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DFS Deutsche Flugsicherung GmbH

Eurocontrol

Measurement of 1090 MHz Extended Squitter Performance and the 1030/1090 MHz Environment In Frankfurt, Germany

May 2001

Final Report

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Performance Experiments in Germany on ADS-B Using Mode S Extended Squitter

Measurement of 1090 MHz Extended Squitter Performance and the 1030/1090 MHz Environment in Frankfurt, Germany

Final Report

4 May 2001

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R&D

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Major contributions to this report were made by the William J. Hughes Technical Center, M.I.T. Lincoln Laboratory, Thomson Airsys/ANS and ERA.

All participating organizations and industry partners supporting the trials execution and data evaluation and their specific roles are described in detail in Chapter 1.3.</td></tr>
</table>

16. Abstract

A program of airborne and ground based measurements was conducted by the FAA, the DFS Deutsche Flugsicherung and Eurocontrol in the vicinity of Frankfurt, Germany in May 2000. The objective was to test the performance of 1090 MHz Extended Squitter signal reception in the highest known interference environment in the world, and also to measure the interference environment and the aircraft traffic density during the test periods. A number of aircraft were included in these tests, and several receiving devices were used on each aircraft. Ground based equipment deployed to two sites was also used. The scope of the measurements included air-to-air reception for several types of receiving equipment, and air-to-ground reception using sectorized receiving antennas for several different Extended Squitter implementations.

The recorded data has been analyzed to assess the data validity and to assess reception performance. The program has yielded a large quantity of useful data for characterizing both interference and Extended Squitter reception performance. The performance assessment was also analyzed with respect to the standards given in the ADS-B MASPS and the Eurocontrol ADS program requirements, and these results generally indicate good performance.

Similar measurements were carried out in the Los Angeles Basin in June 1999. Results of the LA measurements are presented in FAA report DOT/FAA/ND-00/7.

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EXECUTIVE SUMMARY

In May 2000, DFS Deutsche Flugsicherung, Federal Aviation Administration and Eurocontrol, in collaboration with several industry organizations, performed Automatic Dependent Surveillance-Broadcast (ADS-B) flight trials using Mode S Extended Squitter in German airspace. Measurements of interference environments and reception performance were made in a variety of conditions. Both airborne and ground-based receptions were analyzed, and several receiving systems were evaluated. A large quantity and wide variety of data was recorded, as documented in this report. After analyzing the data it was concluded that these measurements were very successful.

Test Configuration

Airborne and ground facilities were assembled to make detailed measurements of the Radio Frequency (RF) Secondary Surveillance Radar (SSR) channel utilization and the air-to-air and air-to-ground performance of Extended Squitter.

Ground stations were installed at DFS facilities at Langen and at the U.S. Army Air Base at Wiesbaden. The Langen station included three separate Extended Squitter receivers, and the Wiesbaden station was configured with a single Extended Squitter receiver and a video digitizing receiver.

Three project aircraft, an NLR [1] Metroliner, a Flight Inspection International Beech King Air and the FAA Boeing B-727 participated in the Frankfurt trials. In addition to the project aircraft, several Extended Squitter targets of opportunity were observed. British Airways has equipped several in-service Boeing B757 aircraft with Extended Squitter transmission capability integrated with their Traffic Alert and Collision Avoidance System (TCAS) installations. These targets of opportunity served as valuable examples of an early commercial Extended Squitter implementation.

The focus of the ADS-B evaluations described in this report was on terminal and en route operations. The flight test profiles were appropriate for the assessment of longer range air-to-air ADS-B performance, i.e., separation assurance and sequencing, flight path deconfliction, and autonomous operations. Most of the flight profiles were flown within existing high-density terminal and en route airspace. At the end of some flight profiles the approaches flown by project aircraft to Wiesbaden approximated parallel approach conditions. In addition, data was gathered using a TCAS 2000 receiver to enable the future assessment of TCAS II Hybrid Surveillance performance.

Test facilities were also configured to allow the assessment of air-to-ground performance. The ADS-B ground stations used for the evaluation were representative of units configured to provide ATC surveillance services in high traffic density terminal and en route environments. The line-of-sight constraints of available ground sites limited the evaluation of longer range air-to-ground performance to relatively high elevation targets in certain preferred directions covered by the ground directional antennas. The data gathered support validation of ADS-B operation in terminal operations, but did not provide as complete a basis for evaluating very long range (greater than 120 nmi) en route air-to-ground surveillance. The results of these studies contribute to a better

[1]The Netherlands National Lucht- en Ruimtevaartlaboratorium.

understanding of the ability of the 1090 MHz Extended Squitter technology to satisfy certain of the other requirements for which the test configuration was not optimal.

Additional data was collected from radar sites throughout Germany during the flight test intervals. Such data served to document the aircraft density and distribution present during the flight tests.

Environmental Results

Extensive measurements were made of the RF environment in the airspace surrounding Frankfurt. ADS-B air-to-air and air-to-ground performance within this same airspace was also characterized. The RF environmental measurements were compared to measurements conducted previously in Frankfurt and at other locations in U.S. airspace.

The results confirm that Germany continues to have very high channel occupancy on the SSR interrogation (1030 MHz) and reply (1090 MHz) channels, relative to measurements made at other sites throughout the world. The ATCRBS fruit rate measured in Frankfurt was 30 to 50 % higher than that measured in Los Angeles in 1999. Mode A and Mode C interrogation rates remain at the same level as 1995 while Mode S and Airborne Collision Avoidance Systems (ACAS)[2] intermode interrogation rates increased significantly with the European ACAS II mandate. Traffic counts indicate a traffic increase of about 50% over Germany since 1994. Although comparable fruit measurements were not made in 1995 and 2000, and thus a direct comparison of airborne fruit rates is not possible, it appears that increases in fruit that would correspond to increases in traffic were offset to some extent by a reduction in the number of active radar sites in southern Germany.

The measured Mode S fruit rate was less than 10% of the ATCRBS fruit rate. Seventy-three percent of Mode S 1090 MHz transmissions were replies to TCAS surveillance interrogations and 23% were acquisition squitters. Extended squitter transmissions account for about 1% of the Mode S fruit rate, while replies to the single Mode S ground sensor account for less than 3%.

Fruit rates depend on both the interrogation rates seen by each aircraft and the distribution of aircraft within reception range of the affected receiver. Therefore it was an essential part of the Frankfurt trials that detailed measurements be made of the number and distribution of all aircraft that could be a source of interference to the ADS-B receivers located in the Frankfurt area. It was estimated that at least 520 aircraft were in view of the sensitive receiver installed on the FAA aircraft.

Analysis of multiple ground radar recordings revealed that most aircraft were below 10,000 feet. Higher altitude aircraft were approximately uniformly distributed between 10,000 and 40,000 ft. Above 30,000 ft, the distribution was seen to be concentrated at the odd thousands, which is consistent with air traffic control practices in Europe. The median altitude in Frankfurt was observed to be about 11,000 ft on work days. On the weekend this value decreased to some extent. However, this was still significantly higher than the altitude distribution in Los Angeles, where the median

[2] ACAS II is equivalent to TCAS II, Version 7.

altitude was measured to be about 4000 ft. It was also observed that the fruit rates did not vary with altitude in general as much as interrogation rates.

Interrogation rates vary with location, time and altitude. A significant difference was observed in the altitude dependence of ATCRBS and Mode S interrogation rates. While ATCRBS interrogation rates increased with altitude, Mode S interrogation rates were observed to peak at an intermediate altitude in the Frankfurt area.

ATCRBS interrogations rates have decreased in southern Germany since 1995, but remain at the same level in the Frankfurt area. An increase in Mode S interrogations was observed, which likely arose from the European ACAS mandate.

Extended Squitter Performance

Three sources for the ADS-B performance requirements have been considered for this study. Currently the most comprehensive source for ADS-B performance requirements is the RTCA Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B), DO-242 . The second source of ADS-B requirements considered was the ICAO Manual of Air Traffic Services Data Link Applications, ICAO Document 9694. The third source of requirements considered were preliminary European requirements for ADS-B provided by the Eurocontrol ADS Programme, which still required harmonization at the time of this report (May 2001).

The performance evaluation focuses on requirements concerning the maximum acceptable state vector and intent (Trajectory Change Point, TCP) update intervals (to a specific confidence level =95%) as well as initial acquisition range and tracking range. Performance requirements are taken from the RTCA ADS-B MASPS (DO-242) and a draft proposition from the Eurocontrol ADS Programme referring to air-to-ground surveillance and air-to-air autonomous operations[3]. Analysis took into account the bearing of the target aircraft since MASPS performance requirements for flight path deconfliction specify the required range per target quadrant (forward, aft, side).

The flight tests took place in a high-density terminal and en-route airspace. The three project aircraft and the British Airways targets of opportunity broadcast position, velocity and in most cases Flight ID squitters but not TCP or mode/status squitters. None of the 1090 MHz receivers were fully MOPS compliant. Consequently update interval and tracking/acquisition range performance was estimated from the per message reception probability measurements using a theoretical model described in Chapter 6.

In all cases analyzed in detail, the airborne receivers were either LDPUs[4] or TCAS 2000 avionics, while the ground receivers were the ANS-MAGS[5] station and the ERA[5] station at Langen and two LDPUs (one at Langen and one at Wiesbaden). All ground stations at Langen shared the same sector antenna. However, only the dual-

[3] Both the RTCA ADS-B MASPs and the Eurocontrol draft requirements are undergoing further development. It is therefore possible that new or revised requirements may emerge from these ongoing activities

[4] Link Data Processing Units produced in the US.

[5] ADS-B equipment produced in Europe.

channel LDPUs were connected to both sector beam antennas, while the ANS -MAGS and ERA receivers were connected to a single sector beam antenna.

The Frankfurt 1090 MHz Extended Squitter trials were performed in a real environment with many sources of TCAS acquisition squitters and severe ATCRBS interference. Since these trials involved a small number of Extended Squitter equipped aircraft, they cannot show how the 1090 MHz system would perform with a large number of aircraft. Additional investigations including simulations will be necessary to address other issues like self interference.

Air-to-Air Performance

In the Frankfurt environment the measurements are consistent with the state vector and intent requirements and 40 nmi range requirements for the separation assurance application. At ranges beyond 40 nmi, as required to support a long range deconfliction application, the measured update rates would typically support the MASPS application requirements (state vector and intent information) up to a range of 75 nmi, and state vector information alone to 90 nmi, in most cases.

Concerning the Eurocontrol proposed criteria for autonomous operations to 150 nmi range, which include the reception of four TCPs, reception probability was observed to be generally adequate for ranges up to 70 nmi.

Performance measurements with the TCAS based receiver were generally similar to that measured with the LDPUs. However, the ranges were consistently shorter due to the less sensitive receiver and time sharing with TCAS surveillance functions.

There were certain exceptions to the effective air-to-air reception range observed offering both shorter and longer range performance. The worst case performance observed during the evaluation was an effective air-to-air range on the order of 40 nmi. However, it was subsequently demonstrated that by applying the advanced reception techniques (as defined in the 1090 MHz ADS-B MOPS) the effective reception range in this worst case situation would have been extended to approximately 60 nmi.

Air-to-Ground Performance

Three different receivers were evaluated at two sites. Differences were observed in the performance of the LDPU, ANS-MAGS and ERA receivers, with the LDPU the most capable and the ERA receiver the least. This is believed to be due the fact that the LDPU was the only receiver that implemented error correction. All three receivers demonstrated performance adequate for terminal operations; the differences were most apparent in long range, en route scenarios.

Air-to-ground reception capabilities were generally line-of-sight limited. An air-to-ground reception range in the Frankfurt environment of at least 150 nmi appears feasible with a single sensor using a properly sited, sectorized antenna.

Based on measurements from the ground station at Wiesbaden, air-to-ground reception performance for aircraft on final approach to land at Wiesbaden indicate that 1090 MHz ADS-B is capable of satisfying the requirements for a PRM application.

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1. INTRODUCTION

1.1 BACKGROUND AND PROBLEM STATEMENT

There is great interest in the use of ADS-B (Automatic Dependent Surveillance Broadcast) for various purposes. Due to the broadcast character both air traffic services and airspace users are interested in its use. This offers a variety of possibilities for air-air, air-ground and ground-ground applications.

Extended Squitter on 1090 MHz is a candidate for ADS-B. ICAO published Standards and Recommended Practices (SARPs) for the transponder features needed to support Mode S Extended Squitter in 1998. SARPs for the message formats and protocols for Extended Squitter were approved by the SICAS Panel in September 2000.

In 1998 US FAA (Federal Aviation Administration) and German DFS (DFS Deutsche Flugsicherung GmbH) started discussing common ADS-B trials with Mode S Extended Squitter to characterize the performance of this medium. Extended Squitter uses Mode S formats that are transmitted on the SSR reply frequency, 1090 MHz. Earlier measurements revealed that Germany, especially the Frankfurt area and the southern part of the country, may "offer" the highest interference environment in the world on this frequency. The high reply rates are caused by a combination of many interrogators (U.S. and German military, and German civil interrogators) and very dense air-carrier traffic.

A description of the proposed trials was published in various groups and organizations in early 1999, although due to institutional difficulties the execution of the trials was delayed until May 2000. Taking advantage of this delay, Eurocontrol was asked to join and participate actively in the trials and agreed to this participation in March 2000. In addition, industry was invited to attend the trials and demonstrate the performance of their equipment.

Due to the common measurement effort it was agreed that all parties would have access to all data and that they would participate in the preparation of one common final report. A test-plan was developed and approved by all participants (Ref. 4) for co-ordination purposes as well as for trials documentation.

Note *Trials have been conducted for the other two candidate links (VDL Mode 4 and the Universal Access Transceiver). The results of these trials will be the subject of separate reports.*

1.1.1 SSR and SSR Mode S

Conventionally, the SSR system is ground oriented. Ground stations interrogate aircraft. The radar stations use interrogations to elicit replies from aircraft that include aircraft identity (Mode A) and altitude (Mode C). Conventional SSR (Mode A and C) interrogations are "all-calls," in that all aircraft within the antenna beam receiving the interrogation will reply. This leads to overlapping replies if aircraft are in close proximity to each other (Figure 1-1).

In this case reply overlap may continue for a period of time. During this period, one of the aircraft may not be visible to the ground system. Each additional aircraft in such an "all-call" system produces an average reply rate proportional to the number of interrogators within view of the aircraft.

The development of Mode S was intended to overcome problems like channel load and code shortage. This was accomplished by selective interrogations to individually access aircraft that operated with geometries that would cause garbling in an "all-call" system. After acquisition of an aircraft, each subsequent interrogation is transmitted addressed to that aircraft (Figure 1-2). This ensures that only one aircraft will reply to each interrogation.

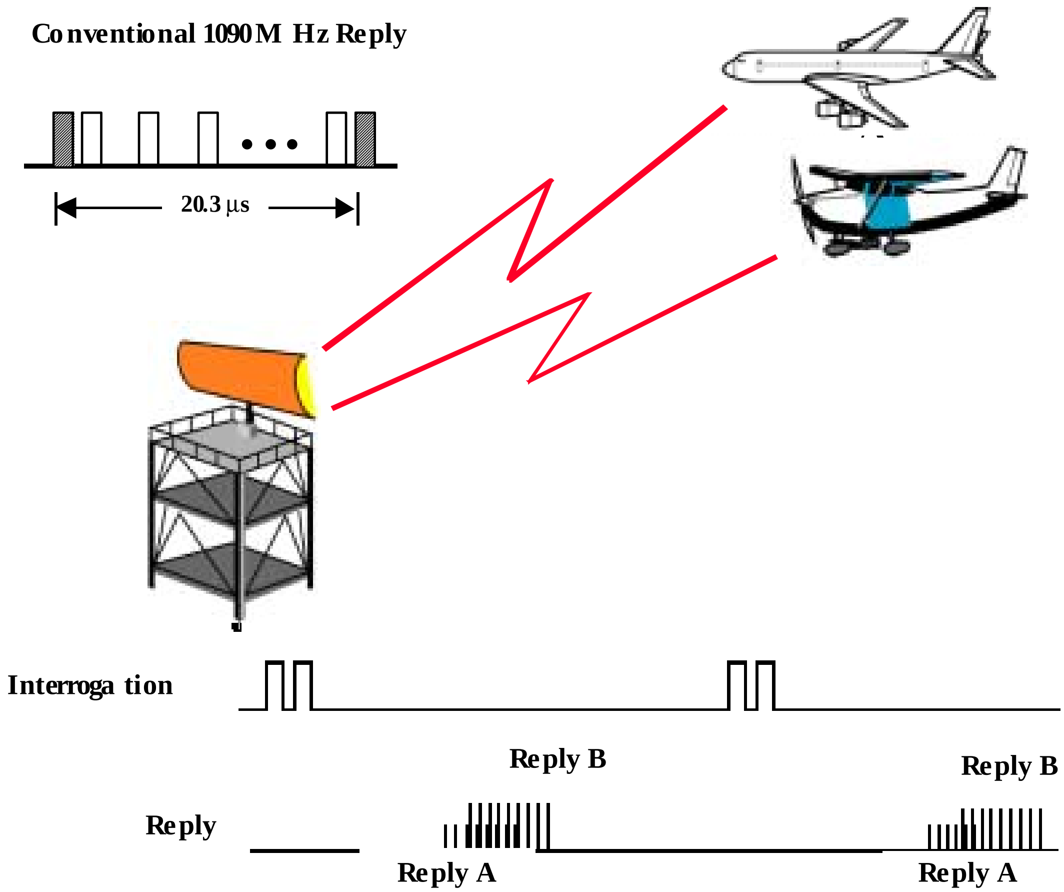


Figure 1-1: Principle of Conventional SSR Mode A/C Technique

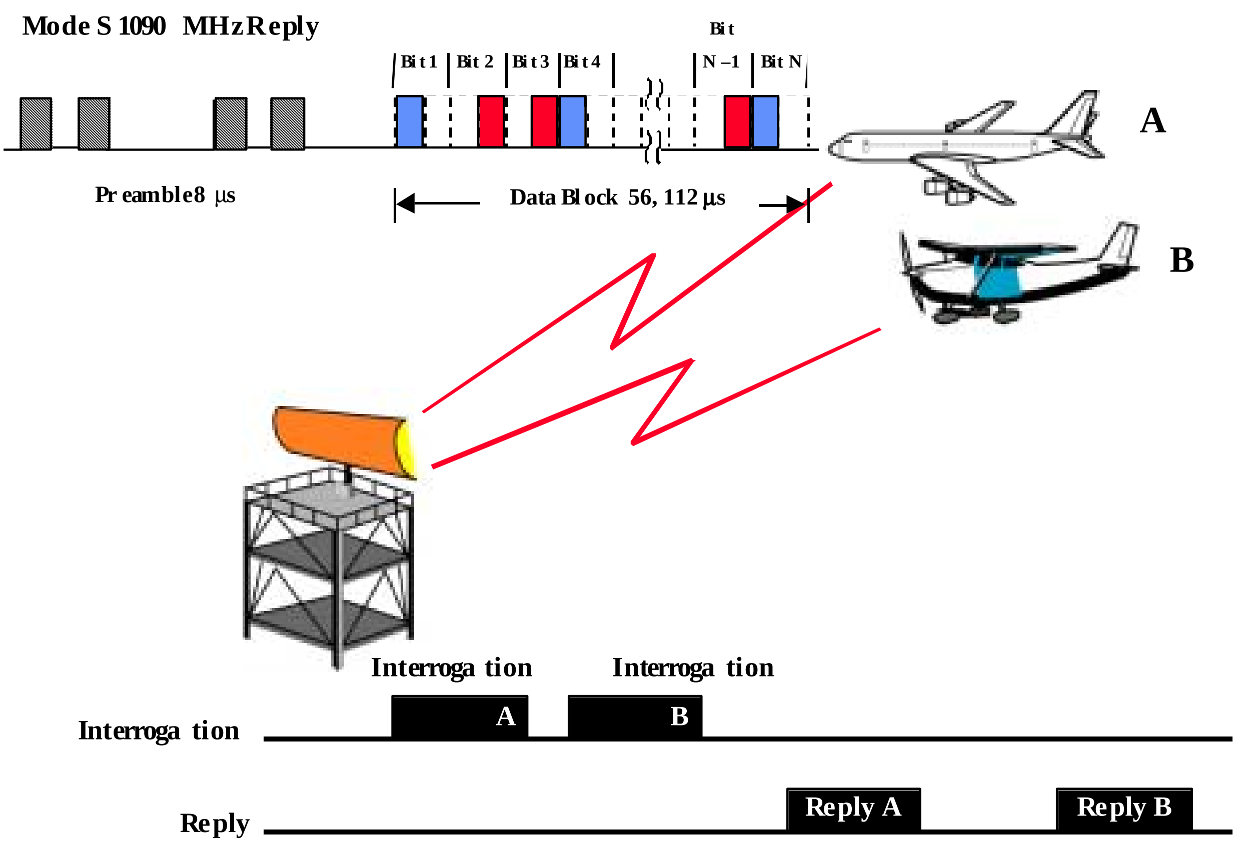


Figure. 1-2: Principle of SSR Mode S Technique

Addressed operation allows a more balanced use of the SSR frequencies. The load is increased on the interrogation frequency, which even in dense environments has excess capacity. At the same time, the load is significantly reduced on the reply frequency. The average reply rate per aircraft is reduced, and the integrity of the surveillance is improved.

The Mode S system was developed to provide means for current and new surveillance applications. The first stage, elementary surveillance, just substitutes conventional SSR surveillance with aircraft identification and altitude reports, but it provides:

1. A reliable link using selective interrogations with error detection and correction;
2. Additional data such as aircraft address, aircraft identification (call sign used in flight), flight status and communication capabilities;
3. A higher accuracy of altitude reports (25 ft, if connected to an appropriate source).

Enhanced Mode S surveillance may use a part or the complete set of Mode S specific services (Ref.2). In addition to the above mentioned advantages, enhanced surveillance provides, data from the aircraft (with appropriate sources connected) to:

1. Allow the use of new applications;
2 Increase capacity while ensuring the same level of safety;
3 Support the traditional approach of ground controlled surveillance.

Mode S is also standardized as an ATN subnetwork. Therefore, it can offer datalink services, as required. This is a feature which requires elementary Mode S, but not necessarily Mode S Specific Services functionality.

1.1.2 Mode S Extended Squitter

Independent from the above ground-initiated datalink capabilities, the Mode S system design also contains a feature called Extended Squitter, to be used as an ADS-B medium. Historically, Mode S transponders transmit acquisition squitters to support ACAS operation. In the early 1990's, MIT Lincoln Laboratory invented the idea of augmenting this squitter function to include position and velocity data (Figure 1-3). This opens possibilities for various applications for both, air-ground and air-air use. Surface management systems may also profit, since special formats adapted to ground requirements are standardized. Extended squitter capability may be implemented in the aircraft either as an enhancement to the Mode S transponder or as dedicated avionics independent of the SSR transponder function. This latter configuration would be primarily of interest to US low-end general aviation users not desiring to equip with a full Mode S transponder capability. However, such a configuration is not foreseen to be used in Europe.

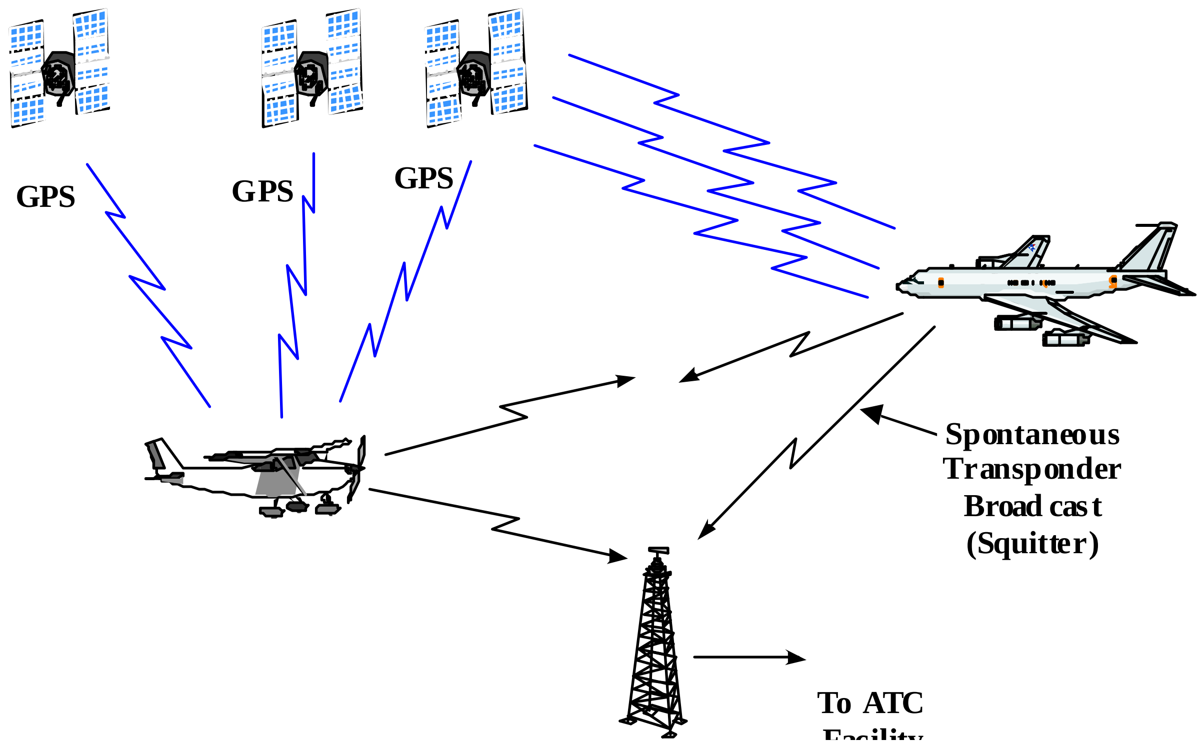


Figure 1-3: Principle of Extended Squitter Operation

To support operation in high interference environments, improved techniques have been developed. These techniques are adapted to fulfill RTCA MASPS (Minimum Aviation System Performance Standards) requirements.

1.2 ACTIVITY GOALS

Occupancy of the 1090 MHz surveillance spectrum is known to be highest in areas where aircraft traffic density is high and each airborne transponder responds to interrogations from multiple sources (e.g., combinations of ground-based ATCRBS or Mode S sensors, and airborne TCAS units). Any additional application that operates within the 1090 MHz surveillance reply spectrum must be robust to these ATCRBS and Mode S replies (also known as fruit) generated as a consequence of surveillance activity. In particular, operation of ADS-B using Extended Squitter must be shown to coexist with existing fruit rates if Extended Squitter is to be considered a viable implementation path worldwide.

The airspace surrounding Frankfurt, Germany, has been shown to have one of the highest fruit rates measured anywhere in the world, due to a combination of high traffic density and very high numbers of ground interrogators (largely military ATCRBS interrogators) that operate at high interrogation repetition frequencies (IRFs). The German CAA, Deutsche Flugsicherung GmbH (DFS), and the U.S. Department of Transportation / Federal Aviation Administration (FAA, with their subcontractor, MIT Lincoln Laboratory) agreed to collaborate on a measurement activity. The purpose of this activity was to improve the current understanding of the radio frequency (RF) environment in the Frankfurt, Germany, area while simultaneously measuring the air-to-air and air-to-ground performance of ADS-B via Extended Squitter in this high interference environment. Eurocontrol was invited and agreed to participate in the measurement activity.

Three aircraft served as calibrated airborne sources of Extended Squitters; one of the aircraft also served as an instrumented platform to characterize the 1030 MHz/1090 MHz channel occupancy and to record Extended Squitters from the other airborne sources. Targets of opportunity also were frequently available during flight missions, as Extended Squitter-equipped British Airways aircraft flew within range of the trials during normal revenue flights. Wherever possible, measurement techniques and flight profiles were configured to allow easy comparison with previous measurement activities conducted in and around Frankfurt. The primary goals of the activity are listed below:

1. Characterize performance of Mode S Extended Squitter in a "worst case" operational environment.
2. Evaluate performance of improved Mode S reply processing algorithms.
3. Characterize the use of 1030/1090 MHz surveillance spectrum, both air/air and air/ground in Frankfurt.

