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EUREKA 147:
Subjective assessment of the error performance of the DAB system, including tests at 24 kHz audio sampling frequency

M. Lever (CCETT), J. Richard (CCETT) *and* N.H.C. Gilchrist (BBC)

Research and Development Department
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THE BRITISH BROADCASTING CORPORATION

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Summary

This Report describes tests carried out by the authors and other members of Eureka 147 Working Group 'A', to assess the performance of the DAB (Digital Audio Broadcasting) system with a low carrier-to-noise ratio at the receiver. The tests were conducted using a number of listeners to judge the audio quality, making collaborative decisions with the knowledge of the conditions under which the system was operating at all times.

The primary purpose of the work described in this Report was to inform the Eureka 147 project about the failure characteristics of the DAB system when using a fourth generation receiver to receive audio programmes sampled at the normal frequency of 48 kHz, and at half that sampling frequency (24 kHz). Knowledge of the failure characteristics is important because it enables broadcasters to monitor system performance, at a time when services are being planned and when receiver techniques are developing. It should also enable the performance of the Eureka system to be compared with that of other systems .

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1. INTRODUCTION

In 1994, the Eureka 147 DAB (Digital Audio Broadcasting) project conducted tests to study the audible impairment of the DAB system at carrier-to-noise ratios approaching the failure point. Conventional subjective tests of the kind normally performed for this type of study would have presented some problems, however. Such tests require very many presentations of different conditions to each listener, for sufficient results to be obtained to provide meaningful graphical data for the various conditions to be tested. Furthermore, with Rayleigh fading, the normal, short test sequences would not be appropriate at the higher carrier-to-noise ratios. This is because, under these conditions, the signal impairment results from short bursts of errors or muting distributed over relatively long periods of time. A new approach to this kind of testing was therefore devised, in which the Eureka engineers adjusted the carrier-to-noise ratio at the input to the receiver to determine the point at which the effects of bit-errors first become noticeable (the 'onset of impairment') and the point at which the muting becomes so frequent that the programme is no longer of interest to the listener, or where speech becomes unintelligible (the 'point of failure').[1] The data obtained from such tests is not suitable for graphical presentations (e.g. to show the subjectively-assessed quality as a function of the carrier-to-noise ratio), but it does convey the most useful indications of the error performance. Normally, indications of the perceived quality at carrier-to-noise ratios between the onset of impairment and the point of failure are not particularly useful.

The testing method described above, in which engineers collaborated to find the onset of impairment and the point of failure of the system, was found to work well, and was adopted for the tests described in this Report.

The 1994 tests used a third generation Eureka DAB receiver. This had been superseded by the fourth generation receiver at the time of the tests described in this Report; but this more recent receiver was not capable of decoding audio signals sampled at 24 kHz,

