® DAB Digital Audio Broadcasting

Field trials with a high–power VHF single frequency network for DAB

Measurement techniques and network performance

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(BBC)

The advent of digital formats such as CD has created demand for uniformly high audio quality from radio, even in vehicles and for portable reception. The Eureka–147 DAB system has been designed specifically to meet these demands and the BBC is undertaking a major experiment to test the system and to gather data which will allow efficient planning of its transmitter network. As a basis for these tests, a network of four 1 kW e.r.p., VHF transmitters has been installed to cover the London area in England.

The results show wide–area coverage from the transmitter network which is in reasonable agreement with computer predictions. The results also provide quantitative values which can be used for coverage prediction and for international coordination of services. Finally, the performance of the system demonstrates a number of the benefits of the Eureka DAB system for mobile and portable reception.

1. Introduction

FM sound broadcasting in Band II was designed as a high–quality system and can provide excellent sound quality. The advent of digital formats such as CD has created a demand for uniformly high audio quality from radio. Also, listeners' requirements of a radio system have changed. People now demand high–quality and rugged audio reception (in stereo) in vehicles and on portable radios. To provide high–quality stereo reception to all receivers, a Digital Audio Broadcasting (DAB) system capable of reliable reception in vehicles and on portable receivers has been developed by the Eureka 147 Project.

Conscious of the need to design a system that could be used in many different countries and situations, the Eureka DAB system was designed to work for both terrestrial and satellite broadcasting at a range of frequencies. This is ensured by providing three modes:

Mode 1, designed for wide–area, terrestrial broadcasting at VHF frequencies. Such networks are likely to be extensively used in Europe.

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Mode 2, designed for local–area, terrestrial broadcasting at frequencies up to 1.5 GHz. Such networks may be used in both Europe and countries in other geographical regions, such as Canada, where the new 1.5 GHz (L–band) allocation is available.

Mode 3, designed for satellite broadcasting at frequencies up to 3 GHz. This may be particularly attractive in large countries, and for continental coverage.

In the United Kingdom, a VHF implementation for terrestrial broadcasting of DAB is preferred for the following reasons:

– A national single frequency network (SFN) can be economically implemented at VHF with large transmitter spacings and using existing broadcasting transmitter sites.

– The propagation of signals, over terrain typically found in the UK and into buildings, is generally better at VHF than L–band.

– L–band is unlikely to be allocated in the UK until 2007. Even then it may be difficult to make efficient use of the limited spectrum for both satellite and terrestrial DAB in the same coverage area.

The BBC is undertaking a major experiment to test the Eureka DAB system and to generate data to allow efficient planning of its transmitter network. The article describes this experimental programme and the rationale behind it.

2. Planning for digital systems, mobile and portable receivers

Eureka DAB is explicitly designed to provide a reliable service to mobile and portable receivers. This introduces a number of issues which must be addressed in the system design and coverage planning.

– Generally, digital modulation systems have abrupt failure characteristics. This means that the received audio signal can change from high quality to total failure with only a small change in input signal level to the receiver.

– Mobile and portable receivers use omni–directional antennas at a low height. Consequently the path from the transmitter to the antenna is rarely unobstructed and the receiver obtains no discrimination against multipath from other objects.

– Portable receivers are usually used in buildings; this means that the additional loss and variability in signal level within buildings must be quantified.

3. Eureka DAB coding and modulation system

Eureka DAB is based upon a coded orthogonal frequency–division multiplex (COFDM) modulation system [1]. COFDM modulation uses a large number of RF carriers each of which is QPSK modulated at a relatively slow symbol rate. The carriers are spaced in frequency such that, as each carrier is demodulated, there is no interference from data carried on adjacent carriers, ie they are orthogonally spaced. The digital audio signals are protected with convolutional coding and the resulting data is distributed across all the carriers in the RF band. Consecutive data samples are also separated in time. As a result, the audio data can still be recovered at the receiver even if some of the carriers can not be demodulated owing to anomalous propagation effects (such as multipath).

In the Eureka DAB system the problem of the swift failure characteristic of digital systems is addressed by the introduction of unequal error protection of the audio signal. This process is described in more detail in [2].

However, two additional features are needed to improve the performance of the system in multipath environments:

– A wide bandwidth (significantly greater than the few hundred kilohertz currently used for FM broadcasting) is needed to reduce the effects of the short–delay multipath that cause flat fading problems. Effectively this introduces frequency diversity into the system; and a wide enough bandwidth is needed to ensure sufficient decorrelation between the different components for the diversity to be effective. To retain spectral efficiency with this bandwidth, a number of programmes are bundled together.

– At the transmitter, each QPSK symbol is transmitted for longer than necessary to fulfil the requirements for orthogonal frequency spacing of the carriers. The extra time is known as the guard interval. At the receiver, an appropriate portion of this extended symbol (chosen to restore the orthogonal frequency relationship) is demodulated. The result is that echoes with a delay of less than the guard interval do not produce inter–symbol interference. The power in this multipath signal can then be used constructively to aid demodulation.

An extra advantage of this system is that simultaneous reception of the same information from more than one transmitter is possible. The delayed signals from the more distant transmitters will simply look like multipath. This can be used to provide more reliable coverage of an area as it introduces spatial diversity. It also allows all the transmitters in a network to use the same frequency – thus providing excellent spectrum efficiency. This mode of operation is known as the single frequency network (SFN).

4. Experimental work

A new system with these additional features poses new challenges for efficient frequency and service area planning. For example, the SFN concept allows a choice to be made between serving an area (be it a city or a country) with a small number of high–power transmitters or a larger number of low–power transmitters. Or, the rugged digital system allows much lower transmitter powers to be used – but reliable coverage now depends on being able to quantify and predict the amount of signal variation which would be encountered by mobile or portable receivers.

For this reason the BBC has installed a network of four 1 kW, VHF, Band III, DAB transmitters around London. With a population of around 10 million people (18% of the UK population) this provides a suitable test–bed for the system. The purpose of the experiment is to extensively test the DAB system in a realistic environment and gather coverage data to allow more accurate planning of the BBC's proposed transmitter network. It also provides a platform for experiments on components of a DAB transmitter network and on receiver implementation.

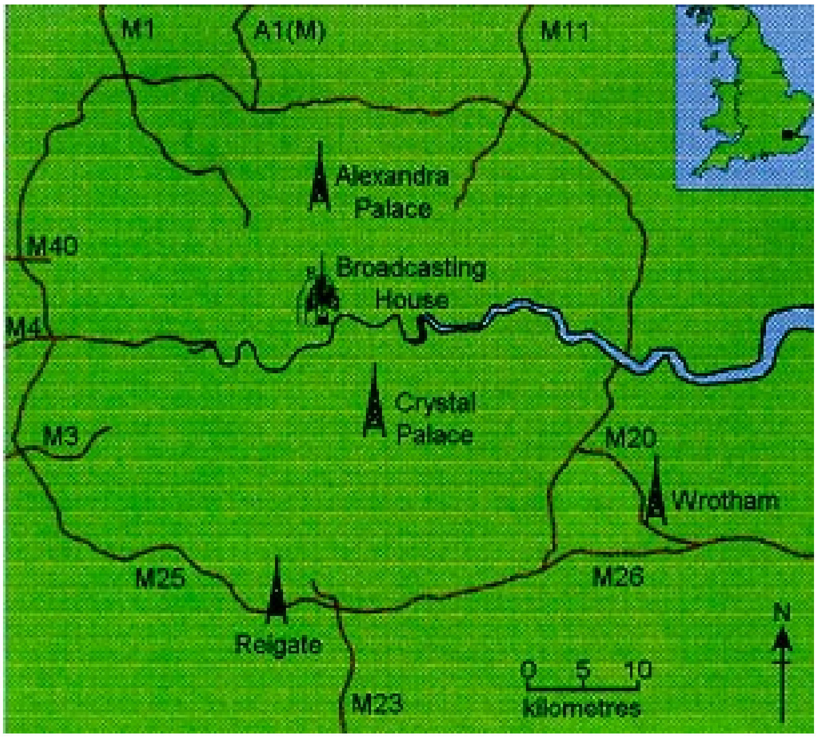


Figure 1
Locations of the London DAB transmitters.

Field–strength predictions and measurements are normally made for 50% (median) location values. If the median field–strength in a particular area is equal to the minimum value for an acceptable service, the area is deemed to be served (assuming no interference or other effects need to be considered). In the case of an analogue system there will still be a service to considerably more than 50% of locations, but with reduced quality. For a digital service such as DAB, however, this would not be the case. The transition from perfect quality to audio muting will occur over a field–strength range of relatively few decibels, depending on the system characteristics. In view of the rapid degradation in digital systems near the failure point, it is necessary to provide an adequate field–strength in a high percentage of locations. A figure of 99% has been suggested for mobile reception. To achieve this, the median field–strength must be increased by a suitable *location correction factor* (50–99% correction factor in this case).

The value of the correction factor is important in planning a DAB service. In general, a small value is desirable since it implies a lower median field–strength, and thus lower transmitter power. Since DAB uses a signal of much wider bandwidth than FM, there is expected to be a degree of frequency diversity. This has the effect of reducing the variations in the field–strength due to terrain effects, multipath, etc. Consequently the location correction factor is reduced. The extent of this reduction was the first object of the BBC study.

If an area is simultaneously served by several transmitters in a SFN, there is expected to be a degree of spatial diversity, resulting in a further reduction in signal variation. The second purpose of this work has therefore been to quantify the improvement.

Finally, the amount of reduction in signal level for reception in buildings has been examined.

4.1. Transmitting system

For this experiment, four DAB transmitting stations were installed. Sites already used for broadcasting conventional television and radio programmes were selected, because these allowed the experimental signal to be radiated from an antenna mounted at a representative height above the ground. The locations of the sites selected are shown in *Fig. 1* and were:

Crystal Palace The main transmitter for UHF television transmissions to London, located in south London.

