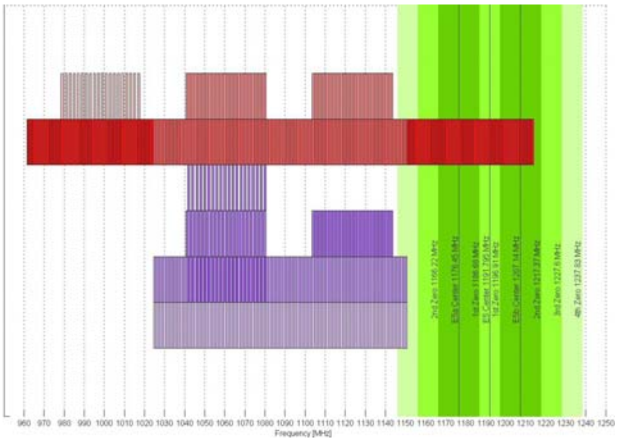

Figure 6 Spectrum allocation of the DME system: Red are reply frequencies, blue are interrogation frequencies. Dark green are the two GALILEO main lobes (E5a&E5b) and light green the sidelobes.

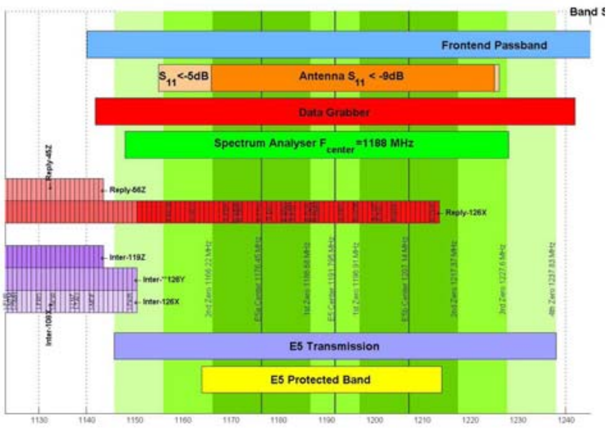

Figure 7 Detail of Figure 6: Frequency bands used by spectrum analyser, data grabber and GALILEO.

Antenna issues

Since a DME receiver in an aircraft is built to optimise the DME reception its antenna is pointing down to earth. In contrast to this situation a satellite navigation receiver is optimised to receive the satellite signal best. Therefore its antenna is pointing skywards. To simulate this situation our measurement antenna was mounted on top of the fuselage.

Figure 8 Combined L1, E1, E5 Antenna used for the measurements

The antenna pattern of our measurement antenna is widely open. If we assume an opening angle of 160° (see Figure 9) the antenna main lobe will not hit the horizon while the aircraft is flying en route. When the aircraft is turning usual bank (roll) angles reach values of 30-40°. Then the antenna main lobe hits the horizon and the likelihood for receiving a DME station by the main lobe is increased.

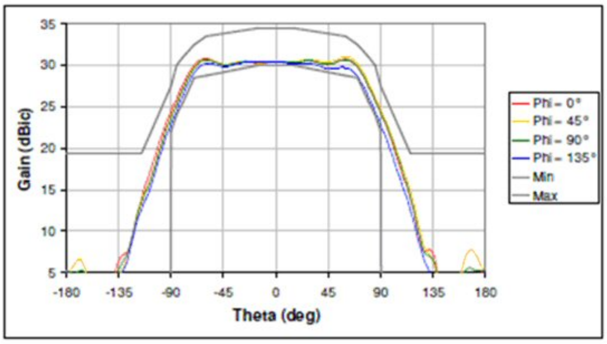

Figure 9 Pattern of the measurement antenna

To gain information about this behaviour we defined a special procedural manoeuvre (see Figure 10) to fly directly over the DME station and turn afterwards. While turning the antenna was always pointing towards the European DME hot spot.

The Measurement Campaign

The measurements were laid out in an area around Frankfurt (Main) in Germany. This area had been chosen since the European DME hot spot has been identified close to Frankfurt/M. . This hot spot matches quite well with the aeronautical navigation point RUDUS. It is located at 50.0477°N, 8.0783° E.

