Digital Audio Broadcasting ®

ARCHIMEDES
– Measurements in an emulated DAB satellite channel

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The European Space Agency (ESA) has investigated the use of multi-regional highly-inclined elliptical orbit (M-HEO) satellites for digital radio systems. These studies have demonstrated, in particular, that it is possible to use the Eureka-147 DAB system – delivered by six HEO satellites – to provide a digital radio service to Europe, North America and East Asia.

This article describes how these studies, sponsored by ESA and carried out by DLR and IRT, set out to answer unresolved questions about the transmission channel and the use of the Eureka-147 system under operational conditions.

1. Introduction

–Now that the Eureka-147 DAB system [1] has proved its value as a high-quality digital audio broadcasting system in terrestrial propagation, its use for broadcasting in a satellite channel [2][3][4] is also being examined.

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The DAB logo has been registered by a member of the Eureka-147 DAB consortium.

The European Space Agency (ESA) has long been investigating the *multi-regional highly-inclined elliptical orbit* (M-HEO) satellite concept within the Archimedes programme [5]. HEO satellites make it possible to cover regions of high latitude more efficiently – the most important economic conurbations are in this geographical region – due to the large elevation angles when compared with geostationary (GEO) satellites. Screening of the signals by obstructions in the vicinity of the receiver occur less frequently at large elevation angles, resulting in a marked improvement in reception – especially under mobile reception conditions.

The studies to date have been embodied in the *mediaStar* concept, proposed by Daimler-Benz Aerospace (DASA). Six satellites – in an 8-hour orbit with an inclination of 63.4° and altitudes of between 1000 km (perigee) and 26,800 km (apogee) – could cover the major industrial nations in Europe, North America and East Asia without interruption [6]. The minimum elevation angle in these nations would be 40° but, in most regions of central Europe, it would be greater than 60° (see *Fig. 1*). The planned uplink frequency will be in the Ku band while the "broadcast link" (between the satellite and receiver) will be in L-band. The above-mentioned DAB system is envisaged for both audio and data transmissions; it will be possible to radiate several DAB programme packages simultaneously from each satellite, for different regions.

Abbreviations

AGC	Automatic gain control
agl	Above ground level
asl	Above sea level
BER	Bit error rate
CRC	Cyclic redundancy check
DAB	Digital Audio Broadcasting
DASA	Daimler-Benz Aerospace
DAT	Digital audio tape
DLR	Deutsche Forschungsanstalt für Luftund Raumfahrt (German aerospace research establishment)
ESA	European Space Agency
FD	Fading depth
G/T	Gain/temperature ratio
GEO	Geostationary orbit
GPS	Global positioning system
HEO	Highly-inclined elliptical orbit
HF	High frequency
IEC	International Electrotechnical Commission
IRT	Institut für Rundfunktechnik GmbH (German broadcast engineering research centre)
ISO	International Standards Organisation
kph	Kilometres per hour
LM	Link margin
M-HEO	Multi-regional highly-inclined elliptical orbit
MPEG	(ISO) Moving Picture Experts Group
VHF	Very high frequency

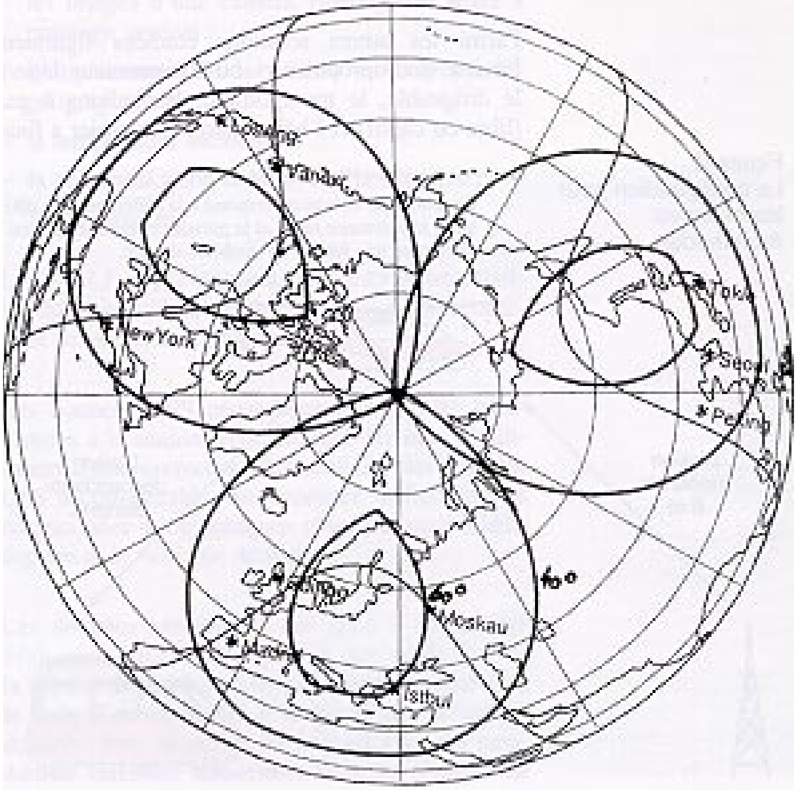
In order to design the broadcast link correctly, its transmission characteristics must be known. For this purpose, theoretical studies [3] and channel measurements [7][8] have been carried out. Further studies are required in several respects, primarily to find out how the DAB system behaves in a real satellite channel which is exposed to interference. Clarification of this matter, and verification of the theoretical studies made in [3], was the purpose of the "Archimedes DAB Measurement and Verification Campaign" [9][10][11] which is described in this article.

2. Measurement concept

The main objectives of the Archimedes campaign were as follows:

1. Assessment of the DAB system in a "quasi-HEO satellite channel", under a large number of typical conditions. These assessments would be based on a HEO satellite simulation in the form of an airborne hovering platform. Selective investigations would be carried out on mobile reception, especially in critical situations where interference could be expected. The effect of varying the elevation angle and

Figure 1
Iso-elevation (60°/40°) areas in the three regions
(courtesy of DASA).



the power radiated from the platform would be considered in particular.

2. Verification of the assumptions about the link design made in the mediaStar concept.
3. Identification of potential problems, possibly leading to ways of remedying them.

The airborne platform would transmit a very stable DAB signal with defined parameters, and a vehicle equipped with DAB receiving and measuring equipment would travel along selected routes, recording all the relevant measured quantities. The routes to be investigated would cover various different types of terrain where critical reception conditions could be expected.

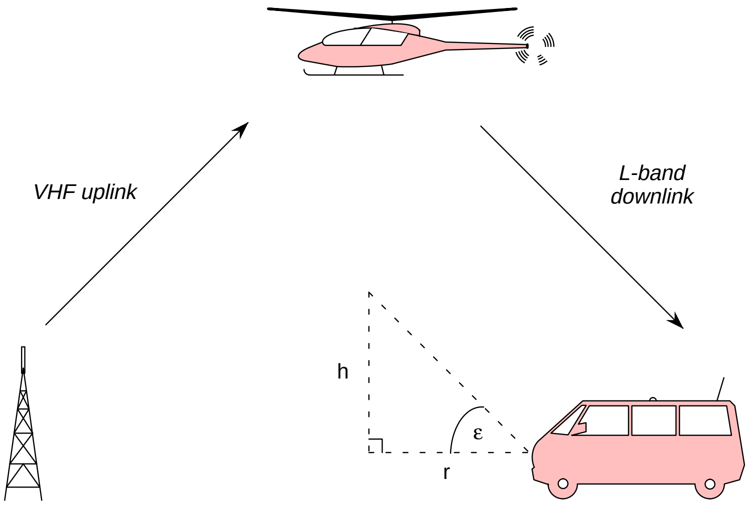
2.1. *Airborne platform*

One of the major questions when setting up the measurement configuration was: which platform would best simulate a HEO satellite, allowing for financial and time constraints? Several marginal conditions had to be taken into account with regard to the platform. Among the most important were:

- its availability during the measurement period;
- the range of elevation angles which it could provide;
- the height above ground level it could achieve;
- the stability of its airborne position;
- the efficiency of its power supply for the measurement equipment;
- the maximum loading it could handle.

A large number of alternative platforms were considered, including available satellites. In fact, in parallel with this investigation, measurements were also made using GEO L-band satellites as transponder platforms (i.e. the Australian Optus B3 [12] and the Mexican Solidaridad 2 [13] satellites). However, the power radiated by these satellites proved to be too weak to provide the necessary link margins[1] for mobile reception. The desired variation of the elevation angle (40° to 80°) would also have resulted in unjustifiably high travelling costs for the measurement vehicle.

Figure 2
The Archimedes measurement configuration.



Among the other alternatives which were examined were turboprop aircraft, light single-engined aircraft, airships, hot-air or gas balloons, tethered balloons and helicopters. The helicopter was ultimately chosen because, among other reasons, it has the greatest positional stability in the hover mode. This criterion played a particularly important role in these measurements because, unlike pure-channel measurements, power fluctuations – which directly influence the audio quality – cannot be eliminated by “post-processing” (i.e. later correction of the measurement results to compensate for determinable quantities, such as positional variations, which falsify the results).

2.2. *DAB signal generation*

Another point to be resolved was the type and method of DAB signal generation. The option of generating the signal on board the helicopter was ruled out, principally because the hardware reliability of the available DAB signal generators could not be guaranteed in the event of the occasional strong vibrations which can occur in helicopters. The preferred transponder option was to radiate a VHF-DAB signal from the ground and, at the helicopter, convert this signal to the L-band for re-transmission *(Fig. 2)*.

A vehicle fitted with comprehensive receiving, measuring and recording equipment was used as the mobile receiving station. The audio signal from the DAB receiver, and the received ISO-CRC words, were recorded and used to assess the quality of the DAB reception.

2.3. *Cyclic redundancy checks*

In the DAB system, CRC words are inserted in the transmitted source-coded data-stream to permit reliable error detection at the receiver. Punctured convolutional codes can be used to generate areas of the data-stream with different error protection levels; these differently-protected areas can be checked by means of the CRC words.