Wrotham The main transmitter for VHF/FM Radio transmissions to London, located to the east of London.

Reigate A transmitter situated on a ridge of hills to the south of London and used to transmit television programmes at UHF to towns to the south of London.

Alexandra Palace A transmitter situated to the north of London and originally used to transmit television programmes at VHF to London.

Provision was made to transmit an e.r.p. of 1 kW from each transmitting site. In addition, the Crystal Palace transmitter was specified to transmit an e.r.p. of 10 kW, if required. The radiation pattern of the Crystal Palace DAB transmission was arranged to be approximately omni–directional. The other three transmitters have patterns which direct most of the power towards London. This allows the SFN concept to be tested.

For the first stage in the experiment the DAB signal was generated at the Crystal Palace transmitter and distributed at UHF to the three surrounding sites. This allowed simple transmitters consisting only of frequency translation and amplifying equipment to be installed at the other sites. As the network moves towards a pilot DAB service for London, more sophisticated distribution methods are being installed.

4.2. Measuring system

For both mobile and portable measurements a DAB receiver, signal level measuring equipment and a computer were installed in an estate car. The survey vehicle (*Fig. 2*), which was specially equipped for DAB measurement, had a low roof line so as to be representative of normal car reception, i.e. approximately 1.5 m. A Band III receiving antenna was fitted in the centre of the roof to give a response as close as possible to omni–directional. Additional antennas were fitted to provide signals to the positioning system and mobile telephone.

The system was designed to allow measurements to be made of position, received signal strength and DAB system performance, up to ten times a second whilst the vehicle is on the move. This data is analysed later. The approach allows the large amounts of data gathered to be processed efficiently and effectively.

4.2.1. Hardware

The vehicle is fitted with a third generation DAB receiver and a Rhode & Schwarz ESVB test receiver to measure the field–strength. Audio material from the DAB receiver is played through the car radio system to allow subjective assessment of the audio quality to be made by the engineers. The following additional information is recorded on a portable PC:

– Violations of the audio scale factor cyclic redundancy checksum (CRC) and occurrences of muting are recorded as an objective measure of audio performance. This is important for two reasons; firstly, it takes into account the combination of degradations due to low signal strength, long–delay (and hence interfering) DAB signals, and non–DAB interference such as man–made noise. Secondly, it allows the performance of the signal to be measured without the need to transmit specific test data – thus the audio programme can continue to be broadcast.
– DataTrak™ and GPS positioning systems are fitted which give positional information to around 50 m accuracy. However, experimental experience has shown that the positional information becomes unreliable when the vehicle is in dense forests and some dense urban areas.

Figure 2
Interior of the DAB survey vehicle.

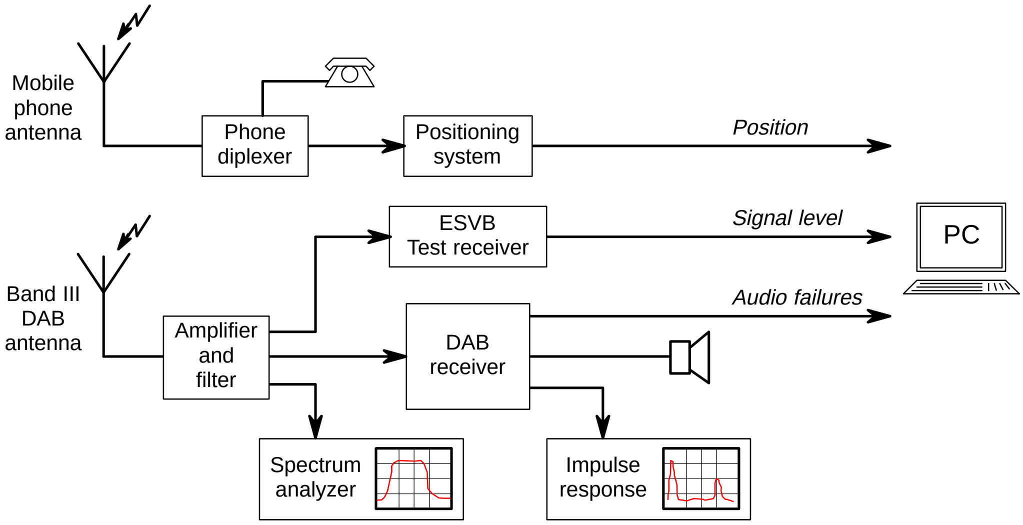


Figure 3
Mobile measuring equipment.

In addition, an oscilloscope and spectrum analyser are provided to assist the engineer making the measurements. The former allows the impulse response (derived from the DAB receiver) to be displayed, thus showing the number and relative magnitude of the signals being received. The latter allows continuous–wave (CW) interferers and man–made noise to be identified. The resulting block diagram for mobile measurements is shown in *Fig. 3*.

Considerable care has been taken to screen the experimental hardware as it has been found that radiation from this equipment (particularly the DAB receiver) can significantly limit the performance of the system. It is anticipated that this problem will be reduced in later versions of DAB receivers which incorporate customised ICs.

In cases where measurements of portable reception quality were to be made in houses, the antenna was taken inside, but the rest of the equipment was left in the vehicle. For measurements in buildings two types of receiving antenna were used. The first consisted of a folded–dipole antenna and was chosen to provide a well–matched antenna for reliable measurement of signal strength, *Fig. 4*. The second was a whip antenna installed on a box of approximately the same size as a conventional radio receiver. This was used for making measurements of expected signal quality in buildings, *Fig. 5*.

In both cases a large number of measurements in each area were made so that valid signal statistics could be calculated – even for relatively small percentages of locations.

Figure 4 ▼
Field–strength measurement in a house.

Figure 5 ▶
Mock portable DAB receiver used to establish subjective requirements for coverage.

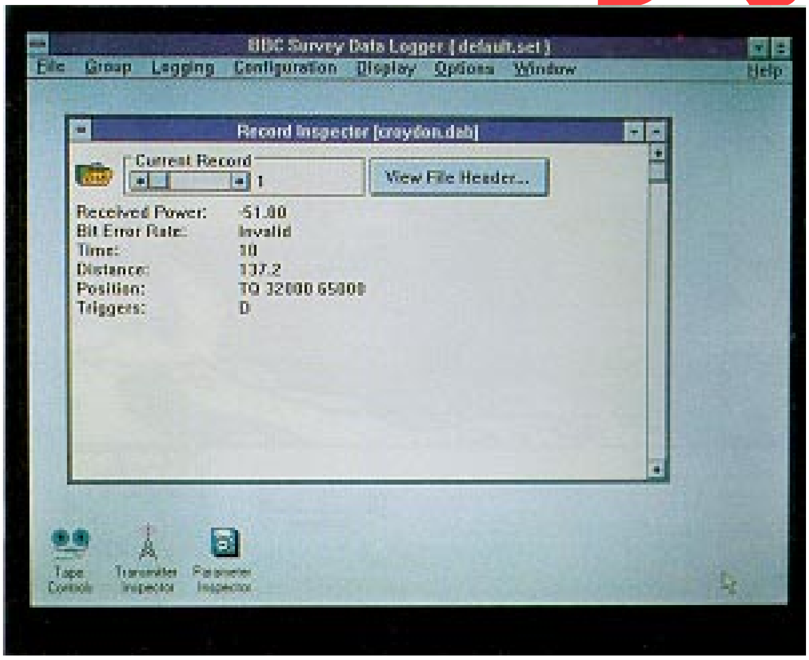


Figure 6
DAB data–logging software.

4.2.2. Logging and analysis software

In order to meet the survey data–acquisition requirements of the high–power DAB field trials, a logging program has been developed. The program runs under Windows 3.1 on an IBM 386 (or higher) computer and presents an easy to use, graphical interface to the operator. At the heart of the program is a fully configurable system for defining the devices and interfaces used to gather the data. A number of interface cards are supported, including RS232, GP–IB and DMA (parallel interface) cards. So long as it has an interface that is supported by the data logging software, a suitable communication link between computer and measurement instrument can be configured. There is no need to write specific software to communicate with a particular type of measurement device. This enables the software to be used for a large number of different data gathering functions.

Once a configuration has been established, it may be saved together with the default information that is to be stored in the data file. This information includes the parameters of the system for which the data was gathered, the date and time, and the identity of the operators.

In addition to the measured data calibration information, survey and project–related details are recorded. The information is stored in a file format which is directly compatible with the suite of analysis programmes.

During data acquisition, the data is displayed to the user as it is gathered, giving a reliable indication of the on–going performance of the system (*Fig. 6*). The same display format is available to display previously–logged data files for comparison

Software has also been written to perform analysis of survey data gathered during field trials. The data files are processed by a suite of programs which have been developed in “C” and written so that each program performs a separate operation in the analysis procedure. A full audit trail is maintained of the processes performed on the data.