These high level goals had to be achieved while:

1. Measuring Mode S Extended Squitter performance in an environment with very high fruit rates.
2. Simultaneously measuring the environment to improve understanding of the results and related mechanisms due to environment (e.g. interference), installation (e.g. antenna lobing) or system implementation (e.g. decoding algorithms).
3. Recording data to provide a sound basis for simulations.
4. Allowing equal access to all project data by all participants and a final report acceptable to all participants.

Participating in this common measurement campaign offered the following benefits for all actively involved parties:

1. Analysis of Mode S Extended Squitter in an environment with very high fruit rates.
2. Comparison of results of European and US equipment operating in the same environment.
3. Collection of data needed to validate simulations (including assumptions).
4. Common measurements and access to all data.
5. Common final report agreed to by all participants.

To achieve this goal, all parties had access to all installation data. In some cases only pre-processed data was useful, which was provided to all parties. Figure 1-4 demonstrates how the measurement results could support simulation validation and also provide a more complete understanding of different scenarios.

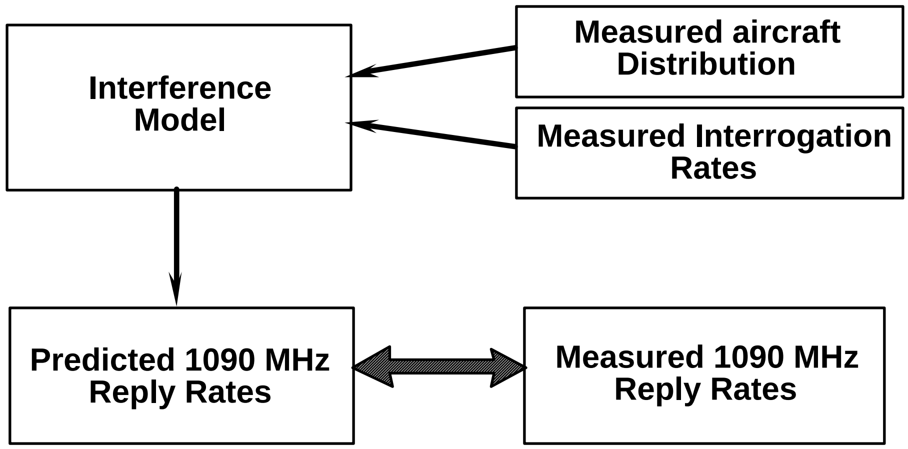


Figure 1-4: Measurement Support for Simulation Model Validation

1.2.1 Particular Questions to be Addressed in the Data Collection and Analysis Effort

The main research questions that were to be addressed through this measurement activity are listed below.

1. What are peak/average 1090 MHz reply and suppression rates and the 1030 MHz interrogation rates in Frankfurt in May 2000?
2. Does the1090 MHz reply rate vary with time, location, and if so, how?
3. Can traffic count, interrogator count, and interrogator IRF explain measured fruit rate?
4. Are transponders that reply to Mode S All/Call interrogations while on the surface at Frankfurt airport a significant source of fruit?
5. What contribution to the interrogation rate (and hence the corresponding 1090 MHz reply rate) is associated with civil and military radar installations?
6. How do measured interrogation rates, reply rates, and suppression rates compare with the measurements made in 1995 in the Frankfurt area?
7. What is the probability of long/short squitter reception in the Frankfurt environment?
8. Does the variation of Extended Squitter performance match model prediction?
9. What is the maximum range at which Extended Squitter provides MASPS-compliant performance?
10. What enhancement in Extended Squitter probability of reception is measured by using a 6-sector antenna for the ground station? Is the performance enhancement necessary? What accuracy of azimuth estimation is obtained by comparing reply amplitude in adjacent sectors of the 6-sector antenna? Is there measurable variation in fruit rate with the azimuthal orientation of the sectored ground antenna?
11. How does the air-to-air and air-to-ground performance compare with results from the FAA-sponsored LAX trials, and the Eurocontrol-sponsored Paris/Toulouse trials?

1.3 PARTICIPATING ORGANIZATIONS

FAA and DFS shared an interest in the air/ground and air/air performance of Extended Squitter in the Frankfurt environment. FAA concentrated on providing equipment, staffing, and data analysis to characterize the air/air Extended Squitter performance, while DFS focused on characterizing air/ground and ground/air Extended Squitter performance. FAA and DFS each concentrated on contributing to RF interference measurements.

FAA supplied one instrumentation/ADS-B aircraft, a Boeing B-727, and the essential elements of a ground station. The FAA ground station elements and the FAA aircraft were based at Wiesbaden Army Base (AB).

DFS supplied one ADS-B aircraft (a Beech King Air B300 operated by Flight Inspection International, FII) and also supplied ground station antennas and instrumentation for the ground station at Langen that was used in conjunction with equipment loaned to DFS by Eurocontrol. DFS also operated the Goetzenhain experimental Mode S radar and arranged for data collection from that radar in support of test flights.

Eurocontrol participated by supplying a UPS AT LDPU ground station equipment and a Fairchild Metroliner II aircraft and crew, equipped with a 1090 MHz Extended Squitter transmitter and receiver (i.e., LDPU). Eurocontrol also arranged for Airsys and ERA ground station equipment. Eurocontrol provided/arranged ground equipment was used to establish three different implementations of Extended Squitter ground receivers at Langen. The Eurocontrol aircraft participated in several of the scheduled data-taking flights. Eurocontrol staff assisted in calibrating and installing all Eurocontrol equipment and analyzing data obtained by the Eurocontrol 1090 MHz receivers. In cooperation with ANS, DFS provided an additional ground station.

MIT Lincoln Laboratory supported FAA by installing and operating a ground station in Wiesbaden and providing and operating measurement equipment on board the FAA aircraft. For both FAA and DFS, Lincoln will reduce and analyze data and prepare the appropriate results.

Flight Inspection International operated an ADS-B equipped aircraft (Beech King Air B300) sponsored by DFS.

NLR operated an ADS-B equipped aircraft (Fairchild Metroliner II) sponsored by Eurocontrol.

German military ATC coordinated with all military forces in Germany for a period of radar interrogator shutdown during two of the scheduled flights. The goal of this activity was to quantify the contribution of military interrogators to the generation of replies on 1090 MHz.

Airsys Navigation Systems operated an ADS-B Extended Squitter receiver at the Langen ground station. The receiver was connected to the same antenna as the LDPU.

ERA operated an ADS-B Extended Squitter receiver at the Langen ground station. The receiver was connected to the same antenna as the LDPU.

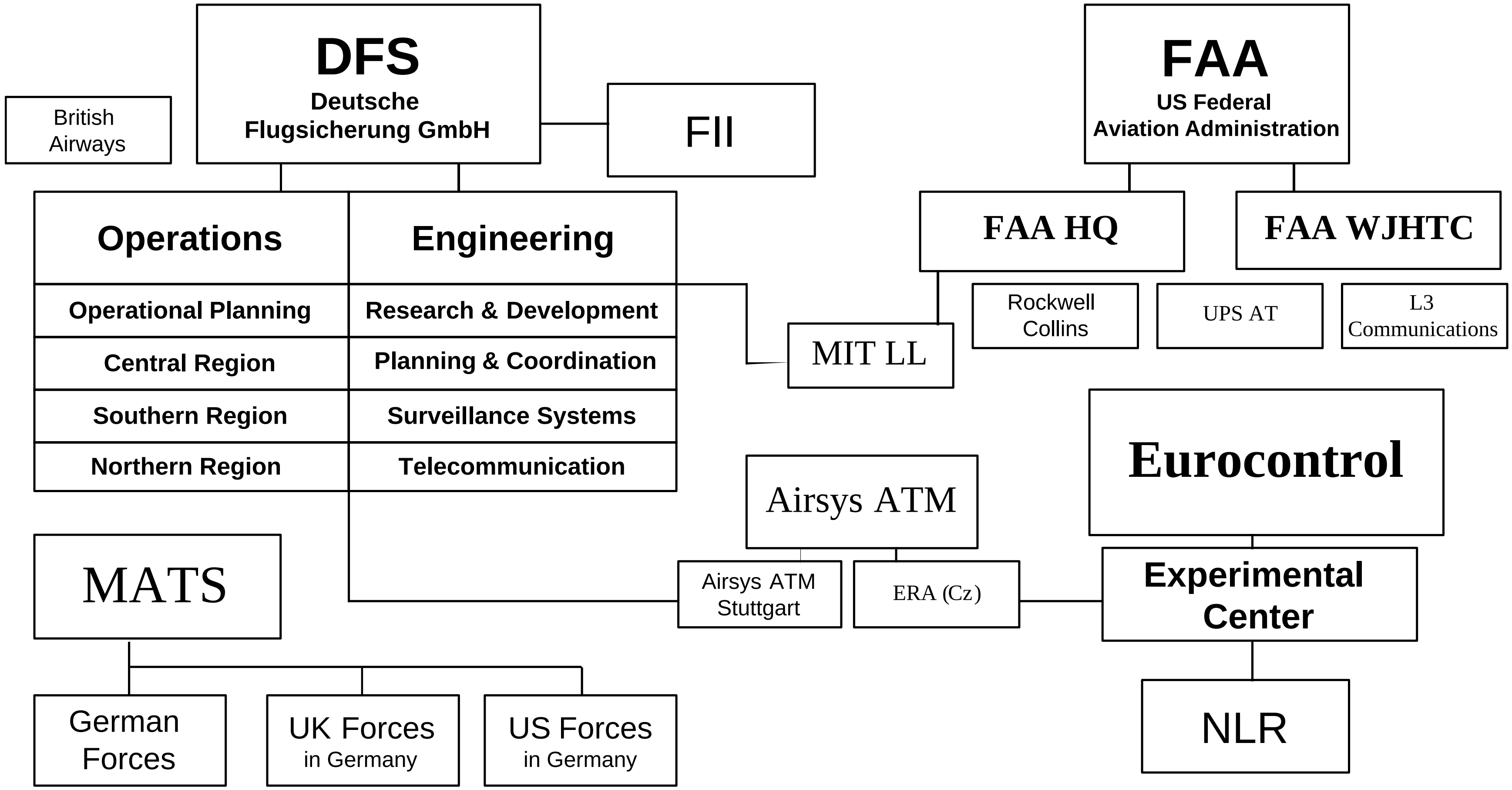
Airsys ATM operated a display system (EASY) connected to the ERA receiver.

UPS Aviation Technology provided airborne equipment (LDPUs, antennas) and provided assistance in reading data files.

Rockwell Collins provided a Mode S transponder with Extended Squitter for the FII aircraft.

L-3 Communications provided the TCAS 2000 and Mode S transponder carried by the FAA 727, and produced the TCAS and transponder equipment carried by the British Airways targets of opportunity. They also provided technical support on interpretation of the measured data.

Figure 1-5 presents an overview of all of the organizations that participated in the measurements program



FAA Federal Aviation Administration
HQ Headqaurter
TC Technical Center

MIT LL MIT Lincoln Laboratory
UPS AT UPS Aviation Technology
MATS Military Air Traffic Services
FII Flight Inspection International

Figure 1-5. Overview of all Participating Organizations

2. EXPERIMENTAL CONFIGURATION

The measurements in Germany made use of three instrumented aircraft and two experimental ground stations, as illustrated in Figure 2.1.1-1. Existing radar ground stations were also used to provide surveillance during the tests. The project aircraft and the ground stations were instrumented with a number of different systems, which are described in this section. In addition to the project aircraft, it was found that a number of operational aircraft were equipped to transmit Extended Squitter, thus providing signals that were received during the tests. These receptions were particularly interesting because they emanated from operational aircraft, and therefore were realistic in regard to the types of aircraft, flight paths, avionics, and aircraft antenna installations.

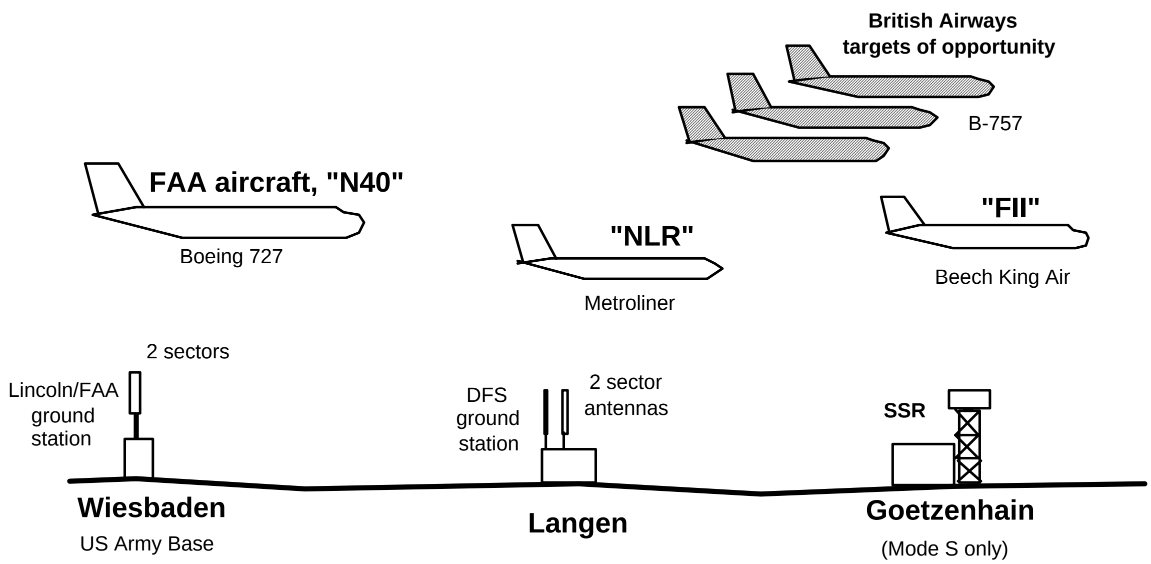


Figure 2.1.1-1. Airborne and Ground Based Facilities in the Tests.

2.1 GROUND FACILITIES

2.1.1 Langen Ground Facility

2.1.1.1 Overview of the Langen Site

Langen was the principal ground data collection site for these measurements. It was equipped with three types of Extended Squitter receivers:

1. <u>UPS AT LDPU,</u> a dual-channel, high sensitivity 1090 MHz receiver that incorporates many of the features of the enhanced reply processing techniques. The dual receiver channels permitted connection to two 66-degree sector antennas for improved coverage of the test aircraft.

2. Airsys Navigation Systems - Mode S Airport Ground Sensor (ANS-MAGS), a single-channel, medium sensitivity receiver without error correction designed for airport applications. This receiver was connected to one of the LDPU sector antennas by means of a splitter.

3. ERA, a single-channel, medium sensitivity receiver without error correction. This receiver was connected to one of the LDPU sector antennas by means of a splitter.

The site was equipped with a test transponder plus additional equipment for data recording, realtime display and communications as show in Figure 2.1.1-1a

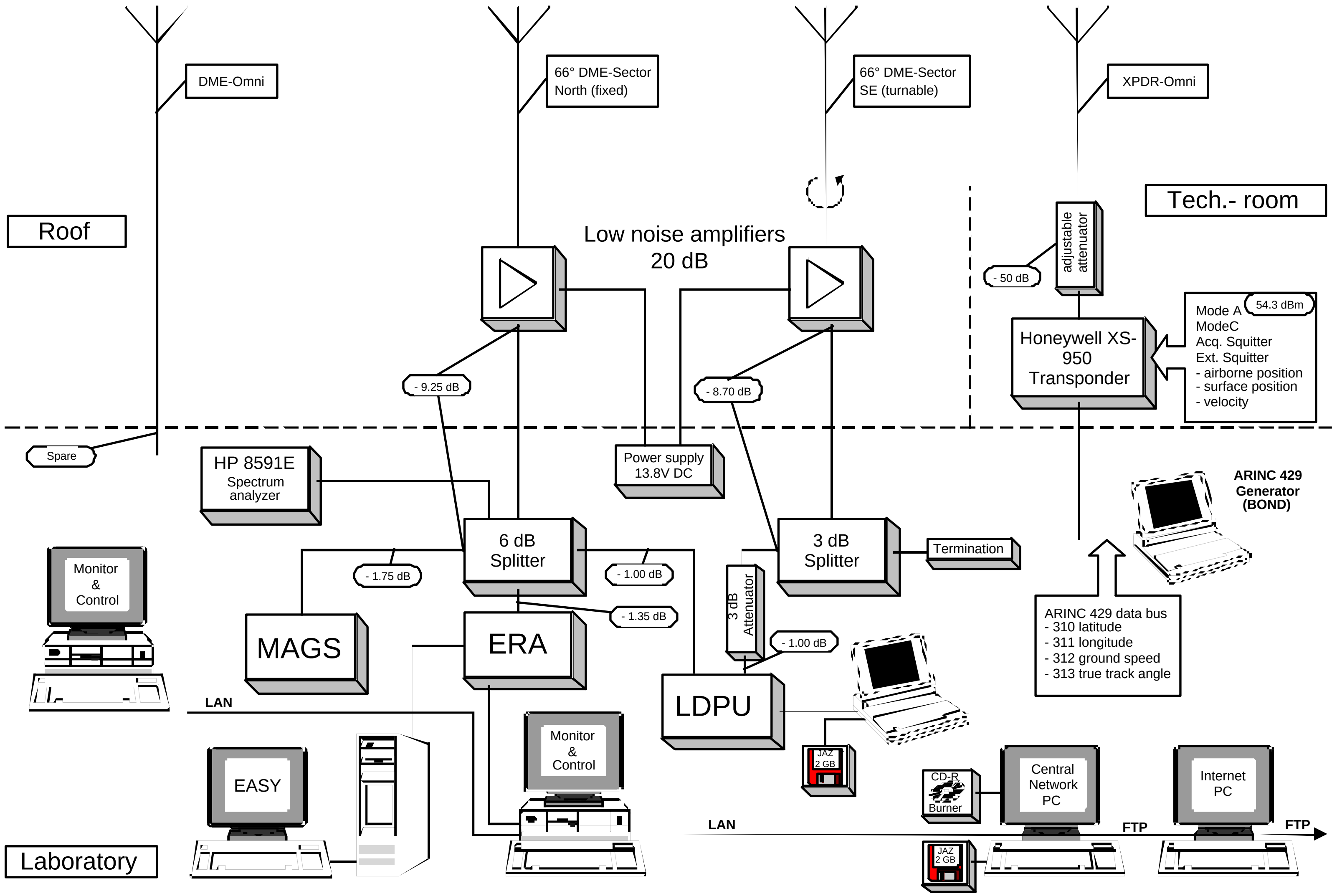


Figure 2.1.1-1a. Langen Ground Station Configuration

2.1.1.1.1 LDPU

A 1090 MHz receiver, part of a UPS AT LDPU, was used to record Extended Squitters. Each receiver of the dual channel LDPU was connected to a sectorized antenna whose nominal azimuthal beamwidth was 66 degrees (-3dB). Connectivity and cable losses are indicated in Figure 2.1.1-1a. The LDPU was configured such that a laptop computer collected the text reports available on the LDPU maintenance port. These text reports were not exhaustive, since reports were only issued by the LDPU as a background task. However, the maintenance file served as a crosscheck on the correct operation of the LDPU. The major data collection within the LDPU was accomplished by writing data to an 80MB flashcard. This card was swapped periodically (which required a 1-2 minute shutdown of the receiver) to ensure that the flashcard data capacity was not exceeded. A realtime, CDTI display was also installed, based on software supplied by FAA WJHTC personnel. This software presented the location of flight test aircraft, based on Extended Squitters decoded by the LDPU, and aided ground personnel in keeping track of the locations of flight test aircraft.

Each LDPU receiver down-converted the input signal to a 60 MHz IF frequency, detected the video signal using a logarithmic amplifier with a 70 dB dynamic range, and then digitized the video at an 8 M sample/second rate prior to applying a series of digital processing algorithms to perform preamble detection and message decoding. The receivers exhibited an approximate gain of 3 a/d counts/dB (in the conversion of input power to digitized video) and an MTL of approximately -87 dBm. Detailed, receiver-specific calibration curves were used to convert all amplitude measurements to dBm referred to the input antenna. These calibration factors accounted for variations from receiver to receiver, and to variations in the cable loss/preamplifier gain combination between each channel of the receiver and its corresponding antenna.

2.1.1.1.2 ANS-MAGS Ground Station

2.1.1.2.1 Overview

The mini-MAGS ground station used during the Extended Squitter trials in the Frankfurt area is a prototype based on a slightly modified MAGS receive-only ground station (MAGS-GSR). MAGS was initially designed for airport surveillance applications. The MAGS system is intended to provide multilateration surveillance and communication services for A-SMGCS. The signal processing algorithms were thus developed to cope with high radio loads and strong multipath influence.

Due to the different operating environment for the Frankfurt trials, some minor modifications were necessary, e.g. an adaptation of the receiver sensitivity and the mechanical realization. Other functions were not integrated for the trials due to the schedule constraints, e.g., ADS-B decoding, ASTERIX output, error correction, etc. The signal processing algorithms, however, remained the same as for A-SMGCS.

The mini-MAGS ADS-B-station comprises two main subsystems:

1. A receive-only ground stations (MAGS -SR), which is able to detect, time-stamp and decode Mode S squitters and Mode S reply signals
2. A central station (MAGS-CS), a Sun workstation computer, that stores all Mode S messages provided by the ground stations on hard disk and monitors and controls the ground station functions.

The two subsystems are connected via a 10BaseT Ethernet LAN which provides sufficient bandwidth for the data transfer. On top of 10BaseT, standard communication protocols from the internet suite (IP, UDP, TCP, SNMP, TFTP, etc.) are used. An additional ISDN router is also connected to the network in order to enable remote control via ISDN telephone lines. The following block diagram shows the mini-MAGS configuration used during the trials.

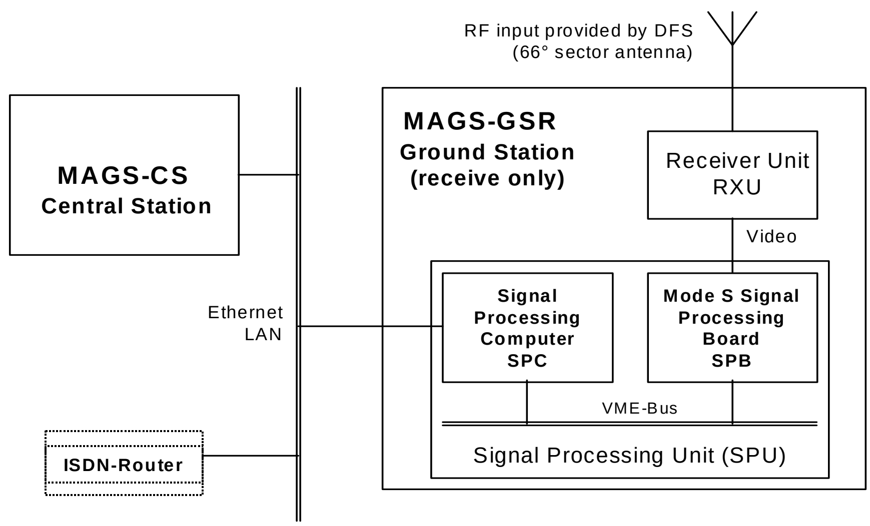


Fig. 2.1.1-1b. Components of the Mini-MAGS ADS-B Ground Station

The MAGS ground station is designed to be a fully autonomous RF and video signal processing unit for the Mode S downlink channel. In order to reduce the amount of data to be transferred to the central station via the internal communication network and to reduce processing load of the central station, the ground station has its own local intelligence. This enables the system to decode and filter the received Mode S reply signals so that only valid and wanted Mode S messages are forwarded to the central station. The functions of the ground station can be monitored and controlled via the network management protocol SNMP.

Due to the prototype character of the mini-MAGS station and the short preparation time, the decoding algorithms for the aircraft positions from the DF17 ME field were not integrated. The mechanical setup of the mini-MAGS prototype does not reflect the final state of the mini-MAGS. Fig. 2.1.1-1c depicts the mini-MAGS installation at Frankfurt.

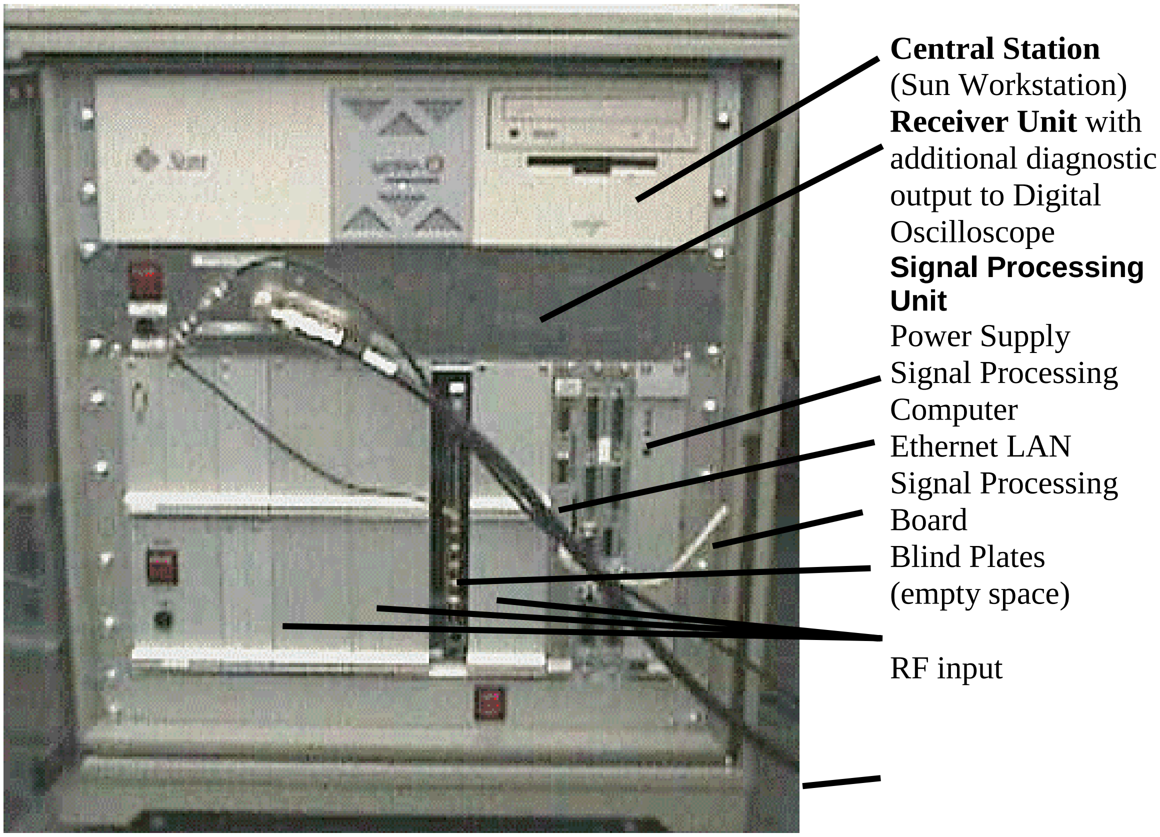


Fig.2.1.1-1c. Mini-MAGS Prototype Used for the Frankfurt Trials

2.1.1.2.2 Receiver Unit (RXU)

The function of the RXU is to receive Mode S downlink signals (1090 MHz) over a large dynamic range and provide a demodulated video signal. Signals from adjacent channels are kept out by means of a bandpass filter. A limiter protects the highly sensitive receiver input against destruction by strong signals.

Due to the short preparation phase, performance matching of the components was not optimal. In particular due to the limited dynamic range of the logarithmic amplifier and the hard cut-off by the limiter, the receiver was easily saturated by the reference transponder whose antenna was close to the receiving antenna. The overall characteristic of the modified receiver can be seen in the following diagram.