The ISO-CRC word checks the control information contained in a DAB audio frame; for example, the

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[1] The link margin is the difference (in dB) between the received power and the minimum power needed on a line-of-sight link.

DAB header, the bit-allocation information and the scale-factor selection information (i.e. the region with the highest error protection [14]). Additionally, an area (where the scale factors are) of medium error-correction capability is checked with four different SCF-CRCs. This check is performed in every audio frame, i.e. every 24 ms. If at least one error is detected in the corresponding areas of the data-stream, the appropriate CRC error flag is set. In measurement investigations, the CRC proved to be a suitable means of objectively assessing the quality of a DAB signal [15]. It is not only easy to handle but also allows conclusions to be drawn about the subjective perception of interference.

Measurements were made using a Philips DAB-452 receiver which issues the CRC error information for each audio frame via a serial interface which also allows control of the internal error-masking strategies.

2.4. Measurement routes

Since it could be assumed that DAB reception would be error-free on routes where there was no shadowing of the “satellite”, more demanding routes – containing a variety of different shadowing conditions – were selected:

- forests;
- avenues lined with tall trees;
- villages;
- suburbs;
- inner cities;
- motorways with bridges and tunnels.

The chosen routes varied in length from about 400 m to 6 km.

The position of the transmission platform was determined and the course of the measurement routes selected such that the distance to the measurement vehicle and the elevation angle along each route could only vary within very narrow limits. For each setting of the *power flux density* and the *elevation*, the measurement vehicle travelled along the measurement routes once in each direction.

2.5. Measured quantities

A number of measured quantities were recorded in the helicopter and in the measurement vehicle during each run. These were used for assessing the quality of the DAB reception, for subsequent analysis of the results and to verify compliance with the parameters.

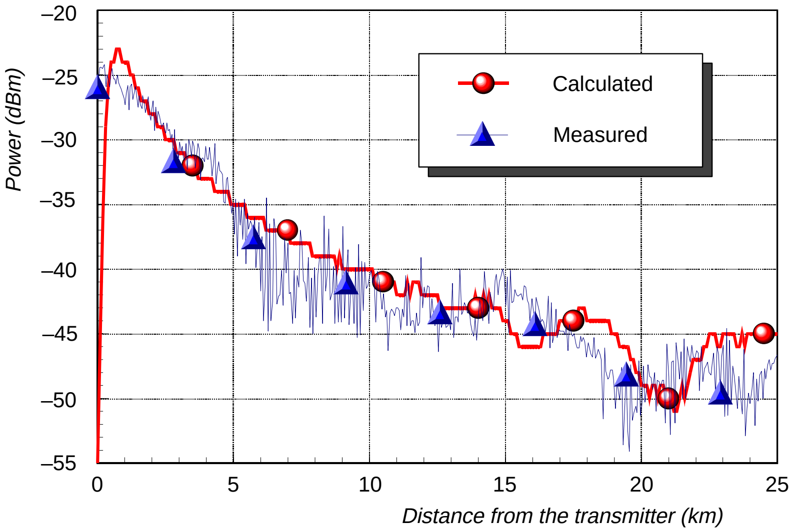


Figure 3
Comparison between the measured and the calculated power at approximately 500 m agl.

The following values were recorded in the helicopter:

- the power level received from the uplink at the transponder input;
- the power level supplied by the transponder to the transmitting antenna;
- the attitude of the helicopter in geographical coordinates;
- the position of the helicopter in the air (roll, pitch, heading);
- the inside temperature;
- radio communication with the car;
- the exact time in order to assure the correct assignment of all measured data.

The following values were recorded in the measurement vehicle:

- the power received at the antenna connection;
- the received radio signal;
- CRC errors;
- the pictures from a vertically-pointing wide-angle video camera;
- the position of the car in geographical coordinates;
- the inside temperature;
- radio communication with the helicopter;
- the exact time.

A detailed description of the measurement set-up in both the helicopter and the measurement vehicle is given in *Sections 3.1* and *3.2*.

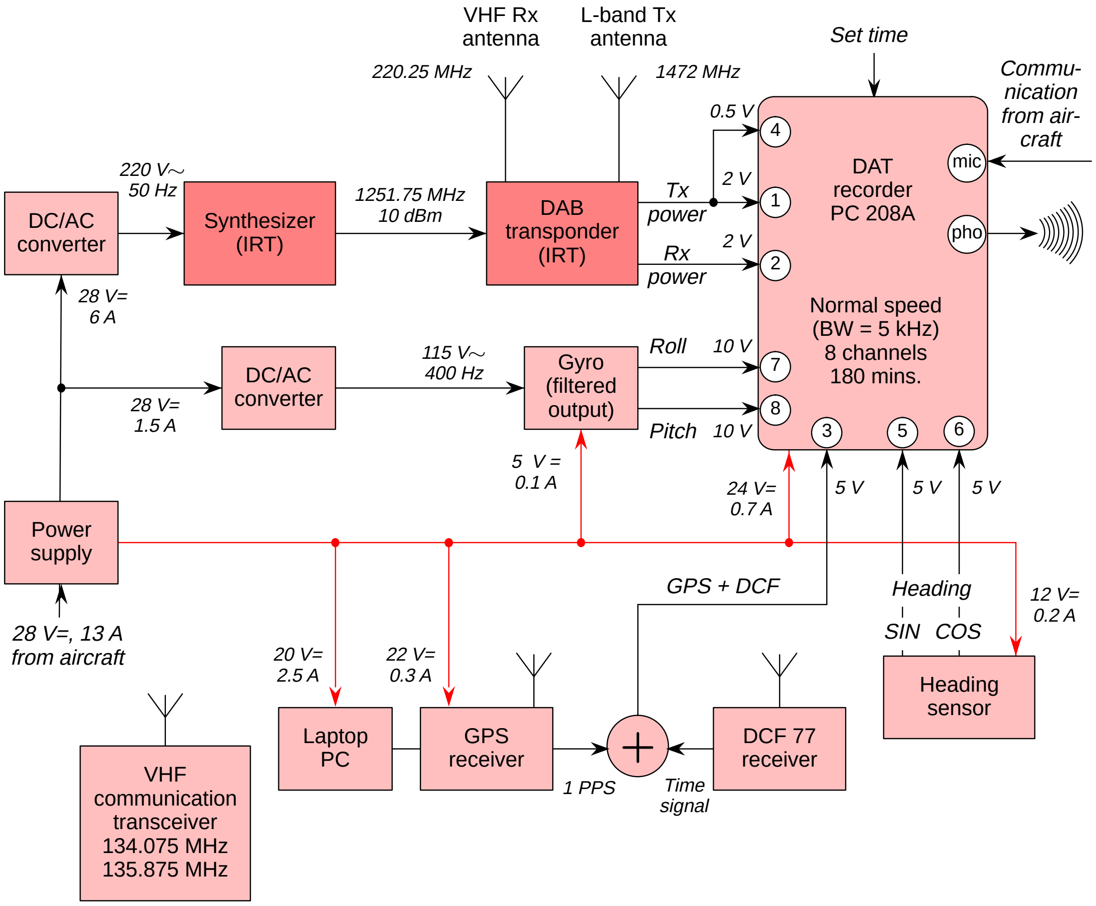


Figure 4
Equipment in the helicopter.

Figure 5
Interior view of the helicoptor.

Stationary GPS data were recorded at a reference ground station. A subsequent differential GPS data correction was applied which significantly increased the accuracy of the resulting geographical coordinates of the helicopter and the measurement vehicle.

The recorded data were used to evaluate the quality of reception both objectively and subjectively. The objective criterion was the CRC error rate at the given power flux density (and hence the link margin) with the variable parameters *environment* and *elevation*. The received audio signal was assessed subjectively. The associated video recording showed the obstructions on the propagation path from the “satellite” to the receiving antenna during the measurement run.

The elevation angle and the power density at the reception point were determined as a function of time for each measurement route. This was performed by means of calculations based on the position of the helicopter and the measurement vehicle, and the power transmitted at a particular instant. This verified that the target parameters had been met sufficiently accurately

3. Measurement configuration

As already mentioned in *Section 2*, the signal needed for the measurements was transmitted via an uplink to the transponder in the helicopter. The DAB signal was generated at the IRT in Munich. This was a DAB multiplex signal (gross bit-rate = 2.304 Mbit/s) which consisted of several MPEG-1

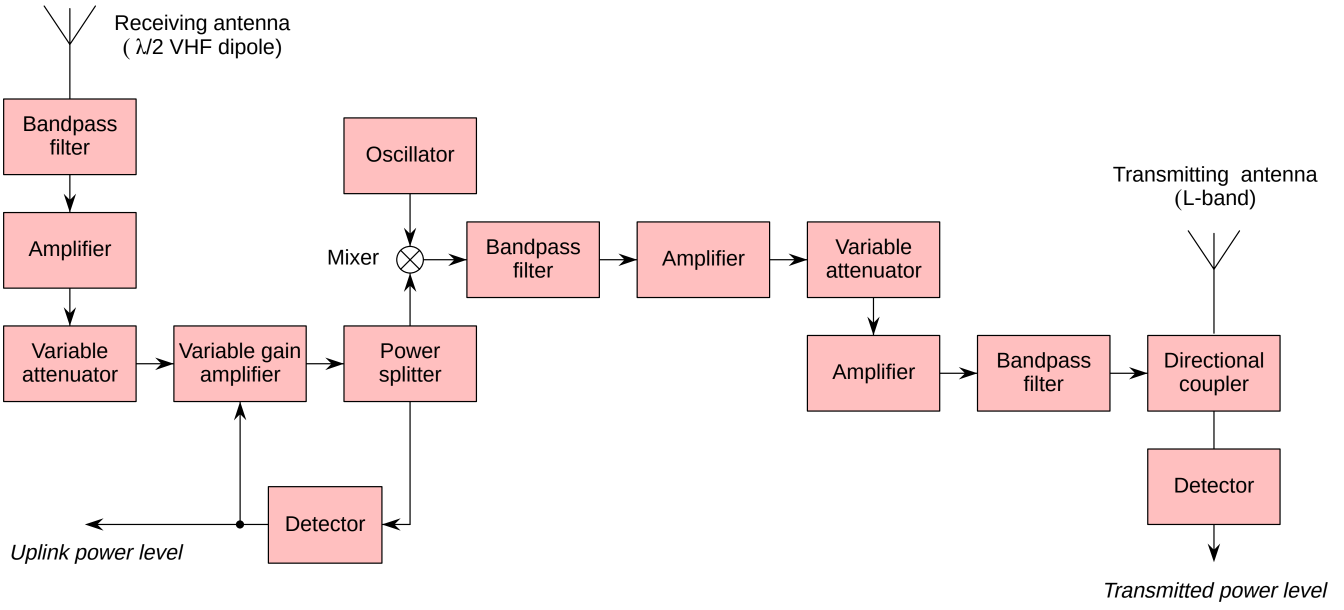


Figure 6
DAB transponder in the helicoptor.

layer II coded, audio signals at 224 kbit/s (classical or pop music) and 192 kbit/s (pop music and voice). The channel coder used a punctured convolutional code which applied unequal error protection, with error protection level 3, corresponding to an average code rate of 0.5.

