Measuring GALILEOs multipath channel

Alexander Steingass
German Aerospace Center
Münchnerstraße 20
D-82230 Weßling, Germany
alexander.steingass@dlr.de

Co-Authors:
Andreas Lehner, German Aerospace Center, Germany

1. ABSTRACT

One leading point in the choice of the signal format for the Galileo System is the multipath transmission channel. Studies concerning the signal structure (e.g. ESA Signal Design Study) [1] had clearly shown that the synchronisation performance of a specific signal strongly depends on the reflections in the environment. Especially, short delayed reflections significantly decrease the performance of the receiver. The positioning error becomes even worse if these reflections are strong and slowly varying over time, which is predominant in pedestrian applications. Although narrowband channels like GSM (COST 207) [2] or UMTS have been measured in the past, it became necessary to analyse the wideband navigation channel to minimize multipath effects in future highly accurate receivers. For these reasons we measured the channel from the satellite to a receiver in critical urban and suburban scenarios. This paper will present first preliminary statements and conclusions for typical applications.

2. INTRODUCTION

In the last years the discussions about a feasible model for the multipath channel (for the European satellite navigation system GALILEO) reached a critical point. In the year 2000 the German Aerospace Centre (DLR) decided to perform measurements on multipath effects for a navigation system. The scope of this gauging has been the mass-market application. Therefore we were focussing on land-mobile applications.

Two of the potential scenarios were of special interest:

- The "Car Application" – A car driver is travelling through a city or a countryside and needs navigational support.
- The "Pedestrian Application" – A pedestrian is walking through a city in a typical way

We selected two cities for the measurements: A very large city: Munich and a small town in the greater Munich area: Fürstenfeldbruck. In addition, measurements were taken in in the countryside, on a motorway and on a country road.

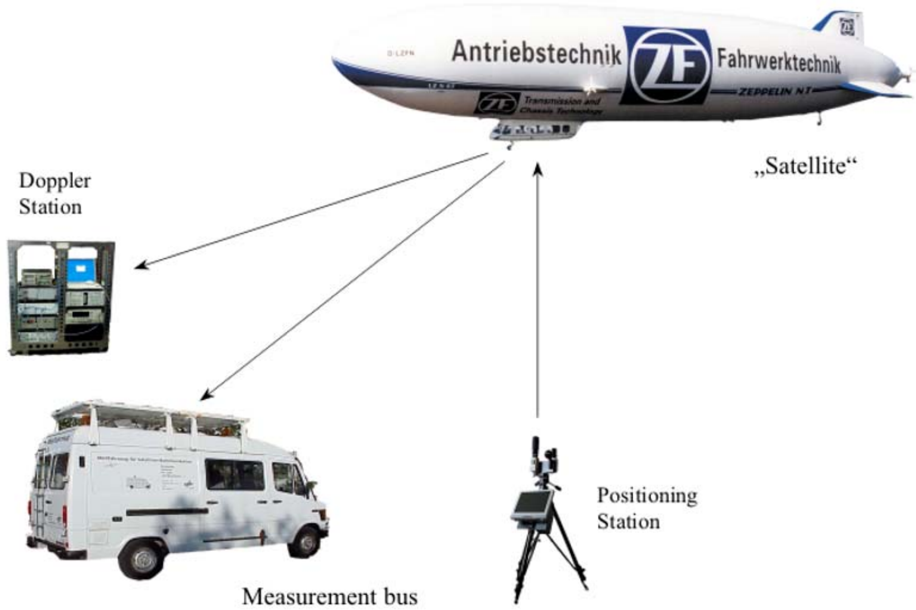

Figure 1 – Measurement setup

3. MEASUREMENT SETUP

3.1 "SKY SEGMENT"

The satellite of a potential navigation system was simulated by a Zeppelin NT. The Zeppelin transmitted the measurement signal between 1460 and 1560 MHz towards the ground using a hemispherical, circular polarised, antenna with 10W EIRP. The signal was a multi-sinus signal. The receiver was mounted in the measurement vehicle which was driven through the measurement area. In the case of the pedestrian measurement the antenna was carried by the walking user followed by the measurement vehicle. In this scenario we used an additional transmission with an unmodulated carrier on 18.8 GHz to determine the movement of the Zeppelin towards the receiver. This Doppler measurement was necessary since the movement speed of the Zeppelin is in the same range as the pedestrian user.

