Analysis of DME/TACAN Interference in the Lower L-Band

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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.

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.

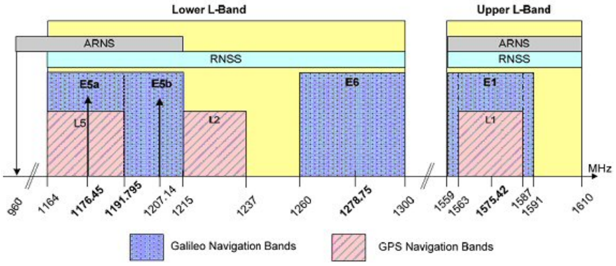

Figure 1 GALILEO frequency plan [3]

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.

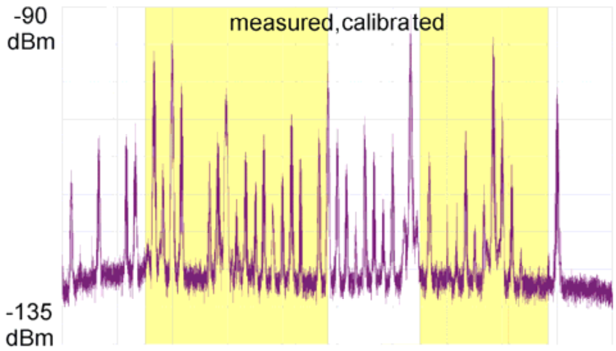

Figure 2 Measured DME spectrum; center frequency 1188 MHz, span 60 MHz.

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 with a VOR (Photo by Yaoleilei).

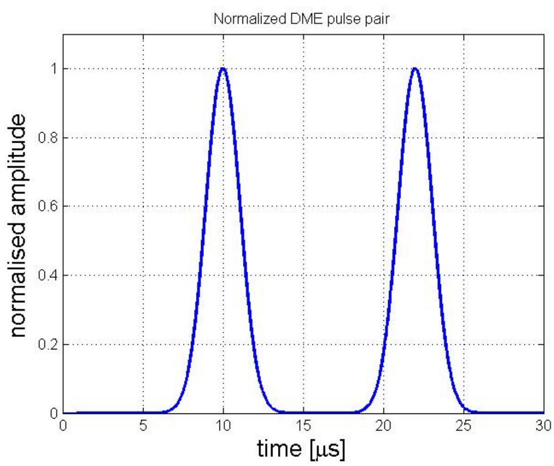

Figure 4 DME pulse pair in mode X.

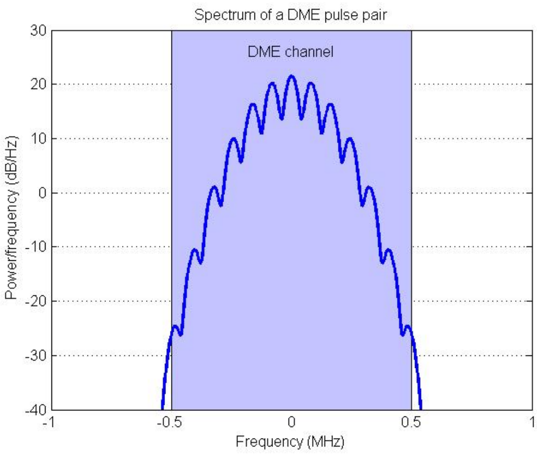

Figure 5 Spectrum of a DME pulse pair.

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.

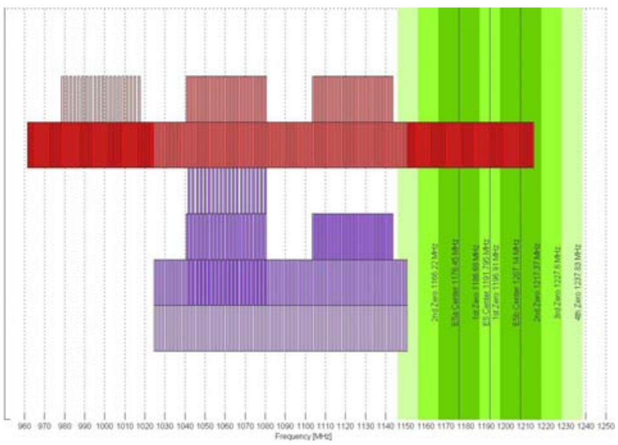

Figure 6 Spectrum allocation of the DME system: Red are reply frequencies, blue are interrogation frequencies. Dark green are the two GALILEO main lobes (E5a&E5b) and light green the sidelobes.

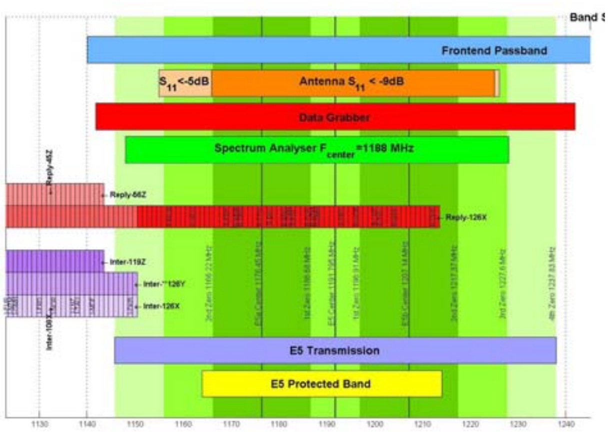

Figure 7 Detail of Figure 6: Frequency bands used by spectrum analyser, data grabber and GALILEO.