The modulated signal (bandwidth = 1.536 MHz) was transmitted from the Freimann transmitter in Munich (see *Table 1*) at a centre frequency ($f_{m/VHF}$) of 220.25 MHz in DAB transmission mode III (the mode for satellite transmission). This uplink signal was received in the helicopter and fed to a linear transponder.

Measurement regions were selected in and around Munich by means of field-strength predictions made at the IRT. The signal from the IRT to be received in the helicopter would have adequate power in these regions and would not be exposed to severe power fluctuations due to multipath propagation (e.g. reflections from mountains) in the event of minor positional changes. An AGC in the transponder compensated for uplink power fluctuations occurring as a result of ground reflections. In order to set the AGC correctly, the dynamic range of the input signal needed to be known. This was taken from the field-strength prediction.

The accuracy of the prediction was verified by calculating the received power at a height of 500 m agl on a 28 km long flight route from the IRT in Munich to Oberpfaffenhofen. The received power on this route was measured and recorded at a later time on a helicopter flight. The calculated and measured received power are shown together in *Fig. 3*. It can be seen that there is good agreement between the calculated and measured values.

3.1. *Equipment in the helicopter*

The equipment in the helicopter, shown in the form of a block diagram in *Fig. 4* and as a photograph in *Fig. 5*, had two important functions. Firstly, it had to receive the VHF-DAB signal transmitted from the ground, convert it to the 1.5 GHz frequency band and radiate it at constant power. A receiving antenna, a linear transponder and a transmitting antenna were used for this task. Secondly, it had to record the measured quantities so that it was possible to verify later how accurately the helicopter emulated a satellite.

For the second task, the levels of the received and transmitted DAB power and the position of the helicopter – in terms of its geographical coordinates and its attitude with respect to the horizontal plane – were measured and recorded.

The VHF-DAB signal was received with an antenna similar to a $\lambda/2$ dipole, mounted below the helicopter, and fed to the linear transponder.

Characteristic	Value
Antenna height (m)	92
Aperture angle, HRP (degrees)	61
Aperture angle, VRP (degrees)	66
Direction of maximum radiation (degrees)	210
Radiated ERP (W)	500

Table 1
Technical data of the Freimann transmitter [7].

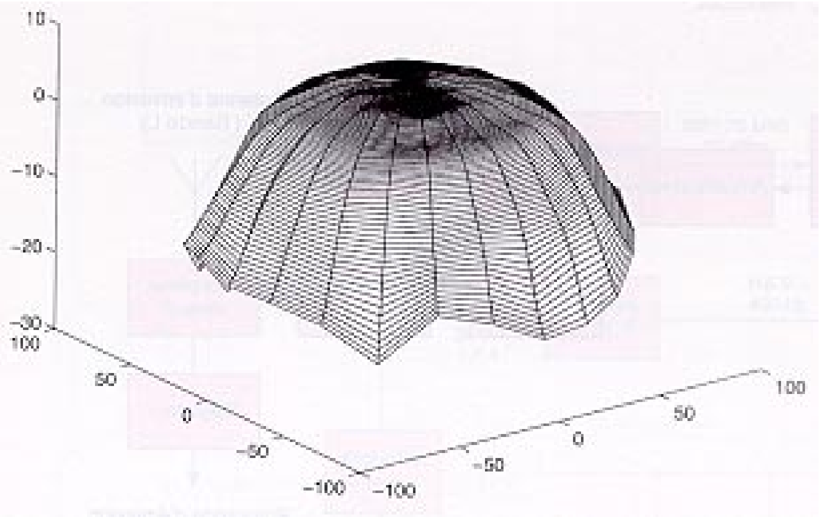


Figure 7
3-D representation of the DAB transmitting antenna radiation pattern.

In the transponder (see *Fig. 6*) the received signal was first filtered and amplified. The signal level was set approximately by a variable attenuator, according to the distance of the helicopter from the transmitter so that fluctuations in its level due to ground reflections could be eliminated by a following AGC loop. The stabilized signal was converted to the 1.5 GHz frequency band, filtered and amplified.

A second gain-controlled attenuator allowed an experimenter on board the helicopter to set the output (radiated) power manually. The measured power values at the input and output of the transponder were recorded on two tracks of an eight-track DAT recorder.

The DAB signal was transmitted omnidirectionally in the azimuth plane, using a left-handed circularly-polarized, double-cylindrical spiral antenna. The 3 dB angle of aperture of its elevation radiation pattern was large (98°) in order to minimize the effect of the attitude of the helicopter on the field-strength amplitude at the reception point on the ground.

The 3-D representation of the radiation pattern is shown in *Fig. 7*.

The position of the transmission platform was measured using a GPS receiver and recorded on a notebook PC. A gyroscope and electronic compass were used to measure the position. The gyroscope measured the pitch and roll of the helicopter and the electronic compass indicated its heading. These data were stored on four tracks of the DAT recorder.

The time received from a DCF 77 clock was recorded on another track of the DAT recorder to allow accurate timing of the measurement data in the helicopter and the car.

There was also a VHF transmitter/receiver, to provide communication with the measurement ve-

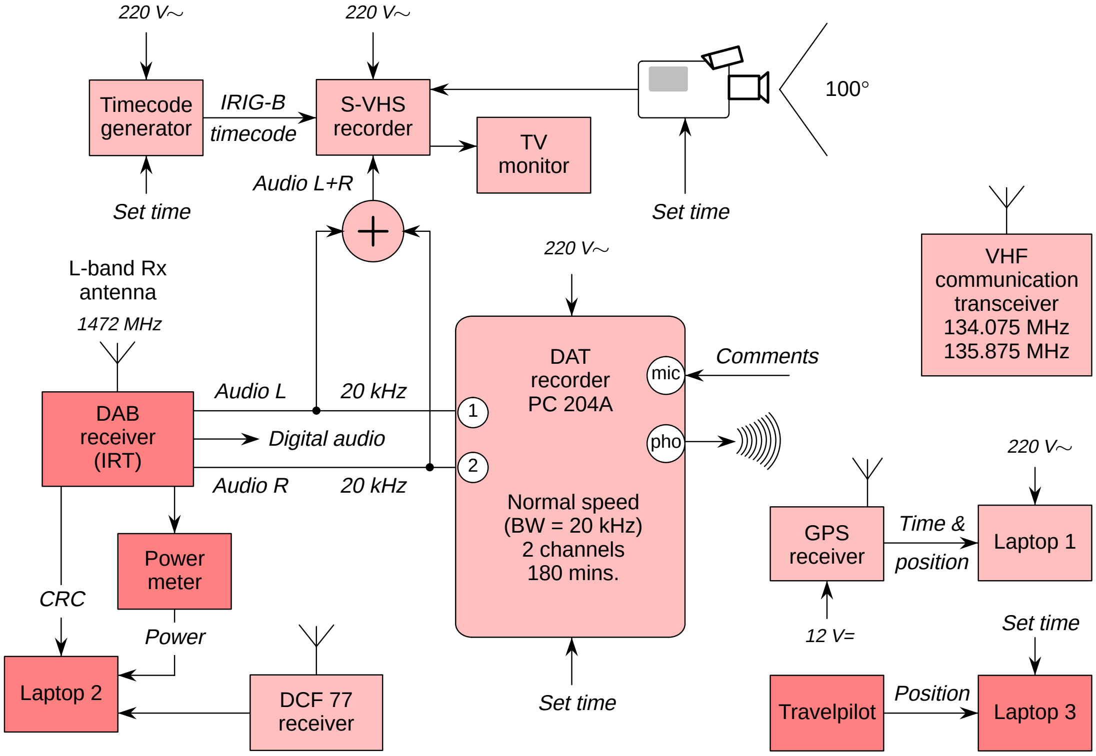


Figure 8
Equipment in the measurement vehicle.

hicle, and a microphone to enable the radio messages to be recorded. A specially-constructed power supply unit provided the necessary supply voltage for all the equipment.

3.2. Equipment in the measurement vehicle

The equipment in the measurement vehicle (shown in the form of a block diagram in *Fig. 8* and as a photograph in *Fig. 9*) had three important functions. Its first function was to receive and evaluate the L-band DAB signal transmitted from the helicopter; secondly, it recorded the position of the measurement vehicle and, thirdly, it made video recordings in order to document the cause of any interference (usually obstacles on the signal path) when evaluating the measured data.

The DAB signal was received with a left-handed, circularly-polarized, turnstyle antenna on a ground plane. An antenna with a constant radiation pattern in the 40° to 90° elevation range, and high gain at elevation angles of less than 40°, would have been ideal – so that variations in the elevation angle, in relation to the transmitter, would not have caused fluctuations of the received signal level, and only weak interference (i.e. man-made noise) would have been received from the environment at lower elevation angles.