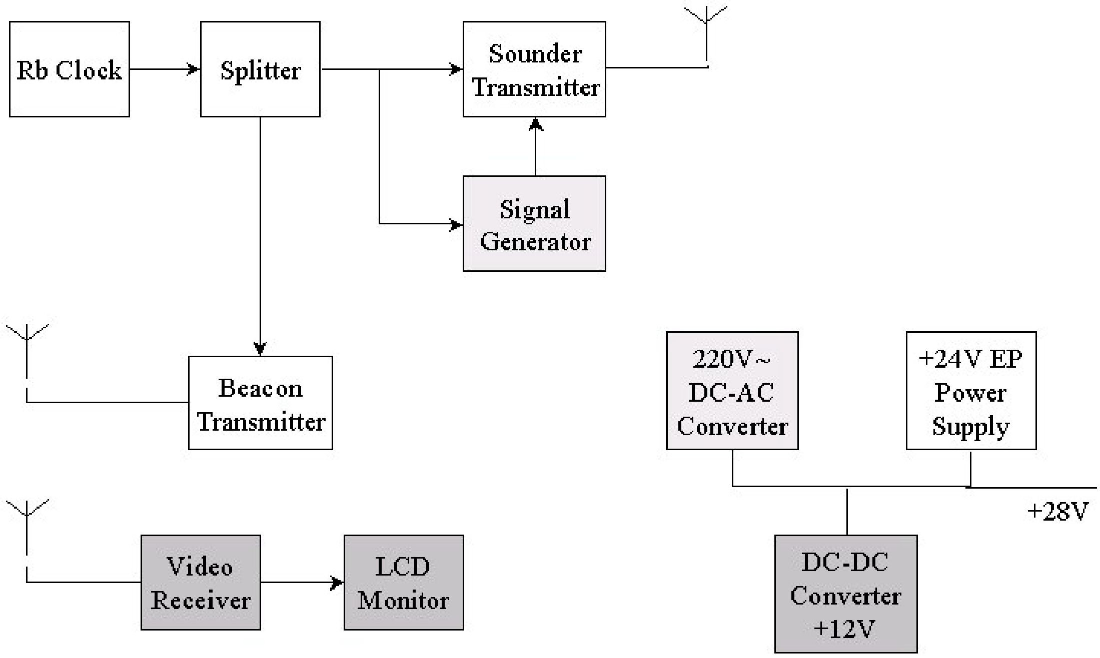

Figure 2 –Zeppelin Equipment

The airship was positioned stationary at one location. The high transmission power and the closeness of the measurement band to the GPS band made it impossible to use a GPS receiver for the positioning of the Zeppelin. In a range of 75 m around the measurement antenna it was impossible to synchronise on the GPS signal. Therefore we had to develop a novel method for the positioning of the Zeppelin: A camera was positioned on the ground pointing directly upright towards the Zeppelin.. The image of this camera then was transmitted into the Zeppelin and displayed directly in front of the pilot. The pilot used the transmitted image of his aircraft to keep the desired position. The altitude was kept by use of a pressure altimeter.

All the transmitters in the Zeppelin were driven by a special prepared atomic clock. This rubidium clock showed an Allen variance of 10^{-11}s measured with an integration time of 1 s. The derivation of all system clocks from one source guaranteed the synchronisation of both, the Doppler measurement and the channel sounding.

3.2 "USER SEGMENT"

The receiving equipment was mounted in the measurement van. Here again a rubidium clock was used to generate the system clock. This clock gave the sounder the absolute time reference. In the beginning of each day of our measurementsall the clocks were synchronised.