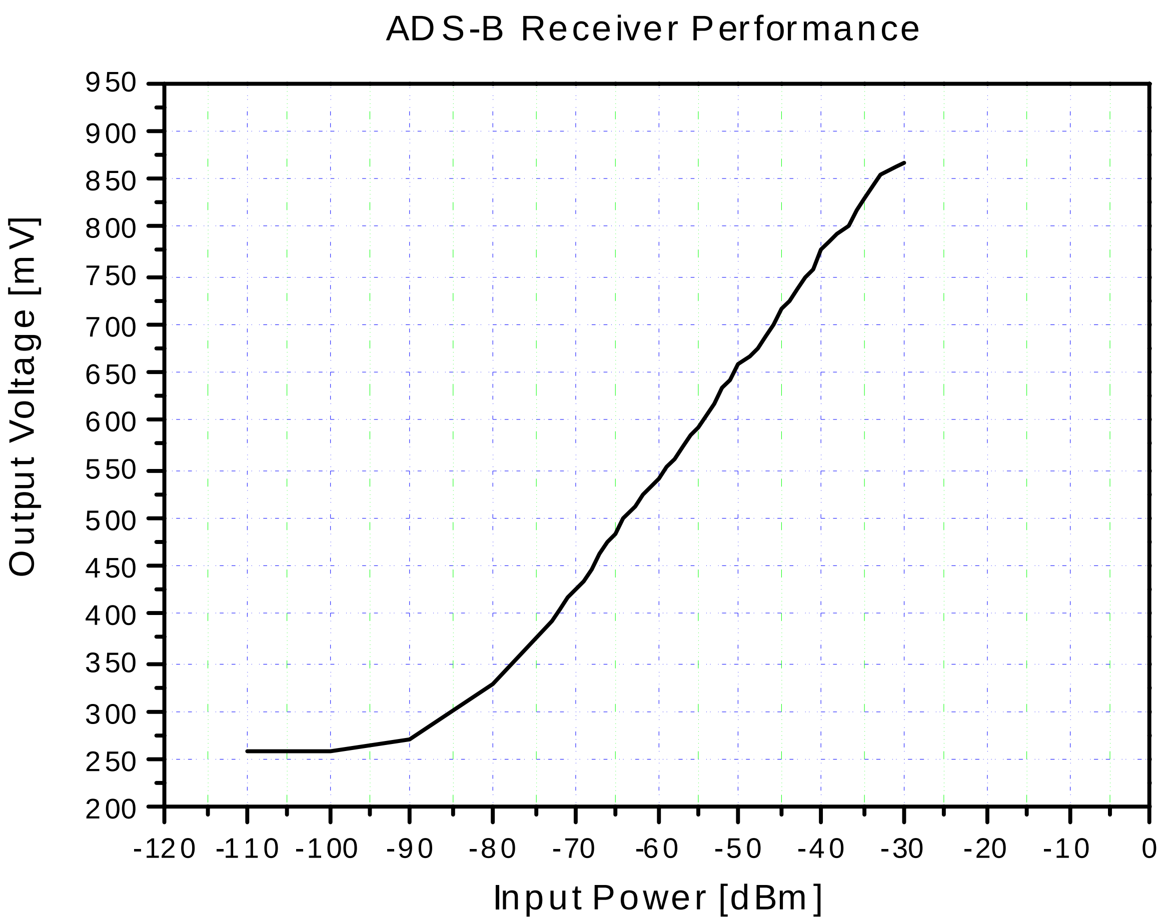


Figure 2.1.1-1d. Performance of Mini-MAGS Prototype RXU

2.1.1.2.3 Signal Processing Unit

The signal processing unit's Signal Processing Board (SPB) is a proprietary ANS board designed according to current industrial standards using surface mounted devices on a multilayer board in double Europe format. It is the essential part of the MAGS ground station and receives, analyses and decodes Mode S downlink messages to store them in a dual-ported memory for further processing in the Signal Processing Computer (SBC). Additionally for each Mode S reception, the time of arrival is determined with a resolution of 7.5ns.

Periodically, the SPB dual ported RAM is polled by the SPC. If there is data available it is read completely. In the next step, the first five bits of the Mode S data block (downlink format number) are evaluated and all formats not configured for further processing are discarded in order not to overload the system with unwanted signals. This filter was set to allow only DF-4, 5, 11,16, 17, 20, 21, and 24 during the trials.

All data correctly received is forwarded via the TCP/IP stack to the network. In order to make best use of the available bandwidth, the packet size for network transfer is dynamically optimized (MAGS runs usually on telephone lines in airport applications).

2.1.1.2.4 Central station

The task of the central station during the Frankfurt trials was only to receive decoded data from the GSR, time stamp it using the absolute system time (10 ms resolution) and store it on hard disk. In parallel the received raw data was output on the screen as a quick reference during the trials.

2.1.1.1.3 ERA

2.1.1.1.3.1 Function

The ERA ADS-B receiver is intended for surveillance and tracking of aircraft that are equipped with Mode S Extended Squitter. The equipment receives broadcast position and velocity as well as aircraft identification.

The system includes one suitably sited <u>receiving station</u>. Signals received by this station are transferred to the <u>central processor unit</u> in real time. The received signals are processed in the central processor. After processing the received signals, an aircraft is unambiguously identified by the following set of data:

1. ICAO 24-bit address (including country of origin)
2. Location defined in latitude and longitude
3. Altitude / GNSS height
4. Mode A code (obtained from Mode S surveillance replies)
5 Call sign - identification

Automatic evaluation / tracking of detected parameters (aircraft identification, position, altitude) is performed by the central processor with the aim of minimizing false messages and improving data validation from garbled replies. Output messages containing data of the tracked aircraft are transmitted in ASTERIX Cat. 20/21 format to the host system for further processing and displaying. The transmitted data together with system status are also available on a local maintenance monitor.

2.1.1.1.3.2 Description

The ERA ADS-B system consists of:

1. One receiving station (receiving antenna, rack with receiver's electronics, cables), and
2. One central processor unit (PC, measuring unit).

The receiving station receives signals from airborne SSR transponders in modes A/C/S satisfying the ICAO Annex 10 requirements. The equipment is composed of the following units:

1. Receiving antenna. The receiving antenna is oriented towards the airspace of the required system coverage and serves for the receiving of signals from SSR transponders (1090 MHz)

2. Rack with receiver's electronics. This unit contains an SSR signals receiver. This rack may be installed either on a dedicated mast or mounted on some part of a building in which the equipment is installed (handrail, rod, etc.). Detected signals from SSR transponders are processed by an SSR receiver and transmitted in the form of amplitude normalized video signals through a coaxial cable to the central processor unit.

The central processor unit consists of the central processor computer (PC), the measuring unit (MU), designed as a PCI card built into the PC, and Software (ADS-B SW)

The central processor unit processes SSR signals received from the airspace covered by the system. Software is an integral part of the central processor unit. The software provides overall control of the receiving station, processes received data, generates messages about tracked aircraft and transmits them to a host system.

The central processor unit performs these main tasks:

1. Reception of signal flow from the receiving station
2. Detection of received SSR code group (modes A/C/S)
3. Decoding of modes A/C/S of SSR code group

4. Correlating decoded and evaluated incoming Mode S replies from the receiver to individual tracked targets based on the 24-bit address
5. Determination of aircraft position / altitude
6. Automatic entering/excluding of aircraft into/from tracking
7. Automatic tracking of 500 aircraft maximum
8. Output message generation for transmission to a host system
9. Display of positions and codes of tracked aircraft on a local maintenance display
10. Display of system status information on a local maintenance display

2.1.1.1.4 Antenna Radiation Pattern at the Langen Ground Station

During the flight trials, two 66° (-3 dB point) beamwidth directional antennae were installed at the Langen Ground Station site. The main lobes of the antennae were directed to azimuths of 0° and to 135° respectively, as it is depicted in Figure 2.1.1-2 and therefore optimized for the northbound and southbound flight profiles. Consequently the calibration profile, also indicated in Figure 2.1.1-2, flown on the first day as well as the round trip profiles flown on the third and the fifth day were only partially covered by the antenna beams.

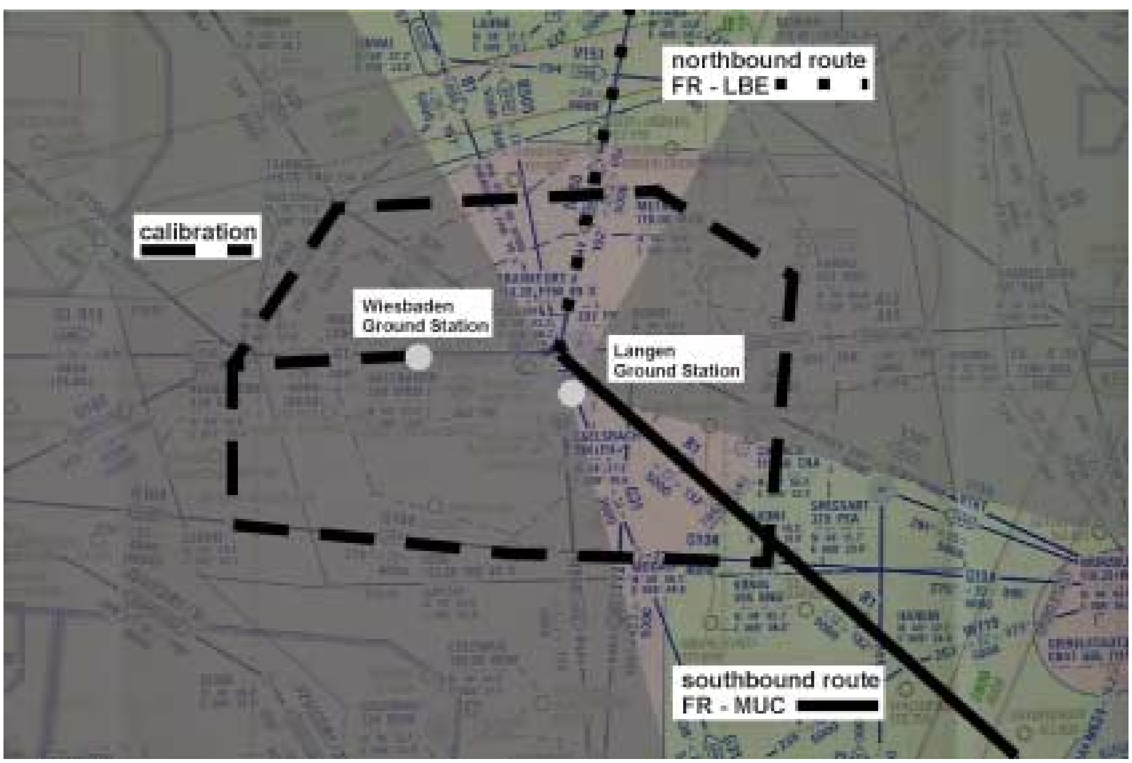


Figure 2.1.1-2. Location of Ground Facilities and Orientation of Langen Antennas

Although not ideal, the Langen antenna site is serviceable for purposes of this test program. Figures 2.1.1-3 to 2.1.1-5 show more specifics. The plan view in Figure 2.1.1-

3 shows the relationship between buildings, including the DFS building where the antennas were installed and several nearby buildings. The antennas were mounted on the roof of the academy building, approximately 15 feet above the roof level.

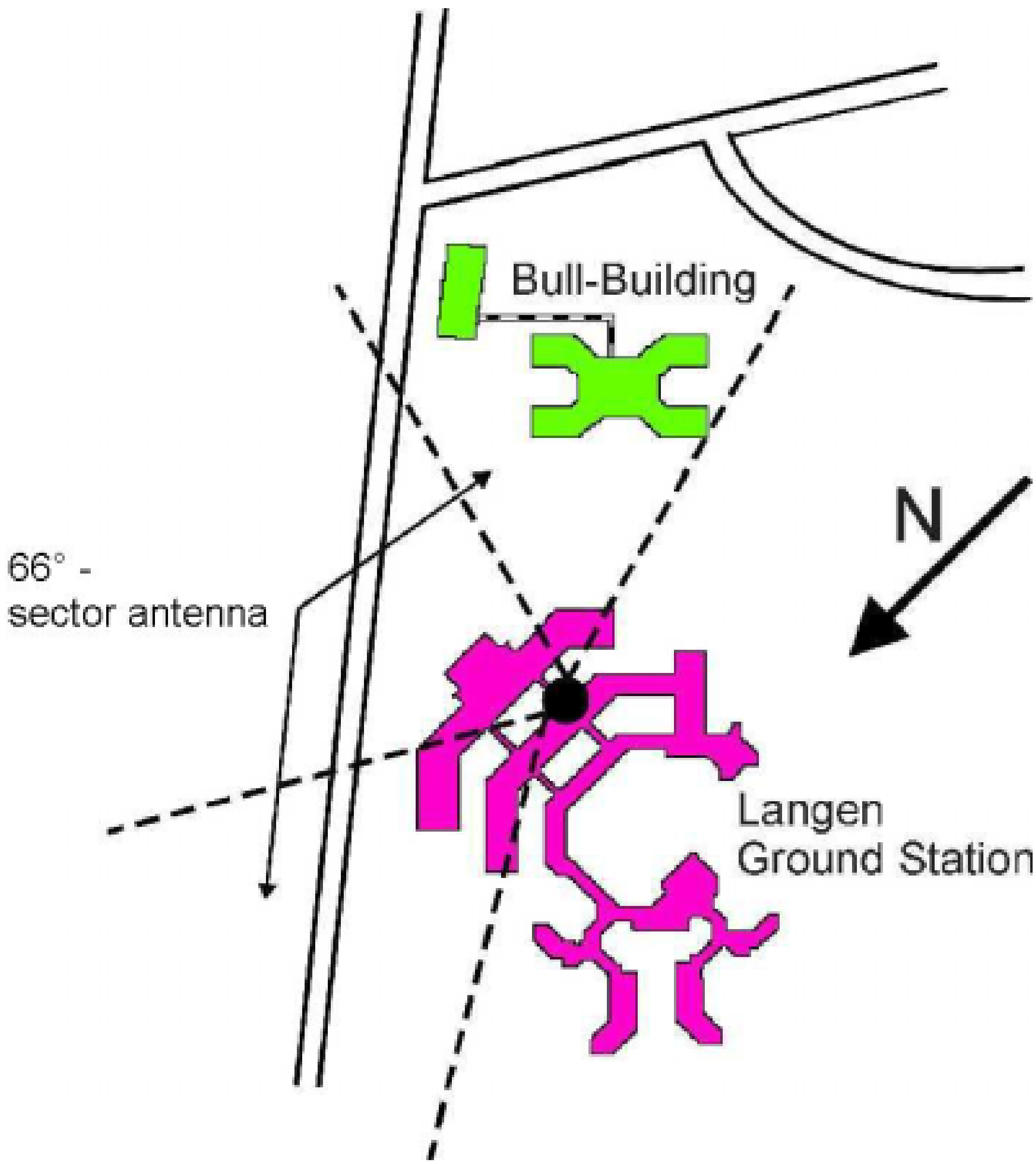


Figure 2.1.1-3. Langen Antenna Location within the DFS Training Center

Figures 2.1.1-4 and 2.1.1-5 are horizon photographs showing the visible horizon from this antenna location. The southeast antenna beam is noticeably affected by the Bull Building, which is higher than the antennas by about 3 meters. The building is about 150 meters away, and therefore blocks the lower 1.2 degrees of coverage in that direction. Note also that in the direction of the center of the Bull Building is a somewhat higher obstruction, which is a more distant building. It obstructs about 4 degrees in elevation over a smaller region in azimuth.

The horizon in the north sector (Figure 2.1.1-5) appears to be significantly better. There are no significant building obstructions in this sector, and the horizon is generally a landscape of trees and distant mountains (the Taunus mountains). However, in the direction between the two towers, the horizon is 1.2 degrees in elevation angle. There is a general rise in horizon elevation going from west to east, and the horizon view is limited to approximately 1 to 2 degrees by the ground and trees. More detailed information on the horizon coverage is given in 2.3.1.

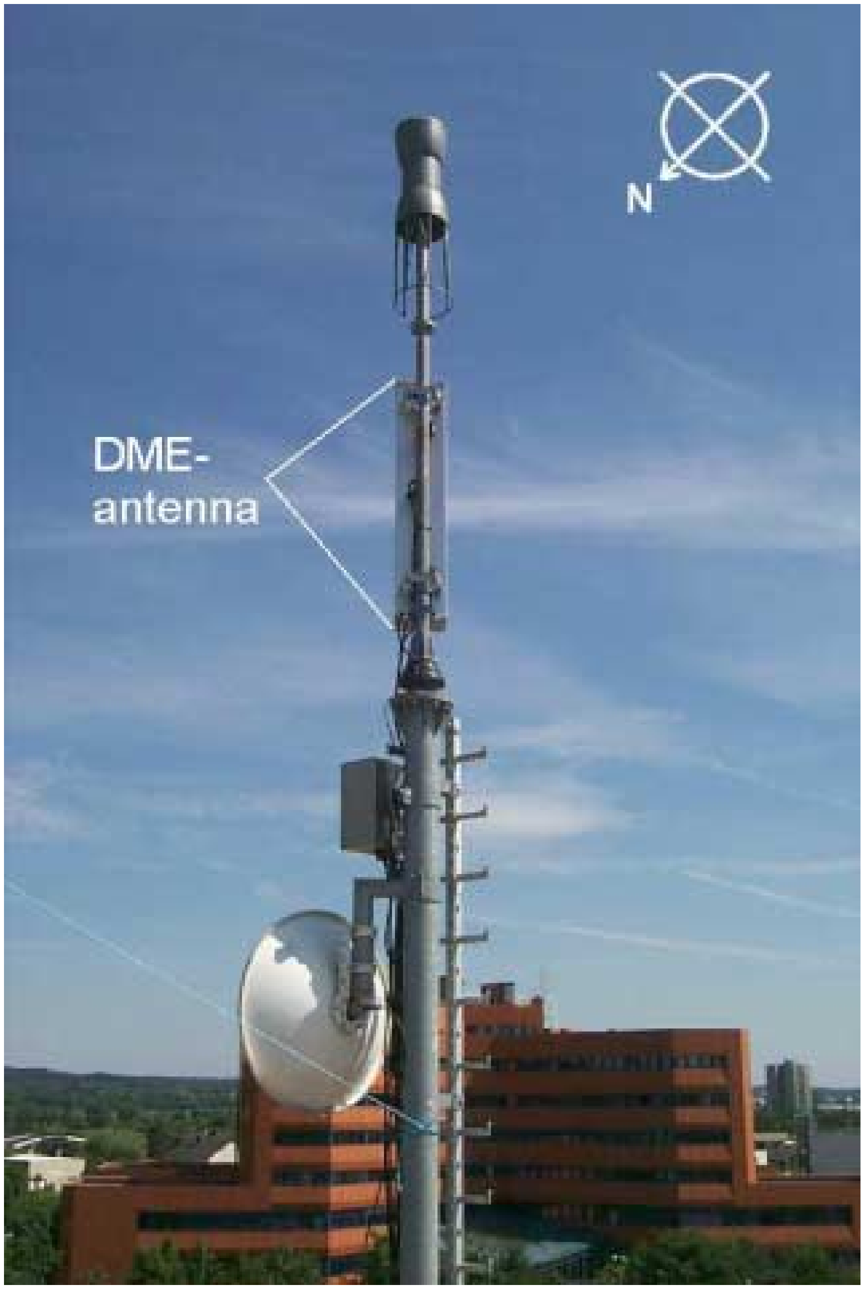


Figure 2.1.1-4. Langen Ground Facility Line of Sight for the 135 Degree Antenna Beam

Note. *The photo shows one of the two antennas. The building obstruction on the horizon is approximately 1.2 degrees in elevation angle throughout much of this sector, with a higher obstruction (4 degrees) in a smaller central region.*

Figure 2.1.1-5. Langen Ground Facility Line of Sight for the 0 Degree Antenna Beam

Note. The hills beyond the two towers are 1.4 degrees in elevation angle.

2.1.1.1.5 Langen Reference Transponder

An L-3 Communications (formerly Honeywell) XS-950 SSR/Mode S transponder was chosen for the trials (Figure 2.1.1-6). This transponder was delivered from Eurocontrol EEC not only for the trials but also for other Mode S related experiments. The XS-950 is able to fill the BDS registers used for Extended Squitter and enhanced surveillance. The ARINC 429 bus data is directly used, no external devices are necessary. A detailed description of this transponder is as follows:

<u>SSR/Mode S transponder L-3 Communications XS-950</u>
P/N 75178000-10002R, S/N 98101509
S/W P/N 200F-00042
<u>Output Power (bench measurement)</u>
Top Antenna Port: 378.9 Watts, 55.8 dBm
Bottom Antenna Port: 380.0 Watts, 55.8 dBm
<u>Antenna type</u>
Rohde & Schwarz coaxial dipole 1000 to 1100 MHz
VSWR 1.25 (typical)
Gain 3.5 dB
<u>Cable loss</u> 4 dB

Attenuation (cable plus attenuator) 50 dB

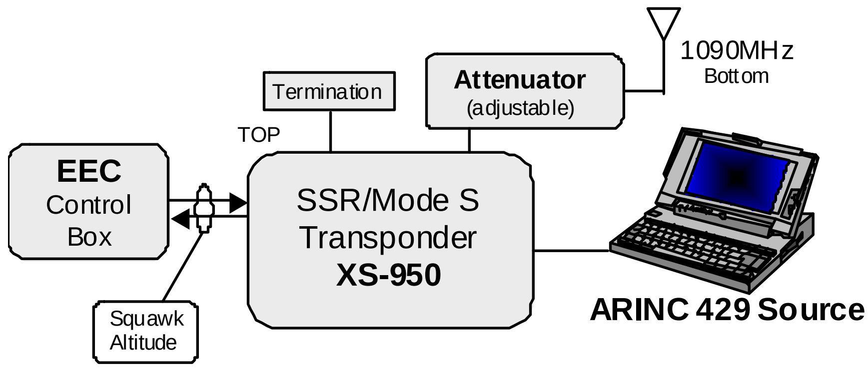


Figure 2.1.1-6. Langen Transponder Installation Scheme

The transponder is installed in a rack, which contains all peripherals needed to operate the transponder (Figure 2.1.1-7). These are in detail:

Power supply/converter (28 DC to 115/400 Hz AC),

Control box (EEC type),

Interfaces to transponder ports for ARINC 429 data,

RF antenna connections

The EEC control box enables the user to program altitude, Flight ID and "squawk ident" without any external data sources. Nevertheless, ARINC data from external sources can be feed into the transponder via the appropriate interfaces (Table 2.1.1-1). As an ARINC 429 source, a portable PC with special hard- and software has been used (Figure 2.1.1-8). By feeding the XS-950 with static ARINC 429 data, the transponder was able to broadcast the Airborne Position, Surface Position and Velocity squitters. Due to a wiring problem the transponder could not transmit the Identity and Type squitter.

During the tests the XS-950 was normally operated with 50 dB attenuation. This prevented the ERA and ANS-MAGS stations from being overloaded by the transponder signal. The LDPU did not have this problem, it received and processed these squitter under all conditions. Transponder operation with the attenuator limited the ability of the project aircraft to make measurements of ground-to-air reception performance with this particular ground transponder.

Figure 2.1.1-7. Langen Transponder Rack

Figure 2.1.1-8. Langen ARINC 429 Source

Table 2.1.1-1. ARINC 429 Data

	Parameter	Value	Unit	Bit rate
310	Present position LAT	50.00793919	deg/180	100 kbps
311	Present position LON	08.65377433	deg/180	100 kbps
312	Ground speed	20	knots	100 kbps
313	Track angle true	45	deg/180	100 kbps
320	Magnetic heading	90	deg/180	100 kbps
325	Roll angle	5	deg/180	100 kbps
335	Track angle rate	+3	deg/sec	100 kbps
365	Inertial vertical velocity	+1000	ft/min	100 kbps

2.1.2 Wiesbaden Ground Facility

2.1.2.1 Overview of the Wiesbaden Site

An Extended Squitter ground facility was assembled at the U. S. Army Air Field at Wiesbaden, Germany. Figure 2.1.2-1 shows the six-sector antenna used at the site, Figure 2.1.2-2 shows the line of sight looking east from the antenna. The LDPU, a dual-channel receiver, was connected to two adjacent sectors of a 6-sector antenna (only these 2 sectors were used during the trials).

The site equipment included the following components:

A 1090 MHz receiver as described in 2.1.1.1.1 installed by Lincoln Laboratory personnel. The connectivity and cable losses for this installation are presented in Figure 2.1.2-3.

An RF Measurement Facility (RMF) installed by FAA WJHTC personnel, which recorded digitized video via a UPS AT receiver/log amp and a 10 MHz digitizer. The RMF shared an antenna (via a dual circulator arrangement illustrated in the Figure 2.1.2-3) with the broadcast transponder.

A test transponder was connected to an omni-directional DME antenna. The transponder was isolated from 1030 MHz inputs through a dual circulator arrangement, which prevented the transponder from responding to interrogations by external equipment (such as TCAS units). The transponder was configured to broadcast 2.2 Extended Squitters per second (2/second position squitters, and 1/5 second ID squitters). The broadcast position and altitude were user selectable. Extended Squitters from this transponder were received by the flight test aircraft to measure the uplink performance in the Frankfurt area.

Figure 2.1.2-1. Wiesbaden Six-Sector Antenna

Figure 2.1.2-2. Line of Site Looking East from the Antenna

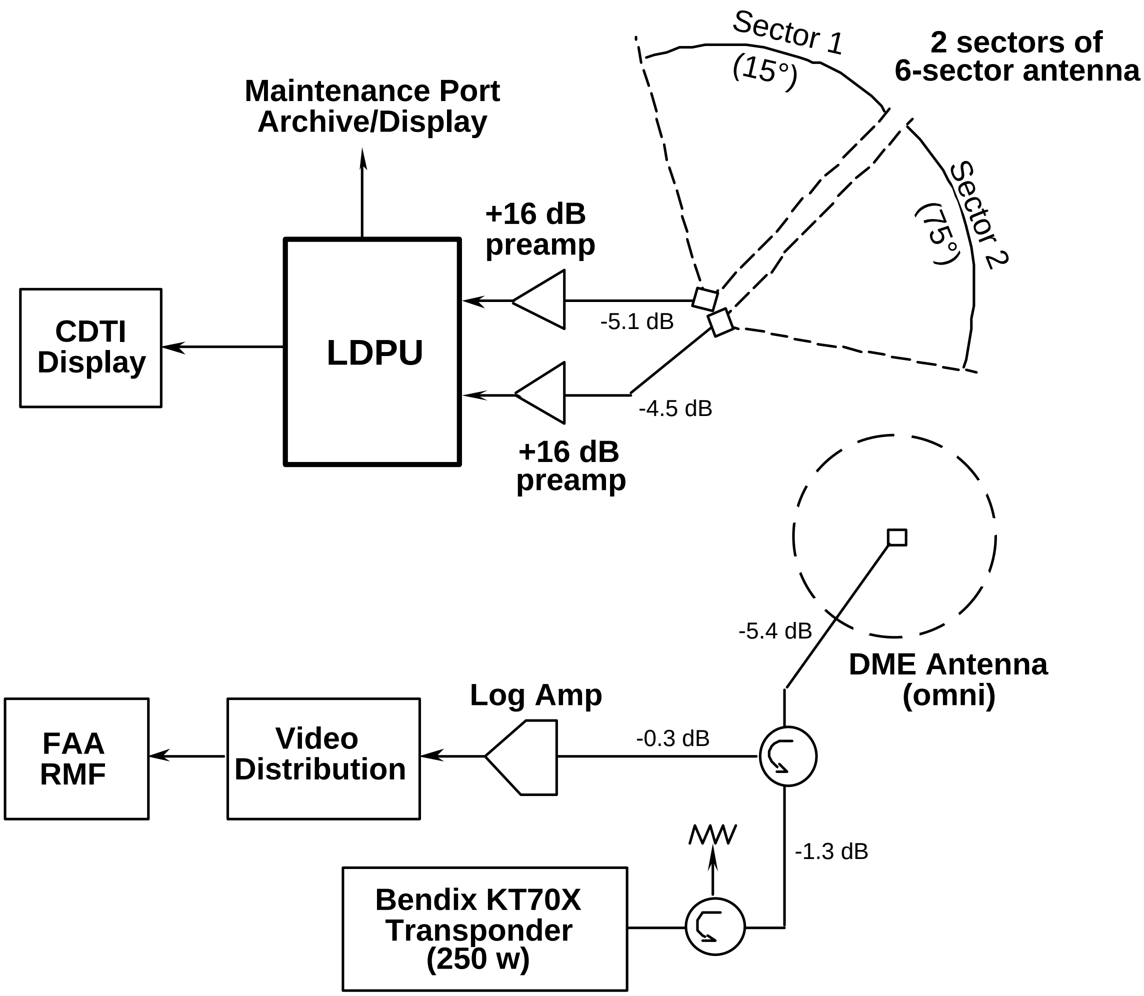


Figure 2.1.2-3. Wiesbaden Ground Facility Connectivity and Cable Losses

2.1.2.2 Receiver Description

The LDPU receiver was similar to units installed at the Langen ground station (2.1.1.1.1), and in the flight test aircraft (FAA B727, FII King Air, and NLR Metroliner).