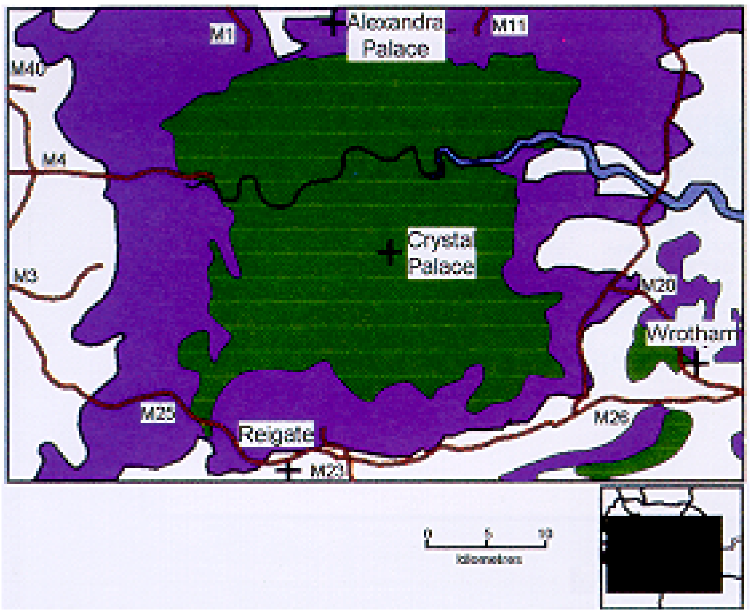
A series of programs may be run on a survey data file to produce the desired analysis. Each individual program performs a simple function on the data such as sorting it, finding various statistics, displaying it, etc. The required analysis is performed by assembling these routines in the required order. This provides a very flexible analysis tool. The results can be output to wordprocessor or spreadsheet applications. Each program has a wide variety of options so that individual programs may be easily tailored to do a specific task in the analysis procedure.

4.3. Experimental methodology

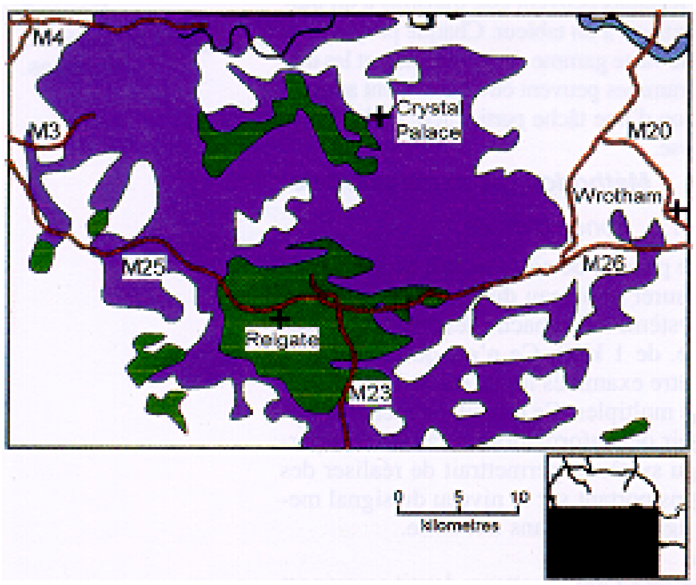
4.3.1 Survey areas

The first priority in the experimental work was to measure the signal level and system performance with individual transmitters (each at 1 kW e.r.p.). Only then could the effects of multiple transmitters be examined. This would simultaneously provide information about the performance of the system and allow comparisons between the measured and predicted signal levels in an area.

The area expected to be covered by the transmitter network is large. To obtain reliable statistics for the signal level and audio quality available at 99 % of locations in a small area requires a large number of measurements in each area. It is clearly impractical (and unnecessary) to survey every area in such detail. Therefore predictions of the expected coverage were obtained and used to target “interesting” areas. In general, these were areas which were expected to be most marginal. However, in the early stages of the experimental work, an exception was made and relatively wide areas were surveyed in lesser density. This was required to identify any system problems which might occur in areas which were expected to be served – and hence would not otherwise be surveyed.



a) Crystal Palace transmitter only.



b) Reigate transmitter only.

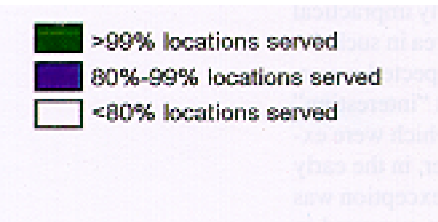


Figure 7
Predicted coverage.

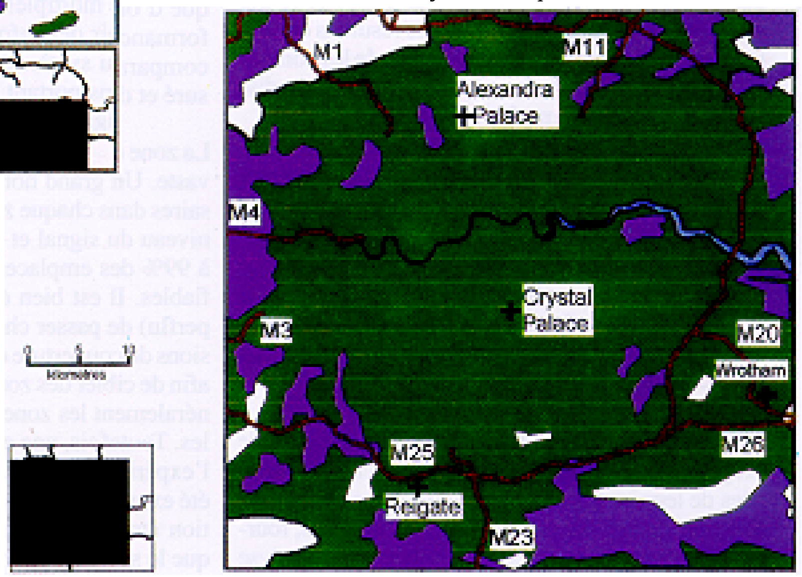
A version of the BBC field–strength prediction method which was developed for planning conventional, analogue television and FM radio coverage was used [3]. However, modifications have been made to allow for the different characteristics of the digital signal, and the low gain and height of the receiving antenna installation [4]. The predicted coverage for two of the individual transmitters and the total network is shown in *Fig. 7*. These predictions are presented in terms of the expected percentage of locations served in each area. To the west of London, relatively flat ground results in an even reduction in signal level with distance from the transmitter. However to the south of London there is a region with many small hills and valleys where very localised changes of coverage are expected. A wide range of types of ground clutter are also encountered, as the centre of London is a dense urban area, whereas further out there are suburban and rural areas.

Measurements were also made in domestic houses. The purpose of this work was to assess the building penetration loss in domestic houses and to obtain a first estimate of the coverage level required by listeners. In this study, the distribution of houses was limited to a selection of those which BBC staff were prepared to make available within the predicted service area .

4.3.2 Measurement and analysis techniques

a) Mobile work

Having targeted areas of particular interest, they were surveyed in detail. For this work, the area was divided into 500 m by 500 m squares and measure-



c) Complete network.

ments were made in a number of these squares in an area. The use of these squares allowed easy comparison of measured and predicted results, as the prediction algorithms currently have a maximum resolution of 500 m.

A number of forms of analysis were performed:

- The mean and standard deviation of the measured field–strengths measured in each square were found. The predicted field–strength was also calculated.
- The measured field–strength and the receiver status were compared to find the minimum field–strength for correct operation of the receiver.
- The objective measure of audio quality derived from the DAB receiver was compared with the subjective result recorded by the engineer in the vehicle.

b) Portable work

In this work measurements of signal level were made in the 500 m by 500 m square in which the house was located, immediately outside the house and in various ground–floor rooms inside the house. The results could then be analysed to find the average building penetration loss and the variation in signal level within a house.

4.3.3. Equipment set–up

The logging system was set to record:

Time	from its internal clock
National Grid Reference (NGR)[1]	from the positioning system
Received power	from the ESVB receiver
Audio scale factor CRC errors (a coarse measure of audio quality).	from the DAB receiver

Readings were initially triggered by elapsed time at the rate of one per second. The ESVB receiver was set for an integration time of 10 ms. This meant that each reading would be averaged over about 10 DAB symbols so that variations in signal level within a symbol period (and across a null symbol) was averaged out. The receiver filter was set to 1.5 MHz in line with the bandwidth of a 3rd–generation DAB signal, and the centre frequency was set to 226.25 MHz, the centre frequency of the experimental transmissions.

After some initial experiments, the arrangement was re–configured to trigger each 96 ms COFDM frame. Measurements were then made more frequently, allowing greater detail of the fast–fading statistics to be recorded. The integration time of the ESVB was correspondingly reduced. Synchronisation of the measurement time to the COFDM frame meant that measurements of signal strength during the null symbol could be avoided.

4.4. Future improvements

A number of improvements to the experimental techniques and equipment can be suggested as a result of our recent experiences. The simplest changes relate to a reduction or the elimination of the amount of measuring equipment requiring mains power. A move to an entirely 12–V powered arrangement is envisaged in the near future. However there are two somewhat longer–term changes which are being considered.

Measurements of the *total* received signal strength can be made satisfactorily using a conventional measuring receiver or a specialist DAB receiver. The only detailed requirement for DAB is that field–strength measurements should not be made during the null symbol. However, measurements of the signal strength from an *individual* transmitter will be required to assess the effect of modifying an SFN. That is, it is highly desirable to measure the field–strength of one transmitter in an SFN on its own. This would be used in an operational environment when the benefit of adding a fill–in transmitter was being considered.

This measurement can be achieved in a number of ways; one such method would involve using the DAB transmitter identification information (TII). The power in the comb of carriers radiated in the null symbol could be calculated. The delay of the signal can be found from the difference in phase between adjacent carriers in the comb and the transmitter can also be uniquely identified. The only problem with this method is that measurements could only be made about 5 times per second (for a Mode 1 signal). However, for most purposes, this may be satisfactory when used in conjunction with a measure of total signal strength, made more frequently.

The second change being considered is a computer display showing DAB performance overlaid on a map. This would greatly improve the targeting of operational survey work.

1. The National Grid Reference serves to define any position in the United Kingdom in relation to a system of linear coordinates in a “flat–Earth” projection.

5. Results

5.1. Calibration

Two calibration issues were considered. Firstly, confidence was needed that the calibration factor arising from the antenna and amplifier gain, feeder loss and voltage–to–power conversion had been correctly measured and calculated. To do this, measurements at a test point with a line–of–sight path to a transmitter were made and compared with predictions.