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.

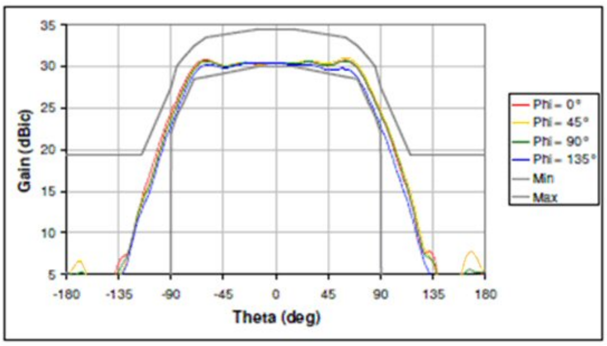

Figure 9 Pattern of the measurement antenna

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.

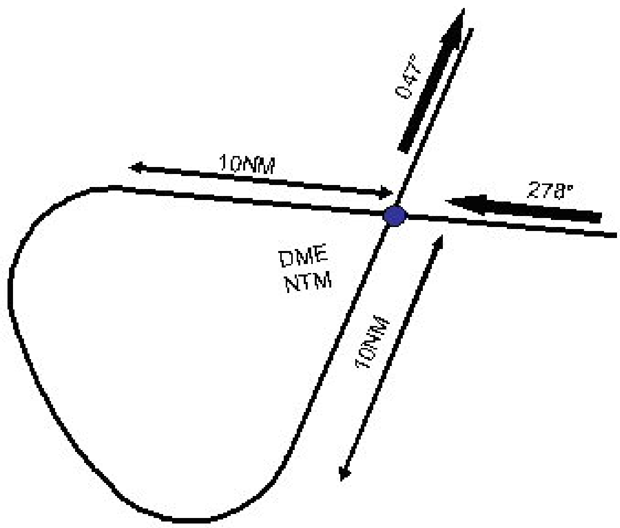

Figure 10 Procedural manoeuvre as an example at the DME station Nattenheim (NTM).

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.

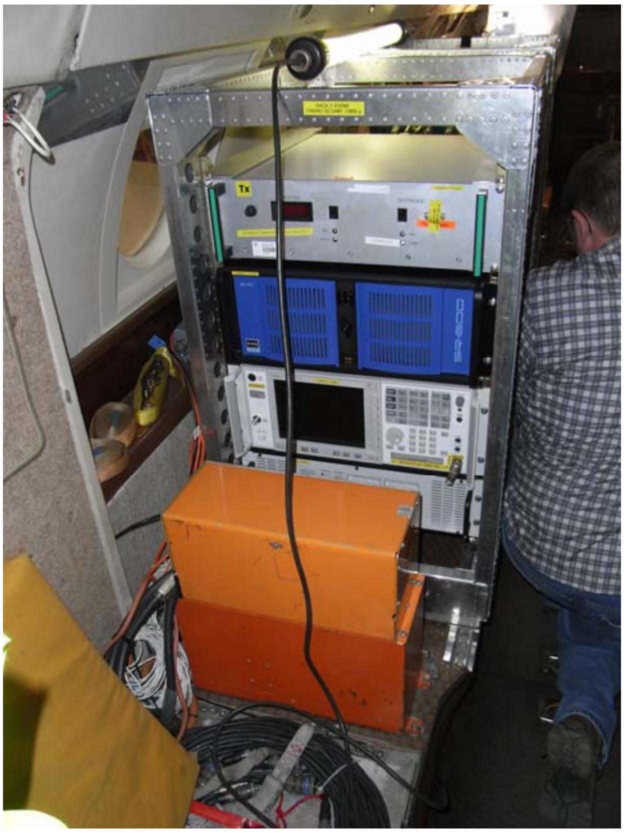

Figure 13 Spectrum analyser rack: Rb clock, PC, spectrum analyser, power supply.

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 control PC, Multi Input Recorder PC.

Data processing

Step 1: Frequency band separation

In this step the 100 MHz wide signal was split into 100 signals on 100 frequency bands. To do this the wide band signal was frequency shifted by a complex sine multiplication so that the desired centre frequency of the channel was moved to the baseband zero frequency. The stations band was extracted by a two stage low pass filter process.

Step 2: Noise level determination

Prior to detect pulses one must define a detection limit which must be violated when a pulse is assumed. Therefore the channels recorded from 1214 – 1240 MHz have been evaluated. These channels are not used by DME stations. So it is assumed that the signal found on these channels is equivalent to the DME channels if no station is present. First results on data processing showed that other pulse noise is present here. The most prominent example for this is the presence of primary radars.
To define the noise level the highest 10% of the noise samples have been removed and the mean of the remaining samples has then been taken as the channels noise figure. The average noise level was calculated as the median of the channels noise figures.
The detection level has been set to two times the average noise level.