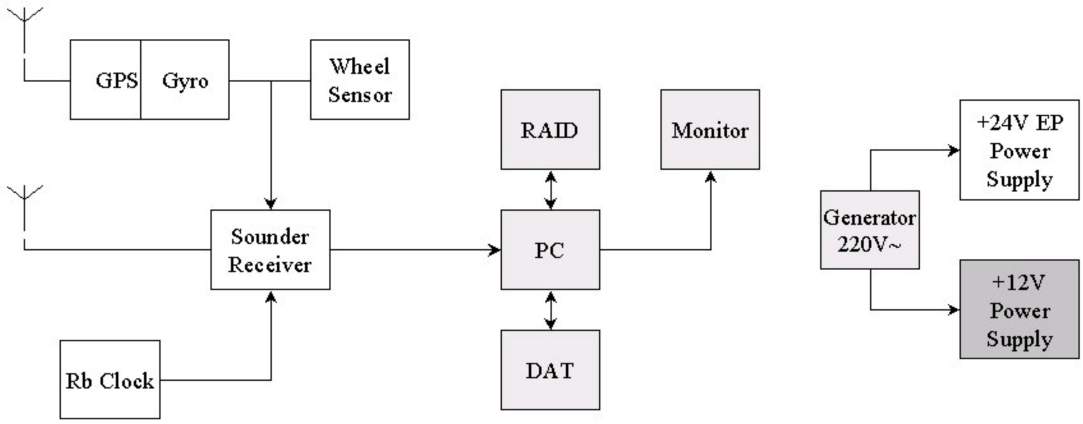

Figure 3 – Receiver in the measurement van

In addition on top of the measurement van a hemisperical, circular polarised, antenna had been mounted. The channel sounder was capable to record other important parameter while proceeding the measurements. A combination of a GPS receiver and an inertial navigation system was used to determine the position, speed and heading of the van. Furthermore two wheel sensors on the two front wheels allowed to determine the distance from start. All these sensors were connected to the channel sounder which recorded this data and combined it with the measurement data. A PC extracted and recorded the measured data.

3.3 DOPPLER STATION

The doppler station was built straight forward:

Two low noise amplifiers (LNAs) boosted the received signal. A rubidium clock was used to generate a reference which was synchronising a signal generator. This drove a phase locked oscillator which finally generated the mixing frequency. The remaining carrier was on 5kHz. We sampled and recorded the down converted signal with 50 kHz directly in LABVIEW.

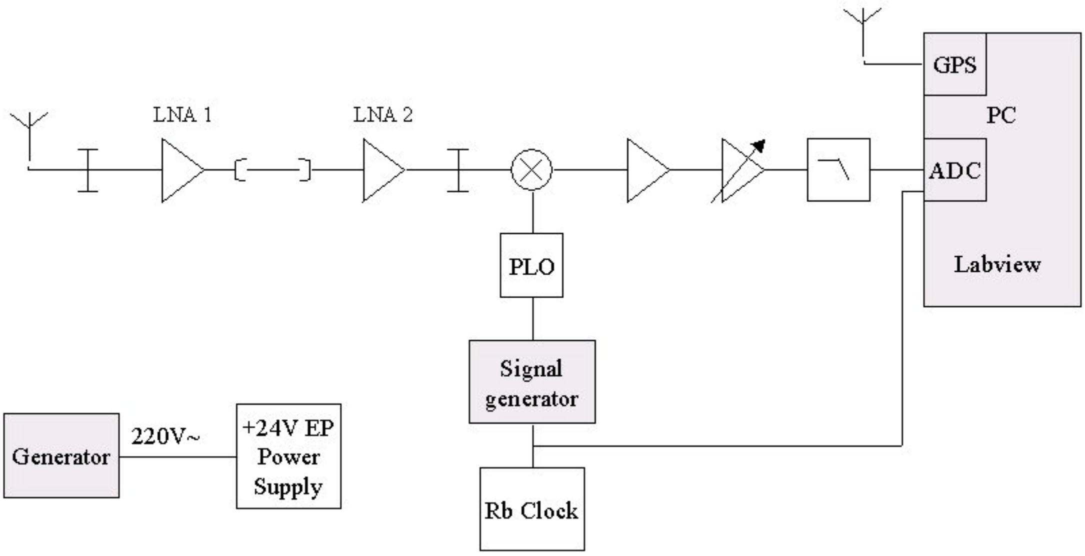

Figure 4 – Doppler receiving station

3.4 CAMERA STATION

To position the Zeppelin correctly two cameras were in use: One with a wide angle lens and one with a tele lens. The wide angle lens was used to guide the Zeppelin into position. After sucessfully prepositioning the aircraft, we switched over to the tele lens for an even more precise positioning. The camera image was shown on a screen and transmitted to the Zeppelin.