Secondly, confidence was needed about the repeatability of field–strength measurements. For this purpose, three sets of measurements were made over a short test route with the vehicle travelling at different speeds and in a different direction around the route. The results for each run were compared and showed differences of significantly less than 1 dB.

In each case the results provided confidence that reliable and repeatable results could be obtained.

5.2. Coverage area of transmitters

5.2.1. Coverage of individual transmitters

The coverage of each transmitter was measured in two ways. First, the subjective quality of the received audio signal was noted. Three categories were used to record this data; areas where the audio signal was unimpaired, areas where the signal was unintelligible and the areas in between. Second, the objective results of the receiver status were analysed as the number of CRC errors and muting events within each 500 m by 500 m square. The squares were classified into one of three categories:

Unimpaired: Less than 1% of samples with CRC errors and no mutes within square

Marginal: More than 1% of samples with CRC errors, but no mutes

Impaired: One or more muting events in square

In cases where fewer than 200 samples were recorded, a small modification was made. A single isolated error may not be audible; for this reason a square is only deemed to be marginal if two or more errors were logged. Mutes, on the other hand, always last for at least one second. Thus the minimum criteria for a square to be deemed impaired was just one mute. It should be noted that this is a very onerous criteria as a single mute can be caused by a small tunnel or bridge, or a high level of man–made noise from a single building. *Fig. 8* shows that good agreement is obtained between the subjective and objective measurements.

The results of the objective measurement of audio quality for two of the individual transmitters are shown in *Figs. 9* and *10*. Whilst the whole area has not been surveyed, comparisons with predictions in *Figs. 7a* and *7b* show results which are similar to those predicted. Some trends can be identified in the differences. Coverage in rural areas was generally found to be better than predicted, and coverage in dense urban areas slightly worse. This is probably because the BBC prediction programme has been optimised for predictions in suburban areas. The system performance in some urban areas was also found to be affected by man–made noise. At a small percentage of locations, high levels were observed.

a) Subjective coverage

b) Objective coverage

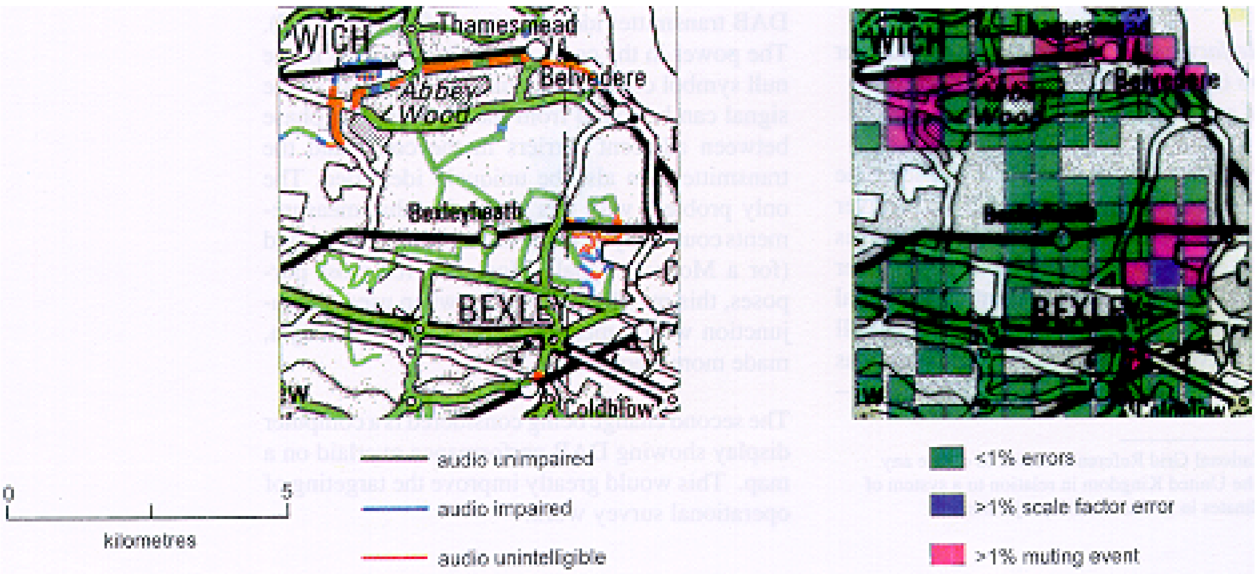


Figure 8
Comparison of subjective and objective measurements of mobile coverage.

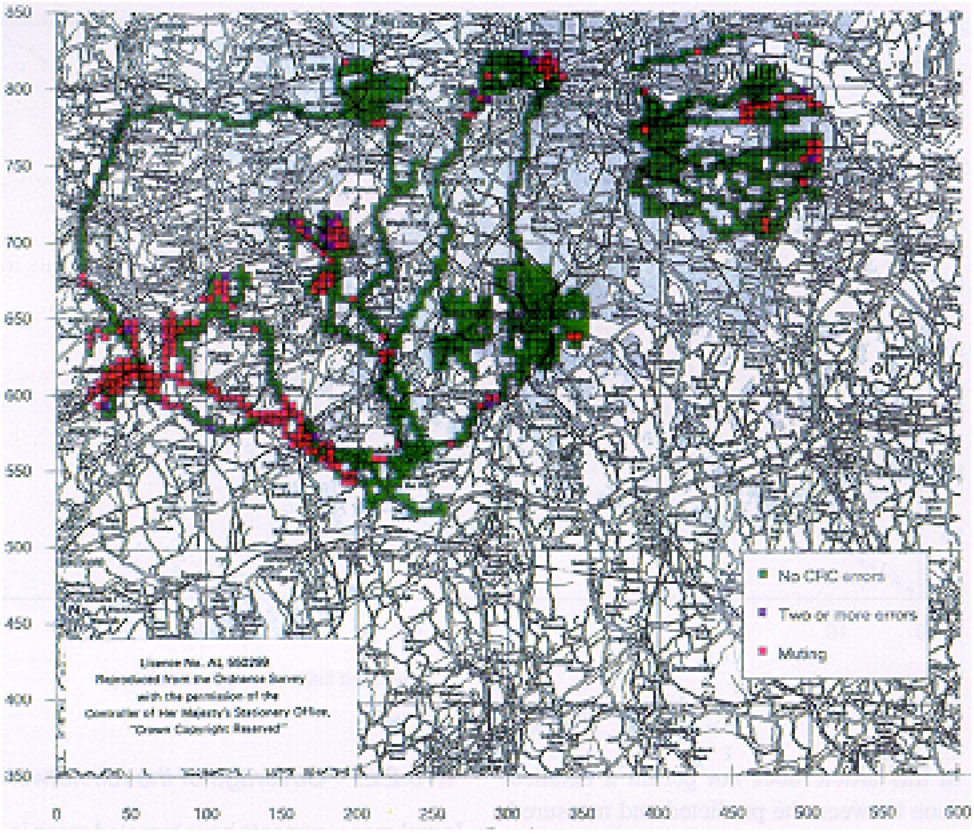


Figure 9
Measured coverage
of the Crystal
Palace transmitter.

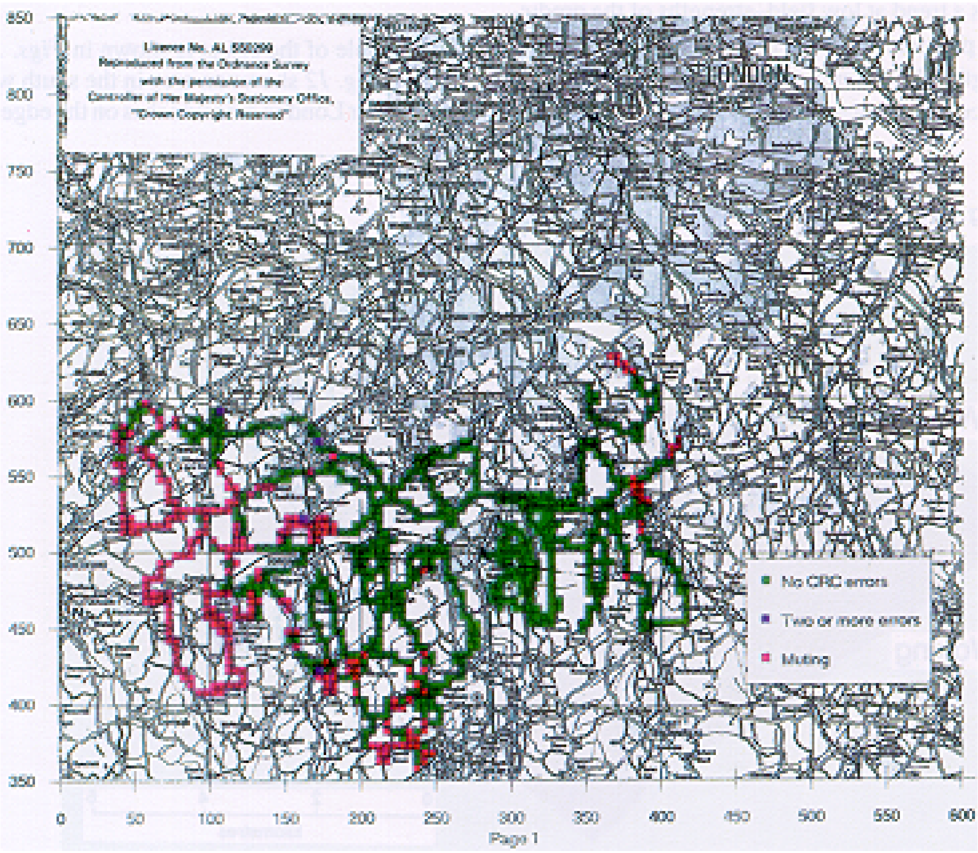


Figure 10
Measured coverage
of the Reigate
transmitter.