The antenna radiation pattern had a 3 dB aperture angle of 90° in the vertical plane and was approximately omnidirectional in the horizontal plane *(Fig. 10)*

The level of the received DAB signal was increased with a low-noise amplifier directly after the antenna. The signal was fed to a downconverter which converted it to band III. In this frequency range, half the signal was fed to a DAB receiver and half to a power measurement receiver *(Fig. 11)*.

A pulse generator in the vehicle triggered a power measurement for every data frame of the DAB signal (i.e. every 24 ms). Likewise, for every frame, the DAB receiver decoded the DAB signal and performed a CRC evaluation whereby a so-called *error byte* was transferred to a notebook PC via a serial interface. The individual bits of this byte corresponded to error flags for the ISO-CRC, the scale-factor CRCs and the time and frequency synchronization errors. The same notebook PC recorded the power measured by a wideband receiver, via an IEC 625 interface. The data was stored by a measurement program so that power values could be assigned to error bytes at any time.

Figure 9
Interior view of the measurement vehicle.

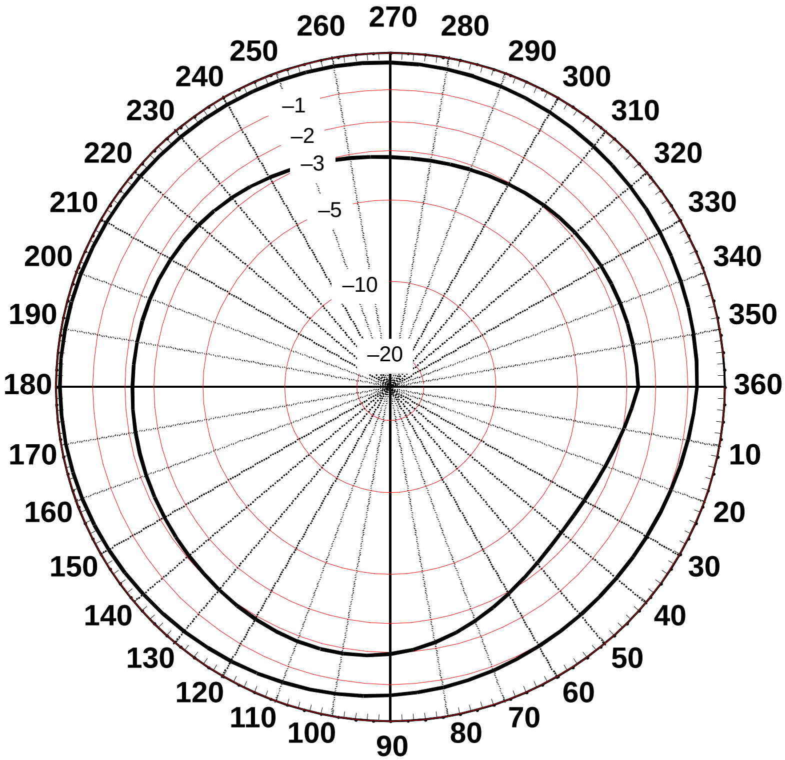


Figure 10
Radiation pattern of the receiving antenna in the azimuth planes at 60° (inner curve) and 80° (outer curve).

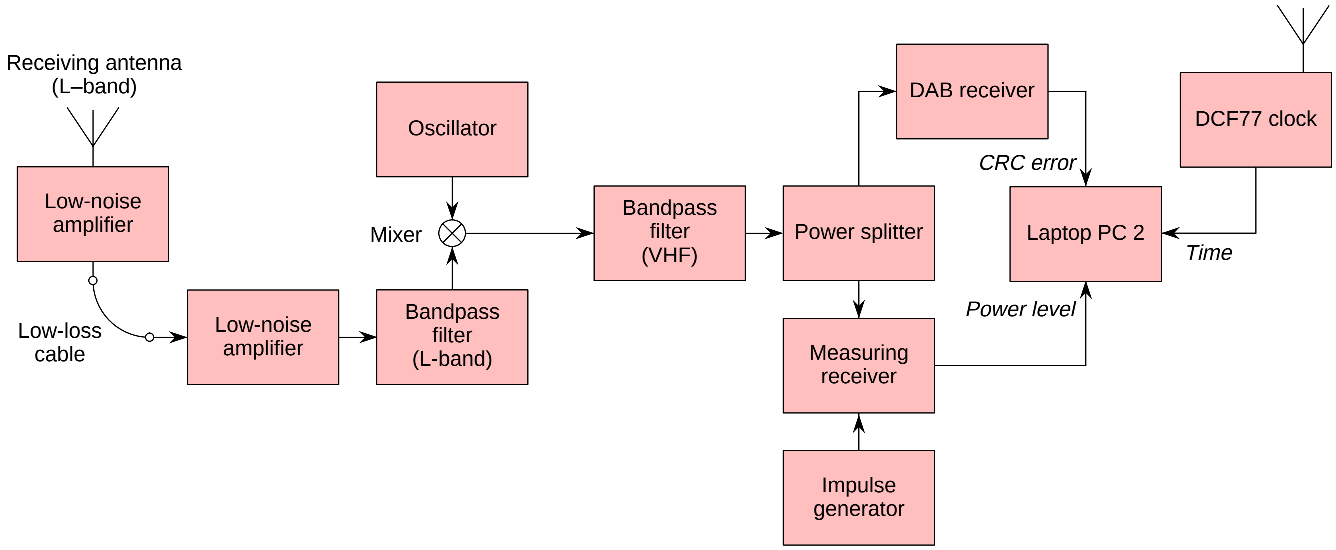


Figure 11
DAB receiving and measuring equipment in the vehicle.

A DCF 77 clock signal was used to synchronize the internal clocks of each computer before the measurements began. This allowed the received data to be correlated accurately with the transmitter data recorded in the helicopter.

The stereo audio signal at the output of the DAB receiver was recorded on two tracks of the 8-track DAT recorder.

Two systems were used simultaneously to record the position of the measurement vehicle: a GPS receiver and a Travelpilot from Bosch. The GPS receiver has the advantage that it gives the vehicle position regardless of whether or not it is on the road, but it has an inaccuracy of up to 100 m. The system accuracy was, however, considerably increased by the use of differential GPS. The Bosch Travelpilot system determines the vehicle position accurately from digitized maps – but only if the vehicle is on a road which is marked on the maps. It also functions under bridges and in tunnels.

The Travelpilot and GPS receivers were each connected to their own notebook PC. The data from both receivers were recorded, together with the time, over the entire duration of a flight.

A video camera with a wide-angle lens (100°), directed towards the sky, recorded the view which approximately corresponded to the range of possible elevation angles. The audio signal from the DAB receiver was recorded in mono on one soundtrack; on the other soundtrack, a time signal from a timecode generator was recorded, again in order to relate the pictures to the other measured data. A monitor in the vehicle was used for controlling the setting of the video camera. A second video camera took pictures in the direction of travel.

There was also a VHF transmitter/receiver for communication with the helicopter, and a microphone to enable recordings of the radio messages to be made.

3.3. Calibration of the measurement set-up

As a link margin of only a few dB can be afforded in satellite broadcasting systems, great attention was paid to the accuracy of the measurements. The components of the measurement set-up were first calibrated individually, then the entire transmit/receive system was calibrated after installation in the helicopter and the vehicle.

A calibration flight was made during which the helicopter took up different positions at 3050 m above sea level to give elevation angles of 40, 60 and 80°, as seen from the measurement vehicle. The received power was measured while the vehicle was stationary, and compared with the computed values. Measurements were then made in which, firstly, the helicopter rotated around its axis while the vehicle was stationary and, secondly, the vehicle drove in a circle while the helicopter hovered. These measurements served to verify the radiation patterns of the transmitting and receiving antennas as measured on the test stand.

It was important that the power flux density should have a constant level and that the error of the measurement apparatus was reduced to a minimum. The equipment in the helicopter was responsible for this.

Fluctuations in the level of the uplink signal were reduced to less than 1 dB by the AGC in the transponder.

The output power of the transponder was also influenced by the temperature of the device which, in turn, depended on the outside temperature and warm-up time. In order to eliminate the effect of the warm-up time, the measurement set-up was switched on 45 minutes before the measurements were taken. A power meter, connected at the output directly before the cable to the antenna, was used for continuous monitoring of the power level and for checking correct operation of the transponder.

If a helicopter is to hover at a fixed point, it has to correct its position constantly which can result in unavoidable rotation and attitude variations. Thus, the transmitting antenna and its radiation pattern were selected so that the variation in power flux density, with normal changes of position and during turns, was very low. For this purpose, extensive measurements of the antenna radiation pattern were made in which even the metal structures of the lower part of the helicopter were simulated since they could have had a considerable influence on the radiation pattern *(Fig. 7)*.

The receiving antenna had a similar influence as the transmitting antenna on the level of the received DAB power. Slight changes in the position of the helicopter, as well as rotation and inclination of the measurement vehicle, resulted in a change in the elevation angle and the azimuth angle in the radiation pattern which, in turn, influenced the level of the received power. Here too, an antenna with maximum isotropic radiation in the horizontal plane and minimum gain variation in the 40° to 90° elevation range was used.

The measurement set-up in the car was also influenced by the ambient temperature. The measured values were adjusted according to correction values which had previously been determined by measuring the temperature characteristics of the equipment in the vehicle.

Since many of the power measurements were taken at signal levels only slightly above the thermal noise level, the error due to the addition of the thermal power was calculated. The measurement error was less than 1 dB for signal powers of more than –107 dBm.

The electronic compass and the gyroscope in the helicopter were calibrated on another flight. The reaction time of the equipment was also measured.

The data of the GPS and Travelpilot systems were compared after a test run with the measurement vehicle. Agreement between the respective values was good. Slight errors in the measurement of the vehicle position had no effect on the results of the measurement campaign.

3.4. Link budget calculations

The helicopter was supposed to simulate the requirements specified for mediaStar as accurately as possible, and also as far as the power flux density at the measurement vehicle was concerned. This was also to be selected to match the receiver used.

Table 2 contains link budget calculations with a link margin of 6 dB taken as an example.

4. Measurement parameters

Three main parameters determined the planning of the measurements:

- the radiated DAB signal power from the helicopter (power flux density);
- the elevation angle viewed from the measurement vehicle to the helicopter;
- the types of terrain.