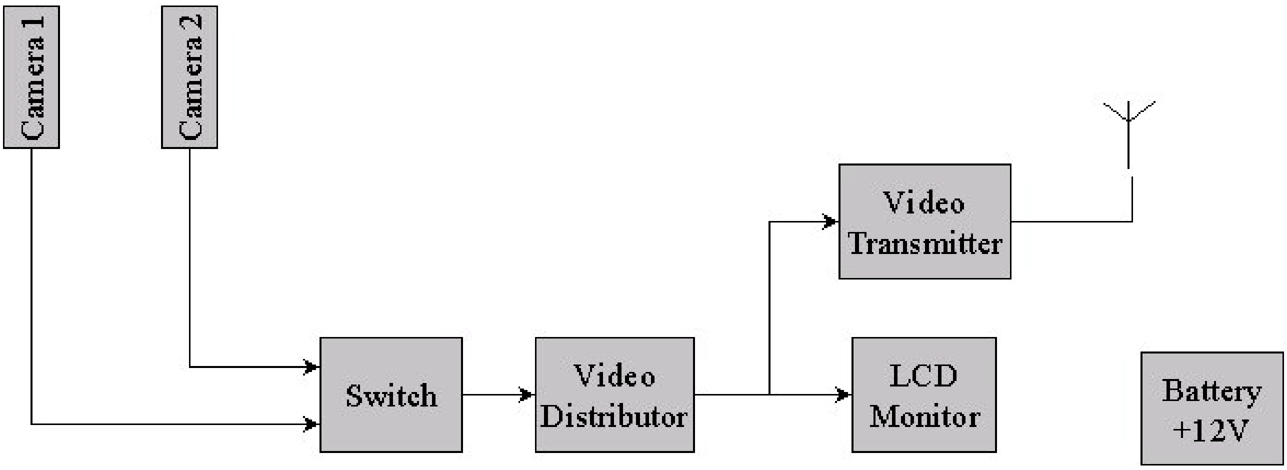

Figure 5 – Camera positioning station

4. MEASUREMENT PARAMETERS

For the measurement we used a commercial channel sounder built by the German company MEDAV. This sounder transmitted a measurement signal which filled the complete bandwidth with eqally spaced sinewaves.

To obtain the channel impulse response (CIR) from the received signal the receiver had to perform a Fourier transformation. Since the transmitted signal is rectangular the real CIR is always convoluted by the sin(x)/x function. Since the used bandwidth was 100 MHz the first zero crossing of the sinc function is at 10 ns. This figure gives the delay resolution. It is planned to use a super resolution algorithm to increase the delay resolution up to 5 ns during the next steps.

To be able to calculate the Doppler bandwidth of the channel reflections the sampling theorem in the time domain had to be fulfilled. A speed limit of the van of 100 km/h made sure that the maximum Doppler shift that could occur was 138 Hz. For that reason usage of a sampling frequency for the impulse responses of at least 278 Hz was necessary. 300 impulse responses per second fulfilled the Nyquist theorem.

The channel sounder transmitted its signal periodically. Since the receiver measures the convolution of the transmitted signal, the CIR the measured impulse response is as well periodically. To avoid the tails of the CIR to be convoluted into the beginning of the CIR the period length of the transmitted signal must be longer than the length of the CIR. A period length of 25.6 μs was selected.

In a reality scenario the satellite is distant that the incoming rays are nearly parallel. To minimize the model error a distance as long as possible between the transmitter and the receiver had to be selected. In our study the distance was kept in a range of 2-4 km.