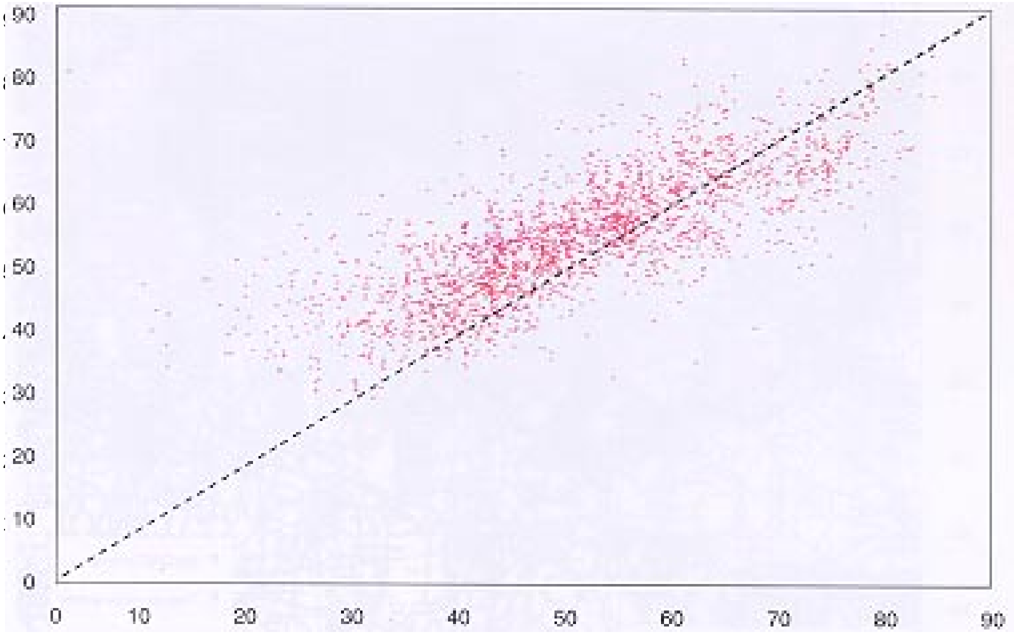


Figure 11
Comparison of measured and predicted field–strengths.

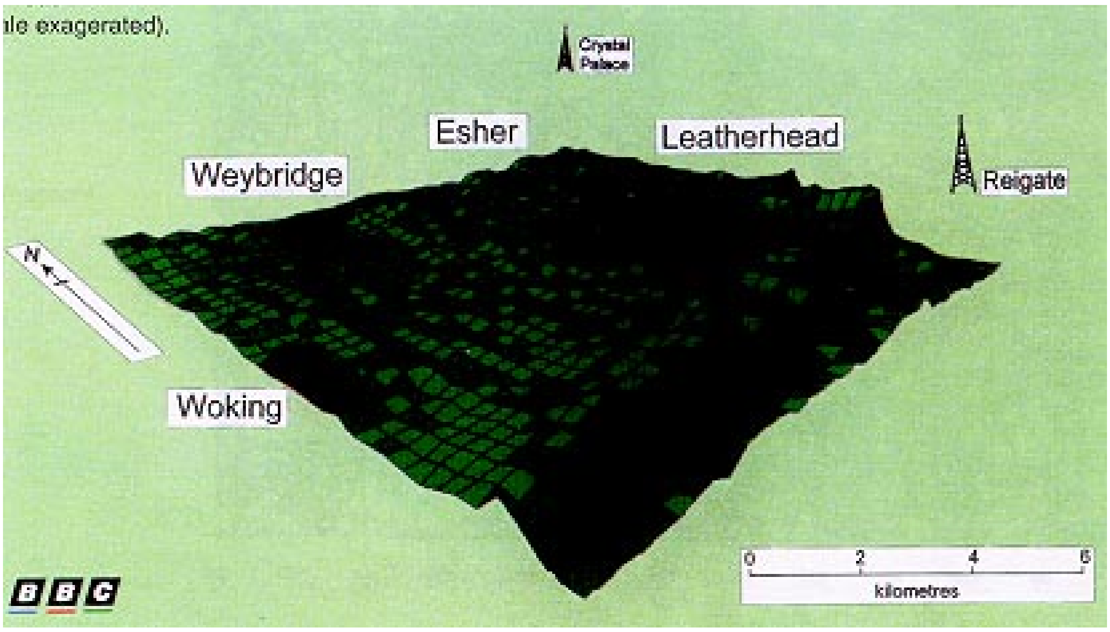
Space in this article does not permit a detailed comparison between the predicted and measured results. However, the general conclusion is that the DAB signal covers a somewhat larger area than predicted. *Fig. 11* compares the median values of the measured and predicted field–strengths. This shows a trend at low field–strengths of the prediction programme under–estimating the field–strength. The difference probably explains the difference in coverage areas.

5.2.2. *Coverage of the full network*

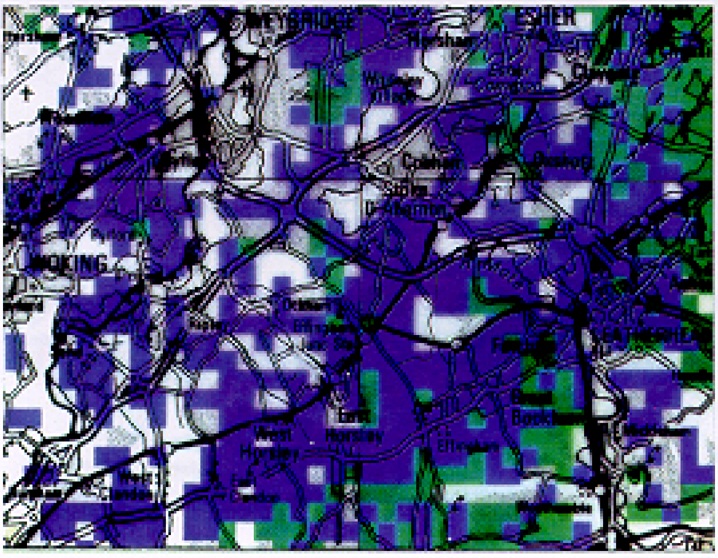
Initial measurements have targeted areas in which the coverage was expected to be marginal. Findings so far have shown the large expected benefit in system performance arising from the simultaneous reception of several signals.

An example of the effect is shown in *Figs. 12*, *13* and *14*. *Fig. 12* shows an area in the south west of the Greater London area which is on the edge of the

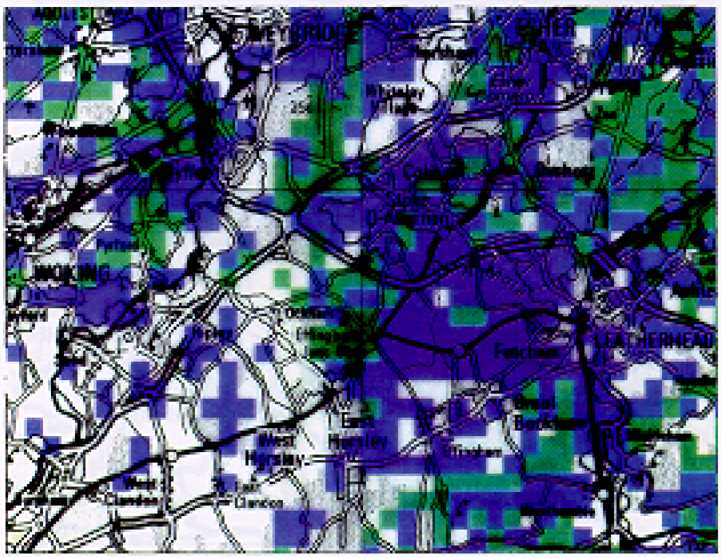
Figure 12
Terrain in the region of Woking and Leatherhead (vertical scale exagerated).



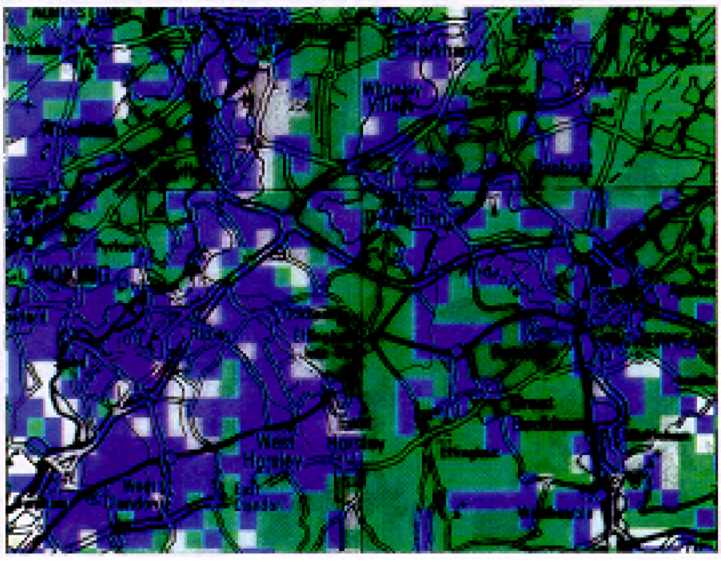
a) Crystal Palace transmitter only.



b) Reigate transmitter only.



c) Crystal Palace and Reigate transmitters together.