The RMF utilized the RF front end and log amplifier from an LDPU. The video output was subsequently buffered in a video distribution system, digitized at 10 M samples/second, and recorded by a Sony digital recorder.

2.1.2.3 Antenna, Cabling, Calibration

The multi-sector receive antenna consisted of an assembly of six modified DME antennas, configured to provide six sectors, each 60 degrees wide at the -3 dB power points. A picture of the multisector antenna is provided in Figure 2.1.2-1. The view to the east from the location of the 6-sector antenna is shown in Figure 2.1.2-2. There were no nearby obstructions within the main beams of the two active sectors of the antenna. However there were various other nearby antennas, light posts and other obstructions at azimuths that were out of the antennas main beams. Also the Taunus Mountains to the north and northwest, and distant hills at other azimuths appear to have limited the ultimate line-of-sight range for targets in the main beams.

An omnidirectional antenna, connected to the RMF (receiver) and the uplink test transponder was mounted slightly behind (to the southwest) the multisector antenna. It can also be seen in Figure 2.1.2-1. Although this antenna was of an omnidirectional design the mounting location was characterized by several nearby obstructions including other antennas and light posts which could be expected to influence this antenna's installed characteristics.

2.1.2.4 Transmitter Description

The uplink transmitter was a Honeywell KT70x Mode S transponder. This transponder was based on a certified general aviation model, the KT70, and modified by the manufacturer to support level 3 Mode S data link and ADS-B Extended Squitter transmissions. The output power at the transponder terminals was 250 Watts. The transponder transmitted Extended Squitters at 2/second (position) and 1/5 seconds (identity).

2.1.3 ATCRBS and Mode S Radar Site Coverage

Five interrogators were used for ATCRBS and Mode S radar surveillance during the trials. The combined surveillance of these radars almost completely covers the flight paths of the trials aircraft. The radars are listed in the following table:

Radar name	**ID**	**Range [nmi]**	**Scan time [s]**	**SAC/SIC**	**Data type**
Neunkircher Hoehe	NKH	150	11.6	62/39	ASTERIX CAT 1, 2
Luedenscheid	LUD	150	10.0	62/38	ASTERIX CAT 1, 2
Deister	DEI	150	11.6	62/36	ASTERIX CAT 1, 2
Nordholz	NHZ	150	11.8	62/33	ASTERIX CAT 1, 2
Goetzenhain	GOT	150/200	10.0	62/30	ASTERIX CAT 2, 16

The experimental Mode S interrogator at Goetzenhain is located 2.5 nautical miles east of Langen. It can be operated in two Mode S configurations (Surveillance or Data Link) or as a 'normal' ATCRBS radar. The Mode S surveillance configuration was used during the trials. In this mode the ASTERIX output is compatible with all recording and display tools, but the target processing is limited to 128 Mode S aircraft per scan. Since more than 128 aircraft are normally flying in the Goetzenhain coverage area, the radar output power was reduced to avoid heavy overload conditions. Nevertheless, in peak times, the number of targets exceeded 128 due to the dense aircraft population in the vicinity of Frankfurt. This caused target losses and problems in target re-acquisition in some cases.

Figure 2.1.3-1 shows the coverage of all ATCRBS radars (the position of GOT is north of NKH), Figure 2.1.3-2 shows the reduced Goetzenhain coverage.

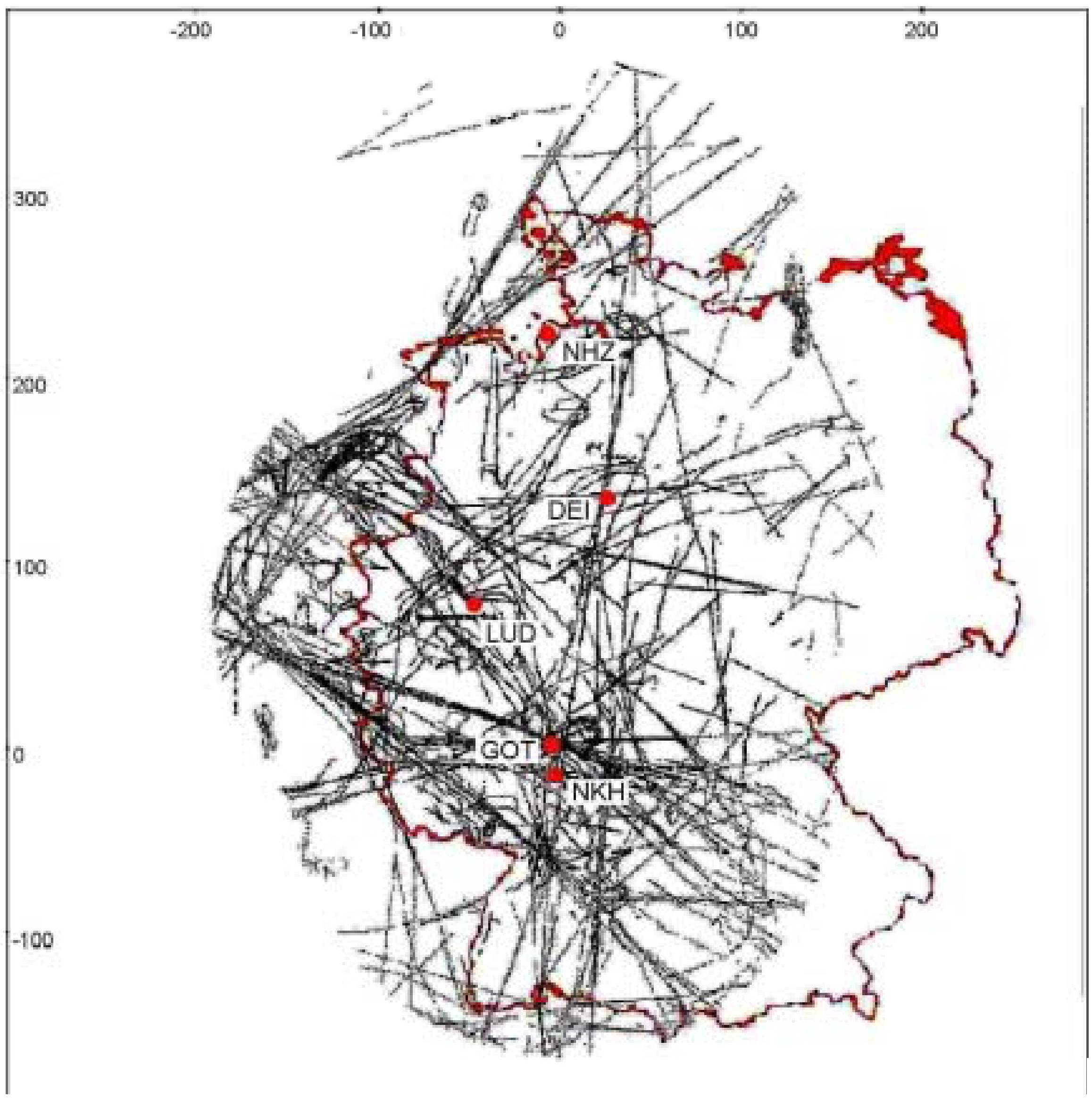


Figure 2.1.3-1. ATCRBS Coverage (4 Radars)

Note: The axes represent the number of nmi from Goetzenhain.

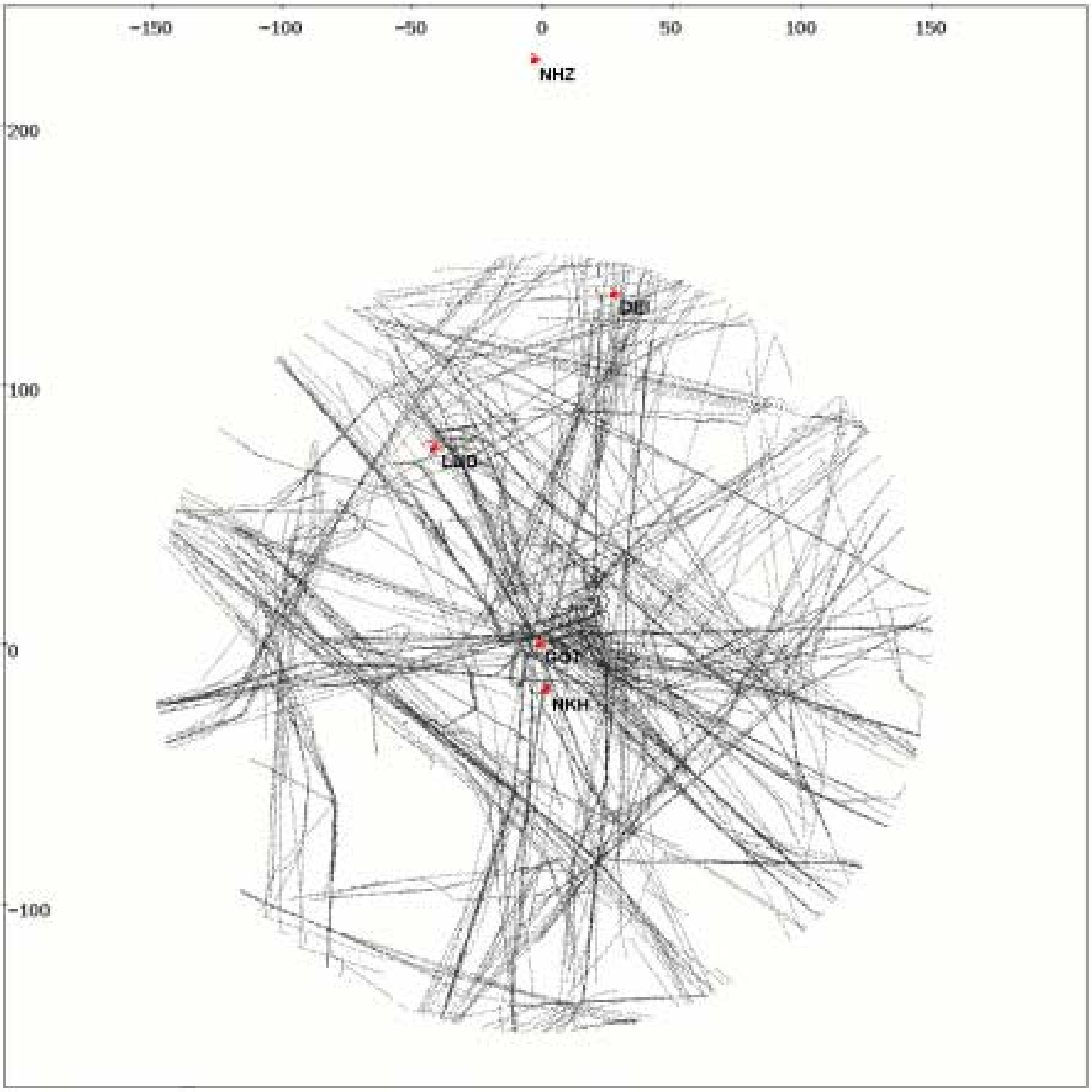


Figure 2.1.3-2. Goetzenhain coverage

Note: The axes represent the number of nmi from Goetzenhain.

2.2 AIRCRAFT AND AIRBORNE AVIONICS

2.2.1 FAA BOEING 727 (N40)

2.2.1.1 Overview

Aircraft N40 was the most highly instrumented of the three project aircraft. In addition to a Mode S transponder for transmitting Extended Squitter signals, N40 was equipped with two ADS-B receiving systems:

1. Link Display Processing Unit (LDPU, UPS AT, 2.2.1.2)
2. TCAS 2000 (L-3 Communications, 2.2.1.3)

and also four instrumented receivers:

1. RF Measurement Facility (RMF, FAA WJHTC)
2. Datalink and Transponder Analysis System (DATAS, FAA WJHTC)
3. Airborne Measurement Facility (AMF, Lincoln Laboratory)
4. 1090 MHz Test Bed (Lincoln Laboratory)

The instrumented receivers were used for calibrated measurements and recordings of squitter receptions and interference. The functions of the instrumented receiving systems on N40 are shown as block diagrams in Figures 2.2.1-1 to 2.2.1-3. Having data recorded simultaneously in several different forms is useful for validating the measurements. This extensive database of recorded data is also useful for performing detailed analyses as may be necessary to investigate particular results of interest.

DATAS (Figure 2.2.1-1) is a flexible instrumentation facility developed by the FAA WJHTC over a number of years. DATAS can be used in both 1030 MHz and 1090 MHz, and includes a pulse detector and a reply detector implemented in hardware. DATAS is described in more detail in 2.2.1.4.

The AMF (Figure 2.2.1-2) is a pulse-level recording system, which was developed at Lincoln Laboratory during the Mode S development program. Pulses are detected in real-time hardware, and recorded individually for post-mission analysis The AMF is described in more detail in 2.2.1.5.

The 1090 MHz Test Bed (Figure 2.2.1-2) was developed in the mid 1990's in the Extended Squitter program at Lincoln Laboratory. Like the RMF, it records reception data in a very detailed form. More specifics are provided in 2.2.1.6.

The RMF (Figure 2.2.1-3) is a dual channel high speed digital recorder using a 10 MHz sampling rate. The RMF was used to record the log-video waveform output from each of the two channels of the LDPU 1090 MHz receiver's front end. The RMF is described in more detail in 2.2.1.7. .

For 1090 MHz, the LDPU receiver provided by UPS Aviation served as an Extended Squitter receiver and also supplied 1090 video to both the DATAS receiver and the 1090 MHz Test Bed. As illustrated in Figure 2.2.1-4, the LDPU was used for front-end reception and conversion to a log-video signal. After that, the video signal was distributed in four ways, to the LDPU processor, to the DATAS processor, the RMF and to the Test Bed.

The interior of N40 with the installed equipment is shown in Figure 2.2.1-5. The antenna configuration on N40 for the Frankfurt flights is indicated in Figure 2.2.1-6. The N40 cabin configuration is shown in Figure 2.2.1-7.

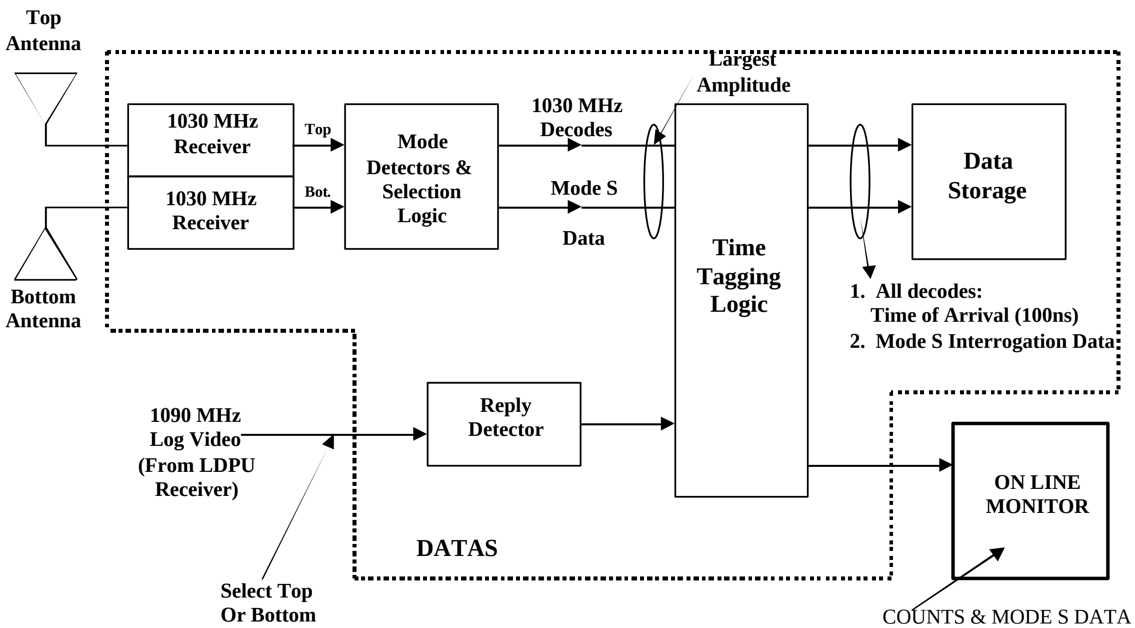


Figure 2.2.1-1. N40 DATAS Equipment

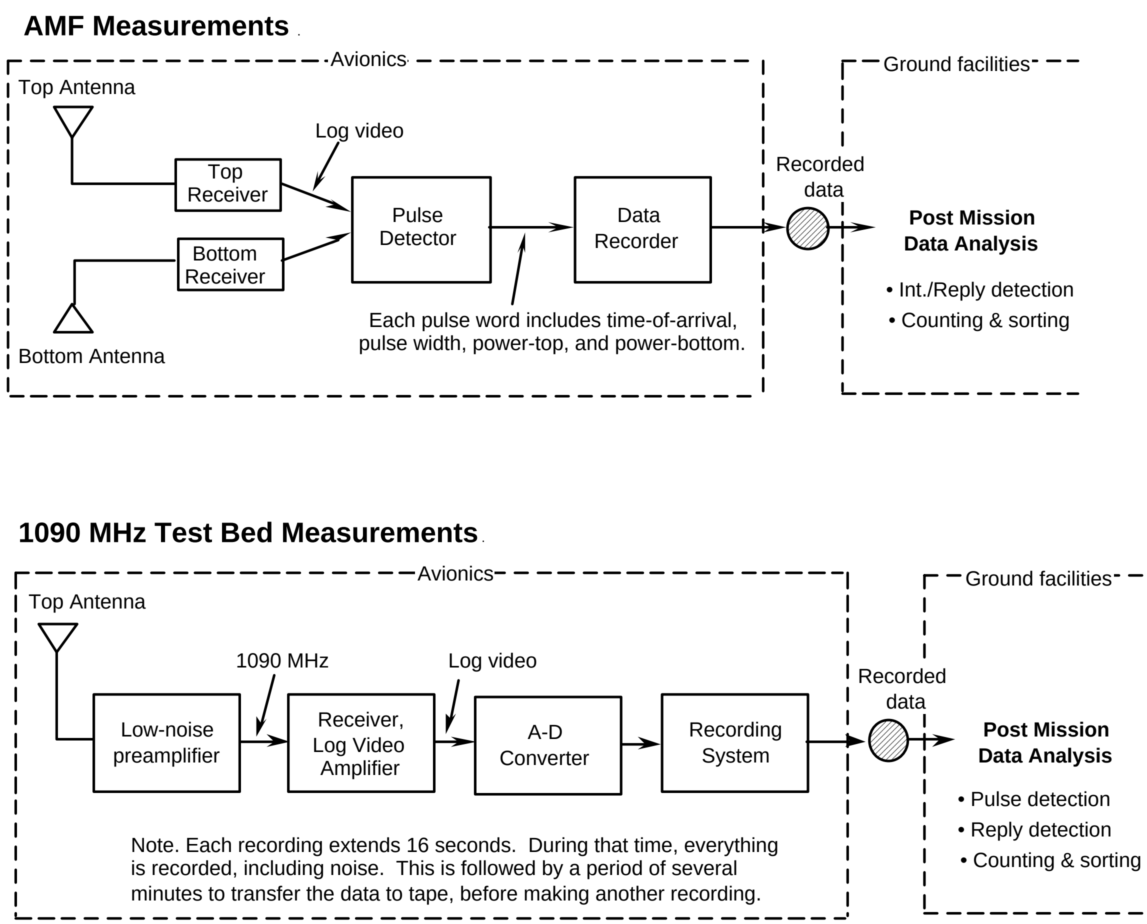


Figure 2.2.1-2. N40 AMF and 1090 MHz Test Bed Equipment

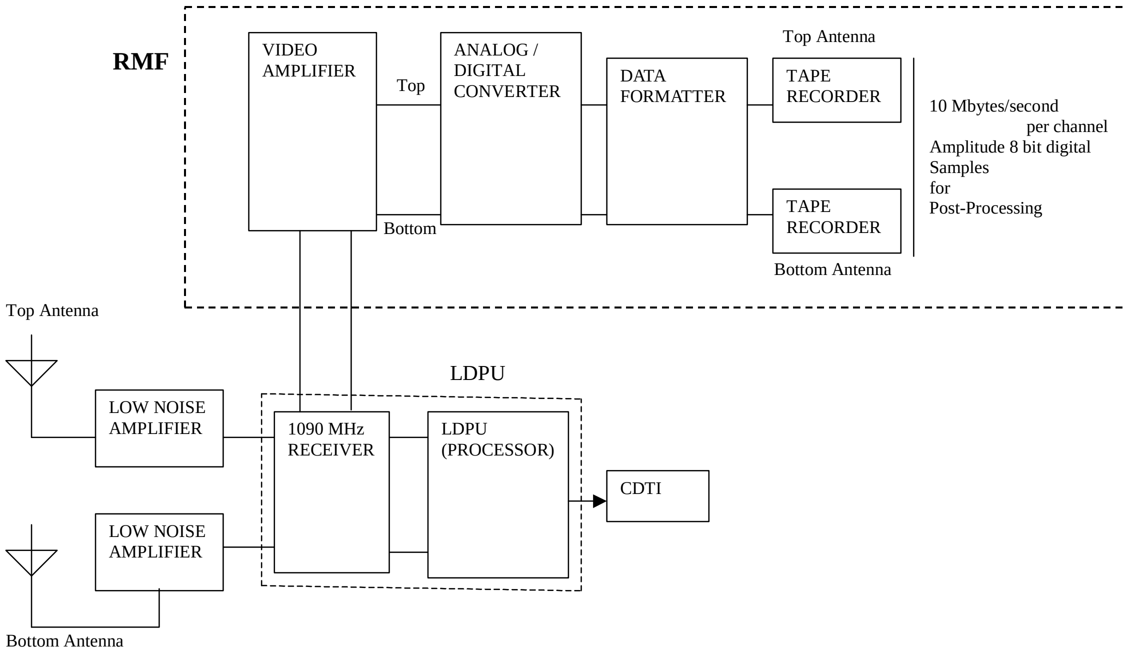


Figure 2.2.1-3. N40 RMF Equipment

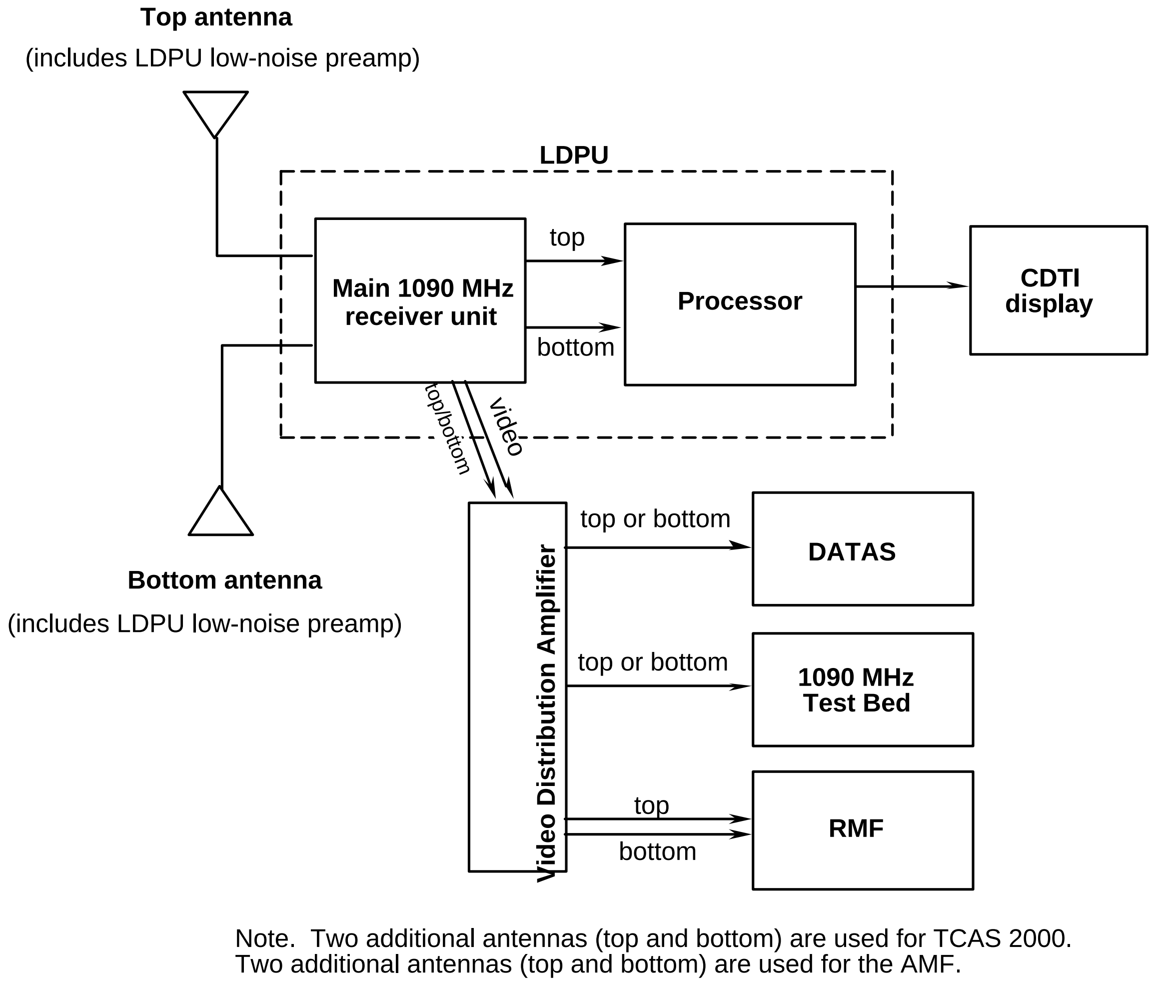
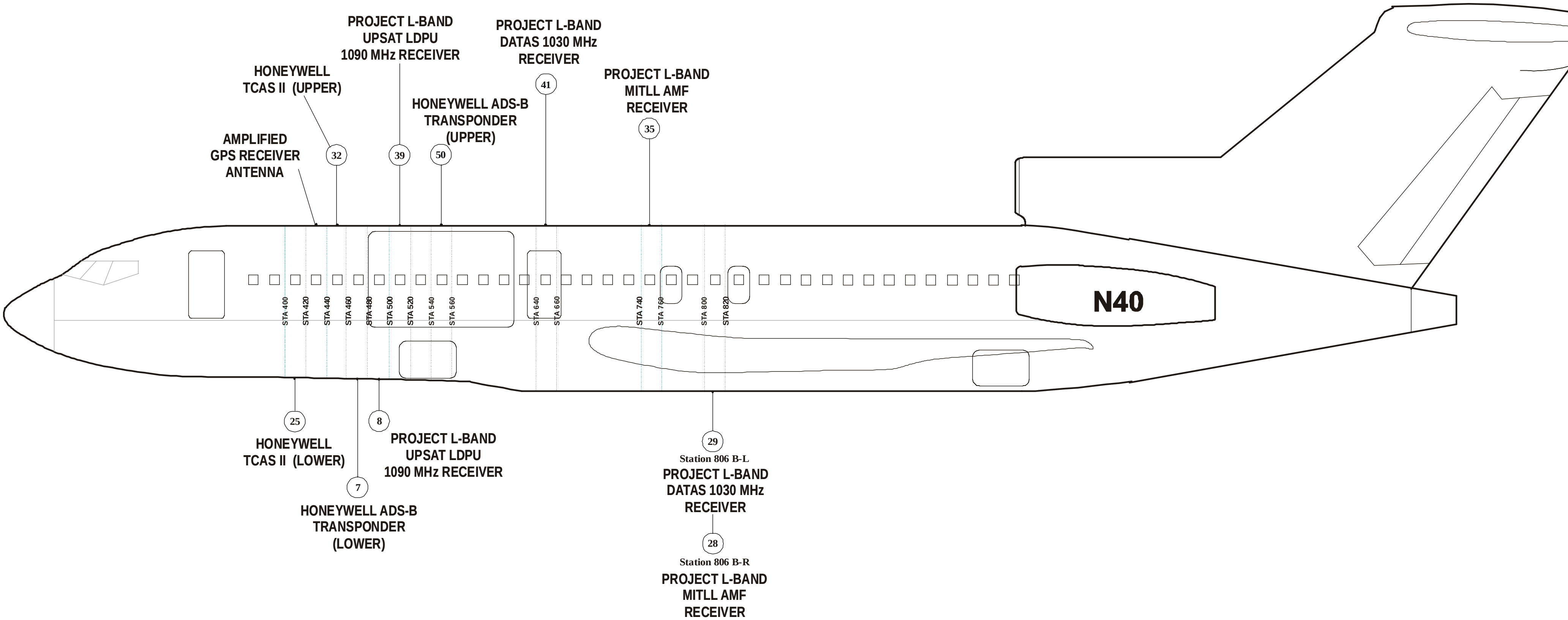


Figure 2.2.1-4. System Connections on N40.