The mutual interaction of these three parameters (which are described in more detail in the following) was the focal point of these studies. The measurements were structured in so-called *takes*, each one being characterized by a particular set of “values” of the three parameters.

Downlink (1472 MHz)	**Helicopter**	**HEO satellite**
Transmitted output power (dBm)	3	53
Gain of transmitting antenna (dBi)	5.3	29
Gain reduction at 40° elevation (dB)	3.5	
Cable attenuation (dB)	0.8	
Free-space attenuation (dB)	108	185
[Distance (km)]	[3.9]	[29,000]
Gain of receiving antenna (dBi)	8	5
Gain reduction at 40° elevation (dB)	5	3
Input power at the down-converter (dBm)	–101	–101
Link margin (ref: –107 dBm)	**6**	**6**

Table 2
Comparison between link budgets for the helicoptor platform and an HEO satellite, assuming a line-of-sight path to the measurement vehicle.

4.1. Radiated signal power of the broadcast DAB link

As mentioned before, an experimenter on board was able to adjust the power radiated from the helicopter. By determining the sensitivity of the receiver beforehand, it was possible to specify a link margin with reference to this sensitivity. The receiver sensitivity was defined as the minimum received power at which reception was possible without any ISO-CRC violations for one minute, with a line-of-sight link between the helicopter and the measurement vehicle. The link margin was defined as the difference between the power actually received on the line-of-sight link and the sensitivity of the receiver. The experimenter on board the helicopter set the link margins between 0 dB and 20 – 26 dB (depending on the geometric conditions of the propagation path) with particular emphasis being laid on the values 2 dB, 4 dB, 6 dB and 8 dB. A measurement, with the maximum available broadcast link transmission power, was also taken in every type of terrain and for every elevation.

4.2. Elevation angle

The elevation angle of the broadcast link changes continuously owing to the orbital motion of a HEO satellite. The minimum elevation angles which occur can, however, be specified for specific regions; in the Archimedes HEO system, they are typically about 60° for central Europe. Measurements were performed at elevation angles of 40°, 60° and 80° as part of this Archimedes campaign.

The variation of the elevation angle has an influence on shadowing and multipath reception, the first factor being of greater significance here, since the DAB system has good resistance to multipath. The purpose of these measurements was to study and quantify this influence in more detail, in order to be able to provide information about coverage as a function of the elevation angle.

Under normal reception conditions, the elevation angle in the Archimedes HEO system changes only slowly. The characteristics of the orbit can be assumed to be quasi-stationary and, thus, the value of the elevation angle can be included in the emulation as an independent variable.

Coordinates for the airborne helicopter were computed so that the elevation angle along a measurement route was largely constant for individual takes. It would have been possible to vary the elevation angle for different takes by varying (i) the height of the helicopter above the ground or (ii) the horizontal distance between the mobile receiving station and the helicopter or (iii) by a combination of both. We decided in favour of using a constant high altitude and varying the horizontal distance.

Setting the altitude as high as possible provides advantages in terms of (i) minimizing the errors in the modelling of the satellite, due to variations in the position of the helicopter [9][10][11] and (ii) reducing the noise nuisance for local residents. We selected a height of 3050 m asl which corresponds approximately to an altitude of 2500 m agl in Munich and the surrounding region.

4.3. Terrain types and measurement routes

The selection of terrain types and measurement routes was intended on the one hand to be as representative as possible but on the other hand to cover a large number of different environments. We selected measurement routes in the following environments:

- rural area (open terrain, fields, forests and villages);
- suburban districts (residential area);
- urban area (residential area and inner city);
- motorway (with bridges and tunnels).

All the test routes were in and around Munich and the measurements were taken at typical driving speeds (between “stop and go” in the inner city and at 160 kph on the motorway). Here too, comprehensive precautions were taken to reduce the effects of the above-mentioned errors in the modelling. This included, for example, choosing relatively short test routes so that variations in the received power on a line-of-sight link during the measuring time could be kept to a minimum. The routes were selected so that the maximum power fluctuation along the route, resulting from variations in the distance between the helicopter and the measurement vehicle, would be 1 dB. The elevation angle varied by ± 5° around its nominal value.

The orientation of the routes was selected so that they were both tangential and radial to the signal propagation direction. Most routes were configured as closed circuits so that the start and end point were at the same place: some routes were driven in both directions.

5. Performance of the measurements

The verification campaign was subdivided into three measurement phases during 1995: phase 1 was carried out in the spring (10 – 21 April), phase 2 in the summer (17 – 28 July) and phase 3 in the autumn (16 October – 9 November). The third phase took rather longer than the previous two because bad weather and poor visibility frequently prevented the helicopter flying in hover mode, thereby causing the planned measurements to be postponed.

Each phase was made up of eight different flights, each covering a specific type of terrain and lasting approximately 2 $^{1}/_{2}$ hours. The flights were divided up into "takes", i.e. a measurement with constant elevation angle and radiated power level.

All equipment in the helicopter and in the measurement vehicle was reset before each flight, on the basis of a check list, and was re-calibrated if necessary.

In order to make optimum use of the costly time during which the helicopter was airborne, it was flown to the designated positions as quickly as possible, using a previously-prepared speech protocol and measurement plan. The power level was set carefully and the measurements were then performed rapidly.

Each take was made up of three main parts. The first consisted of a calibration measurement lasting about 10 seconds which was made with a line-of-sight link between the stationary measurement vehicle and the helicopter. This was followed by the measurement proper, during which the measurement vehicle drove along the selected route. The third part consisted of another calibration measurement lasting about 10 seconds under the same conditions as the first part. When possible, it was also carried out at the same place and thus acted as an additional check for the measurement configuration parameters.

The length of each take was between two and eight minutes and was thus short enough to minimize any fluctuations in the power at "tree-top level". The power at tree-top level is the power measured without any shadowing at the antenna of the measurement vehicle.

6. Results

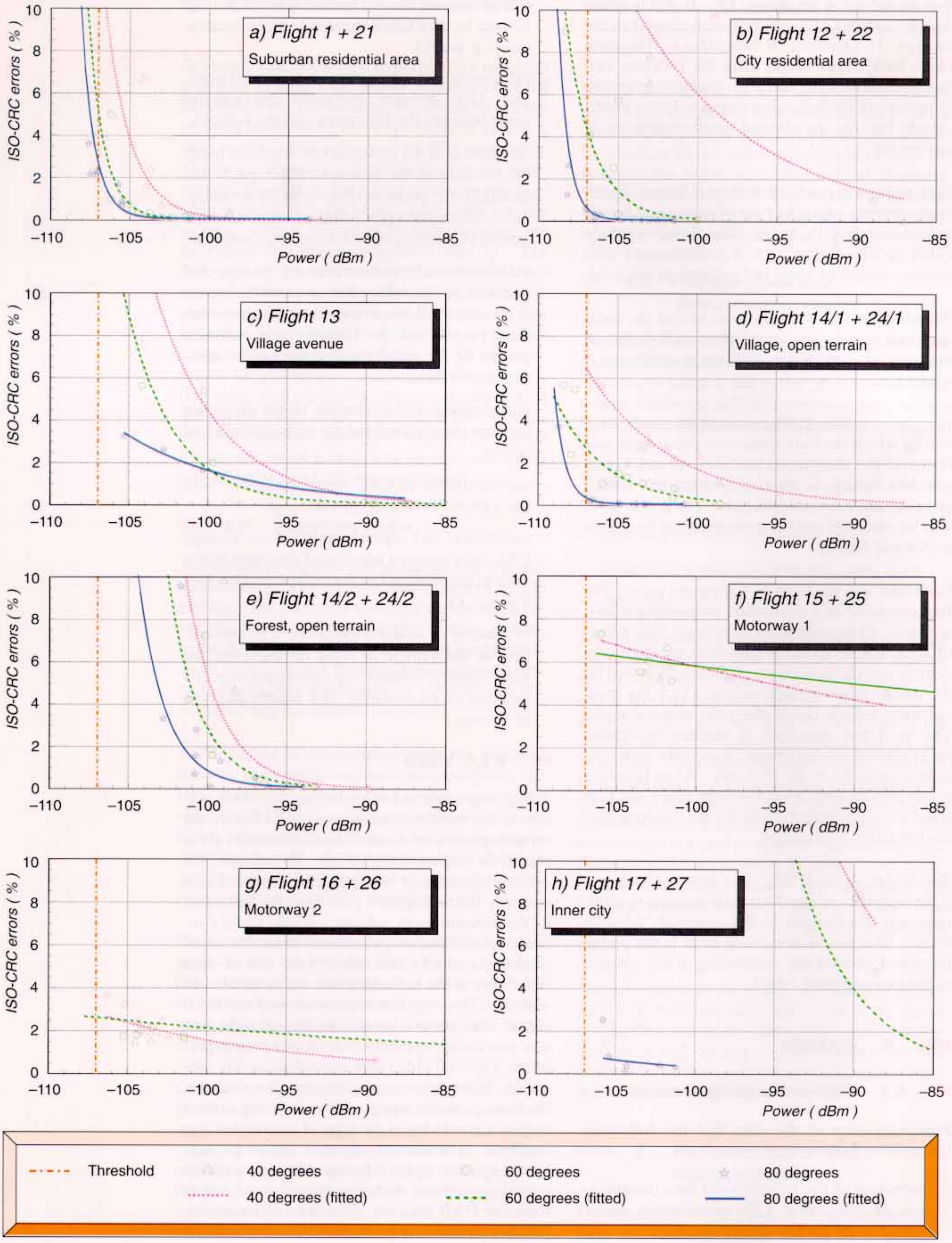
6.1. Post-processing concept

Post-processing of the data had the following functions and objectives:

- correction of the geographical data (computation of differential GPS coordinates, transformation of the Travelpilot data);
- conversion of the measured quantities (e.g. voltage level) to the associated original quantities (e.g. angle);
- calculation and representation of derived quantities (e.g. distance, elevation and azimuth angle between the helicopter and the vehicle);
- calculation of the power at tree-top level using the position of the helicopter (roll, pitch and heading), the position relative to the measurement vehicle and the 3-dimensional radiation pattern of the helicopter transmitting antenna;
- calculation and representation of the expected received power, taking into account the power at tree-top level, the orientation of the measurement vehicle and the 3-dimensional radiation pattern of the receiving antenna on the measurement vehicle;
- representation and evaluation of the difference between the expected and the measured received power;
- representation of CRC errors compared with the measured received power;
- calculation and representation of an average CRC error rate as a function of the mean power with a line-of-sight link for every take (see *Section 6.2.3.*);
- evaluation of audio/video/power/CRC recordings in the vehicle in order to determine the audio quality, subjectively and objectively, as a function of the elevation, link margin and type of terrain.