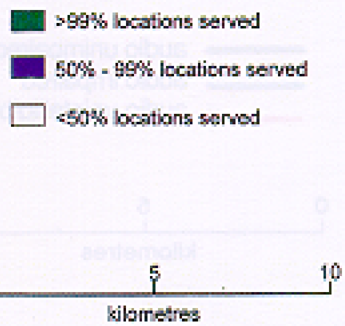
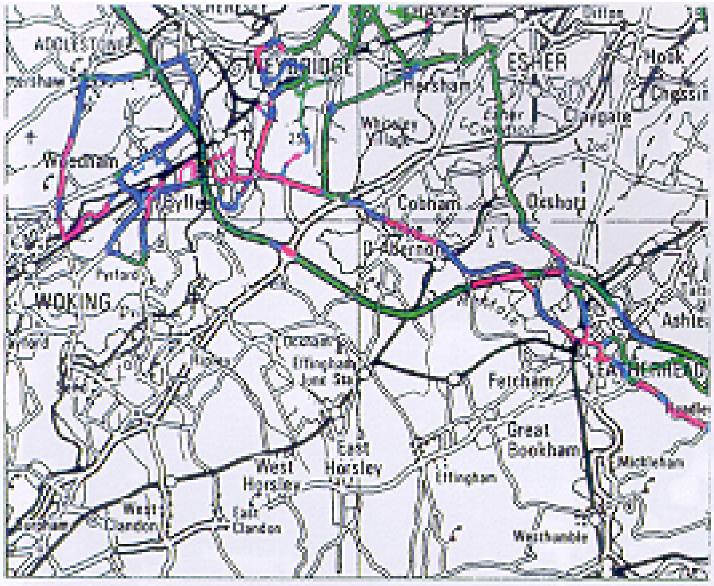
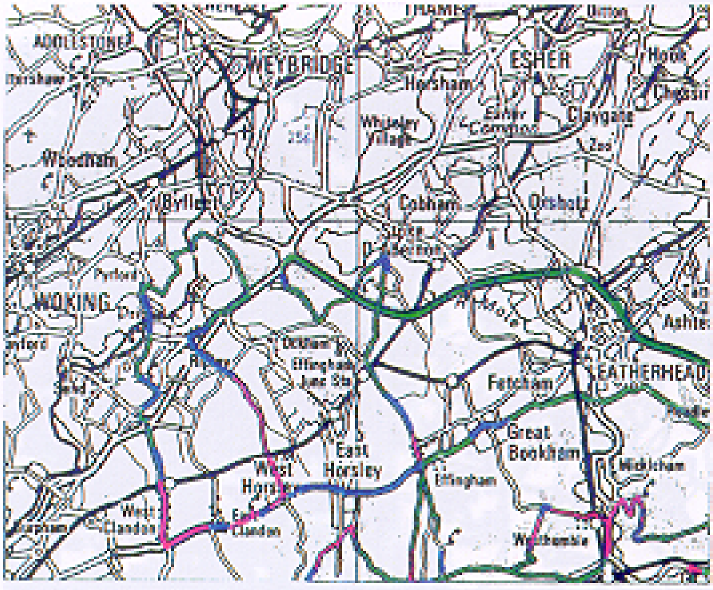


Figure 13
Predicted coverage.

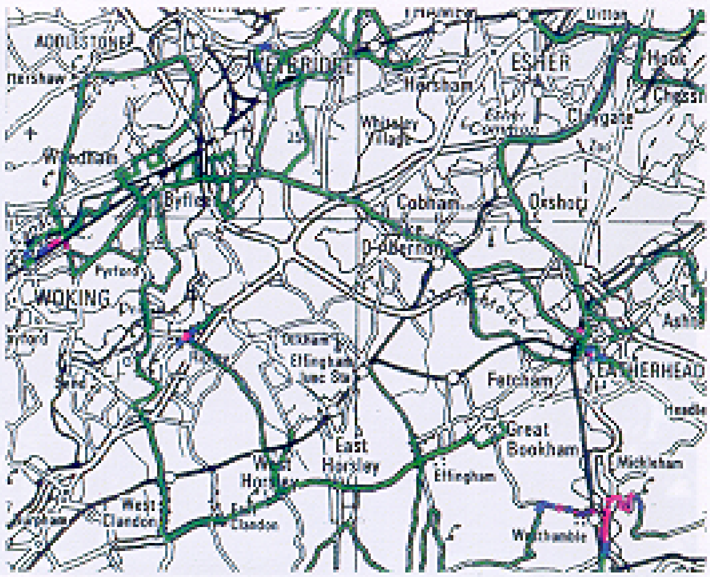
a) Crystal Palace transmitter only.





b) Reigate transmitter only.

c) Crystal Palace and Reigate transmitters together.



audio unimpaired
audio impaired
audio unintelligible

0 5 10
kilometres

Figure 14
Measured coverage.

service area from both the Crystal Palace and Reigate transmitters. The area is also interesting as it contains a relatively flat area to the north and a more hilly ridge of land in the south of the area. The predicted coverage of the area from the individual transmitters and for the whole network is shown in *Fig. 13*. These show that a significant benefit from “network gain” can be expected in this area but, even so, the area is only expected to be marginally served.

The area was also measured in each of the three conditions. The results are shown in *Fig. 14*. These show a somewhat better measured coverage than that which was predicted. They also show that the expected benefit of anticipated network gain is realised in practice. As a result, the only area which was not found to be covered was a small valley in the hilly area. This is actually a well documented deficiency for analogue signals and is served by a transmitter to the south. Detailed coverage results for the whole network have been made and similarly show that the predicted coverage is being obtained.

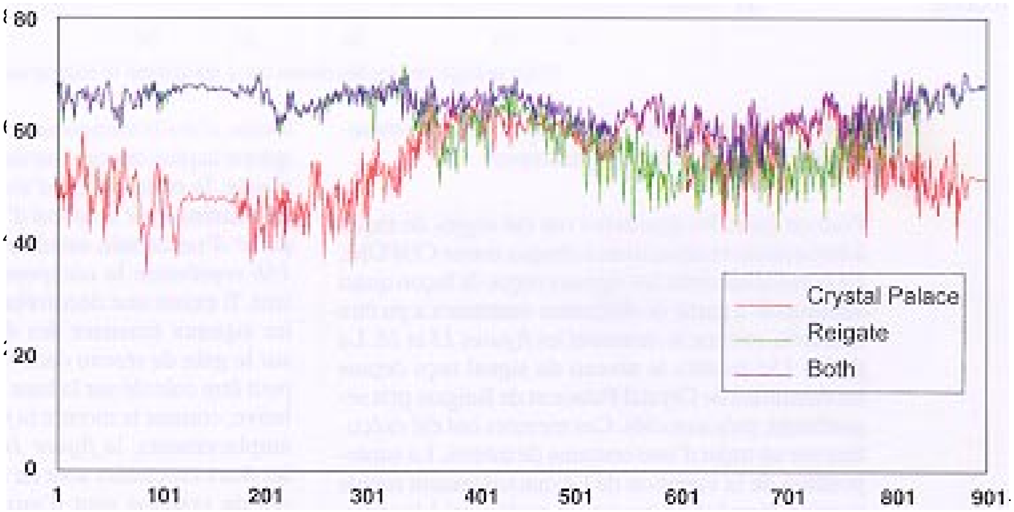
5.2.3. *Network gain*

The transmitter and logging arrangement has allowed the fast–fading statistics and the correlation

Figure 15
Field–strength vs. distance (Epsom Downs test route).

a) Not averaged.

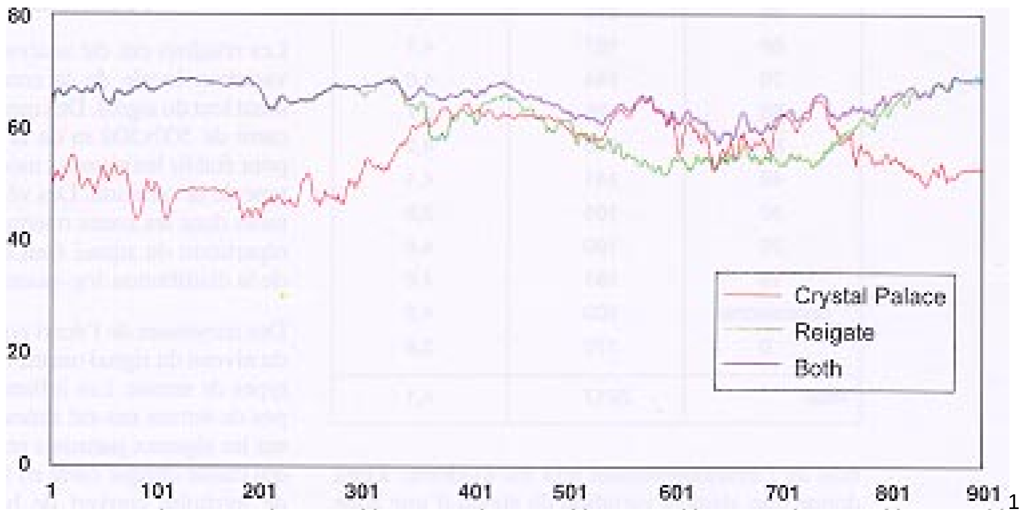
Field–strength (dBμV/m)



Reading number

b) Moving averaged.