Selection of the measurement tracksTwo methods of selecting the measurement tracks were used

- "Small area method"

  Using this method a small area was identified in which the receiver was moved while keeping in mind that the elevation did not change much. This enabled the performance of several measurements with predetermined elevations. An elevation range of 5 to 80 Degrees was covered. Figure 6 shows the selected path for the "Lindwurmstrasse"- scenario: car measurement in Munich.

- "Large area method"

  Driving high speed e.g. on a motorway significantly changes the elevation in a short periodThis made it impossible to measure over a long period with a more or less constant elevation. Therefore the van was driven along distance while themeasurement was splitted in segments which contained a certain elevation range. The combination of several of these measurements enables a suitable statistics.

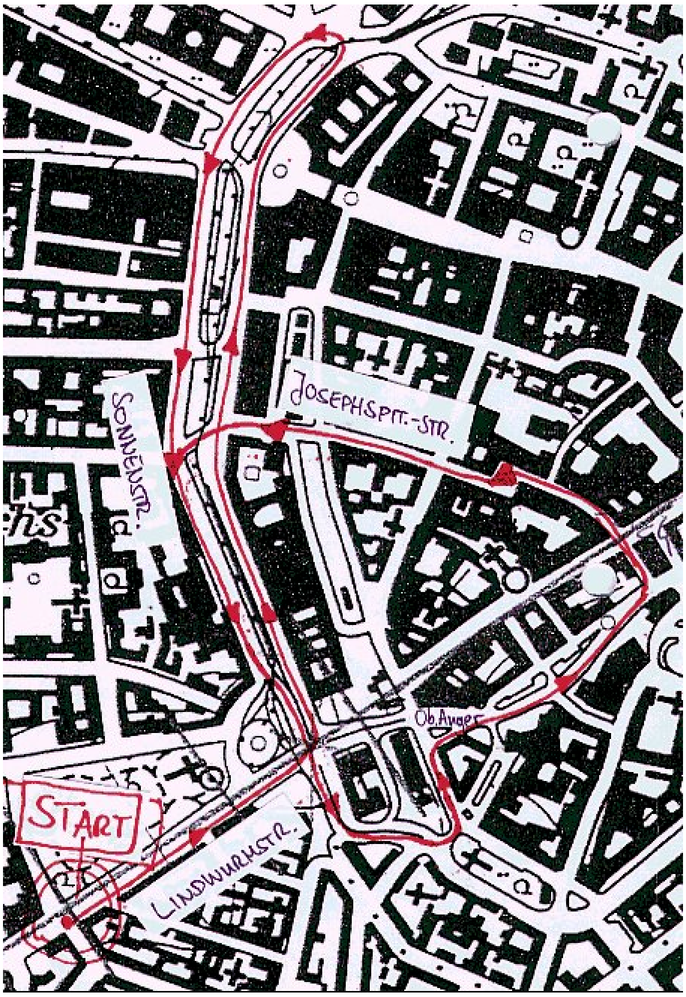

Figure 6 – Measurement Area "Lindwurmstrasse" in Munich

5. FIRST RESULTS

Following are some first results. To avoid double images we refer to [1] and [4] for other results of the measurement.

Figure 7 shows the measurement figure of the car track in the "Lindwurmstrasse" area in Munich (see Figure 6). For this low elevation the visibility of the satellite is naturally quite low. In comparison to a visible satellite in the zenith the power is attenuated about –30 dB. In some areas during the measurement the power came up to about –20 dB. When the satellite is at this low elevation for very long echoes are occuring. In reality it is very typical for this kind of situation that a car is driving towards a reflecting item so that the reflection comes closer and closer to the shortest path and finally matches it. In Figure 7 at the time position around 500 s a multiple reflection is visible. The reason for this significant data was an urban canyon where most likely the incoming wave bounced several times.