Figure 2.2.1-5. Interior View of N40.



Antenna Ref #	Antenna Station #	Cable Type	Length Antenna->panel	Length Panel->Pallet	Length Pallet->Avionics	Use
	430 T				2.0 ft ECS 311201	GPS Antenna Splitter
32	450 T	ECS 3C142B	18.50 ft			L3-Comm TCAS II Directional
25	410 B	ECS 3C058A	11.00 ft			L3-Comm TCAS II Directional
50	550 T	ECS 310801 ECS 3C142B	26.50 ft 1.83 ft			L3-Comm ADS-B Transponder
7	470 B	ECS 311501 ECS 3C142B	6.67 ft 1.83 ft			L3-Comm ADS-B Transponder
39	510 T	ECS 310801	17.82 ft	27.08 ft ECS 311201	2.0 ft ECS 311201 or 2.0 ft RG-142	UP SAT 1090 MHz Receiver
8	490 B	ECS 311201	21.04 ft	27.20 ft ECS 311201		UP SAT 1090 MHz Receiver
41	650 T	RG-214/393	23.68 ft			DATAS (1030 MHz)
29	806 B-L	RG-214	45.72 ft			DATAS (1030 MHz)
35	750 T	ECS 311201	24.76 ft			MIT LL AMF (1030/1090 MHz)
28	806 B-R	RG-214	44.32 ft			MIT LL AMF (1030/1090 MHz)

Figure 2.2.1-6. N40 Antenna Configuration

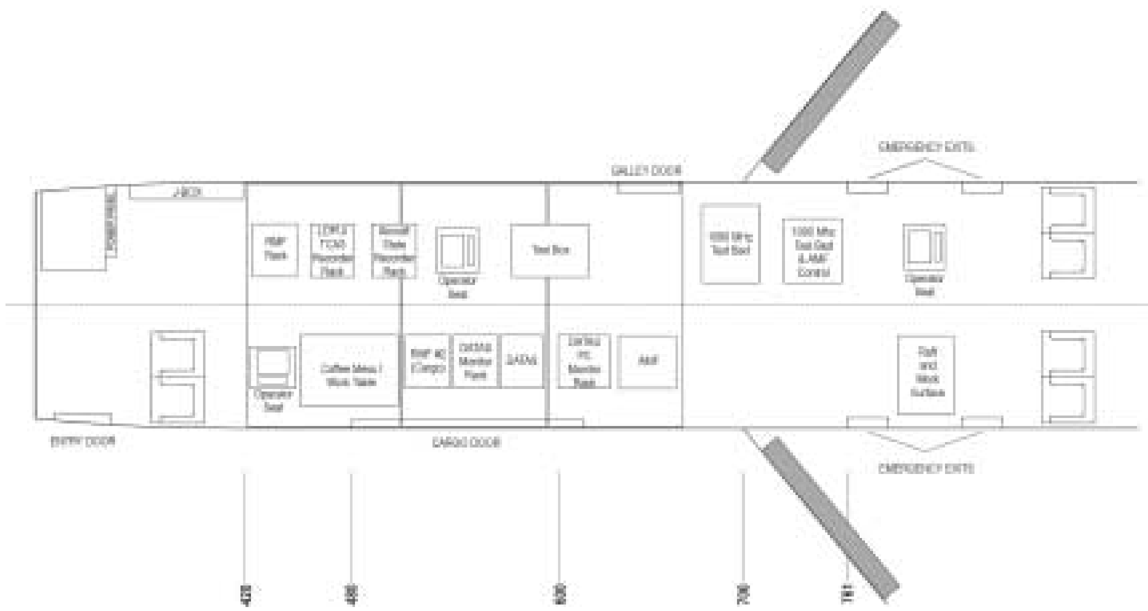


Figure 2.2.1-7 N40 Cabin Configuration

2.2.1.2 LDPU Installation and Calibration

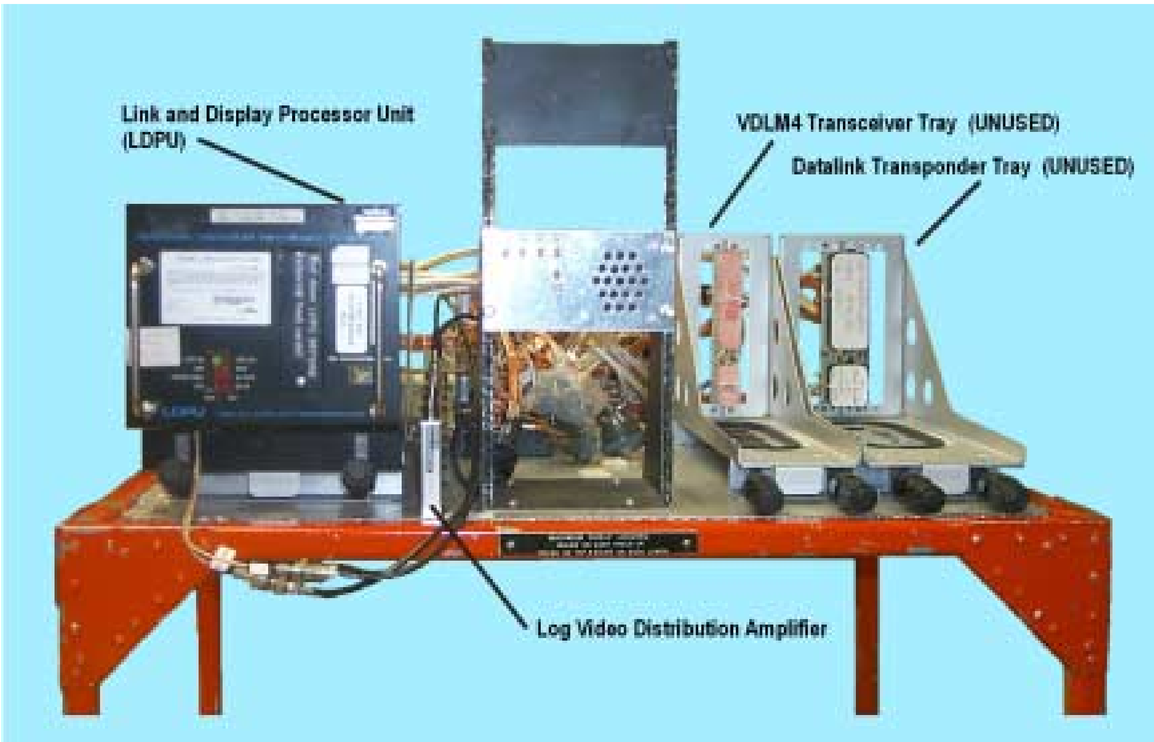


Figure 2.2.1-7a. N40 LDPU Pallet

The UPS Aviation Technologies equipment was mounted on a pallet (Figure 2.2.1-7a) designed for general use on the Technical Center's test aircraft, vans, or laboratories. For the Frankfurt flight trials, the pallet's VDL Mode 4 transceiver was not used. The datalink transponder tray also remained empty as the ship's transponders (Figure 2.2.1-8) were used for the tests.

The Link Processor and Display Unit (LDPU, leftmost tray) manages the data link with respect to ADS-B messages. The LDPU collects own aircraft information from the ship's digital air data computer and inertial navigation systems and assembles it into ADS-B messages for transmission from the ship's transponder. The LDPU accepts decoded ADS-B messages from all ADS-B data link transponders and processes the data to update traffic data files, drive a Cockpit Display of Traffic Information (CDTI) emulator in the cabin (not shown), and record the data on its removable flash cards. The buffered log video signals from the LDPU 1090 MHz receiver are also provided for recording and processing by the RMF, AMF, and 1090 Test Bed systems (2.2.1.4 through

2.2.1.6). In Figure 2.2.1-7a the two brown and black coaxial cables carry the video signals from the LDPU to the video distribution amplifier.

2.2.1.3 TCAS 2000 Installation and Calibration

N40 was equipped with the L3 Communications (formerly Honeywell Corporation) TCAS 2000 receiver/transmitter (R/T) unit with "Change 7" software and two XS-950 Mode-S Data Link ICAO " Level 4" transponders with Extended Squitter capabilities. Figure 2.2.1-8 shows the permanent certified installation of these units in the avionics compartment.

Figure 2.2.1-8 N40 TCAS R/T and Transponder Installation

In addition to providing active (interrogation-based) TCAS tracking of up to 50 aircraft in traffic densities of up to 24 aircraft within 5 nautical miles (0.3 aircraft/nm^2), the TCAS 2000 incorporates a passive (receive-only) surveillance function to support the 1090 MHz implementation of ADS-B. The R/T architecture uses a shared antenna for both active and passive modes to reduce installation requirements. In the equipment as supplied, the passive receiver only "listens" 70% of the time; passive listening is disabled during whisper shout intervals. This listening interval may be increased to 90% with a software change to the whisper-shout processing modules. The nominal sensitivity of the passive receiver is -81dBm at the back of the R/T unit.

Additional wiring was installed between the avionics compartment and cabin to provide formatted data to the transponder for squittering and from the TCAS R/T for recording the TCAS traffic display bus and internal TCAS performance data. Figure 2.2.1-9 shows the TCAS configuration on N40.

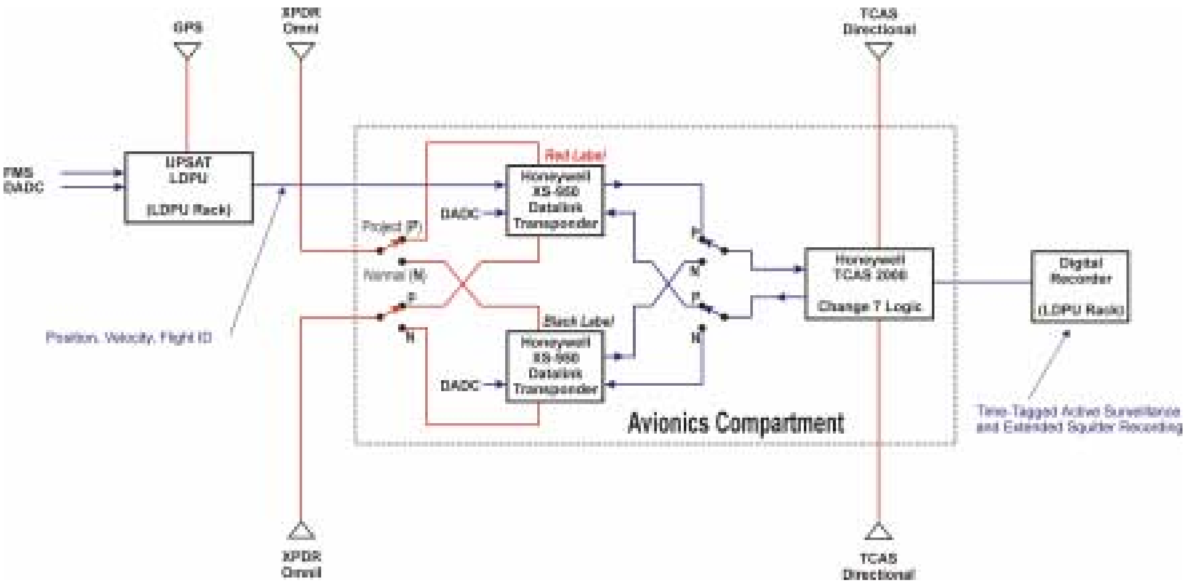


Figure 2.2.1-9. N40 TCAS Configuration

The position, velocity, and flight ID messages were formatted by the LDPU for the ADS-B Extended Squitter function. A separate ARINC 429 bus delivers altitude data to the transponder for the Mode C/S and TCAS functions. Discrete signal and control circuitry are not shown in the diagram.

All TCAS surveillance, tracking, and advisory parameters are recorded on an external militarized (CP-1933/UYK) personal computer. The raw information, including position, received power, and associated status bits, from the high-sensitivity Extended Squitter receiver is saved in data block #7"Squitter Replies". This data is post-processed to create a database for further analysis. Active surveillance data is also recorded for analysis and comparison with passive surveillance at some future time. The TCAS recorder is located on the middle shelf of the LDPU rack (Figure 2.2.1-7) in the cabin.

2.2.1.4 DATAS Installation and Calibration

DATAS has various configurations and is adapted according to the data collection needs of the mission. DATAS was configured to the 1030 MHz Interrogation data collection mode that was utilized in the 1995 Frankfurt flight tests. A difference from the 1995 configuration was an enhancement to simultaneously decode ATCRBS and Mode S replies on 1090 MHz. Duty cycle for data storage is 100% for both links.

The data source for the 1090 MHz link is the output of the LDPU receiver. Data from the top or bottom antenna can be selected. The log video is processed to detect ATCRBS and Mode S replies.

Separate top and bottom antennas were provided for the 1030 MHz link. Interrogations signals were processed from both top and bottom antennas. After detection of the mode pulse data, the source (top or bottom antenna) with the largest amplitude was selected for storage. The Mode S interrogation data is also stored from the same antenna producing a Mode S preamble.

The time of arrival of all decode data is stored to 100ns resolution. All data is stored for post flight analysis. Data rates precluded the storage of interrogation and reply amplitudes during the data collection. An online monitor shows the interrogation rate for each decode type and Mode S data for different TCAS aircraft as determined by TCAS broadcast interrogations.

DATAS contains a calibrated frequency source that was used during calibration. Signals were injected at the antenna patch panel onboard the aircraft to all systems using the LDPU video. In this way, all systems had access to the calibration signal simultaneously. Mode S replies and interrogations were used. The ‘address field' of the replies contained the value of the amplitude. The calibration scenario consisted of reply (or interrogation) amplitudes that varied from -90dbm to -20dbm, in 1db steps. The ‘on line' monitor displayed the results as the data was collected.

Both 1030 MHz top and bottom receivers of DATAS had an MTL of approximately -77dbm. Including cable losses to the two antennas, the net MTL of the top antenna was approximately -74dbm and the bottom was -72dbm (referred to the respective aircraft antennas).

The MTL of the DATAS 1090 MHz channel was set to approximately -76dbm (via software control) when referred to the selected antenna. Referring power levels to the antenna is a standard condition, described further in 2.2.1.9.

This data was planned ‘for monitoring purposes only' as much more detailed 1090 MHz data was available via the RMF, although the RMF data required post processing. Also, since the ATCRBS rates were high in the Frankfurt area, overlap processing is necessary to derive actual reply rates. DATAS ATCRBS rates were not adjusted for this effect.

2.2.1.5 AMF Installation and Calibration

The AMF is a flexible receiving and recording system for making detailed measurements at both 1030 MHz and 1090 MHz. The AMF includes two sensitive receivers, used for top and bottom antennas. The receivers amplify receptions and convert them into a log video signal. Real time processing of the log video signal is used to detect pulses and record the pulse characteristics. Whenever a pulse is detected, it is sampled and a recording is made of the pulse event. The recording includes time of reception, pulse width, and received power levels from the top and bottom antennas. Recorded AMF data is processed after the mission to recognize pulse combinations that constitute interrogations (for 1030 MHz receptions) and replies (for 1090 MHz receptions). After interrogations or replies have been detected during data analysis, these are then counted to determine the reception rate. An overall block diagram of the AMF and the post mission data processing is shown in Figure 2.2.1-2. The functions of the AMF are documented in more detail in references 14 and 15

The AMF can be used for both 1030 MHz receptions and 1090 MHz receptions but not both at the same time. In the Frankfurt tests, the AMF was used in both bands by switching between the two frequencies. During the times when N40 was flying in oval patterns, the AMF was kept in one frequency for one complete cycle, which was about 10 minutes.

Because the AMF records data in a detailed form, it is possible to conduct diverse and comprehensive analyses. In some cases in the past, more detailed analyses have been applied to single-out a particular interrogator from all of the rest. This makes it possible to determine the interrogator's scan rate, received power level, and antenna patterns.

When the AMF is used for 1090 MHz receptions, the received pulse rate is so high that a special technique is necessary to keep within the system's recording capacity. To reduce pulse rate, a gating function is applied to the received signals. The on-time is 1 ms, followed by an off-time of 99 ms. This pattern is repeated steadily during the time 1090 MHz measurements are being made. In subsequent data processing, the complementary factor 100:1 is applied to correct for this gating. This technique was developed in the 1980s and has been used successfully in a number of measurement programs. It was used for example in the LA Basin measurements reported in reference 10.

AMF power thresholding is done in two ways. The real time AMF processing includes a fixed threshold, which was set at a low value during the Frankfurt measurements, -80 dBm referred to the AMF input. As a result, all pulses stronger than this level were detected and recorded, each having a measurement of its received power level. In the subsequent data processing, a second power threshold is applied.

In the normal mode of AMF data processing, the software threshold is selected to achieve an effective system threshold of -74 dBm referred to the antenna, which is the standard value for TCAS receptions. Referring received power levels to the antenna is described in more detail in 2.2.1.9.

Most of the AMF measurements are presented in this report using the fixed standard threshold. In other cases, post-mission processing used multiple power threshold values. This was done in order to generate the power distribution of received signals.

2.2.1.6 1090 Test Bed Installation and Calibration

The 1090 MHz Test Bed is an instrumented receiver for recording 1090 MHz receptions in a very detailed form. The log-video waveform is sampled at a steady rate of 8 samples per microsecond, and all of these samples are digitized and recorded for post-mission analysis. The sampling continues steadily, even when no signals are detected. This technique requires a large amount of data storage, but the benefit is that this type of recording allows very detailed investigations to be performed.

Because of the high data rate of the recorded data, there is a limit of 16 seconds for the duration of a particular recording. During the Frankfurt measurements, a Test Bed operator on the aircraft synchronized the recordings to the timing of the oval flight paths. One 16-second recording was made during each of the straight portions of the flight.

The 1090 MHz Test Bed includes a very sensitive receiver so that long-range ADS-B receptions can be studied. For the Frankfurt measurements, the receiver of the LDPU was used instead of the built-in receiver, as illustrated in Figure 2.2.1-4. The LDPU receiver is also very sensitive, especially so because it includes a low-noise preamplifier within the antenna.

When airborne data is analyzed after a mission, software processing is used to detect pulses, and detect both ATCRBS and Mode S replies. Mode S reply and squitter detection can be done in several different ways, to obtain results for several signal processing designs. In particular, the enhanced reception techniques that have been developed for Extended Squitter reception can be used. A given recording can be processed in two ways, once using the enhanced reception techniques and a second time using the existing reception techniques, currently being used in TCAS.

Power calibrations were performed on the 1090 MHz Test Bed in order to be able to relate the airborne measurements in Frankfurt to absolute power levels. Power calibrations were performed at several times in different situations. The most directly applicable power calibrations were performed in Frankfurt, on 18 May using the 1090 MHz Test Bed as installed for the airborne measurements.

Antenna cabling in N40 includes one cable leading from the antenna to a patch panel, and a second cable from the patch panel to the LDPU, as shown in Figure 2.2.1-6. The second of these cables was included in the calibration measurements on 18 May. Therefore this cable is included in the calibration and does not need to be accounted for separately. An adjustment was then made to account for the preamplifier (15.2 dB gain), which is combined with the antenna, and the cables from the antenna to the patch panel (-0.7 dB top, -1.7 dB bottom). When these factors are combined, the result is an absolute power calibration of the 1090 MHz Test Bed as installed and used in the Frankfurt measurements.

2.2.1.7 RF Measurement Facility (RMF) Installation and Calibration

The RMF recorded and analyzed the video signal used by the LDPU for Extended Squitter message detection. RMF records both top and bottom antenna video from the LDPU 1090 MHz receiver. The signal is digitized at a 10 MHz sampling rate and continuously recorded on a digital tape media for post processing. The RMF system was cabled from the video distribution amplifier, which distributes the LDPU receiver output to each recording device. The amplitude level from the amplifier is adjusted so that the video signal is in the proper range of the analog to digital converter, which samples the video signal.

The RMF was calibrated prior to each flight. The purpose of amplitude calibration is to relate the data recorded by the high speed video recorders to the known amplitudes of a calibration signal source. An RF Calibration Unit was designed and constructed to produce RF signals with known amplitudes. The RMF is calibrated using the RF signals from the calibration box. Software was developed to analyze the recorded calibration data, detect the signal pulses of known amplitudes and build a calibration table to relate the numbers of recorded data samples to the known pulse amplitudes. The calibration table is used for off-line data reduction and analysis.

The calibration procedure was performed as follows. With the RMF equipment installed on the aircraft, configured for flight data recording, the antenna inputs (both antenna ports) were disconnected at the LDPU receiver input and replaced with identical dual outputs from the calibration box. The calibration box was activated to transmit the varying calibration signal (-16 to -95 dBm in 1-dB steps) and the RMF was activated. The signal was recorded for approximately 10 seconds. The calibration data was extracted from the two tapes and processed separately by the calibration software to produce calibration files for analyzing data from both the top and bottom antennas. Other calibration sources were provided by other systems, such as the Lincoln Laboratory Calibration Unit and DATAS, and those calibration signals were recorded by the RMF and processed for further calibration verification.

Power calibration was performed in such a way that received power levels can be given as referred to the antenna. This is a standard condition, described in more detail in 2.2.1.10.

2.2.1.8 Transponder Characteristics

The L-3 Communications XS-950 Mode S Data Link Transponder is fully certified airborne equipment implementing all currently defined Mode S functions - with built-in capability for future growth.

Current TCAS systems actively interrogate Mode S and ATCRBS transponders to identify and track aircraft position, including altitude. The XS-950 adds to this capability by allowing the operator to transmit and receive digital messages between aircraft and air traffic control. This data link capability provides more efficient, positive, and confirmed communications than is possible with current voice systems.

The XS-950 meets all requirements for a Mode S transponder as described in RTCA DO-181B (Ref 17). The unit conforms to ARINC Characteristic 718 with interfaces for current air transport applications, and includes dual altimeter inputs for Gilham (discrete 11 wire), synchro (ARINC 707), ARINC 429 and ARINC 575 interfaces. TCAS II is fully supported, including "diversity" (top and bottom) antenna ports. Diversity provides for reliable RF communication links between both ground-based and airborne (TCAS) interrogators. The transponder incorporates a TCAS II interface and is designed to work with all TCAS II systems conforming to ARINC 718/735 characteristics.

The XS-950 is an ICAO Annex 10"Level 4" system. It is capable of transmitting and receiving 16-segment extended length (112 bit) messages. The 16-segment Level 3/Level 4 message capability also meets the RF duty cycle requirement for the envisioned ICAO Level 5 transponder.

Part number 7517800-10003/55003 units provide Extended Squitter and partial Downlink Aircraft Parameters (DAPs) capabilities. The DAPs capability allows ground stations to request and receive aircraft position information from the transponder on demand.

Software in the transponder is certified to DO-178B, the FAA requirement for software development and certification. Software updates can be completed on-board the aircraft by means of an ARINC 615 portable data loader. The data loader port is located on the front connector.

The transponder's output power and MTL were measured with an IFR 1400/1403 transponder test set (Serial Number 1581) and are as follows:

Manufacturer:	Honeywell	
Model:	XS-950	
Serial Number:	98030578	
Antenna Port:	UPPER	LOWER
Power:	414 Watts	394 Watts
MTL:	100% reply at -74 dBm	100% reply at -74 dBm
	80% reply at -75 dBm	82% reply at -75 dBm
	30% reply at -76 dBm	57% reply at -76 dBm
	0% reply at -77 dBm	1% reply at -77 dBm

These are raw measurements and do not take into account the transponder/test set cable loss of 0.8 dB.

2.2.1.9 Power Levels Referred to the Antenna

In presenting all of these measurements, an effort has been made to state power levels referred to the antenna. This is a standard form for expressing measured results, which is intended to facilitate comparisons between these measurements and other measurements. Because of the use of antenna preamplifiers in some cases, this convention deserves a brief explanation.

The most direct application of the convention is for signals transmitted by a transponder. For such transmissions, the reference point is the antenna end of the cable between the transponder and the antenna. Therefore the transmitter power level referred to the antenna is equal to the power level at the transponder reduced by the amount of the cable loss.

Similarly for reception by a transponder, the reference point is also the antenna end of the cable between the transponder and the antenna. Because of the cable loss, the receiver MTL value referred to the antenna is correspondingly higher than the MTL value referred to the transponder.

In the cases in which a preamplifier is used, housed within the antenna radome (as shown in Figure 2.2.1-4), the same principle is followed. The reference point is the point where the signal is output from the antenna and input to the preamplifier, even though this point is not directly accessible.

2.2.2 Flight Inspection International Beech King Air 300 Aircraft

2.2.2.1 Equipment Installation

The installation of the equipment on the Beech-300 (Figure 2.2.2-1) was accomplished shortly prior to the trials. A Collins SSR/Mode S transponder model TDR-94D and an LDPU were installed and connected to the aircraft avionics (Figure 2.2.2-2). The transponder and LDPU used the same passive antenna type. Since no other (amplified) antennas could be installed on the aircraft, 15dB pre-amplifiers were installed at the signal input of the LDPU which would be expected to degrade the system noise level by the amount of the cable loss (3 dB). This is not the installation configuration as specified in the LDPU manual. However no serious performance reductions were observed.

Because this is a highly instrumented aircraft, antenna installations were constrained more than normal. As seen in Figure 2.2.2-1, the top transponder antenna (A) and the bottom receiving antenna (D) were substantially off-center, to the right.

The check flight was performed on 17 May 2000. Due to a wiring error, the aircraft was not visible to the ground station. A second wiring error was caused by wrong documentation and forced the transponder to squitter a fixed position. This was corrected on 21 May.