Field–strength (dBμV/m)



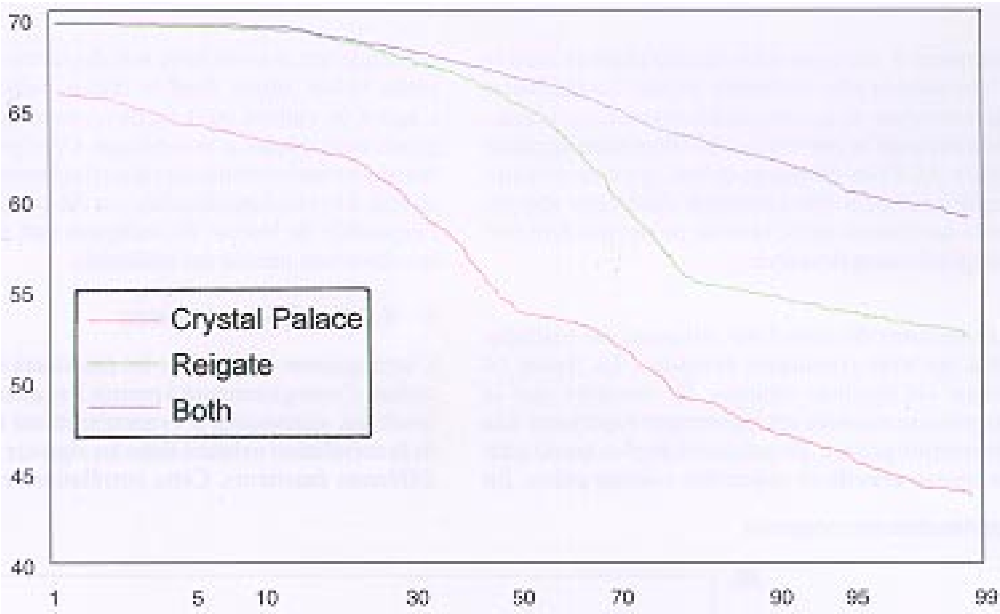


Figure 16
Cumulative distribution for the test route shown in Fig. 15 (Moving average data).

between signals from different transmitters to be explored in more detail. The correlation is, of course, an important quantitative measure of the network gain that can be expected.

To enable this the transmitters were put in a state where they were switched on and off each COFDM frame. The correlation between signals received quasi–simultaneously from different transmitters could be measured. This effect is demonstrated in *Figs. 15* and *16*. *Fig. 15a* shows the received signal level from the Crystal Palace and Reigate transmitters alone and the case when both are switched on. These measurements were made on around 100 m of road. The superposition of the fast–fading (local multipath) variation on the slow–fading variation can be seen. As it is the slow–fading component of the signal variation in a local area which is particularly important in the consideration of network gain, the fast–fading component was removed by calculating a moving average across a number of measurements. The slow–fading component is shown in *Fig. 15b*. It can be seen that there is significant decorrelation between the signals from the two transmitters. The effect on the network gain at the 99% locations level can be found by calculating the cumulative distribution; this is shown in *Fig. 16*. At the 99% locations point, *Fig. 16* shows that the performance of the system with both transmitters operating is around 6 dB better than the performance with only the Crystal Palace transmitter. This result is particularly important as the Reigate transmitter is producing a median field–strength in the area which is considerably lower than that from Crystal Palace.

Table 1
Standard deviation of the signal variation in local areas.

Amount of building cover (%)	Number of areas in the category	Weighted average standard deviation (dB)
100	151	4.3
90	215	4.1
80	167	4.1
70	144	4.0
60	126	3.7
50	148	4.2
40	141	4.1
30	105	3.8
20	150	4.0
10	181	4.0
occasional	509	4.2
0	170	3.9
Total	2217	4.1

5.3. Local–area variations in signal strength

The measured results were analysed to find the local–area variation in the slow–fading component of the signal. For this purpose, measurements gathered in each 500 m by 500 m square over the area were analysed to find the median signal levels and the standard deviation of the variation. Sample areas were checked to ensure that the signal distribution was a reasonable approximation to log normal.

The standard deviation of the local area variations in signal level were averaged for different terrain types. The information about terrain types was obtained from a clutter database of the area which

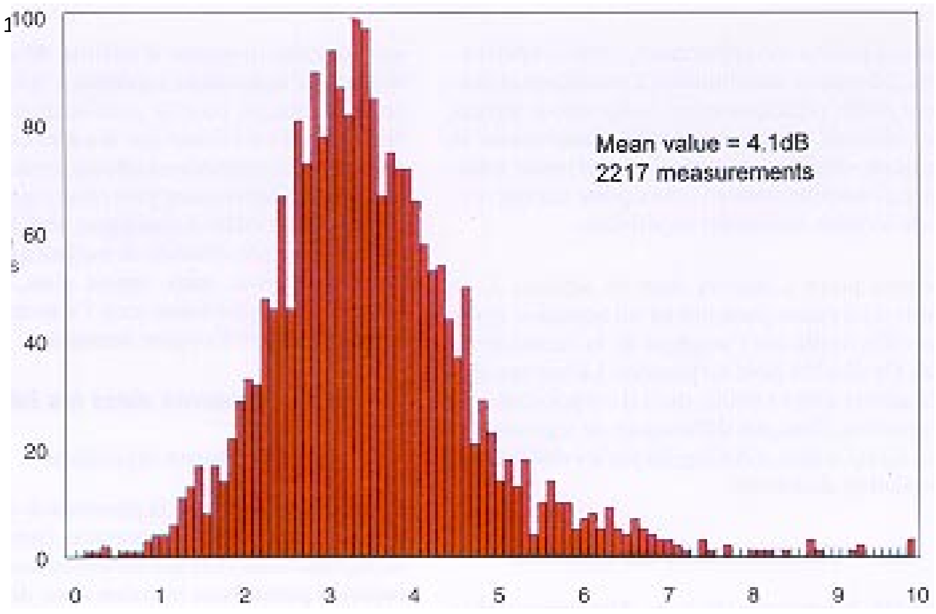


Figure 17
Variation of field–strength in a local area.

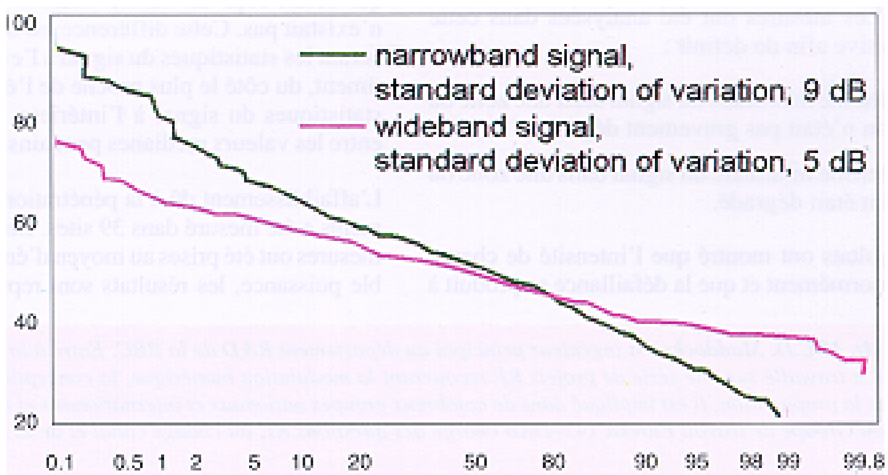


Figure 18
Difference in amount of signal variation for wideband and narrowband systems.

categorises each square by the percentage of the area covered by buildings. This percentage provides an approximate indication of rural, suburban, urban and dense urban areas. In averaging the standard deviations, the results were weighted by the number of samples recorded in each area. The results are summarised in *Table 1*.

The results for over 2200 areas showed an average standard deviation of 4.1 dB. The spread in the values of standard deviation is shown in *Fig. 17*.

The results show (as expected) significantly less signal variation than occurs with narrowband systems, for which a value of 9 dB is implicitly assumed in ITU–R Recommendation PN.370 [5]. This confirms a result which has been measured using low–power transmitters in an earlier network. In that experiment, measurements were made in the same area, from the same transmitter, of the signal variation using a wideband and narrowband signal. The results, *Fig. 18*, showed standard deviations of signal variation of 9 dB and 5 dB for the narrowband and wideband signals respectively.

The second point to note from these results is that the standard deviation is slightly lower than has been measured before [6]. The reasons for this are still being studied in detail, but the most likely are:

– that the current measurements concentrate more on the slow–fading component of the signal and consequently a longer power integration period is used than before;

– a wider variety of terrain has been surveyed.

The second point is important, in that earlier experiments were confined to a relatively small area, much of which was located in relatively undulating terrain. The effect of this is to increase the amount of signal variation in a small area. The current work explores a wider range of terrain types.

The third point to note from the results in *Table 1* is that the amount of ground clutter appears to have relatively little effect on the amount of signal variation. This is perhaps an unexpected result. Once again this area is still being studied, but it is possible that any variations due to differences in ground clutter are being swamped by differences in the amount of terrain undulation.

5.4. System performance results

The purpose of this work was to determine the failure field–strength for the DAB receiver. To do this, the mobile measurements were analysed to determine:

- the maximum signal strength in an area where the audio was not badly degraded;
- the minimum signal strength in an area where the audio was degraded.

The results showed a wide variation in field–strength with a mean failure field–strength of around 40 dBμV/m. This result is slightly higher than the value sometimes assumed for DAB planning; however, the current measurement arrangement is known to suffer from higher levels of man–made noise than would be expected in a domestic arrangement. Considerable care has been taken in the measuring vehicle to screen the relevant equipment; however, even so, a significant cause of the man–made noise is the 3rd–generation DAB receiver itself.

5.5. Measurements in buildings

5.5.1. Objective measurements

An important value for planning the coverage to portable receivers inside buildings is the building penetration loss. That is, the difference between the signal level inside the building and the level that would have been received in the same place if the building were not there. This is found by measuring the signal statistics outside the building, on the side nearest the transmitter, and the signal statistics inside. The difference in median values can then be found.

39 building penetration losses have been measured. The first 26 were measured using low–power transmitters and the results have been reported in [7]. Most of these were typical domes-

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Mr. J.A. Gree*n joined the BBC in 1973 and has been with the Service Planning Section at BBC Research and Development Department since 1978. He graduated from the Open University in 1992. He has worked on a variety of research projects including the development of objective measurements for VHF/FM reception quality in vehicles, and the techniques and methodology of DAB coverage surveys.*

tic houses located in suburban areas. During the high–power experiments a further 13 buildings have been measured. These concentrated on buildings in urban and dense urban areas.