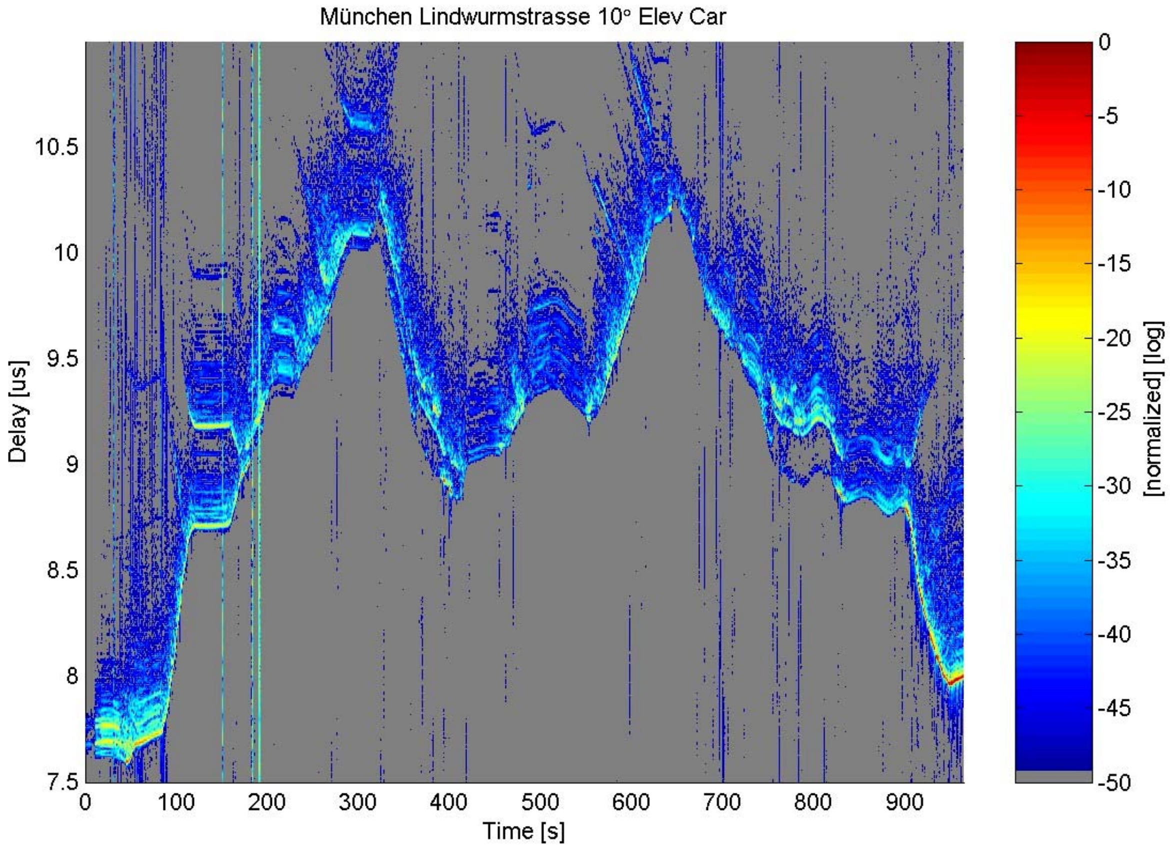

Figure 7 – Measurement "Lindwurmstrasse" in Munich Elevation 10 Degrees

Figure 8 shows the same measurement at 40 degrees elevation. In this situation the visibility increases dramatically. The tendency for long echoes is reduced. Unfortunately another characteristic comes up: The "building echo". When the incoming ray is arriving at an azimut from the side it is very likely that an echo occurs with a delay matching the street width (best to be seen between 120 and 180 s). The power of this reflection is quite high and reaches values around –15 to –20 dB. If the incoming ray is arriving from the front the echo tends to be shorter (best to be seen at 440-450 s).