2.2.2.2 Aircraft

Type:	Beech 300 King Air
Registration:	D-CFMC
Aircraft address:	$3CCE6E_h$
Operator:	FII Flight Inspection International GmbH / Germany

2.2.2.3 Transponder

SSR/Mode S transponder Collins TDR-94D
P/N 622-9210-004, S/N 4516

Output Power (bench measurement)
- Top Antenna Port: 250 Watts (54.0 dBm)
- Bottom Antenna Port: 250 Watts (54.0 dBm)

2.2.2.4 LDPU

UPS Aviation Technologies LDPU
Model: Apollo SF-22
P/N 430-6070-50R, S/N 6018561
Antenna type: CHELTON-A177BP3

2.2.2.5 Calibration Results

Unit	Antenna	VSWR	Cable length	Path loss in cable 1090 MHz (type of cable)
TDR-94D	Top (A)	1.2	8 m	2.0 dB (RG 393 / TNC)
	Bottom (B)	1.2	8 m	2.0 dB (RG 393 / TNC)
LDPU	Top (C)	1.2	12 m	3.0 dB (RG 393 / TNC)
	Bottom (D)	1.2	12 m	3.0 dB (RG 393 / TNC)

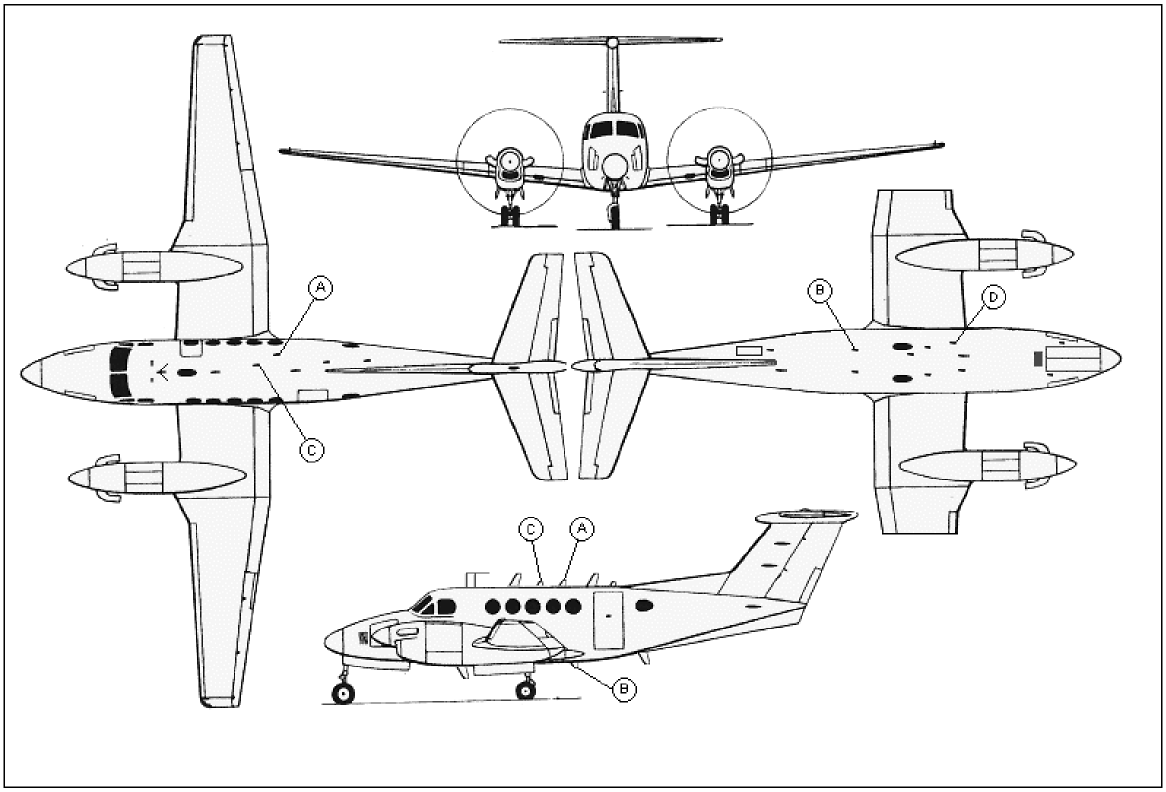


Figure 2.2.2-1. FII Beech King Air 300 Aircraft Antenna Positions

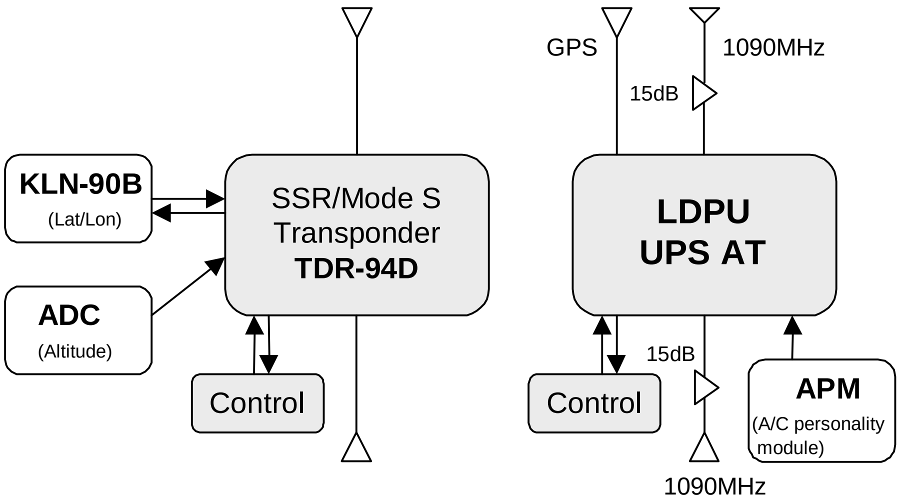


Figure 2.2.2-2. FII Beech-300 Hardware Installation Scheme

2.2.3 NLR Metroliner Aircraft

2.2.3.1 Equipment Installation

The NLR Metroliner (Figure 2.2.3-1) had been equipped prior to the trials with an SSR/Mode S transponder having Extended Squitter functionality and an LDPU (Figure 2.2.3-2). For Extended Squitter reception, normal antenna locations were not available on this highly instrumented aircraft. As seen in Figure 2.2.3-1, the top receiving antenna was mounted on the nose, forward of the cockpit. The bottom receiving antenna was mounted on the slanted section aft of the cylindrical portion of the aircraft. While these antenna installations would not be appropriate for operational use, they are serviceable for the purposes of this test program.

Installation tests were performed on 2 and 8 May, and after the trials on 14 June 2000. The results are documented in a Eurocontrol report (8 May, 2000) and in the tables below. During the measurement on 8 May the aircraft was situated outside the hangar but very close to the hangar, due to the limited length of the power supply cables. This made it very difficult to get reliable and stable power measurements probably due to reflections from the hangar and nearby buildings.

Measurements were made at various positions around the aircraft and from varying distances. The top antenna showed a significantly lower power output than the bottom antenna. The Honeywell (formerly Allied Signal) transponder showed a significantly higher power output than the L-3 Communications transponder. The decision was taken that NLR would try to change the top antenna and the top cable before flights. EUROCONTROL decided to fit the Honeywell transponder for the flight tests.

The above mentioned different measurement results and the equipment change (antenna, transponder) were the reason for an additional test shortly after the flight trials.

2.2.3.2 Aircraft

Type:	Fairchild Metroliner
Registration:	PH-NLZ
Aircraft address:	$48406F_h$
Operator:	NLR - National Aerospace Agency of the Netherlands

2.2.3.3 Transponder

Enhanced Mode S Transponder BENDIX/KING (Honeywell) TRA 67A ATC;
P/N 066-01127-1601, S/N 11880;

Output Power (lab measurement)

- Top Antenna Port: 417 Watts (56.2 dBm)
- Bottom Antenna Port: 447 Watts (56.5 dBm)

Output Power (as defined in 2.2.1.9)

- Top Antenna Port: 209 Watts (53.2 dBm)
- Bottom Antenna Port: 200 Watts (53.0 dBm)

2.2.3.4 LDPU

UPS Aviation Technologies LDPU
Model: Apollo SF-22
Antenna type: AT-129 (passive) with preamplifier (15 dB)

2.2.3.5 Calibration Results (June 14, 2000)

Unit	**Antenna**	**VSWR 1090 MHz**		**VSWR 1030 MHz**		**Path loss in cable (type of cable)**	
		at cable	antenna without base	at cable	antenna without base	1090 MHz [dB]	1030 MHz [dB]
TRA-67A	Top (A)	1.3	1.1	1.3	1.1	3.0 (RG400/N)	
	Bottom(A)	1.0	1.0	1.0	1.0	3.5 (RG58/BNC)	
LDPU	Top (B)					3.2 (thick coax)	3.0
	Bottom (B)					2.2 (thick coax)	2.2

Note: The N connector RG-400 to the top antenna for Mode-S seems to make bad contact during this test: see the big difference in VSWR for the antenna plus cable and the antenna without base.

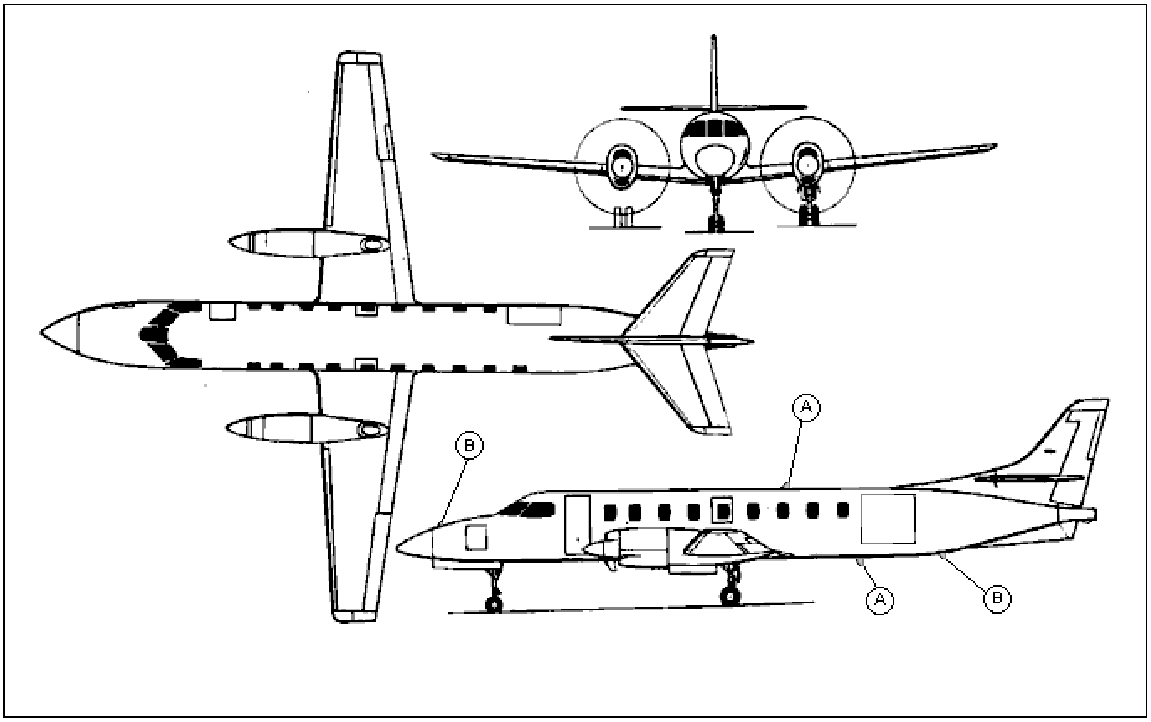


Figure 2.2.3-1. NLR Metroliner Aircraft Antenna Positions

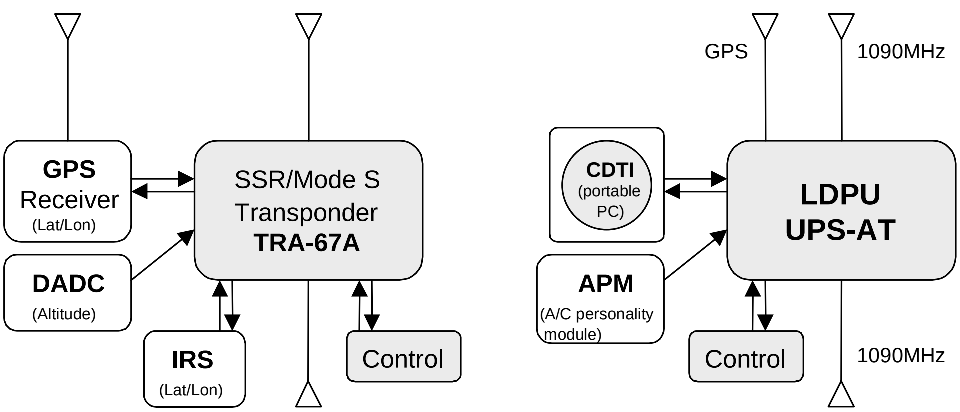


Figure 2.2.3-2. NLR Metroliner Hardware Installation Scheme

2.2.4 Targets of Opportunity

In addition to the three project aircraft, other aircraft were observed to be transmitting Extended Squitter signals. These "targets of opportunity" were determined to be passenger carrying aircraft operated by British Airways. The Extended Squitter receptions included ADS-B state vector information, from which it was possible to determine the flight paths of these aircraft, and therefore to make measurements of reception reliability as a function of range. Obtaining measurements from these aircraft is considered to be particularly useful in this test program because the flight paths are normal rather than being selected for test purposes, and also because the transmissions come from commercial avionics and certified operational antenna installations.

Through inquiries, it was determined that British Airways has begun equipping their aircraft with TCAS 2000 systems manufactured by L-3 Communications that are capable of transmitting Extended Squitters. The British Airways targets of opportunity were all Boeing 757 aircraft. The latitude-longitude information transmitted originated not from GPS, but from FMC systems. Therefore the information was based on IRS/DME. The FMC frequently reinitializes the IRS using DME multilateration whenever multiple DME stations are visible from the aircraft. It is therefore thought that the accuracy of the latitude and longitude positions transmitted by the BA aircraft was fairly high. British Airways plans to install GPS on its Boeing 747 aircraft beginning in 2001. These aircraft will also carry TCAS 2000 with Extended Squitter capability. Through analysis of the squitter receptions, it was further determined that these aircraft transmitted both position and velocity, including barometric altitude, and Call Sign (in most cases). Intent and Status information were not transmitted.

2.3 LINK BUDGETS

2.3.1 Air-to-Ground Links

The following section gives an estimate of the theoretical maximum range between the aircraft and the ground station based on the environmental conditions during the flight trials. The subsequent paragraphs are intended as a plausibility check for the measured results rather than to provide an in-depth analysis of the results.

The maximum range between a transmitter and a receiver for the relevant frequency $f_{DL} = 1090 MHz$ depends mainly on two issues:

1. Geographical aspects: Under optimal conditions, free-space propagation could be assumed. Due to the far from optimal location of the southeast pointing antenna at the Langen ground station, the influence of diffraction has to be taken into account. The diffraction has to be considered as an additional attenuation in the power budget.
2. Power budget: Following up the shortcomings imposed by the geographical aspects, the power budget for the equipment can be calculated depending on the measurements provided in sections 2.2.2 and 2.2.3.

The power level received at a ground station can be calculated by using the radar equation:

$$P_{RCVR} = P_{XPDR} \cdot \frac{G_A \cdot G_T}{L_{at} \cdot L_T \cdot L_R} \cdot (\frac{\lambda}{4\pi})^2 \cdot \frac{1}{R^2}, \tag{1}$$

where

P_{XPDR}	is the power emitted at the transponder output,
G_A, G_T	are the antenna gain of the ground station antenna (A) and the airborne antenna (T),
L_T, L_R	are cumulated losses (cable attenuation, power splitter etc.) between the airborne transponder (T) ground station receiver (R) and the related antennas,
L_{at}	is the loss due to atmospheric attenuation,
λ	is the wavelength and
R	is the range between the airborne and the ground station.

The following equation can be used to derive the power level in dBm received at a ground station for a given range from aircraft to the ground station, and for a given transmitter power level.

$$p_{RCVR} = p_{XPDR} - l_T + g_T - 0.009 \cdot \frac{R}{nmi} dB - 20 \cdot \log(\frac{R}{nmi}) dB + g_A - l_R - 98.54 dB, \qquad (2)$$

where R is in nautical miles and all values are in dB.

The received power has been calculated using the given values for the different installations indicated in sections 2.2.2 and 2.2.3. The results (Figure 2.3-1) show a theoretical range of 360nmi and 390nmi between the Langen LDPU and the FII and NLR aircraft respectively.

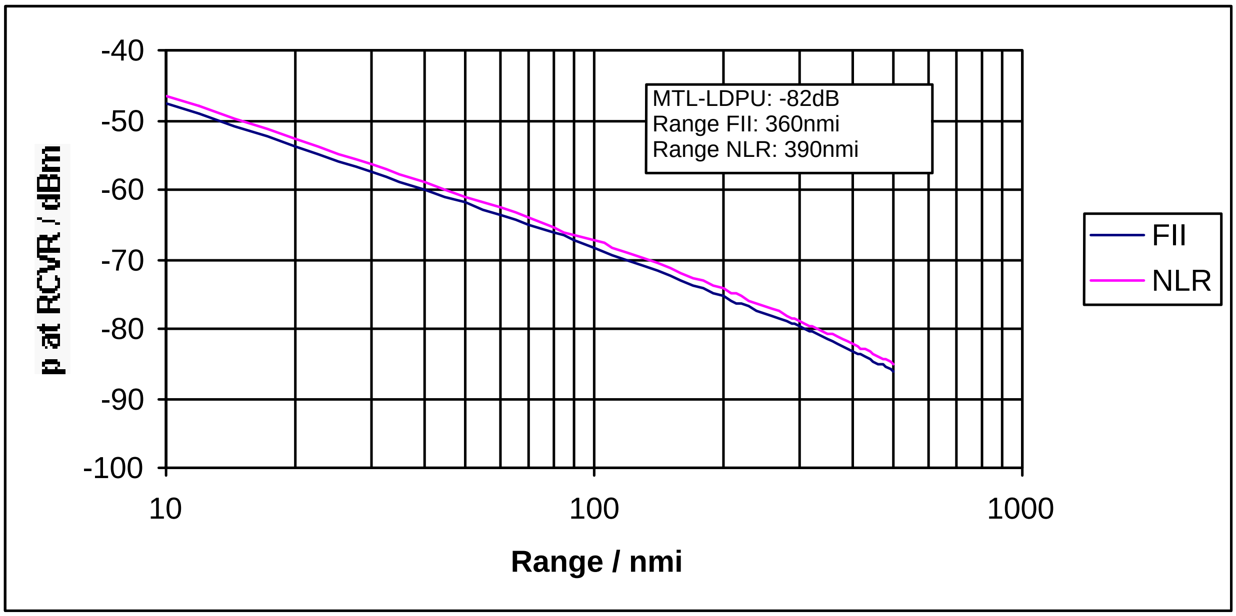


Figure 2.3-1. Relationship between Received Power and Range

However the maximum range is also constrained by the radio horizon which is also a limiting factor. The radio horizon in feet (i.e., the range of visibility) is

$$R = 7.47 \cdot 10^3 \cdot \sqrt{ft} \cdot \left(\sqrt{h_{XPDR}} + \sqrt{h_{RCVR}}\right), \qquad (3)$$

where

h_{XPDR} is the altitude of the aircraft,
h_{RCVR} is the height of the Ground Station Antenna.

Figure 2.3-2 plots the maximum range as a function of the altitude h_{XPDR} with a measured height for the Langen ground station of 56 ft.

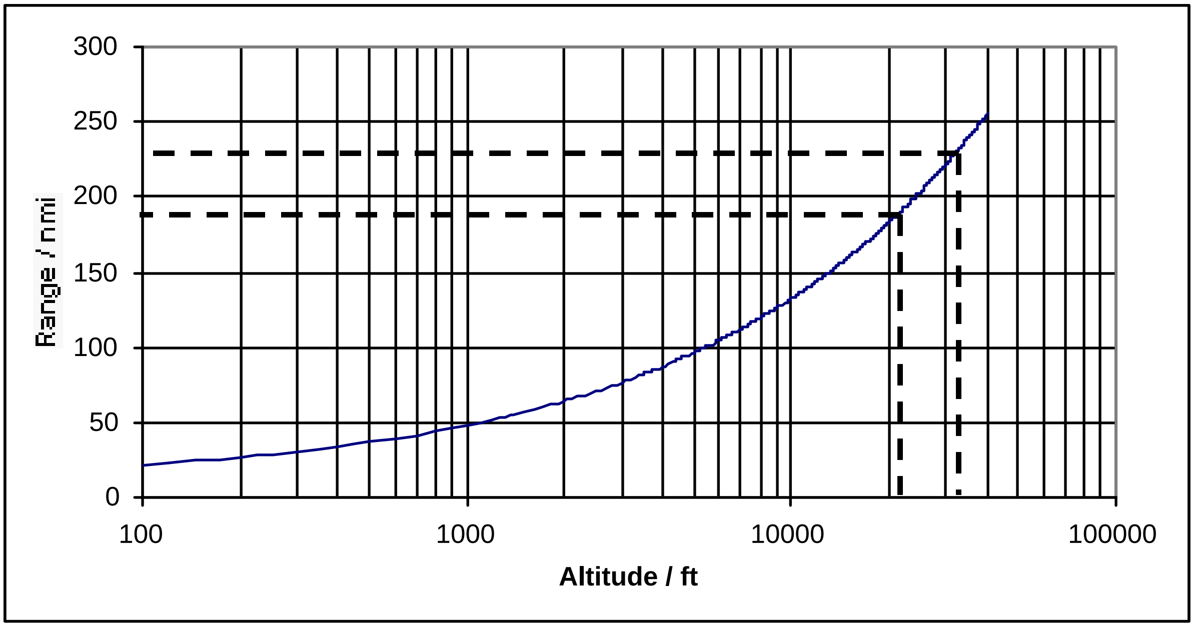


Figure 2.3-2. Radio Horizon at the Langen Ground Station

With respect to the flight trials the altitudes of major interest are 22000 ft (the standard orbit of the test aircraft) and 33000 ft, the typical altitude of the targets of opportunity seen several times during the trials. The resulting ranges of 191 nmi and 232 nmi are significantly lower than the calculated maximum range, only considering the power budget.

It should be highlighted, that these ranges could only be obtained if no obstacles appear in the line of sight. At the Langen ground station this prerequisite may be assumed for the north-antenna but of course not for the antenna directed to the southeast due to a nearby obstruction. Figure 2.3-3 shows the view from the antenna on top of the Langen Ground Station.

Figure 2.3-3. Langen View to the Southeast

Note. See Figure 2.1.1-4 for more details.

Obviously the building causes diffraction phenomena which reduces the received power level. To be able to give at least an estimate for the additional attenuation caused by the nearby building, l_D, the following equation can be used:

$$l_D = 20 \cdot \log \left| \frac{1}{2} - e^{-j\frac{\pi}{4}} \cdot \frac{C(\nu) + jS(\nu)}{\sqrt{2}} \right| dB, \tag{4}$$

where

$$C(\nu) = \int_0^{\nu} \cos(\frac{\pi \cdot t^2}{2}) dt \qquad (5a)$$

$$S(\nu) = \int_0^{\nu} \sin(\frac{\pi \cdot t^2}{2}) dt \qquad 5(b)$$

are the Fresnel Integrals of the parameter

$$\nu = H \cdot \sqrt{\frac{2}{\lambda} \cdot \left(\frac{1}{r_{XPDR}} + \frac{1}{r_{RCVR}} \right)}. \qquad (6)$$

The variables in equation (6) are as follows:

H	is the height of the obstacle in the line of sight,
r_{XPDR}	is the distance between the transponder and the obstacle in sight,
r_{RCVR}	is the distance between the ground station antenna and the obstacle in sight and
λ	is the wavelength.

Figure 2.3-4 shows that ν becomes nearly constant for ranges above 100km (54nmi), at r_{XPDR}=100km the exact value for ν is 1.552. Consequently, the maximum additional attenuation l_D, caused by the nearby building, is 17dB. It should be emphasized that this value will only be reached, when the aircraft flies on the border of the radio horizon (Figure 2.3-2).

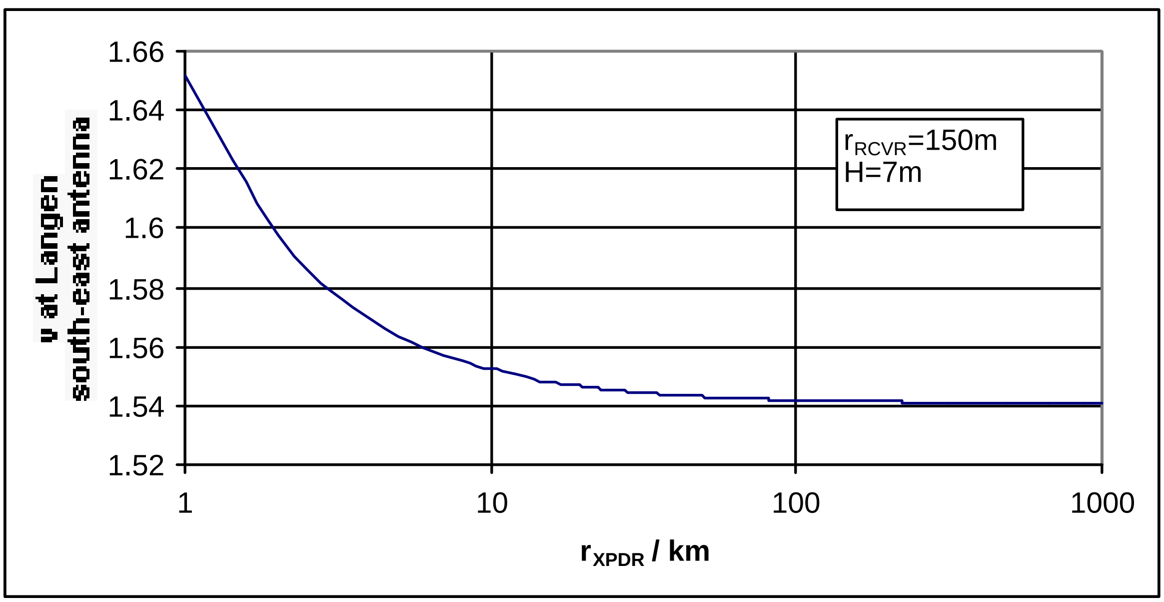


Figure 2.3-4. Relationship between Range and Fresnel Parameters, Adopted to the Langen Ground Station

The coverage horizon for the two antenna sectors at Langen is shown quantitatively in Figure 2.3-5. A corresponding plot for the Wiesbaden antenna site is shown in Figure 2.3-6. The elevation angles shown here were derived from visual sightings and topographic information.

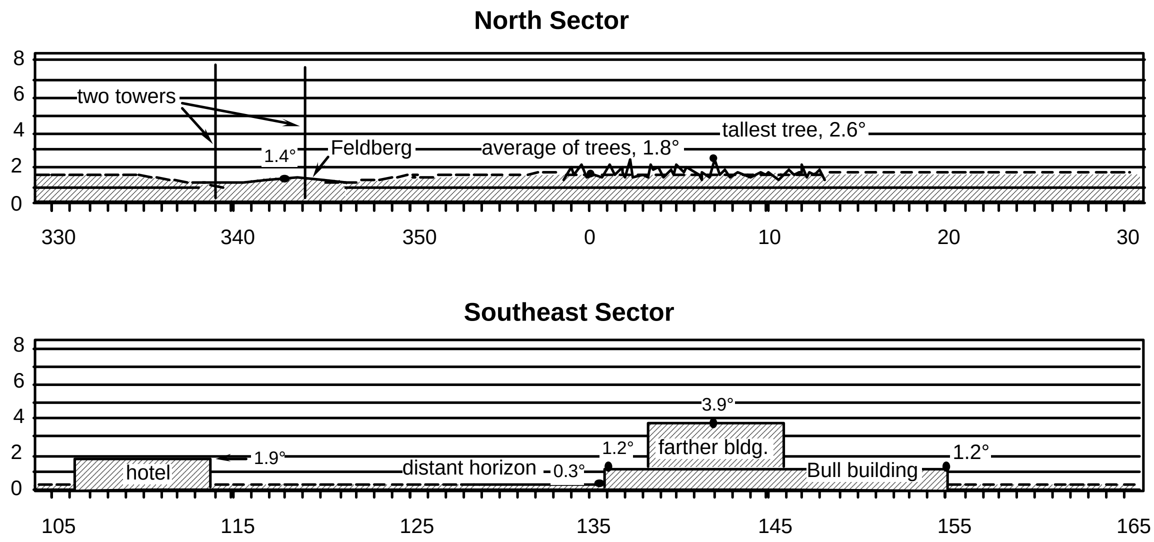


Figure 2.3-5. Horizon Coverage for the Langen Station

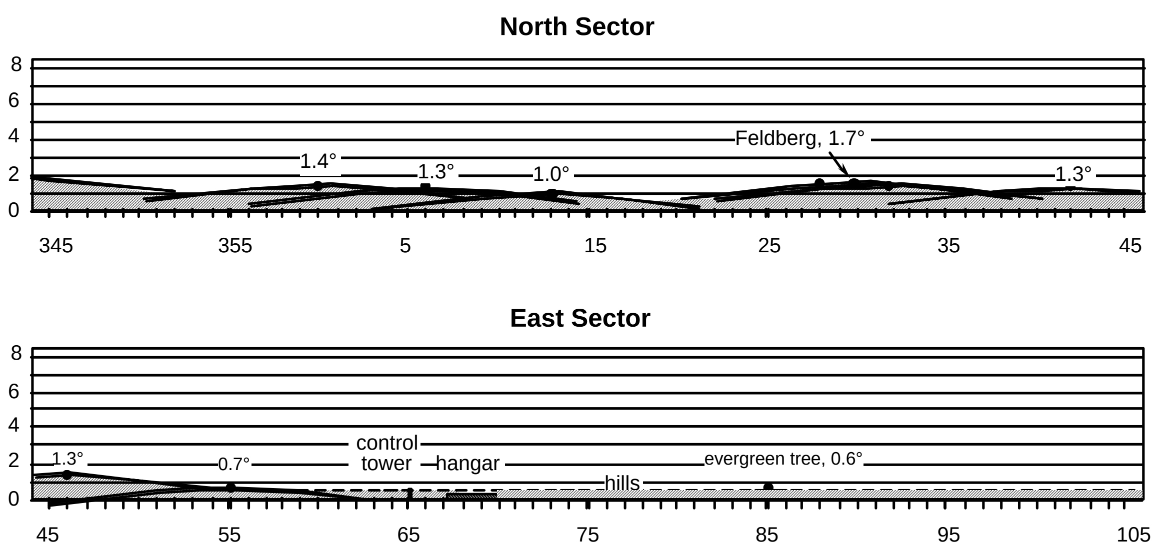


Figure 2.3-6. Horizon Coverage for the Wiesbaden Station

2.3.2 Air-to-Air Links

Air-to-air links follow the same principles, although the antenna gain values correspond to the omnidirectional aircraft antennas, whose gains are nominally 0 dB. In most cases there is a clear line-of-sight between the transmitting aircraft and the receiving aircraft, and the issue of obstruction by buildings is not relevant.