6.2. Video

A highly graphic aid to evaluating the DAB system in the satellite channel was provided by the recording taken by a video camera mounted at the rear of the measurement vehicle. By orienting the camera upwards, it was possible to reconstruct optically the propagation path from the helicopter to the measurement vehicle. Audio signals recorded simultaneously illustrated the influence of shadowing and the relevance of the line-of-sight link between the helicopter and the measurement vehicle. The very fast regeneration of the DAB signal after restoration of the line-of-sight link was also clearly apparent. For demonstration purposes, a special video tape was subsequently produced. In the first recorded sequence on this tape, the route is shown using a forward-facing camera to give a good idea of the type of terrain that was involved. The second sequence shows pictures taken by the upward-facing camera, simultaneously combined with the stereo sound output from the DAB receiver. The tape offers an impressive demonstration of the effect that different


a) Flight 1 + 21
Suburban residential area
b) Flight 12 + 22
City residential area
c) Flight 13
Village avenue
d) Flight 14/1 + 24/1
Village, open terrain
e) Flight 14/2 + 24/2
Forest, open terrain
f) Flight 15 + 25
Motorway 1
g) Flight 16 + 26
Motorway 2
h) Flight 17 + 27
Inner city
ISO-CRC errors (%)
0
2
4
6
8
10
Power (dBm)
−110
−105
−100
−95
−90
−85
Threshold
40 degrees
40 degrees (fitted)
60 degrees
60 degrees (fitted)
80 degrees
80 degrees (fitted)

elevation angles and link margins have on the received DAB sound quality.

6.3. Results of the CRC evaluation

Subjective assessment of interference in the reception of the DAB audio signal can vary depending on the signal source (e.g. classical music, pop music, voice) and the particular listener. In order to avoid these subjective influences, the CRC described earlier was used to provide an objective criterion for the assessment of the DAB audio quality.

6.3.1. Threshold

The threshold is defined as the minimum reception power level at which no ISO-CRC violations occur over a period of about 1 minute. In this configuration, the threshold level was –107 ± 0.5 dBm; it was measured at all elevations for each individual flight. It is included in all the diagrams described in the next section as a reference line for estimating the link margin.

The measured threshold value agreed well with the theoretical prediction (assuming a minimum theoretical energy-per-bit of 6.8 dB, corresponding to a BER of 10^{-3}, an information bit-rate of 1.152 Mbit/s, a code-rate of $^{1}/_{2}$, a minimum required carrier power level with respect to Kelvin system noise of –161.2 dBW/K, a system noise temperature of 23 dBK and an implementation loss of 1 dB).

6.3.2. Evaluation of the takes

During post-processing, an average CRC rate and the mean received power level on a line-of-sight link were calculated for every single take along each measurement route. These results were then charted using a different chart symbol for each of the three elevation angles considered during the campaign (40, 60 and 80°). Separate charts were produced for each of the different types of terrain studied. Finally, on each chart, continuous curves were derived by using the technique of exponential curve fitting and by reducing the influence of "outliers" obtained during some of the takes (which arose from singular events such as long stops at red traffic lights or from other special traffic conditions).

The charted results from measurement phases 2 and 3 are shown together in *Figs. 12a-h*. The sensitivity threshold is also entered on each chart.

Fig. 12a shows the results for a suburban residential area. The single- and two-storey houses here had no influence on reception but individual roadside trees did cause a slight degradation of the DAB signal.

Fig. 12b represents an urban residential area with high-rise buildings of up to seven stories. At an elevation of 40°, these buildings caused a significant shadowing of the propagation path; at elevations of 60° and 80°, most links were line-of-sight with considerably lower CRC error-rates for the same power.

Fig. 12c shows the results for the avenue and village types of landscape. Some of the errors here resulted from an underpass and various two- and three-storey buildings close to the road, while the rest were caused by shadowing due to an avenue of trees over the road.

The measurements plotted in *Fig. 12d* were taken in a village and in open countryside. Here too, the propagation path was disturbed by two- to three-storey buildings and a few, but tall, trees.

One half of the measurement route depicted in *Fig. 12e* consisted of dense woodland while the other half ran through open countryside.

Fig. 12f shows the results obtained over a section of motorway with nine bridges and a tunnel. The route was driven at a speed of about 80 kph.

Fig. 12g, on the other hand, shows the results of driving at a speed of up to 160 kph along a motorway section with two bridges.

The results for a densely built-up inner city area, with 6-storey buildings close to the edge of the road, is shown in *Fig. 12h*. At elevation angles of 40° and 60°, the propagation path between the helicopter and the vehicle was frequently shadowed; at 80°, however, the CRC error-rates dropped dramatically.

A reference must be established between the objective quantity, CRC, and the subjective auditory sensation in order to interpret these results. After detailed listening tests among the persons involved in the measurement campaign, the threshold for just-acceptable reception quality was established at an ISO-CRC error-rate of 1 %.

If this precondition is included, the following conclusions can be drawn for the mediaStar system.

a) Very good mobile DAB reception conditions prevail when the propagation path between the transmitter and the receiver is not blocked (which also applies at high travelling speeds).

b) In open terrain, a link margin of 3 dB is adequate for elevation angles of 40° and more.

◄ Figure 12
Charted results of measurement phases 2 and 3.

c) Blocking of the signal by buildings, bridges, tunnels and trees usually results in severe power losses and, consequently, in seriously-degraded reception.

d) In the inner city area, shadowing by tall buildings is the decisive reception-quality factor. The shadowing density here is heavily dependent on the elevation angle and indicates that HEO satellites have a clear advantage over GEO satellites in temperate latitudes. In the absence of shadowing by buildings, the required link margin is typically less than 3 dB.

e) Shadows caused by dense forests result in a necessary link margin of around 10 dB. In avenues, the shadowing effect of individual trees was sometimes clearly “audible”.

f) On motorways, interference to reception is caused predominantly by bridges and tunnels. The ability of DAB to eliminate the effects of shadowing due to bridges depends primarily on the width of the bridge and the speed of the vehicle. It might be possible to take advantage of the multipath capability of DAB and apply a gap-filler concept for covering wide bridges and tunnels. High speeds (measurements were made up to a maximum of 160 kph) do not cause any problems because of the relatively-high elevation angle (low Doppler effect).

The ISO-CRC violations to be expected in the areas under investigation are compiled in *Table 3* as a function of the link margin (2, 4, 6 and 8 dB) and the elevation angle (40, 60 and 80°). It should be remembered when looking at this table that, although a large number of typical terrain types were covered in this verification campaign, it does not necessarily represent a balanced statistical cross-section of the distribution of landscapes.

Figs. 12a-h provide a means of estimating the link margins for the corresponding routes. The effect of different elevation angles is of particular interest for a HEO satellite system. In order to quantify this, we defined two types of link margin (LM) here, which also allowed a comparison with the results of the evaluation of the cumulative power distributions (see *Section 7.5.).* $LM_{1\%,CRC}$ is the difference between the threshold power and the power at which an ISO-CRC error-rate of 1 % occurs; $LM_{5\%,CRC}$ is the corresponding difference at

Table 3
Percentage of ISO-CRC violations as a function of the elevation angle and the type of terrain.

Link margin (dB):	**2**			**4**			**6**			**8**		
Elevation angle (degrees):	**40**	**60**	**80**	**40**	**60**	**80**	**40**	**60**	**80**	**40**	**60**	**80**
Suburban residential area	4	0.75	0.5	1	0	0	0.5	0	0	0	0	0
City residential area	>10	1.75	0	9	0.75	0	6.5	0	0	5.5	0	0
Village avenue	>10	8.5	3	9.5	4	2.5	5	2	1.75	3.5	1.5	1.5
Village, open terrain	4.5	1.5	0	3	1	0	2	0.5	0	1.5	0.25	0
Forest	>10	>10	>10	>10	>10	3.5	8	4	1.25	3	1.5	0.5
Motorway 1 (nine bridges and tunnels)	>10	8	–	>10	7.75	–	>10	7.5	–	>10	7.25	–
Motorway 2 (two bridges)	2.5	2.5	–	2.25	2	–	2	1.5	–	1.75	1	–
Inner city	>10	>10	0.5	>10	>10	0.5	>10	>10	0.5	>10	>10	0.5

Table 4
LM_{CRC} “gain” at higher elevation angles. The differences in LM_{CRC} (in dB) taken from the ISO-CRC diagrams are shown as a function of the differences in the elevation angles.

ΔLM (elevation angle):	**LM(40°) – LM(60°)**		**LM(60°) – LM(80°)**		**LM(40°) – LM(80°)**	
Type of link margin:	$\Delta LM_{1\%CRC}$	$\Delta LM_{5\%CRC}$	$\Delta LM_{1\%CRC}$	$\Delta LM_{5\%CRC}$	$\Delta LM_{1\%CRC}$	$\Delta LM_{5\%CRC}$
Suburban residential area	2.5	1.5	1	0.5	3.5	2
City residential area	18	8	2	1	20	9
Village avenue	4.5	2	–1.5	>4	3	>6
Village, open terrain	6	3.5	5	0	11	3.5
Forest, open terrain	1.5	1	2	2	3.5	3
Motorway 1 (nine bridges and tunnels)	–	–5	–	–	–	–
Motorway 2 (two bridges)	–	–	–	–	–	–
Inner city	–	>5	>20	>15	>20	>20

an ISO-CRC error-rate of 5 %. *Table 4* presents the relative changes in the link margins when the elevation angle changes; they can thus be interpreted as the LM_{CRC} “gain” as a function of the elevation.