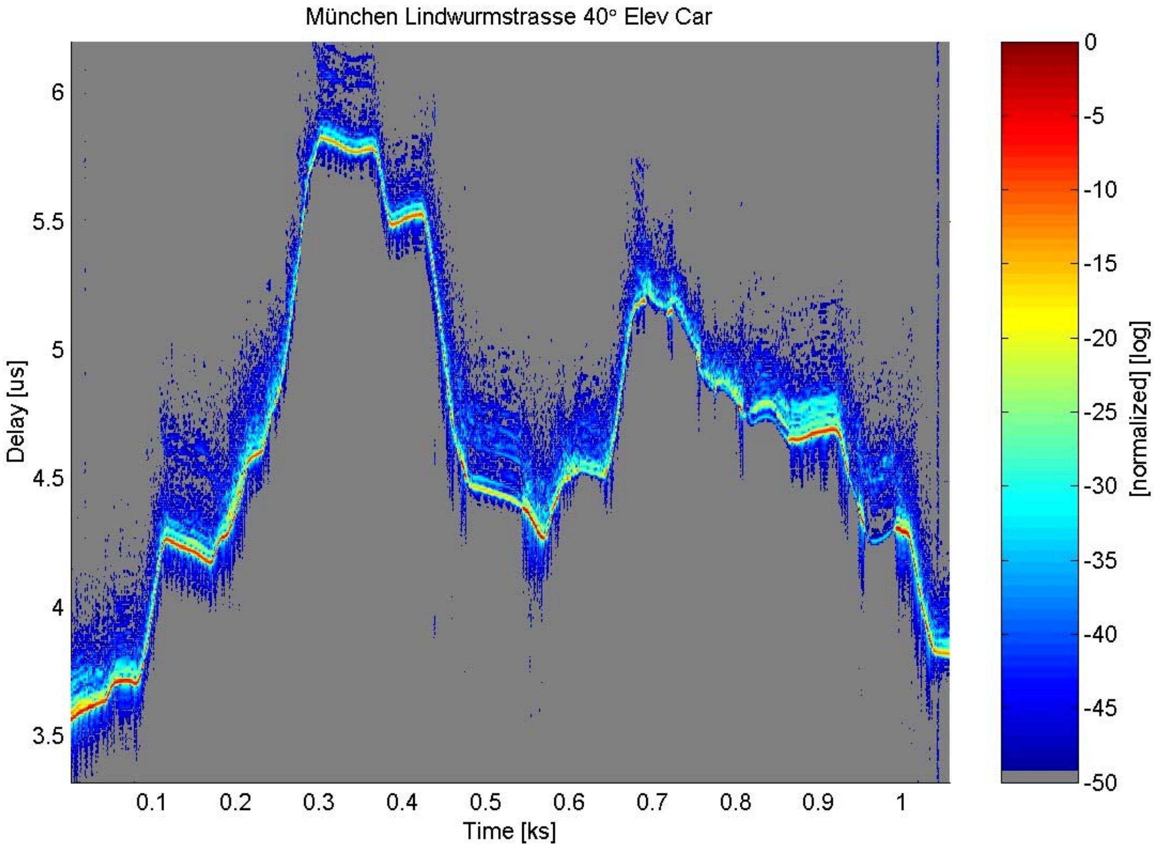

Figure 8 - Measurement "Lindwurmstrasse" in Munich Elevation 40 Degrees

Figure 9 shows the same track with the Zeppelin at 80 degrees elevation. There the visibility is very high. The echoes tend to be short and strong. Again the mentioned dependeny on the azimuth can be seen: If the ray is coming from the front the echo delay is much shorter than on coming from the side.