Depending on the location of the installed aircraft antenna, it is possible in some cases for the signal to be obstructed by a part of the aircraft. Such considerations have prompted a viewpoint in which the entire aircraft is considered to be part of the antenna. Using this approach, antenna gain is considered to be a characterization of the installed antenna, including all effects of the aircraft.

Because ground based antennas typically have substantial antenna gain, the received power levels for a given range are correspondingly lower for air-to-air links. Following is an example air-to-air link budget, applicable to a nominal case, and for 50 nmi range.

Transmitter power (250 watts at antenna)	54	dBm
Antenna gain, transmitting	0	dB
Free space path loss for 50 nmi range	-132.5	dB
Antenna gain, receiving	0	dB
Received power, at antenna	-78.5	dBm
Minimum Triggering Level	-87	dBm
Excess power	8.5	dB

The result indicates an 8.5 dB power margin under these conditions. Therefore the air-to-air range can be extended before reaching a condition in which the signal is too weak for reception. If range were extended to balance the amount of the excess at 50 nmi, the resulting range would be

Range = (50 nmi) * 10^(8.5/20) = 133 nmi

The maximum useful air-to-air range is also limited by deviations in the individual terms in the link budget, including the aircraft antenna gain values. These deviations sometimes cause stronger signals and sometimes weaker signals. Therefore in tests such as the May 2000 tests in Germany, it is to be expected that the observed maximum air-to-air ranges will differ on different days and for different aircraft pairs.

Therefore, for Extended Squitter signals, reliable air-to-air reception for most aircraft pairs in an interference-free environment is to be expected out to a range substantially less than 133 nmi when using omni-directional antennas. The amount of this range reduction depends on three factors, (1) the amount of transmitter power deviations, (2) the amount of receiver sensitivity deviations, and (3) the deviations in aircraft antenna gains. In cases in which top-bottom antenna diversity is used both for transmitting and receiving, the deviations in antenna gain can be expected to be small relative to the other deviations. For the diversity-to-diversity case, a serviceable estimate of the maximum reliable range can be obtained by allowing a total of about 3 dB for all of the power deviations. The resulting system air-to-air range, in an interference-free environment, is therefore about 90 nmi.

The above values apply to omnidirectional receiving antennas. To enhance air-to-air range it is also possible to use a directional receiving antenna that favors forward directions. The maximum increase in antenna gain that can be achieved using azimuth directivity is about 3 to 4 dB, and this gain must be traded for a reduction in the aft direction. Using such an antenna, the air-to-air interference-free range in the forward direction would be increased to approximately 125 nmi, while the range in the aft direction would be approximately 60 nmi.

2.3.3 Conclusions

High flying aircraft having elevation angles above the horizon angle are in clear view and are expected to produce strong signals relative to receiver sensitivity. Lower altitude aircraft for which the elevation angles are lower than the site horizon will, in most cases, yield severely attenuated signals that are not receivable.

The maximum air-to-ground range for reception of Extended Squitter signals at Langen and Wiesbaden is limited more by horizon effects than by free-space path loss. Particularly in the southeast direction for the Langen station, a large building in this direction may be expected to limit the maximum air-to-ground range considerably.

Of course interference in the Frankfurt area has a considerable effect, but for comparison, a calculation has been made of the maximum air-to-air range as limited only by power levels. The results indicate that there will be considerable variability between one test and another, due to the varying effects of aircraft antenna gain, and also due simply to the fact that different aircraft may transmit different power levels. For reliable air-to-air reception, where both aircraft are equipped with top-bottom antenna diversity, and using a sensitive receiver and omnidirectional receiving antennas, the maximum interference-free air-to-air range may be expected to be about 90 nmi when using omni-directional antennas.

3. FLIGHT PATHS AND PROCEDURES

3.1 FLIGHT PROFILES

The participating organizations provided aircraft for performance of the flight trials. FAA supplied one instrumentation/ADS-B aircraft, a Boeing B-727 (N40). Flight Inspection International (FII) operated an ADS-B equipped aircraft (Beech King Air B300) sponsored by DFS. NLR operated an ADS-B equipped aircraft (Fairchild Metroliner II) sponsored by Eurocontrol. All aircraft had ADS-B transmitters (Extended Squitter capable transponders), and ADS-B receivers on board. While all transponders were from different manufacturers, the receivers were all from UPS AT (but different versions). This allowed a comparison of receiver performance operating in different environments at the same time period.

Various issues had to be taken into account for flight trial preparation and performance, which were documented in the trials test plan. These issues include equipment calibration and regular checks on proper equipment operation. In trials preparation, Wiesbaden airfield was chosen as base for the FAA aircraft N40. Ground calibration was performed with the Wiesbaden ground station and the three aircraft, N40, FII and NLR. While the other aircraft had tested their equipment during the flight to Wiesbaden, N40 performed the test during in flight operation and calibration of measurement equipment in a separate flight profile. This was also intended to collect data on specific profiles for comparison with earlier measurements.

Usually, N40 orbited in the Frankfurt area since this was the best location for all the on-board measurement equipment. The intent was to measure SSR channel load, interrogation and reply rates, and investigate Extended Squitter performance under worst case conditions. However, to get information on the environment in which the controlled test targets (FII and NLR) were operated, one of N40's flights covered the area from Frankfurt to southern Germany.

The trials activity consisted of several flight days in order to get representative results. While there was limited time available for the whole program, the schedule benefited from earlier flight trial experience. However, complications arose due to significant changes in airspace structure on 18 May. Therefore, the first flight was performed on the 19 May as an equipment test and calibration flight. In addition, all other flight profiles during the flight trial period for all three participating aircraft had to start at Wiesbaden airfield.

Earlier results from 1995 revealed limited changes in interrogation and fruit rates during the day between 6 am and 7 PM. Results obtained in the middle of the week or during the weekend showed more significant differences, since the number of active interrogators was reduced during the weekend. In order to investigate the minimum load on the SSR channels (which was expected to correspond with the highest squitter performance) one flight involving all three project aircraft was scheduled for Saturday afternoon, 20 May.

For Monday 22 May two aircraft (N40 and FII)were available. For this flight profile the FII aircraft remained in a holding over Frankfurt while N40 flew en-route, generally southeast bound, toward Munich.

Due to the high SSR channel load in Germany and the Frankfurt/Main area in particular civil and military ATC authorities are discussing possibilities for interference reduction. All stationary and active mobile radar stations contribute to the channel load. DFS as civil ATS provider operates about 25 radars while the number of military stations, operated by German and allied forces is several times greater. In addition, it is assumed that in the dense European environment civil and military radars in neighboring states have overlapping coverage in certain areas. There was a common interest in estimating the contribution of the military to the high SSR channel load. Therefore, German military ATC coordinated with all military forces in Germany for a period of military radar interrogator shutdown during two of the scheduled flights. The goal of this activity was to quantify the contribution of military interrogators to the generation of replies on 1090 MHz. Flights were scheduled around this period on Wednesday, 24 May involving all three aircraft.

A summary of the participating test aircraft is listed below:

Organization	**Aircraft type**	**Aircraft address**	**Registration**
FAA-WJH Technical Center, USA	B727	$A4AA47_h$	N40
FII Flight Inspection International, Germany	Beech-300 King Air	$3CCE6E_h$	D-CFMC
NLR National Aerospace Laboratory, The Netherlands	Fairchild Metroliner	$48406F_h$	PH-NLZ

All tracks were recorded and analyzed with the AMOR system (Analysis tool for Mode S Radar data). AMOR is designed to record radar data on various interfaces and allow the user to analyze the data interactively by use of a graphical interface. The aircraft were identified with their aircraft address derived from Mode S radar data and their squawks recorded from ATCRBS radar stations. The following figures show the extracted flight profiles for each flight day in X-Y plots and altitude (derived from Mode S data) vs. time combined with the targets of opportunity tracks. All aircraft are marked with their aircraft address or name (for the project aircraft). The plots also show the radars used and major German cities. In addition to the test flights, it was possible to use British Airways aircraft on scheduled flights for the performance assessment. These targets of opportunity were also equipped with transponders that use Mode S Extended Squitter for transmission of their position.

The BA Aircraft addresses are:

- 400652_h
- 400663_h
- 400664_h
- 400665_h
- 400667_h

Figure 3.1-1 shows the relationship between the typical flight paths of the project aircraft and the cities and countries in central Europe. Specifically, these were the flight paths used on 24 May, but essentially the same paths were used on the other test days, except for swapping the roles of the three aircraft. The ground stations at Wiesbaden and at Langen are also shown in the figure.

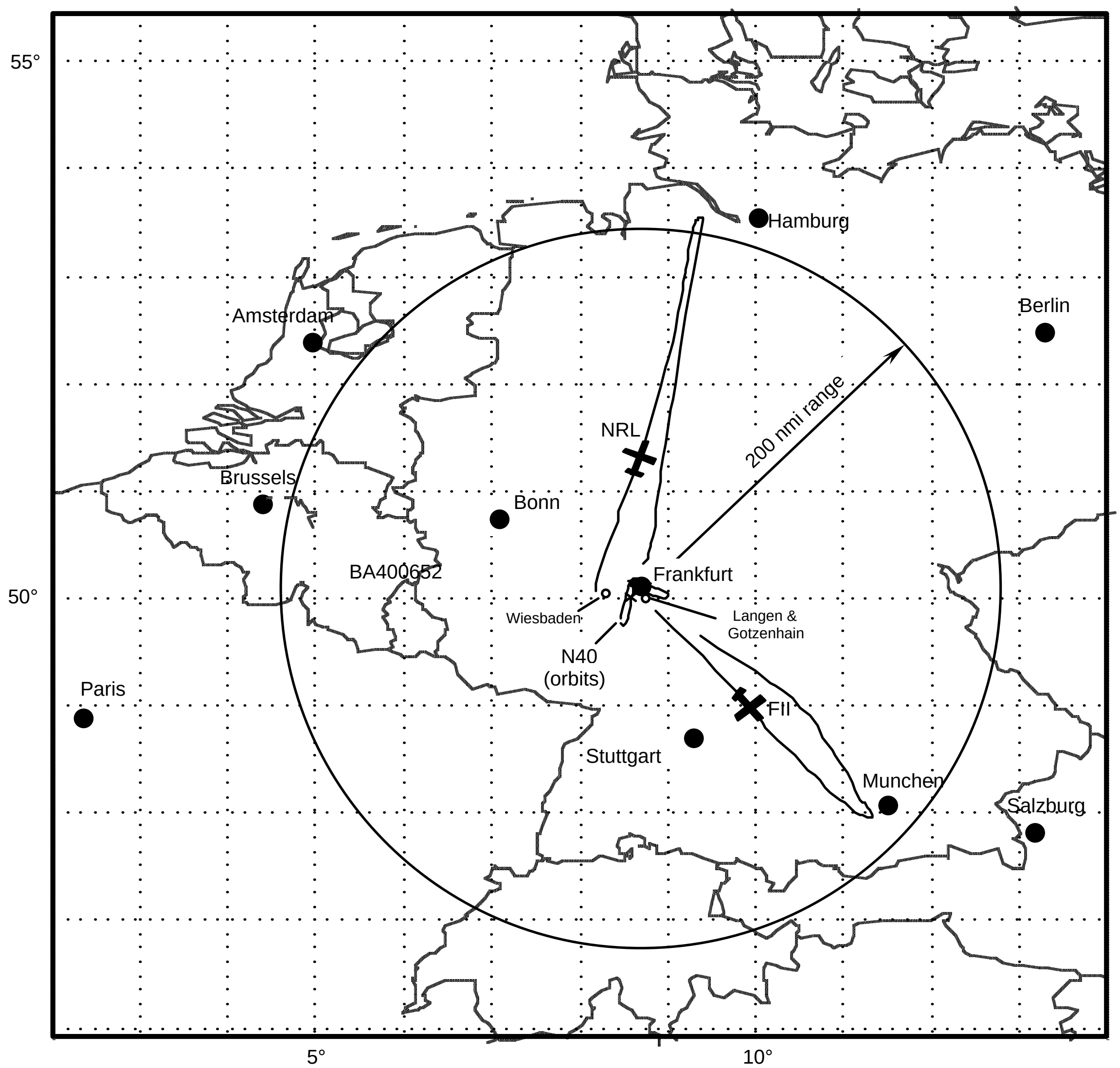


Figure 3.1-1. Illustration of the Test Locations Relative to Cities in Central Europe.

Note: The figure also shows flight paths of the project aircraft on 24 May.

3.2 FRIDAY, 19 MAY 2000 (Shakedown and Calibration)

Profile 1 N40 calibration flight

Route: Wiesbaden departure - RUDUS - ECHO - RIED - KÖNIG - HANAU - METRO - TAUNUS - RUDUS in FL 100-120 Frankfurt Holding max. FL240 approx. 20 min. in North/South orientation approx. 20 min. in East/West orientation approx. 30 min. in FL150, approx. 30 min. in FL100, - Wiesbaden arrival, duration approx. 3 hours

Log report on board N40

06.30 Taxi out, SSR-code A3714, check of test systems
06.40 Take off, climb to 4000 ft
06.47 Start of calibration flight (profile 1) in FL120, SSR-code A1245 over ECCHO
06.51 Over RID in FL120
06.54 Over KNG in FL120
06.59 Over HNU in FL120
07.02 Over MTR in FL120
07.08 Over TAU in FL120
07.10 Over RUD in FL120, climb to FL220 with vectors to FFM-holding
07.15 Approaching FFM-holding in FL220
07.22 First FFM-holding in FL220
07.32 Second FFM-holding in FL220
07.40 Change to RID-holding pattern in FL220
07.48 First RID-holding in FL220
07.57 Second RID-holding in FL220
08.05 RID-holding (profile 1) completed in FL220, descend to FL150 (profile2)
08.10 First RID-holding in FL150
08.20 Second RID-holding in FL150
08.30 RID-holding completed in FL150, descend to FL100
08.31 First RID-holding in FL100
08.40 Second RID-holding in FL100
08.50 RID-holding (profile 2) completed
08.51 Start of descend to ETOU
09.05 Visual approach to ETOU
09.11 Arrival ETOU, Taxi in
09.18 Completion of flight

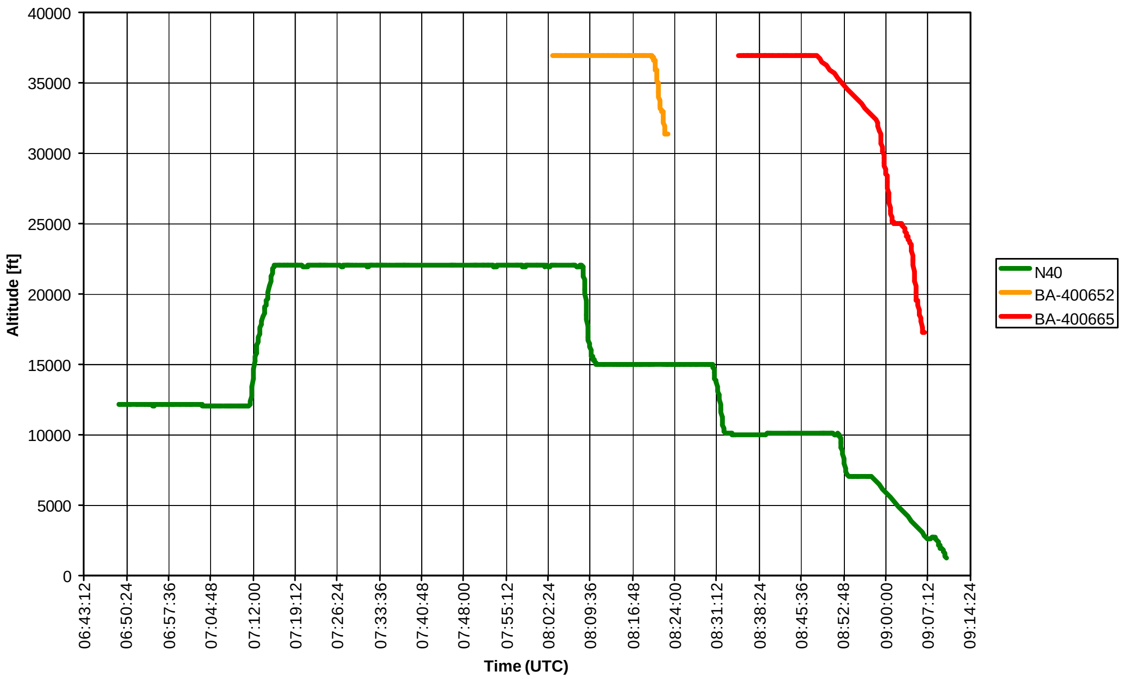


Figure 3.2-1a. 19 May 2000, Aircraft Altitudes

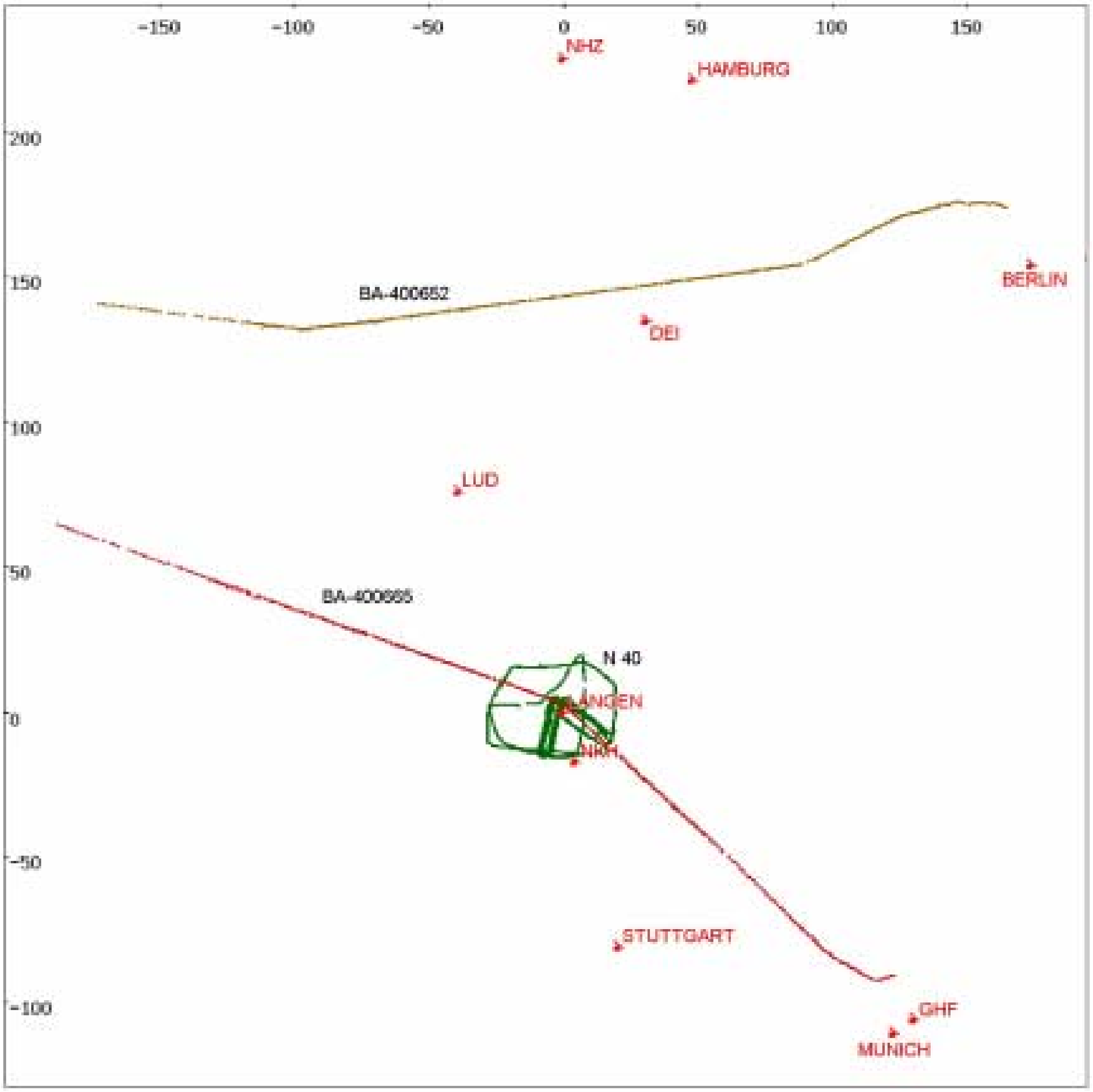


Figure 3.2-1b. 19 May 2000, X-Y Plot

3.3 SATURDAY, 20 MAY 2000 (Afternoon, Weekend)

Profile 2 N40 in holding pattern and D-CFMC & PH-NLZ en-route

N40

Route: Wiesbaden Dep - Frankfurt Holding (possibly pattern orientation variation) - Wiesbaden Arr., Altitude max. < FL240, duration up to 4 hours

FII (D-CFMC)

Route: Wiesbaden Dep - A9 to LBE - A9 to FFM or B1 to MUN - ALB G104 to FFM - Wiesbaden Arr., Altitude between FL180 and FL240, duration approx. 3 hours

NLR (PH-NLZ)

Route: Wiesbaden Dep - B1 to MUN - ALB G104 to FFM or A9 to LBE - A9 to FFM - Wiesbaden Arr., Altitude between FL180 and FL240, duration approx. 3 hours

Log report on board N40

13.30	Taxi out, SSR-code A3720, check of test systems
13.37	Take off PH-NLZ, SSR-code A3721, southbound route to MUC
13.40	Take off N40, to FFM and RID holding patterns
13.46	Take off FII411, SSR-code A3722, northbound route to LBE
13.50	Climb to FL220, start of profile 3
13.55	First FFM-holding in FL220
14.05	Second FFM-holding in FL220
14.14	Third FFM-holding in FL220
14.23	FFM-holding completed in FL220, change to RID-holding
14.25	PH-NLZ reported turning at MUC
14.26	First RID-holding in FL220
14.35	Second RID-holding in FL220
14.45	Third RID-holding in FL220
14.50	FII411 reported turning at LBE in FL220
14.52	First FFM-holding in FL220
15.02	Second FFM-holding in FL220
15.11	Third FFM-holding in FL220
15.20	FFM-holding completed in FL220, change to RID-holding
15.23	First RID-holding in FL220
15.30	Arrival of PH-NLZ at ETOU
15.33	Second RID-holding in FL220
15.43	Third RID-holding in FL220
15.44	RID-holding (profile 3) completed
15.45	Start of descend to ETOU
15.46	Arrival of FII411 at ETOU
16.02	Visual approach to ETOU
16.09	Arrival ETOU, Taxi in
16.15	Completion of flight

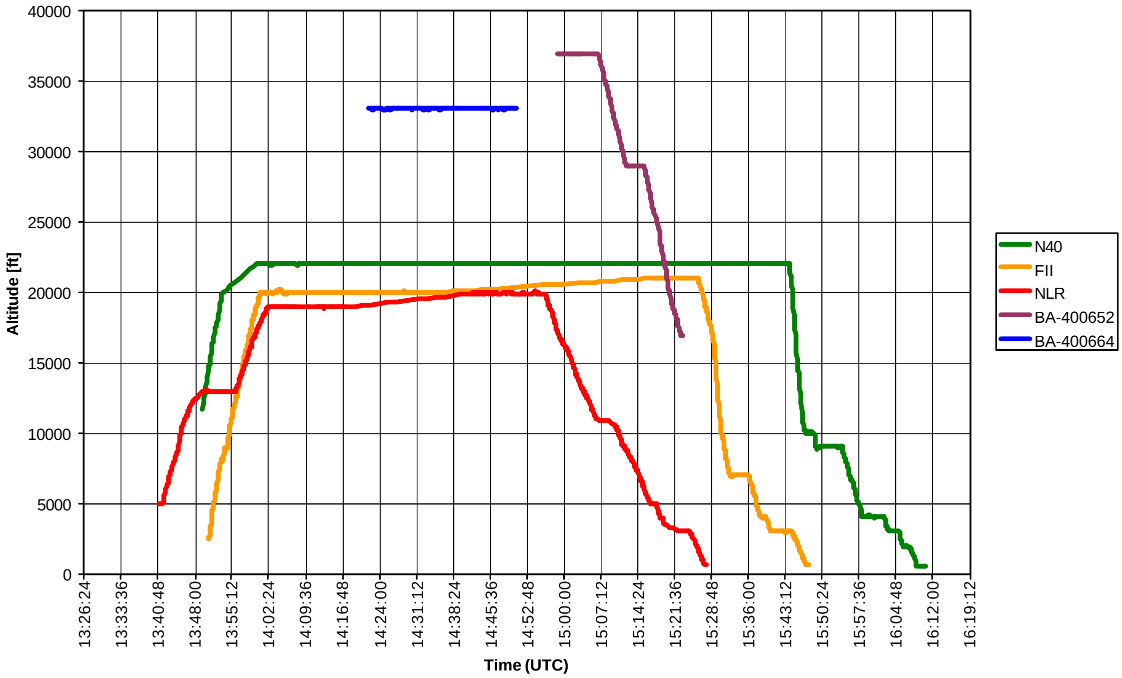


Figure 3.3-1a. 20 May 2000, Aircraft Altitudes

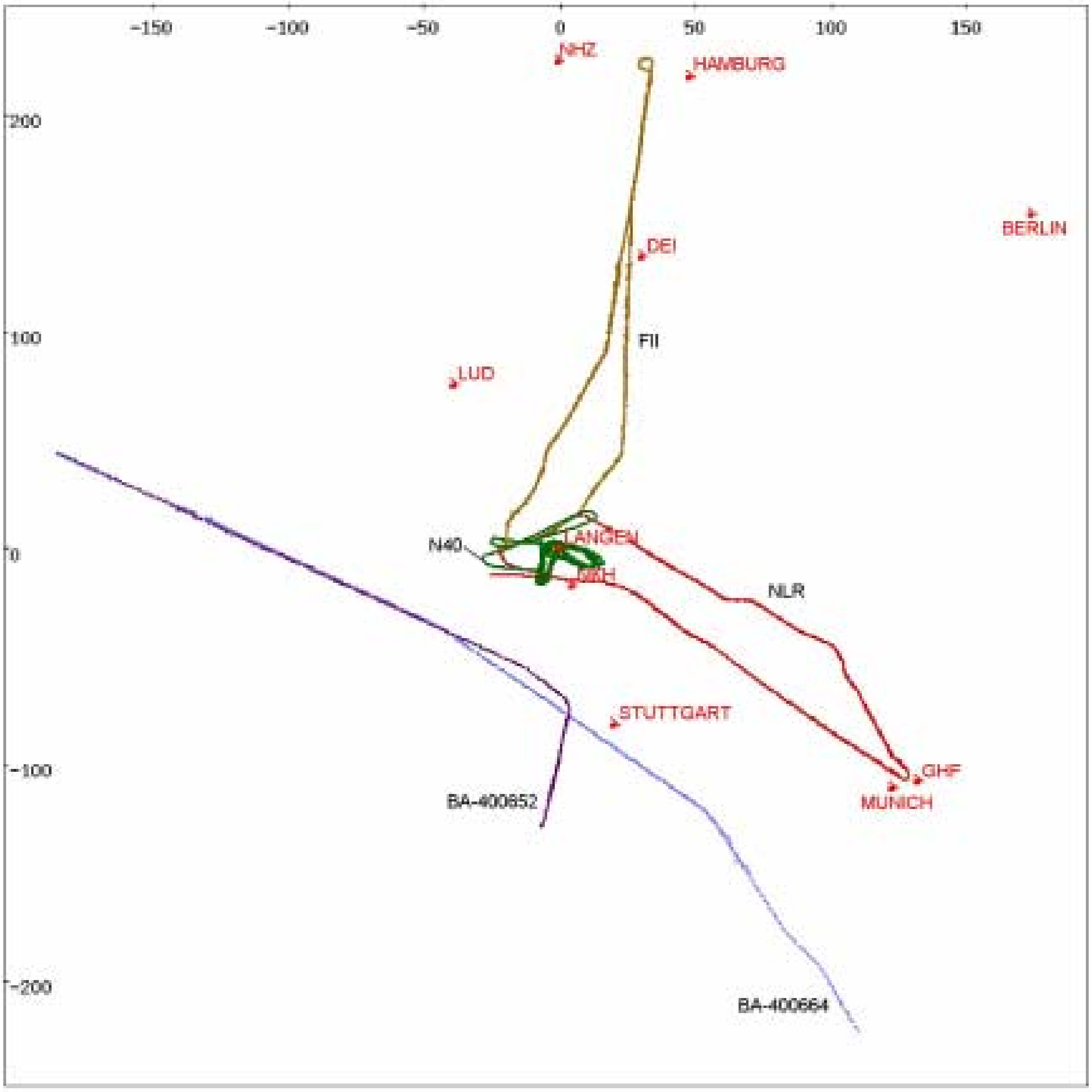


Figure 3.3-1b. 20 May 2000, X-Y Plot

3.4 MONDAY, 22 MAY 2000 (Afternoon)

Profile 4 FII (D-CFMC) in holding pattern, N40 en-route

FII

Route: Wiesbaden Dep. - Frankfurt Holding (possibly pattern orientation variation) - Wiesbaden Arr., altitude: max. < FL240, duration up to 3.5 hours