Spaces in the table indicate either an absence of measurements, or measured values which could not be read. “Greater than” signs (>) indicate a lower estimate in cases where it was not possible to interpolate the wanted value from the measured ones.

Clearly visible is the extent to which the increase in elevation resulted in a reduction in the necessary LM_{CRC}, except in the motorway case: in the urban area, an increase in the angle of elevation from 40 to 80° caused a reduction in LM_{CRC} of more than 20 dB. Even in rural areas, a reduction in LM_{CRC} by up to 11 dB is possible under these conditions.

On motorways, where bridges and tunnels are the principal factor in CRC error-rates, LM_{CRC} can actually increase with the elevation angle. This explains the negative value for motorway 1; the link margin at 40° was 5 dB smaller than at 60°. The reason for this is that, at low elevation angles, the DAB signal may penetrate better under bridges and into tunnels (depending, of course, on its direction of arrival).

6.4. Cumulative power distributions

Another method of estimating the link margin for different landscape types and elevation angles, which does not depend on the use of CRCs, is the evaluation of the statistical distribution of the received power; it is characterized by the fading depth, FD. For this purpose, cumulative power distributions were drawn up for selected takes on all the flights in phase 2, with high transmission power relative to the threshold. This prevented large power losses due to shadows from causing the signal level to disappear into the system noise. These power distributions were plotted on log-normal axes and analyzed.

Fig. 13 shows an example of the power distribution on a section of flight 14/2, i.e. a route passing partly through open countryside and partly through forest. This measurement sequence was made at an elevation angle of 40°. The figure shows how two different distributions are evident on this route. The upper part of the curve predominantly represents the part of the route during which there was a line-of-sight link to the helicopter. The lower part of the curve represents the weaker power distribution in the forest, caused by the shadowing effect of the trees. The entire curve shown here can effectively be simulated by a combination of two Gaussian distributions with different median values, standard deviations and percentage weighting.

Since this involves evaluation of the measured input power to the receiver, two factors in particular had to be taken into account. One was the zero symbol of the DAB signal which, at the selected measurement pulse-rate, was reached about every 100 frames during the measurement sequence and resulted in a non-corrected, slight loss of power. The other concerned the unwanted variations of the propagation path. These two factors resulted in a slight deviation from the ideal power distribution, even in the case of free-space propagation between the helicopter and the measurement vehicle. This deviation is evident from the slight levelling of the line in the diagram (it should ideally be vertical). In order to obtain a reference value for the fading depth, the median value of the power distribution with a line-of-sight link was calculated by analyzing the power distribution and the power as a function of time.

Fig. 14 shows the power distribution along the route presented in *Fig. 13*. This time, however, it is shown as the probability of exceeding the reference value for the fading depth. This representation agrees with the one selected by Goldhirsh and Vogel in [8] and thus enables a comparison to be made with their measurement results. Their results show a difference of about 1.5 dB in the CRC 1 % value in the case of a measurement route through similar countryside, but with an elevation angle of 45° and at a transmission frequency of 1.5 GHz ([8] , *Fig. 2*). If one takes into account that a different reference value was used by Goldhirsh and Vogel, this difference vanishes almost completely and thus shows good agreement between the two sets of measurement results.

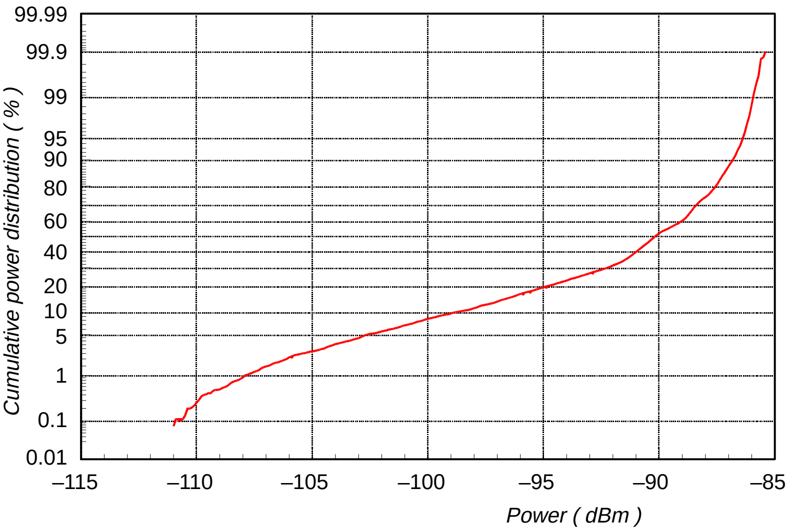


Figure 13
Power distribution along a section of flight 14/2.

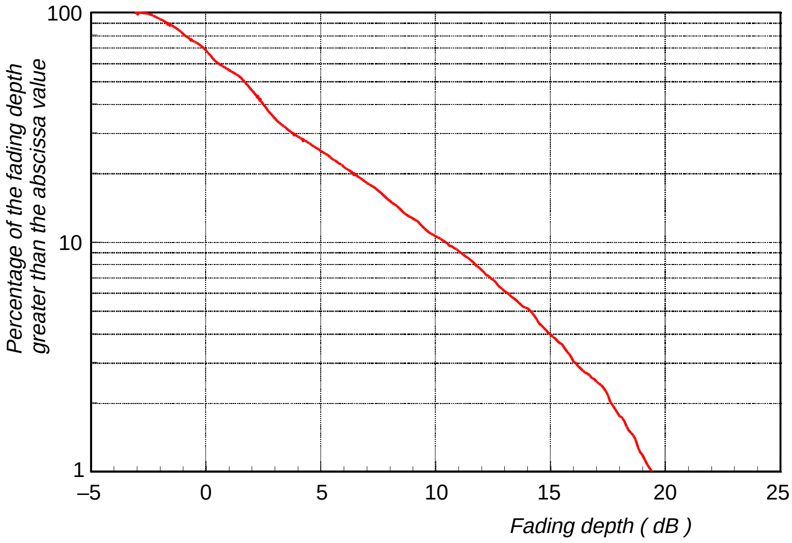


Figure 14
Power distribution along a section of flight 14/2, shown as the probability of exceeding the reference value for the fading depth.

The 1% value and 5% value for the probability of exceeding the fading depth were taken from the power distribution. These values are defined here as FD$_{1\%}$ and FD$_{5\%}$ – to differentiate them from the reference value just mentioned – and are shown in eight diagrams *(Figs. 15a-h)* covering a selection of the different measurement routes used (a short description of these routes is given in *Section* 6.3.2.). They demonstrate a significantly lower fading depth for higher elevations along almost all the routes except the motorway sections.

Figure 15 ➤
Fading depth values, at different elevation angles, over a selection of measurement routes.

Fig. 15c shows the result for a measurement route which mainly follows the course of an avenue. Comparison with [16], where the so-called “extended empirical roadside shadowing model” (EERS) is presented, shows that in our case the fading depth at 40° was slightly higher (1 dB) while at 60° it was significantly higher (FD$_{1\%}$ = 2.5 dB, FD$_{5\%}$ = 7 dB) than was predicted in [16]. The reason for this was an underpass on the measurement route which strongly influenced the 1% value and also the 5% value, particularly at higher elevations.

In the subsequent evaluation, particular importance was attached – as in the case of the CRC evaluation *(Section 6.3.2.)* – to the change in fading depths according to elevation. For this reason, in *Table 5* the fading depth differences are entered in each case over corresponding elevation differences.

The spaces in the table for the motorway routes can be explained by the fact that no measurements were carried out here at an elevation angle of 80%. This was not possible because of the route, and the deviation from the nominal elevation in this case would have been too great. It is striking that three of the four motorway values are negative. This suggests that a higher elevation does not have a positive effect in the case of bridges and tunnels, in complete contrast to the other routes where – with a few exceptions – there was an improvement, i.e. reduced fading depth. In particular cases this was quite considerable, e.g. a change of elevation from 40% to 80% resulted in a reduction in FD$_{1\%}$ of up to 21 dB in the urban area, and up to 10 dB in rural areas.