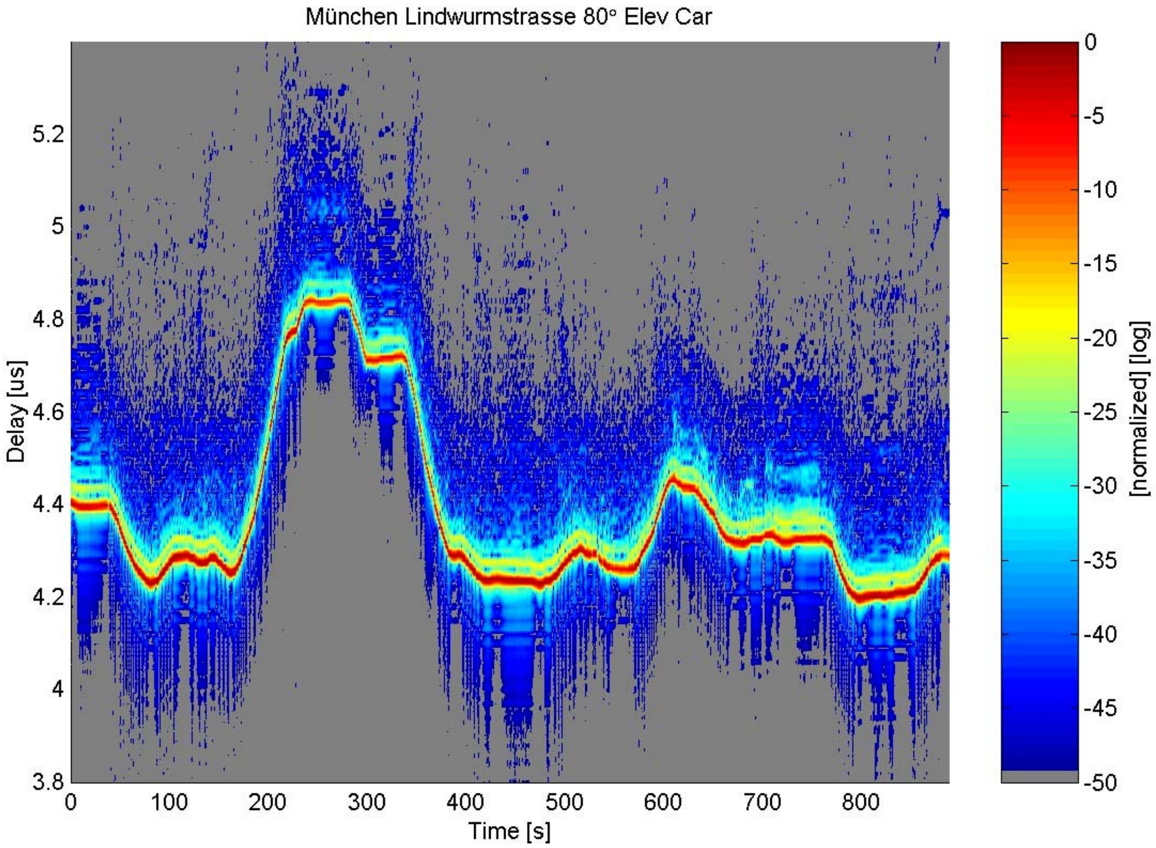

Figure 9 - Measurement "Lindwurmstrasse" in Munich Elevation 80 Degrees

6. CONCUSIONS

In autumn 2002 the German aerospace center (DLR) performed a large measurement campaign to clarify the lack of data for the land mobile navigation channels. This campaign brought a complete set of channel data describing all relevant applications. A first overview of the results was given.

7. FURTHER WORK

In a next step we will analyse the whole data using the super resolution algorithm ESPRIT. This will result in a large number of discrete echoes which will then be statistically analysed. The result of this work will be a set of channel models for the land mobile navigation channel.

8. ACKNOWLEDGEMENTS

We would like to thank all of our colleagues of the DLR who supported us during the last two years on organizing this very demanding project. During the two weeks of our measurements

over 60 research scientists and staff members worked for this project and contributed to its success.

Figure 10 – Representing the whole team: some of our dedicated supporters

References

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[2] COST 207 WG1: "Proposal on channel transfer functions to be used in GSM tests 1986", Technical report, CEPT Paris, 1986.

[3] Steingass, A., Lehner, A.: " Characteristics of the Land Mobile Navigation Channel for Pedestrian Applications ", GNSS 2003, Graz, Austria., 22nd-25th April 2003.

[4] Lehner, A., Steingass, A.: "Characteristics of the Land Mobile Navigation Channel for Pedestrian Applications", GNSS 2003, Graz, Austria., 22nd-25th April 2003.

[5] Lehner, A. , Steingass, A.: "The Influence of Multipath on the Positioning Error", GNSS 2003, Graz, Austria., 22nd-25th April 2003.