The first set of measurements found an average building penetration loss to ground floor locations of 7.9 dB. As expected, it was found that signal levels on upper floors in houses were higher. The measurements concentrating on houses and basement flats in built–up areas were expected to find a higher building loss; however an average value of 8.3 dB was measured. This was not significantly different from the earlier measurements. On reflection, the absence of change with degree of ground clutter is believable as the clutter loss will usually affect both the signal level outside and inside the house. The spread of building penetration losses measured is shown in *Fig. 19*.

The average standard deviation of the signal variation, considering only the measurements taken on the ground floors of houses, was found to be around 4 dB.

5.5.2. Subjective requirements for reliability of coverage

One of the tasks identified earlier was to investigate the subjective coverage requirements for portable reception in buildings. That is, to make some measurement of the percentage of locations within a building which must be covered before, on average, a listener will find the service acceptable. Such a figure could then be incorporated into coverage criteria.

Investigating this subject is fraught with difficulties. As with all subjective testing, the problem of justifying terms such as what constitutes a service is difficult. The problem is exacerbated by the fact that not only are a number of different people sampled, but also the opinion of each of them is sought in a different house. Finally, their listening habits, expectations and uses of radio receivers are often different.

As a first step in investigating this issue, the opinion of the owner of the house was sought as to the minimum acceptable coverage in their house; this was done when making the penetration loss measurements. An attenuator was added in the signal path between the receiving antenna and the receiver. This was adjusted until the house was just deemed to be served. The percentage of locations in the room for which the audio did not have scale factor CRC errors was then measured.

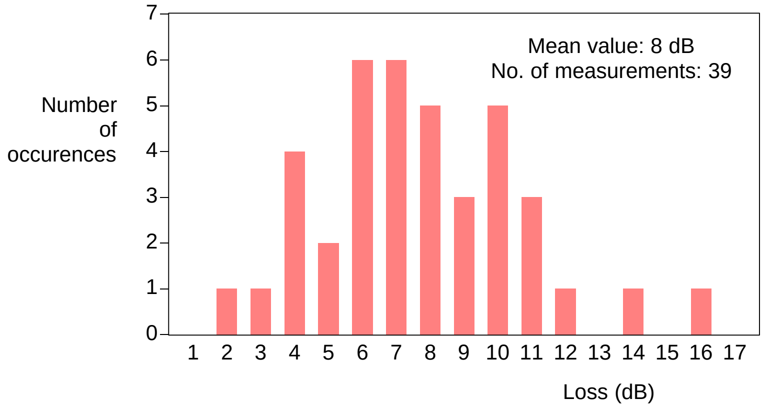

Figure 19
Spread of building penetration losses.

The results suggest that around 80% of locations should be served within a room before it is deemed to be served. However, this percentage varied greatly from house to house or person to person. Primarily, it appears that this is because there are relatively few places where people are prepared to put receivers. If it works there – fine; if it does not, then it is less than acceptable.

The second important point was that, once a satisfactory location had been found, it was very important that it should stay satisfactory as people moved around the room and other channel disturbances occurred.

6. Discussion

The first results from the network of transmitters around London have demonstrated a number of interesting properties of the Eureka DAB system. They have confirmed, over a large number of measurements made in many different areas, that the frequency diversity which is inherent in the system provides a significant reduction in the amount of signal variation. This is an important property of any digital system designed to serve mobile and portable receivers, as a very high level of availability for the system is required.

The results have also provided an important validation of the performance of the system. Good audio reception has been found over the area expected from predictions and simulations of the system. This indicates that the system and the first equipment built to the system specification is operating as expected.

Detailed analysis of the measurements obtained when several transmitters are received simultaneously is still in progress, but the results so far show significant improvements in coverage even when there are relatively large differences in the median signal levels from the different transmitters. This supports earlier experiments which have shown a reduction in the amount of signal variation when multiple signals are received and a consequent reduction in errors in the received data stream [8].

An interesting consequence of this work is that satisfactory reception has been found in most of the London area using relatively–low transmitter e.r.p.s.

The results have provided data which is being used to refine the algorithms and methods used for coverage prediction. This is an important input at a time when the BBC is planning the locations and e.r.p.s of the network of transmitters which may be used to serve the whole of the United Kingdom with DAB services. Experience in the development of these techniques is showing that the experimental measurements can have a major impact on the accuracy of the coverage prediction algorithms. Significant modifications to the techniques normally used for analogue broadcast signals are required.

However, there are still a number of important topics which are being investigated using the network. Examples are:

– Experiments are being performed to measure the correlation between signals from different transmitters. This is an important measure to quantify the benefit derived from the spatial diversity (which occurs when signals from more than one transmitter are received simultaneously).
– Different solutions for local–area broadcasting using the system will be investigated.
– More accurate quantification of the magnitude and effect of long–distance interference from transmitters is needed. Such work is, of course, time consuming as high levels of interference only occur for a small percentage of time and long measurement periods are required to achieve statistically significant results.

7. Conclusions

This article has described the first results from field tests of the Eureka DAB system. These tests are being conducted in and around London and use four 1 kW, VHF transmitters operating as a single frequency network.

The results show wide–area coverage from these transmitters which is in reasonable agreement with experimental predictions. This indicates that the current equipment, built to the Eureka DAB specification, is operating in the way that would be expected from theoretical studies and simulation.

The results also provide quantitative values which can be used for coverage prediction and for international coordination of services. These values are similar to those measured in earlier work.

Finally, the performance of the system demonstrates a number of the benefits of the Eureka DAB system for mobile and portable reception. In particular, it shows the reliability that can be achieved without needing very high–power transmitters; this results from the frequency diversity which is inherent in the system and the spatial diversity which can be obtained if more than one transmitter radiates the same signal at the same frequency. All this has given the BBC the confidence to proceed with plans towards implementing a UK national single–frequency DAB network for its national programme services.

Acknowledgements

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The IAB welcomes its first students

Located in Montreux, Switzerland, the **International Academy of Broadcasting** has been created with the aim of offering interdisciplinary postgraduate studies in the art and science of radio and television broadcasting. Now, after one year of intense preparations, the Academy has opened its doors to the first generation of students.

Arriving from different parts of the world (Algeria, Ghana, Hungary, Iceland, Romania, Sweden, Switzerland, Ukraine and ex–Yugoslavia), and with different university backgrounds, the IAB students gathered on 23 September 1994 to celebrate the official opening of their school. Also present at the Opening Ceremony were IAB Council members, professors and patrons of the IAB, representatives of other schools, numerous guests from the EBU Member organizations, the EBU Headquarters and the Montreux and Vevey municipalities, along with distinguished members of the local community.

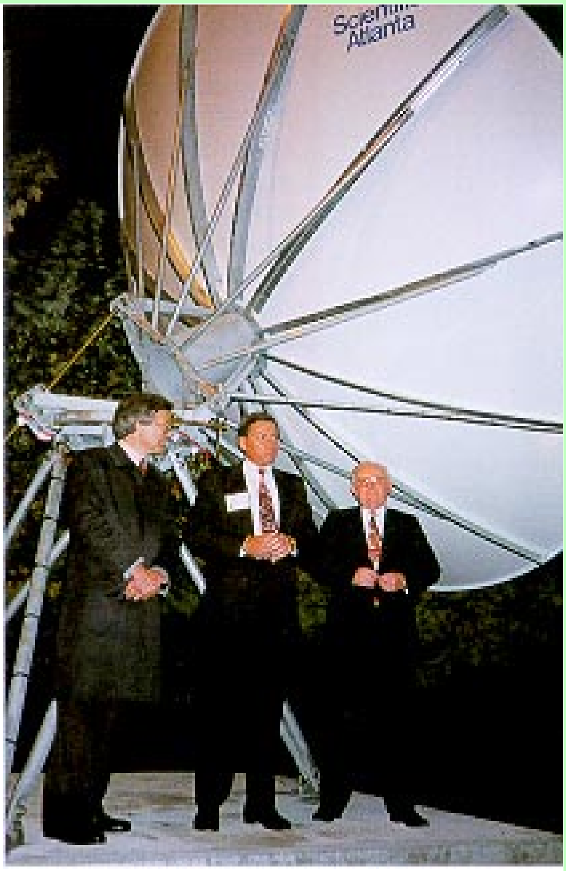
IAB

The President of the IAB Council, Dr. George T. Waters, welcomed the students and guests, and expressed his happiness to see "history in the making" ... "a dream becoming true". Monsieur Ernest Guibert, representing the Montreux municipality, stressed the importance of establishing such a prominent academic institution in Montreux. Commenting that the city is already well known for its media events and its high–quality educational institutions, he expressed his personal belief that the IAB would successfully grow on that fertile ground.

The highlight of the Opening Ceremony was the appearance of the President of the EBU, and Patron of the IAB, Professor Albert Scharf. He wished the Academy and its students every success, and stressed the importance of this new educational institution to the future of the broadcasting industry. Professor Scharf closed his inspiring address by declaring the International Academy of Broadcasting open.

Another IAB Patron, Sir Peter Ustinov, was unfortunately unable to attend the Opening Ceremony. However, he was nevertheless present in a way which is most appropriate for a broadcasting school – through a video tape recording.

Substantial support for the IAB has been forthcoming from the broadcast industry and the Academy has been especially fortunate to be given a fully–equipped earth station by Scientific Atlanta. Taking advantage of the presence of representatives of the industry at the IAB Seminar on Digital Video Broadcasting, a reception was organized to mark the official hand–over of this facility by Mr. D. Ozley (Scientific Atlanta).



Presentation of the IAB earth station
(l–r: Prof. A. Todorovic, Mr. D. Ozley, Dr. G.T. Waters)