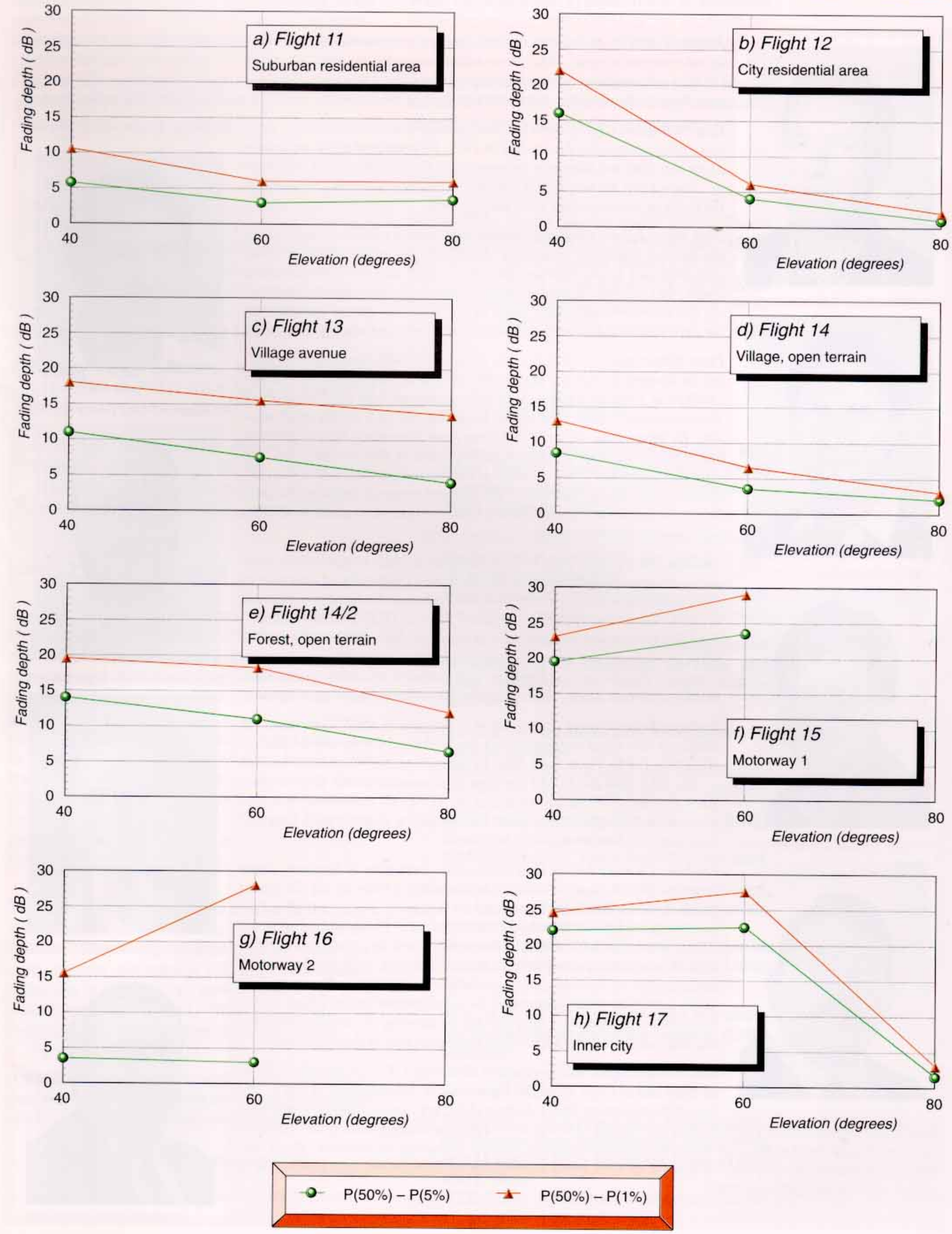
Compared with the evaluations of the CRC results, the results described here demonstrate the advantage of reduced dependence on the transmission system used. Nevertheless, there are clear parallels in both sets of results which indicate a close relationship between the power and the CRC results [15]. The considerably higher absolute values of fading depth compared with the LM$_{CRC}$ are an indication of how well the time interleaving of the Eureka-147 DAB system can deal with short-duration power losses.

6.5. *System noise according to the type of terrain and the receiver G/T*

In addition to the takes described above, measurements were also made on various routes with no transmitted signal. The purpose of these measurements was to determine the magnitude of the system noise. They showed that the type of environ-

Table 5
Reduction in the fading depth at higher elevations. The differences in the fading depths (in dB) taken from the cumulative power distributions are shown as a function of the differences in the elevations.

ΔFD (elevation):	**FD(40°) – FD(60°)**		**FD(60°) – FD(80°)**		**FD(40°) – FD(80°)**	
Type of fading depth:	**$\Delta FD_{1\%}$**	**$\Delta FD_{5\%}$**	**$\Delta FD_{1\%}$**	**$\Delta FD_{5\%}$**	**$\Delta FD_{1\%}$**	**$\Delta FD_{5\%}$**
Suburban residential area	4.5	2.75	0	–0.5	4.5	2.25
City residential area	16	12	4	3	20	15
Village avenue	2.5	3.5	2	3.5	4.5	7
Village, open terrain	6.5	5	3.5	1.5	10	6.5
Forest, open terrain	1.25	3	6.25	4.5	7.5	7.5
Motorway 1 (nine bridges and tunnels)	–6	–4	–	–	–	–
Motorway 2 (two bridges)	–12.5	0.5	–	–	–	–
Inner city	–3	–0.5	24.5	21	21.5	20.5


a) Flight 11
Suburban residential area
b) Flight 12
City residential area
c) Flight 13
Village avenue
d) Flight 14
Village, open terrain
e) Flight 14/2
Forest, open terrain
f) Flight 15
Motorway 1
g) Flight 16
Motorway 2
h) Flight 17
Inner city
Fading depth (dB)
Elevation (degrees)
0
5
10
15
20
25
30
40
60
80
P(50%) – P(5%)
P(50%) – P(1%)

Jürgen Frank, *born in 1964, studied electrical engineering at the University of Stuttgart with an emphasis on telecommunications. After completing his studies in 1992, he joined the Institut für Rundfunktechnik (IRT) as a scientific employee in the specialist field of antenna systems and wave propagation. His special area there is the planning and implementation of measurements and system tests in the DAB radio channel.*

Raul Schramm (right), *born in 1948, studied telecommunications at the Technical University of Bucharest. After completing his studies in 1971, he remained at the university as an assistant and later as a lecturer in the field of microwave technology. Since 1983, he has been a scientific employee at the IRT, working in the fields of antennas and wave propagation.*

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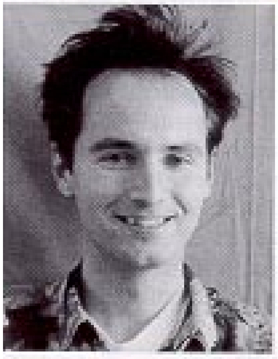
Thomas Wörz (below left), *born in Stuttgart in 1961, completed his studies in electrical engineering at the Technical University of Stuttgart in 1988 and received a doctorate from the Technical University of Munich in 1995. He has worked since October 1988 at DLR in Oberpfaffenhofen. He interrupted his activities there from June 1991 to September 1991 to work at the Communication Research Centre (CRC) in Ottawa, Canada. His present research includes aspects of coded modulation, mobile communication, channel modelling and communication systems.*

Andreas Schmidbauer (right), *born in Munich in 1967, completed his studies in electrical engineering at the Technical University of Munich (TUM) in 1994. From June 1994 to September 1995 he jointly worked for the DLR and the TUM's Institute of Communications Engineering. Since October 1995 he has worked at the TUM. He is currently involved in research in the fields of communication theory, channel modelling and communication systems.*



Frederic Clement Trevor Gale (left) *comes from Kent in England. Since January 1981 he has worked at the Research Centre of the European Space Agency. His first project was the design of special interfaces for satellite test purposes (hardware and software). He later worked in the "Crew Work Station Test-bed" laboratory. where he carried out technological research experiments including the design, implementation and investigation of various zero-g parabolic test flights. At present, he works within the main department for telecommunications where he has developed a software package for the monitoring of satellite links and has also supported the Archimedes campaign that is described here.*

Bob Harris (right), *born in 1943 in Coventry, UK, was awarded a B.Sc. in 1966 and a Ph.D. from the University of Southampton in 1971. He joined the European Space Agency (ESA, previously ESRO), where he is head of the Department of Transmission Technology. He was involved in the development of the transmission systems for most of the ESA telecommunication satellite projects including Archimedes. He is currently responsible for transmission aspects of work being carried out by ESA for the next generation of global satellite navigation systems.*

ment can cause the value to vary according to the number of objects "seen" by the receiving antenna. Each object that is picked up by the main lobe of the antenna emits radiation which adds to the received thermal noise. Three different cases in which the level of system noise varies are described below.

1. If no objects are "seen" by the antenna (e.g. in open types of terrain), this results in a system noise power of –114 dBm and hence a system noise temperature of 192 K. Using the data sheets for the downconverter amplifiers, the noise temperature here works out at 92 K. The difference between these two noise temperature figures (100 K) gives the antenna noise temperature. The receiver G/T is –16 dB/K.
2. System noise powers varying between –114 dBm and –112 dBm occur in residential areas, town and avenues.
3. In densely forested areas and in tunnels, the average system noise power increases to –112 dBm and thus corresponds to the theoretical value for thermal noise power at 290 K.

7. Conclusions

The "Archimedes DAB measurement and verification campaign" [9][10][11] was extremely successful in terms of the results but also as far as accuracy and reproducibility of the data are concerned. The measurements confirm that very good mobile DAB reception from satellites is possible on the majority of motorways and roads in Europe, North America and East Asia – at the transmitter powers available today and at those planned for the mediaStar system – with elevation angles exceeding 40°. Greater elevation angles are, however, necessary in critical reception situations.

The probability that obstacles will block the propagation path increases as the elevation angle decreases. Shadowing of the signal by buildings, trees, bridges and tunnels will result in a marked reduction in the received power (which has been quantified in this study). Short interruptions in reception can be bridged by the DAB system.

If the implemented link margin is not sufficient to guarantee error-free reception in cases of severe shadowing, the following solutions are possible:

- terrestrial gap-fillers can be employed;
- diversity reception techniques can be used at the receiving antenna.

With the mediaStar system, there is additional scope for making improvements: for example, increasing the transmission power; restricting the service to areas with large elevation angles; improving the design of the receivers (e.g. implementation of improved error-masking techniques) and the design of the receiving antennas.

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Two achievements enhance the global market for DAB

Geneva, 22 April 1997

The WorldDAB Forum has welcomed two major achievements which will contribute to the successful world-wide introduction of Digital Audio Broadcasting (DAB).

The first is an agreement reached among broadcasters, transmission operators, consumer electronics manufacturers and the regulatory bodies on common frequency rasters at VHF and L-band. This agreement allows the use on a global basis of both the CEPT (European Post and Telecommunications Conference) and the Canadian frequency rasters. It will help to ensure that DAB radio receivers are simpler and are easier to tune and, by reducing the number of possible rasters, increased costs should be avoided.

The second achievement is the successful completion of the Multimedia Object Transfer (MOT) specification which takes DAB into a new multimedia era. In will allow DAB *inter alia* to carry Internet pages reliably to mobile and portable, as well as static, receivers. Radio is now assured a place in the multimedia environment, capable of carrying not only CD-quality sound but also text and graphics, still and moving pictures, and Internet pages.

Welcoming these two important achievements, the President of the WorldDAB Forum, David Witherow, said: *These two agreements have come at the right moment as we move into the consumer phase of DAB. They enhance the global market for DAB receivers and they keep DAB on the track. These important agreements reflect the spirit of co-operation which has characterized its development to the point where it is now the recognized world standard.*

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