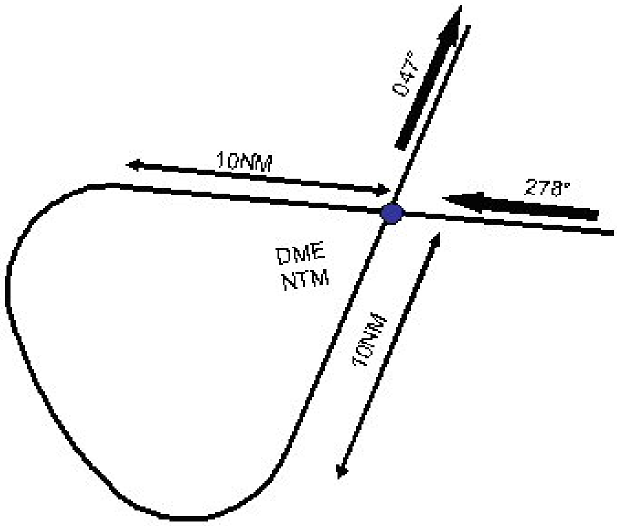

Figure 10 Procedural manoeuvre as an example at the DME station Nattenheim (NTM).

In the area around this hot spot are a number of aeronautical beacons. We defined a flight path which is crossing these stations (see
Figure 11).

Figure 11 Flight pattern used for the measurements in different altitudes.

It is widely known that the flight altitude influences the DME reception a lot. To gain most information out of this, we have flown through the defined pattern in different altitudes:

- FL 50 to record the situation for terminal traffic.
- FL 150 for turbo prop traffic.
- FL 300 for European traffic
- FL 390 for intercontinental traffic.

As receiving aircraft we used the DLR Falcon 20 E experimental jet. This aircraft is equipped with various modifications which allow an easy mounting of an experimental antenna on top of the fuselage.

Figure 12 DLRs experimental aircraft D-CMET

Main data of the aircraft:

- Falcon 20 E (D-CMET)
- Pressurised cabin
- max. Takeoff Mass 13 755 kg
- Max. Altitude FL 400
- max. Range 2000 Nm
- Endurance 5h
- Max. Speed 410 kts TAS

Measurement equipment:

To record the DME interference two different systems were used:

- An Agilent E4443A Spectrum analyser

This System was configured so that it recorded 150 ms every 30s to a PC. The recording bandwidth was set to 80 MHz the centre frequency was 1188MHz. In this configuration the spectrum analyser recorded band from 1148 to 1228 MHz covering the complete E5 band.

- Furthermore a data grabber was used to continuously record the signal.

This system was sampling the E5 band with 100 Msamples/s and at the same time the L1 and E1 band with 50Msamples/s.

Figure 13 Spectrum analyser rack: Rb clock, PC, spectrum analyser, power supply.

Since this data grabber recorded the signal continuously, the amount of recorded data is enormous. This system generates 300 Mbytes/s and transfers this data stream in real time on 32 hard disks. In this mode the system records 1 TB/hour. During the whole campaign 18 TB of data were recorded.

Figure 13 shows the rack carrying the spectrum analyser branch mounted in the aircraft.

Figure 14, Figure 15 and Figure 16 are showing the data grabber as well mounted in the aircraft.

Figure 14 HSR rack: RF Frontend, Highspeed Recorder PC, Data Storage (32 disks).

Figure 15 Operators rack: Power distribution box, Monitor drawer, PC start box, KVM switch, network switch, Operators PC.

Figure 16 Auxiliary Rack: Intercomm, Breakoutbox, ALC coltrol PC, Multi Input Recorder PC.

Additional experiments

Beside the measurements in different altitudes in the pattern additional experiments were performed:

- Low runway fly over

Since we figured out that there is a very strong altitude dependency and in addition the biggest change is from 0ft to 500 ft above ground we recorded a flight over the runway with a climb directly after. The so gained data shall support a low altitude propagation model.