N40

Route: Wiesbaden Dep. - NKR B104 - AALEN B6 - WALDA B1 - MUN A12 - ERL A65 - WRB V152 - GED - METRO - Wiesbaden Arr., altitude: between FL180 and FL240, duration up to 4 hours

Log report on board N40

13.34	Taxi out FII411, SSR-code A3732
13.35	Taxi out N40, SSR-code A3730, check of test systems
13.40	Take off FII411
13.45	Take off N40, climb to 7000 ft, direct routing to NKR
13.50	Start of calibration flight (profile 4) climbing to FL220, SSR-code A3163
13.55	N40 in FL220 inbound to NKR
13.56	FII411 enters FFM holding in FL220
13.58	Over NKR in FL220
14.04	Over LBU in FL220
14.10	Over AALEN in FL220
14.15	Over RIDAR in FL220
14.17	Over WLD in FL220
14.23	Over MUC in FL220
14.39	Over ALB in FL220
14.43	Inbound to ERL, direct routing to LAU in FL220, SSR-code A3132
14.44	Over ERL in FL220
15.08	Over LAU in FL220
15.15	Over WRB in FL220, direct routing to FTZ
15.19	Over FTZ in FL220, SSR-code A3163
15.21	Start of descend to FL100, SSR-code A1270
15.25	Inbound to GED in FL100
15.27	Descend to 7000ft (profile 4 completed)
15.29	Over GED in 7000ft, start of approach (METRO PAR) to ETOU
15.44	Arrival ETOU, Taxi in
15.50	Arrival of FII411 at ETOU
15.52	Completion of flight

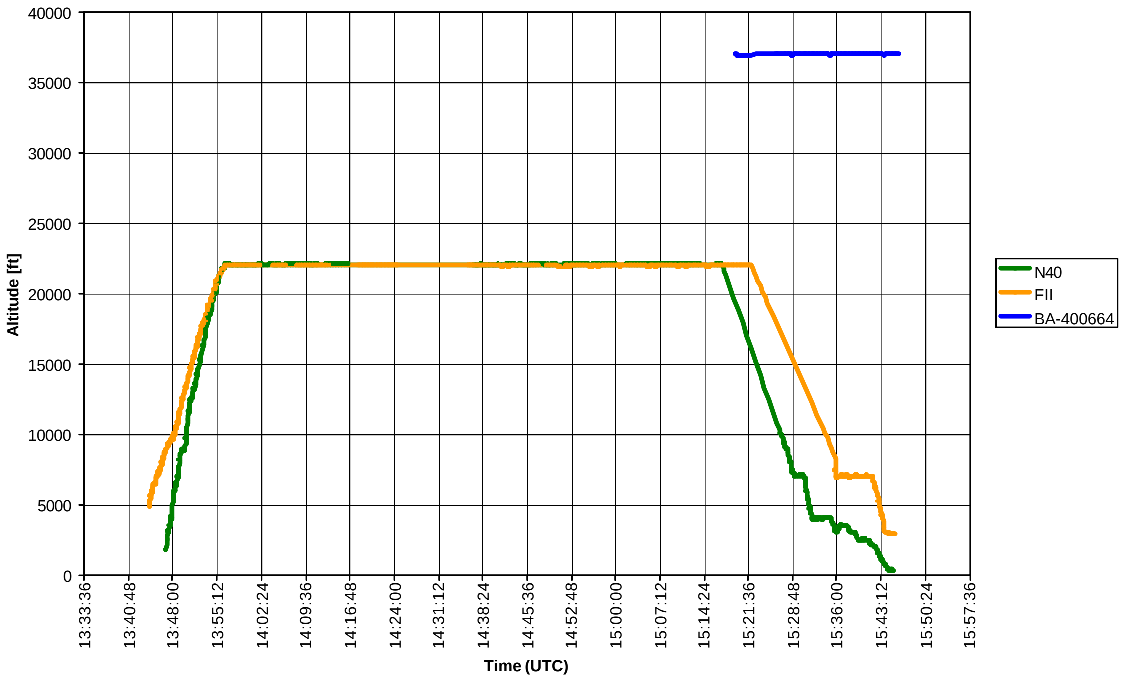


Figure 3.4-1a. 22 May 2000, Aircraft Altitudes

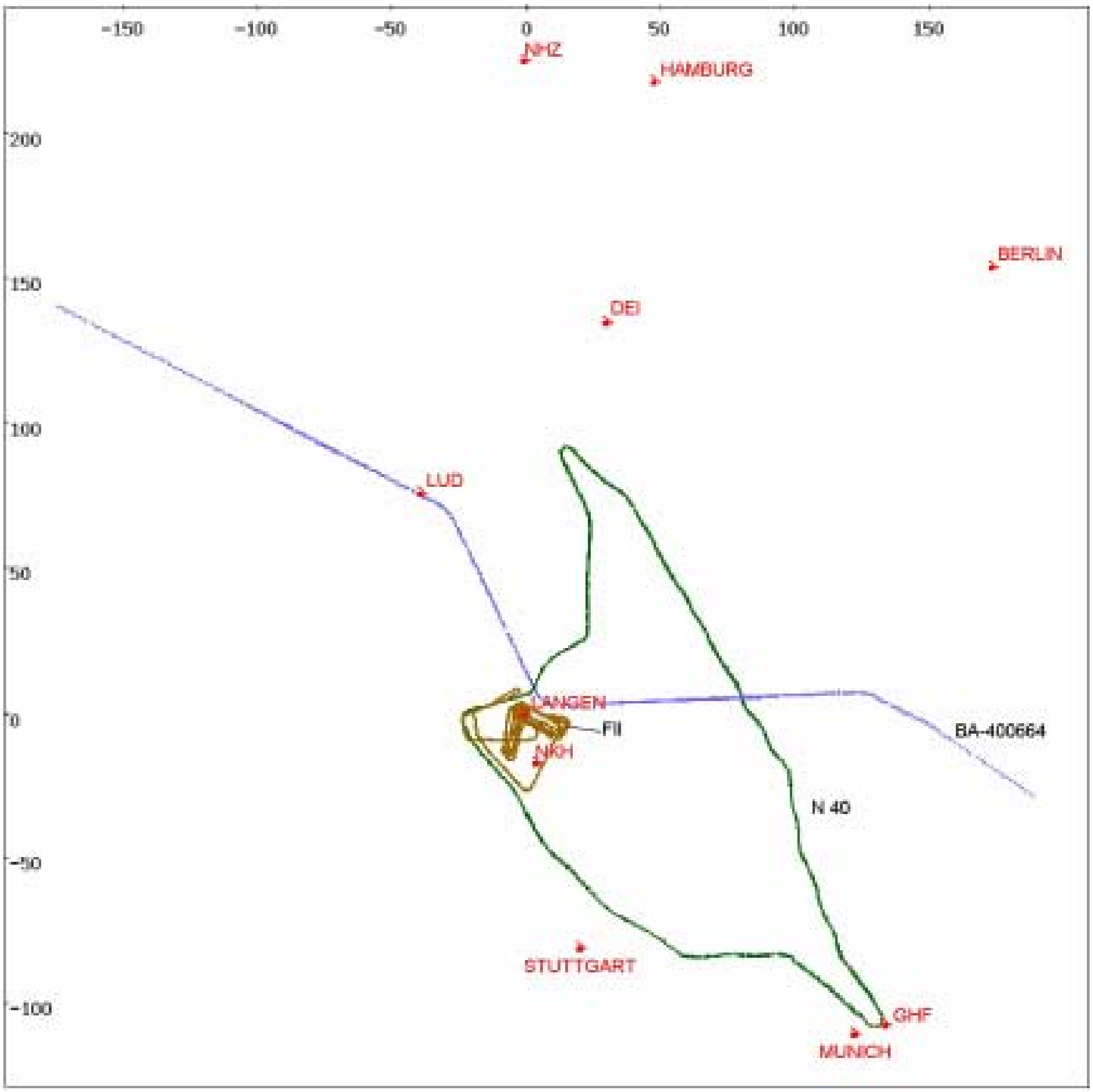


Figure 3.4-1b. 22 May 2000, X-Y Plot

3.5 WEDNESDAY, 24 MAY 2000 (Military Radar Shutdown)

Profile 5 N40 in holding pattern, D-CFMC & PH-NLZ en-route with military scenario

N40

Route: Wiesbaden Dep. - Frankfurt Holding (possibly pattern orientation variation) - Wiesbaden Arr., altitude: max. < FL240, duration up to 4 hours

FII (D-CFMC)

Route: Wiesbaden Dep. - A9 to LBE - A9 to FFM - or B1 to MUN - ALB G104 to FFM - Wiesbaden Arr., altitude: between FL180 and FL240, duration approx. 3 hours

NLR(PH-NLZ)

Route: Wiesbaden Dep. - B1 to MUN - ALB G104 to FFM or A9 to LBE - A9 to FFM - Wiesbaden Arr., altitude: between FL180 and FL240, duration approx. 3 hours

Log report on board N40

10.20	Taxi out N40, SSR-code A3714, check of test systems
10.29	Take off N40, to FFM and RID holding
10.35	N40 climb to FL170, SSR-code A1267
10.39	N40 approaching FFM holding (start of profile 5) in FL200
10.46	N40 climb to FL220 in FFM holding
10.48	Second FFM-holding in FL220
10.56	Take off PH-NLZ, northbound route to LBE
10.58	Take off FII411, southbound route to MUC
10.59	Third FFM-holding in FL220
11.08	Transfer to RID-holding in FL220
11.18	Second RID-holding in FL220
11.28	Third RID-holding in FL220
11.36	Transfer to FFM-holding in FL220
11.45	Second FFM-holding in FL220
11.55	Third FFM-holding in FL220
12.05	Transfer to RID-holding in FL220
12.14	Second RID-holding in FL220
12.24	Third RID-holding in FL220
12.33	Transfer to FFM-holding in FL220
12.42	Second FFM-holding in FL220
12.50	FFM-holding (profile 5) completed in FL220, start of descend to ETOU
12.55	Direct routing to MTR, descend to FL090, start of approach
13.01	Arrival of FII411 at ETOU
13.05	PH-NLZ vectored to ETOU, N40 climb to 5000 ft MTR holding
13.15	N40 start of GCA Approach to ETOU
13.18	PH-NLZ arrival at ETOU
13.26	Arrival of N40 at ETOU
13.45	Completion of flight after additional data collection on the ground

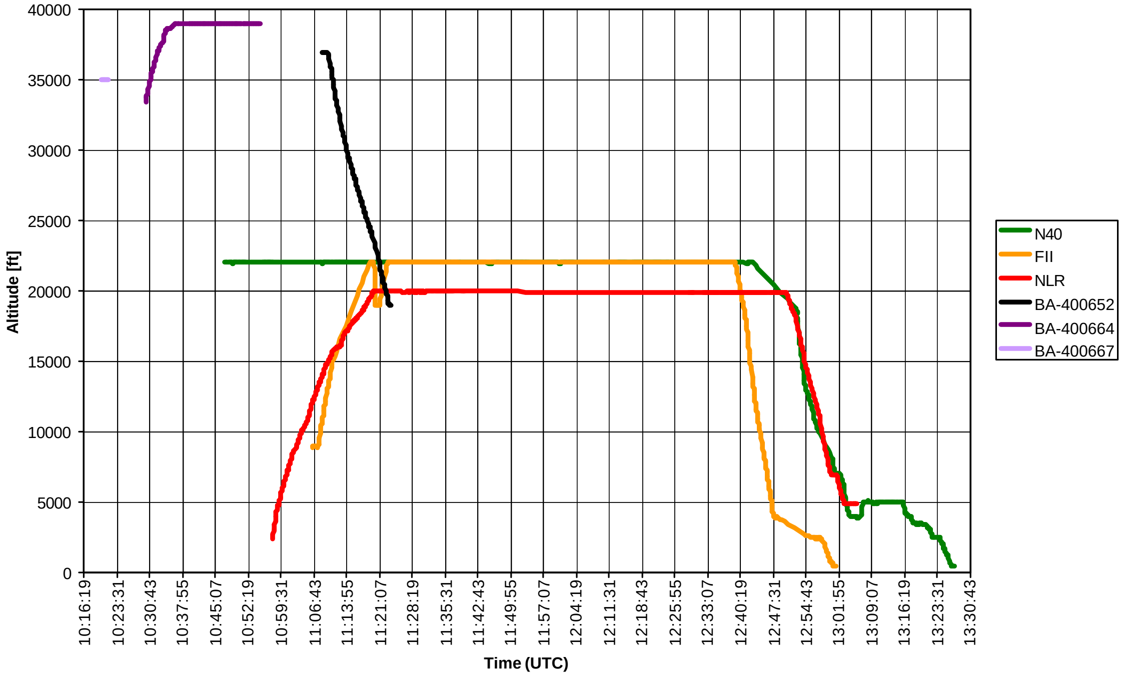


Figure 3.5-1a. 24 May 2000, Aircraft Altitudes

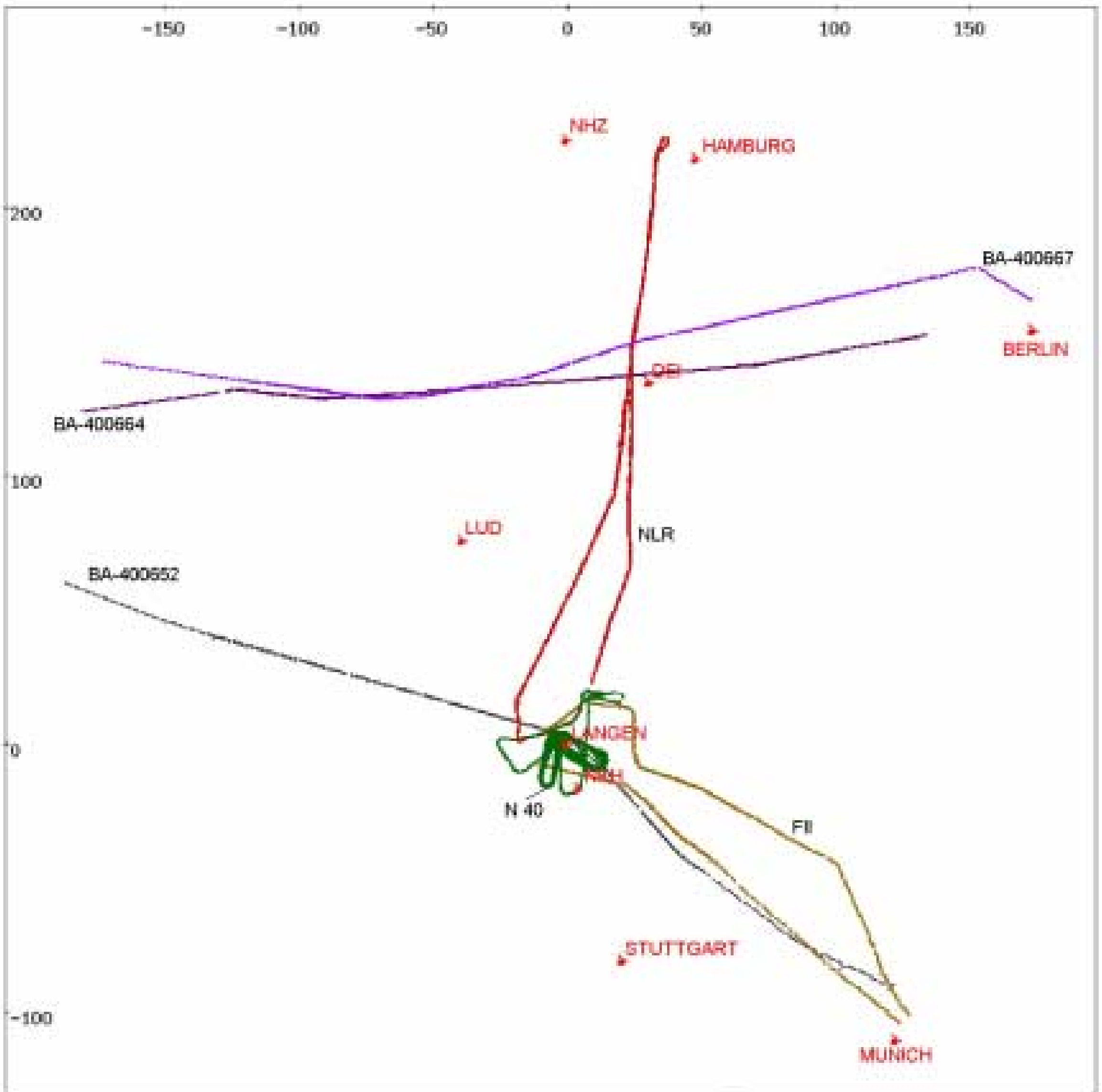


Figure 3.5-1b. 24 May 2000, X-Y Plot

Note. *The BA-400667$_h$ was considered as a "target of opportunity", but never received by any of the aircraft or ground stations.*

3.6 THURSDAY, 25 MAY 2000 (Military Radar Shutdown)

Profile 6 N40 in holding pattern with military scenario, en-route afterwards

Route: Wiesbaden Dep - Frankfurt Holding - NKR B104 - AALEN B6 - WALDA B1 - MUN A12 - ERL A65 - WRB V152 - GED - METRO - Wiesbaden Arr., altitude max. < FL240, duration up to 4 hours

Log report on board N40

10.30	Taxi out N40, SSR-code A3723, check of test systems
10.37	Take off N40, climb to 9000 ft
10.45	Direct routing to FFM, climb to FL220
10.47	Change of SSR-code A3130
10.50	N40 starts FFM holding in FL200 (profile 6) climbing for FL220
10.52	FFM-holding in FL220
10.55	Change of SSR-code A3165
11.02	Second FFM-holding in FL220
11.10	Third FFM-holding in FL220
11.20	Transfer to RID holding in FL220
11.26	First RID holding in FL220
11.36	Second RID holding in FL220
11.46	Third RID holding in FL220
11.49	Completion of holdings and transfer to en-route part, climb to FL230
11.53	Over NKR in FL230
11.58	Over LBU in FL230
12.03	Over AALEN in FL230
12.06	Over RIDAR in FL230
12.07	Over WLD in FL230
12.13	Over MUN in FL230
12.17	Inbound to ALB, direct routing to ERL in FL230
12.21	Climb to FL240
12.27	Over ERL in FL240
12.38	Over MBA in FL240
12.41	Over LAU in F240
12.44	Over FTZ in F240, direct routing to MTR start of descend to FL100
12.55	Start of approach to ETOU, profile 6 completed
13.04	Arrival ETOU, Taxi in
13.32	Completion of flight after additional ground measurements

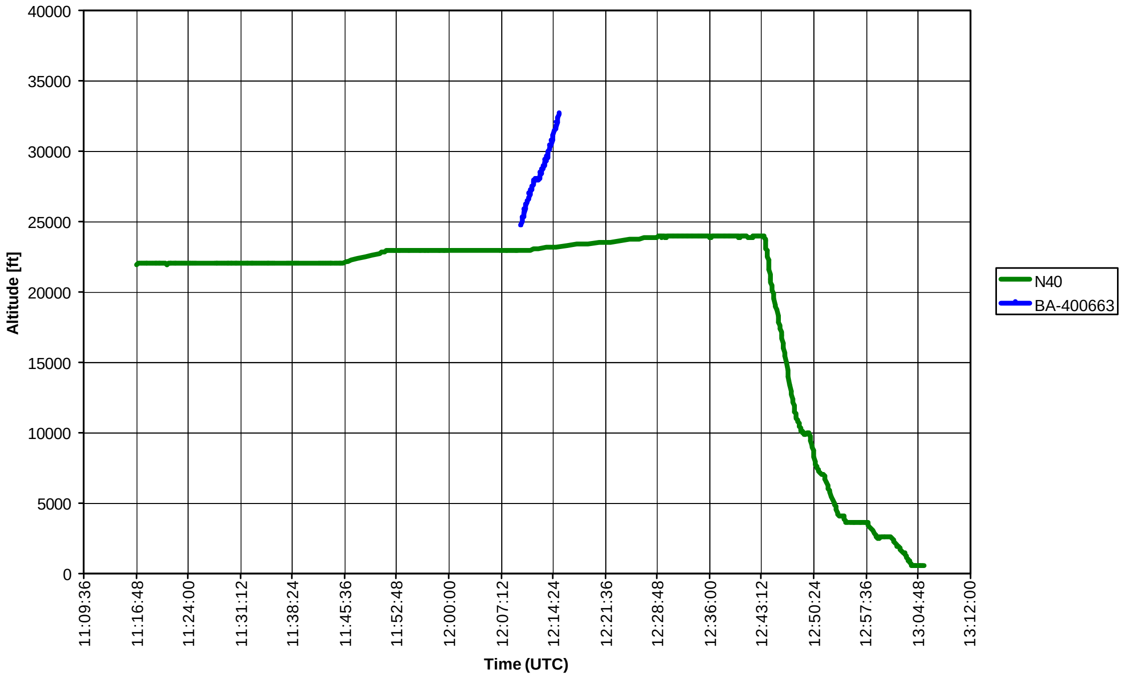


Figure 3.6-1a. 25 May 2000, Aircraft Altitudes

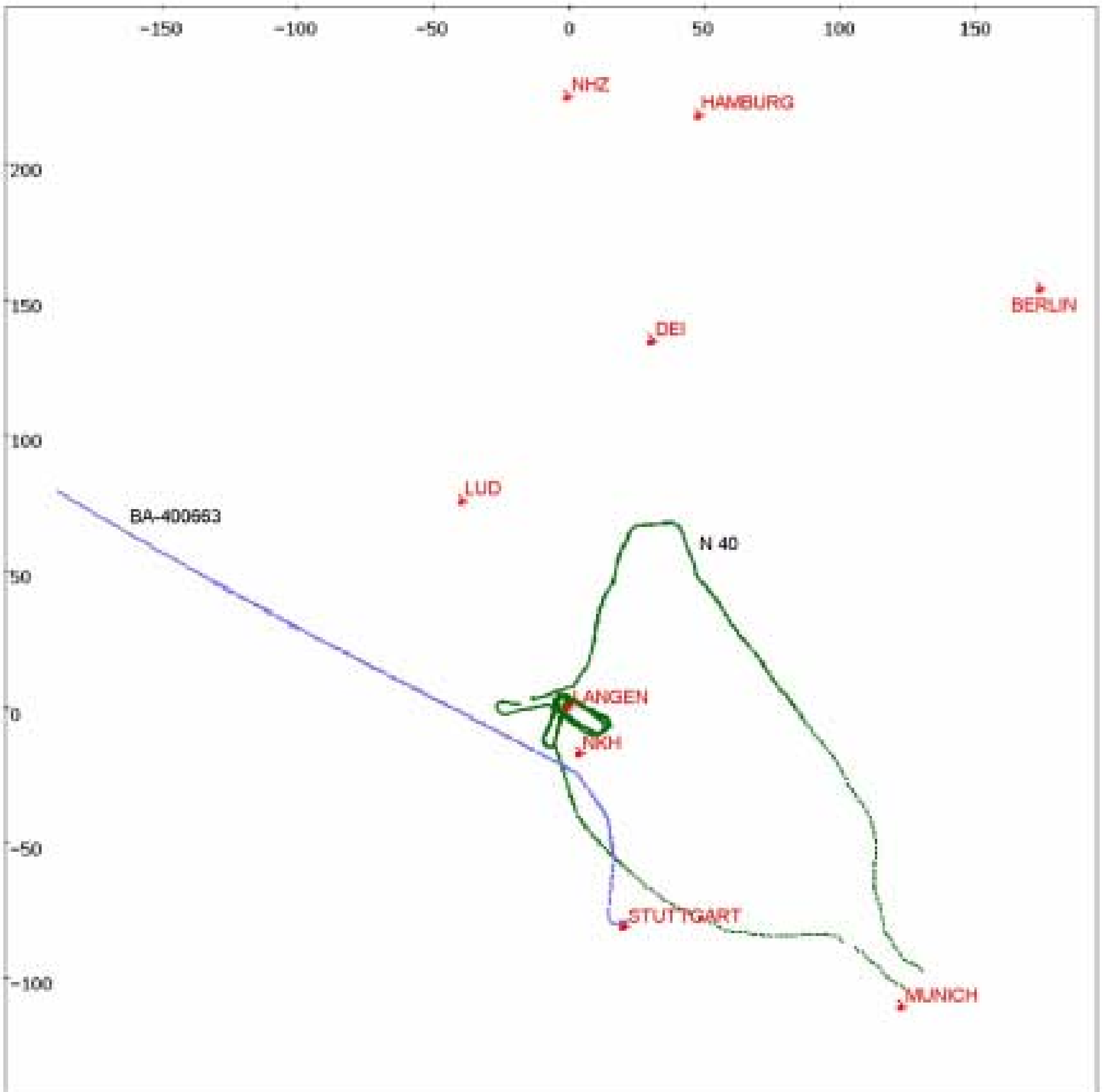


Figure 3.6-1b. 25 May 2000, X-Y Plot