Step 3: Matched filtering

In the next step the signal has been passed through a matched filter for noise suppression. It should be mentioned that the definitions in [4] for DME pulses allows a huge variation. As an example the 50% pulse width can be 3.5-4.5µs. The pulse attack and decay are defined independently. A verification of the data has proofed that these variations do occur in the reality. As a best possible approach an average has been used for the matched filer: For the impulse response a Gaussian pulse with 4µs (50% level) has been used.

Step 3: Determination of pulses

Every sample that is above the detection level is assumed as a potential pulse. A search algorithm found the local maximum it more than one sample was involved in a pulse candidate. For every pulse its energy, position and frequency offset has been estimated.

Step 5: TACAN burst detection

In order to allow the determination of the radial TACAN stations are transmitting main and auxiliary burst sequences. These sequences can be detected by their unique pattern an are removed from the pulse list.

Step 4: Determination of twin pulses.

It proofed as a very good screening tool to filter for the pulse distance: pulses that occur with no other pulse at 12µs (Mode X), 30µs or 36µs (Mode Y) are assumed as noise.

Step 5: ID detection

Both TACAN and DME stations are transmitting their ID in morse code. When the (virtual) Morse key is pressed down the station changes their mode from replying the DME requests from aircrafts to transmitting twin pulses at a constant rate of 1350 pulse pairs per second. Again the pulse code modulation of the DME stations proofs very robust against the always present fading and amplitude modulations on the transmission channel. So in the processing every twin pulse that exists with another twin pulse in a distance from 1/1350s~740µs is marked as an ID pulse. To regain the ID of the station the time is divided into segments of 1/80s in which the number of present ID pulses is determined. Last but not least if a threshold for the ID occurrence is reached for this interval the Sample representing the 1/80s interval is set to true otherwise to false. The resampling of the ID on 80 Hz has been chosen since a dot of the Morse code is 1/8 second which results in 10 samples for a dot.

Step 6: ID decoding

In the last step the resampled ID signal on 80Hz is demorsed which results in a 3-4 letter station ID.

Results

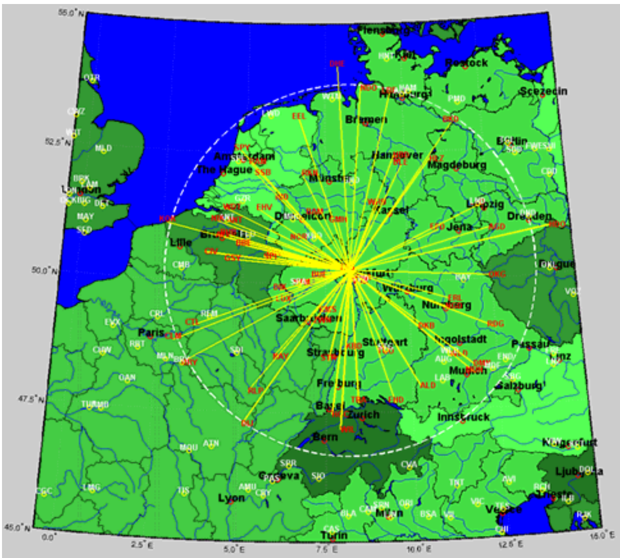

Figure 17 reception situation over middle Europe.

Figure 17 shows an example of the reception situation over Europe. The yellow lines are indication a contact from the aircraft to a station. This contact is assumed if in a 66.6s interval a stations ID (which should be transmitted twice during this period) is at least one time successfully decoded. In this case the stations name is printed in red. The yellow circles with white names indicate stations that are transmitting at frequencies which could be received but were not. In the middle of the yellow star was the aircrafts position flying at FL 390 which equals roughly 11 900m. In this situation 30 stations have been detected.

The white circle indicates the visibility range (radio horizon) for this altitude.

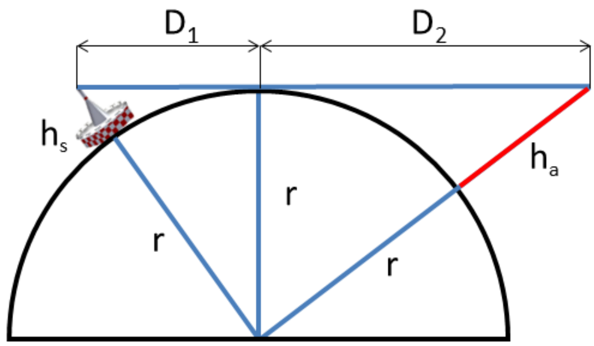

Figure 18 Calculation of the radio horizon - h_a is the altitude of the aircraft; h_s is the height of the station; r is the radius of the earth. Figure not to scale.

The (optical) visibility range for the station can be calculated with the help of Figure 18 and Pythagorean trigonometric identity:

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.

Acknowledgements:

This work has been promoted by the European Union in the ANASTASIA project.

Furthermore we want to thank the German air traffic control (Deutsche Flugsicherung – DFS) for their flexible and professional support.
We thank Lufthansa, Air Berlin and the Royal Air Force for the opportunity of a rendezvous.

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