- Low approach in Frankfurt (Main) & DME Fly over

One goal of the measurements is to determine the maximum power level that can hit a GNSS receiver. Therefore we performed a flight over the TACAN station FFM (50.053742°N, 8.637092°E) in an altitude of only 300 ft above ground.

- Rendezvous with an airliner

Another possibility to receive large power levels is by interrogation: We used a regular Airbus A340 which was flying only 1000ft above the receiving aircraft. The Airbus was tuned on the DME station Dinkelsbühl (DKB) on the channel 125X. This channel interrogates the ground station on 1149MHz. The DME station replies on 1212 MHz. In this special case both the interrogation signal as well as the reply signal are in the E5 transmission band. But in contrast to the usual situation where the sky looking GNSS antenna receives a signal from the ground – which is then attenuated by the antenna pattern in the rendezvous case the interrogating Airbus is transmitting with its earthwards looking DME antenna directly into the skywards looking GNSS antenna. The close distance of both aircrafts of only 1000ft had been chosen since this is the minimum IFR (Instrument Flight Rules) separation – this will lead to a very strong signal. This experiment was repeated with a Dash 8.

- Rendezvous with an air tanker

Luckily during the flight campaign there was a tanker of the Royal Air force in airborne operation. Even more: we were allowed to follow this tanker in an altitude distance of 2000ft. This experiment is interesting since these tankers are carrying their own DME station on board to allow other aircrafts to find it. Since this airborne station is much stronger than a regular DME equipment this might lead to an even higher interference level.

- DME self interference

Since DME antennas are mounted on the fuselage it is expected that a creeping wave is travelling from the DME antenna to the GNSS antenna. Due to improper transmitter filters it is expected that the GNSS antenna picks up the aircrafts own DME interrogation signal or its sidelobes. Therefore we performed measurements while the aircraft DME was interrogating DME ground stations

- Radar interference

During the flight we saw that frequency sweeping military radars were received by the measurement equipment. Furthermore the aircrafts owns secondary radar system was received although it is clearly out of band (1030 & 1090 MHz). Therefore recordings were done to determine power levels of this type of interference.

- Fast descend

Again to support the modelling of the altitude dependency of the DME interference we performed a fast descent from FL 390 to FL 50 within 10 minutes reaching descent rates of more than 7000ft/min.

First measurement results:

Although the measurements did end in March 2009 it is a quite early stage to publish results. But we wanted to use the opportunity to show first plots of the data to give an impression of the airborne interference situation. Please note that due to a pre amplifier from all power levels 45 dB have to be subtracted in all figures. All spectrograms are covering the frequency range from 1148 to 1228 MHz on the x-axis. The displayed time span on the y-axis is 10 ms. All measurements have been taken over the European DME hotspot RUDUS during different flights at different days.

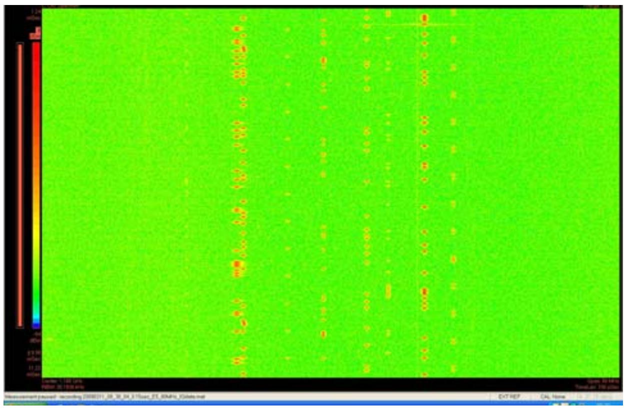

Figure 17 Spectrogram of the DME signals in Flightlevel 50

Figure 17 shows the reception situation at flight level 50 over the European DME hot spot. Please note that due to a FFT length of 100µs every “spot” on the plot represents a double Gaussian pulse of the DME. Knowing the frequencies of the DME stations in the measurement area they can easily be identified:

From left to right in Figure 17:

- **Ramstein** Channel 81X, 1168 MHz reply, Sign: RMS
- **Wiesbaden** Channel 88X, 1175 MHz reply, Sign: WIB
- **Frankfurt** Channel 89 X, 1176 MHz reply, Sign: FFM
- **Zweibrücken** Channel 95X, 1182 MHz reply, Sign: ZWN
- **Nattenheim** Channel 100X, 1187 MHz reply, Sign: NTM
- **Frankfurt** Channel 106X, 1193 MHz reply, Sign: FRD
- **Nörvenich** Channel 109X, 1196 MHz reply, Sign: NOR
- **Taunus** Channel 114X, reply 1201 MHz, Sign: TAU
- **Buchel** Channel 118X, 1205 MHz reply, Sign: BUE

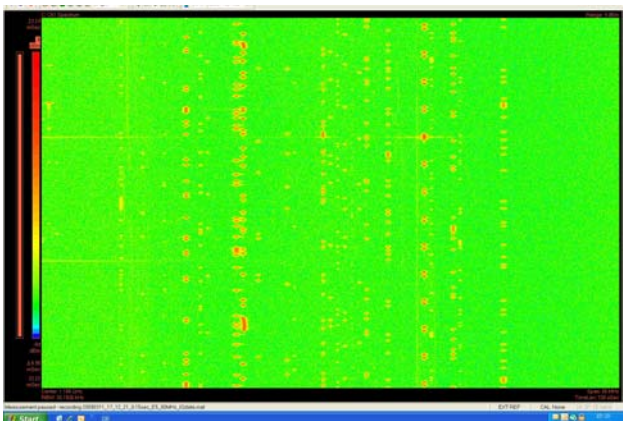

Figure 18 Spectrogram of the DME signals in Flightlevel 150

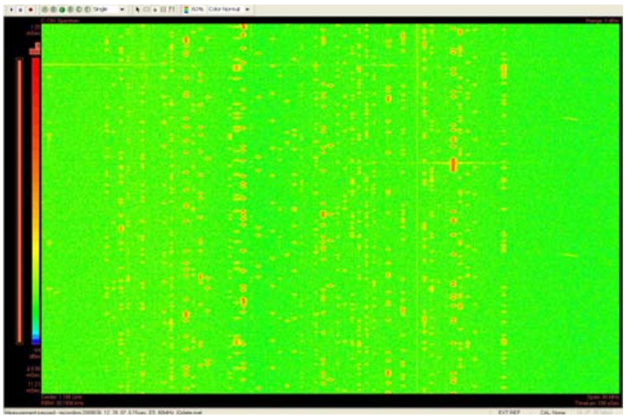

Figure 19 Spectrogram of the DME signals in Flightlevel 300

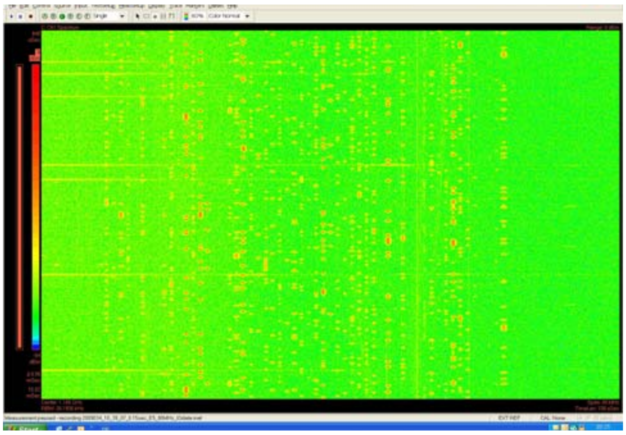

Figure 20 Spectrogram of the DME signals in Flightlevel 390

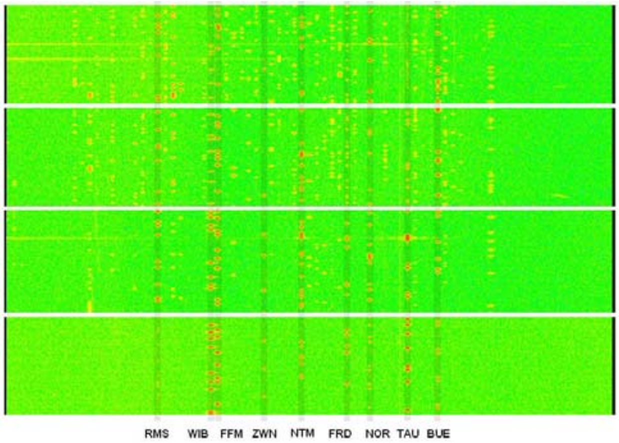

Figure 21 Comparison of the spectrograms in different flight levels. From top to bottom: FL 390, FL 300, FL 150, FL 50

Increasing the flight altitude on a second flight to FL 150 (see Figure 18) is dramatically increasing the number of visible stations. This trend is pursued at FL 300 (see Figure 19) and finally FL 390 (see Figure 20).

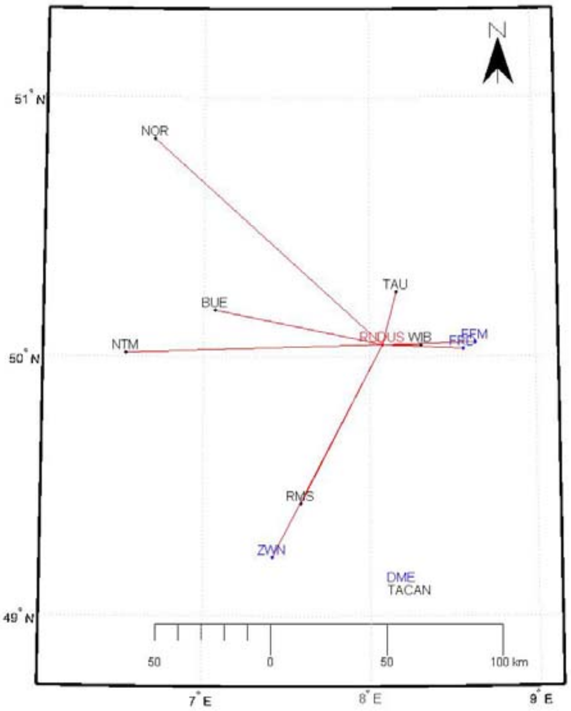

Figure 22 Locations of the received DME stations in Flightlevel 50

Figure 21 shows the direct comparison of the different flight altitudes. It can be seen that the number of visible stations is increased with the altitude in general. Interestingly for some stations the trend is the opposite: The DME stations Taunus (TAU) and Wiesbaden (WIB) are showing much lower power levels for high flight levels than for lower flight levels. Figure 22 shows the location of the DME station received in FL 50. It can be seen that the stations WIB and TAU are the nearest stations to the hot spot. We explain the disappearing of these two stations by a combination of two effects:

1. The transmission antenna of the DME station is a vertical mounted dipole. This antenna type has a zero in the zenith.
2. By increasing the altitude the elevation of the station is increased. In this case the skyward mounted GNSS antenna is more and more shadowed by the airplane itself.

Next Steps:

We will further analyse the data to derive more information on:

- Radio horizon.
- Maximum and average pulse rates.
- Maximum and average pulse power.
- Interference range of DME stations.

The general goal of this activity is to derive a DME interference model.

Summary

In March 2009 the German aerospace centre (DLR) has measured DME interference over the European DME hot spot in various altitudes. The aim of these measurements was to determine the interference situation in the GALILEO E5 and GPS L5 bands caused by distance measuring equipment (DME) stations on the ground.
First results at the hot spot show a strong reception in low altitudes of a small number of stations. By increasing the altitude the number of visible stations is increased dramatically. The general power level hence is reduced.

The general goal of this activity is to derive a DME interference model.

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