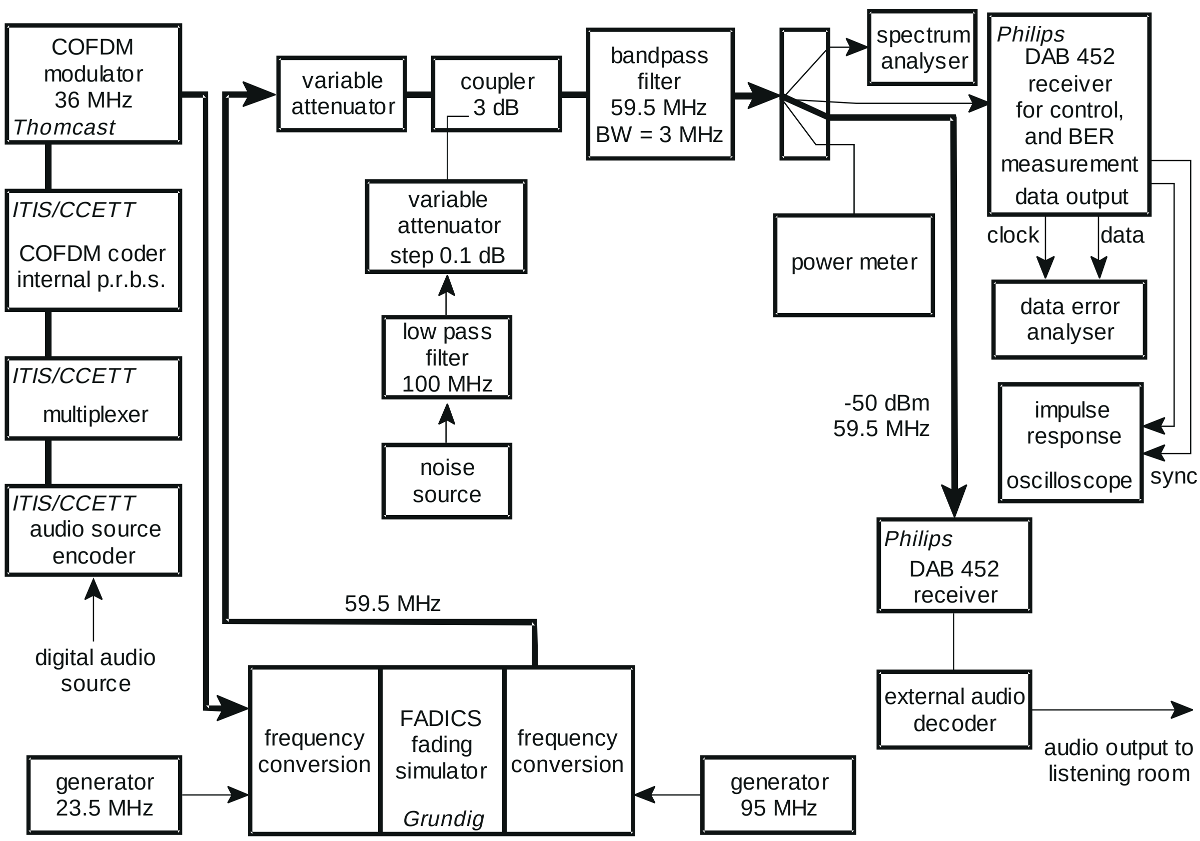

Fig. 1 - Block schematic diagram of the test arrangement Gaussian and Rayleigh channel.

according to the new (MPEG-2) extension of the standard. A fourth generation receiver (Philips type DAB452) was therefore used as a channel decoder, feeding an external audio decoder with MPEG-1 or MPEG-2 DAB bitstreams. This external audio decoder was used in all the test conditions described in this Report. It was based on a third generation (the so-called 'DABDEC3') board, with a modified software from Philips, supporting the 24 kHz audio extension for DAB. A special adaptor was built by CCETT to supply power and to interface the data to the external decoder and, according to the error protection profile in use, to select the 'audio window' (audio with Unequal Error Protection, UEP) or the 'data window' (audio with Equal Error Protection, EEP). As the audio decoder was the same as that used in the 1994 tests, the error concealment strategy was also the same.

In 1994, some additional tests were included to enable transmission Modes I and II* to be compared under identical conditions. Both Modes were found to have the same failure points, and the onset of impairment occurred at the same point, too.[1] In the more recent tests, described in this Report, transmission Mode I was used for the tests at Band III (VHF) and Mode II was used for the tests at L-Band.

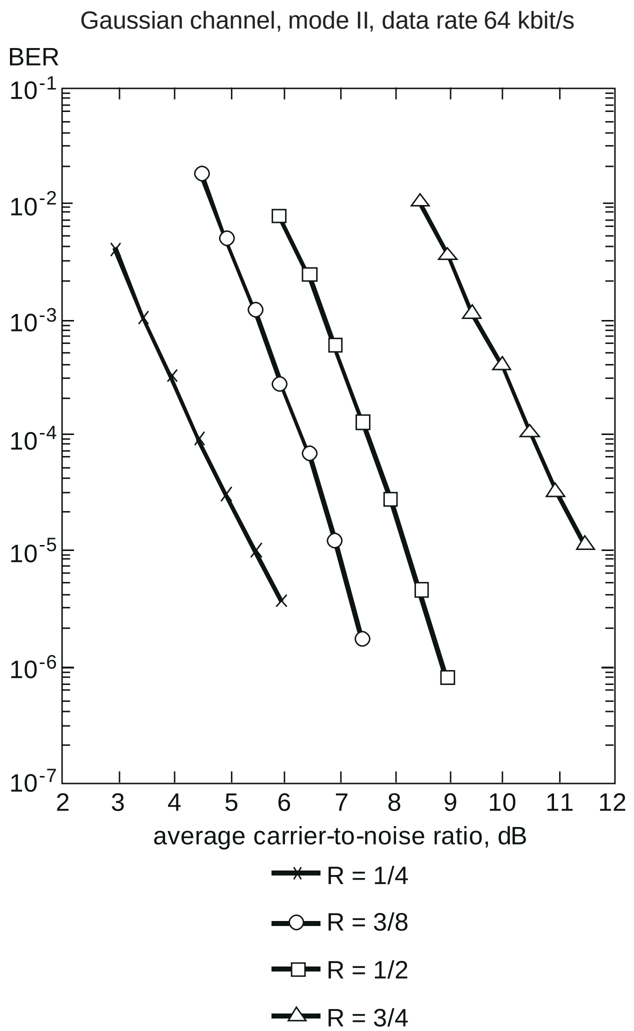

Fig. 2 - Bit-error ratio measured in a data channel of the fourth generation receiver, as a function of the carrier-to-noise ratio.

* Mode I: 1536 carriers, 1 kHz spacing.
Mode II: 384 carriers, 4 kHz spacing.

2. DESCRIPTION OF THE TESTS

A group of audio engineers from Working Group 'A' of the Eureka 147 project met at the CCETT laboratories in Cesson-Sévigné to conduct the tests. They used a laboratory DAB chain commencing at the audio coder and ending at the output of a receiver with a radio-frequency (r.f.) path simulation capable of presenting an r.f. signal with a wide range of carrier-to-noise ratios at the receiver input. A block schematic diagram of the test arrangement is shown in Fig. 1 *(previous page)*. The r.f. conditions during the tests were monitored and adjusted by engineers experienced in r.f. techniques.

A second DAB receiver was used in the laboratory to measure the bit-error ratio (BER) on a separate data channel in parallel with the receiver being used for the listening tests. This data channel had the same or a higher bit rate than the audio channel, and was protected with an equal error protection (EEP) profile at an equivalent code rate. This measurement enabled the engineers to verify that the receiver performed in accordance with expectations at different values of carrier-to-noise ratio (C/N) in Gaussian and Rayleigh channels. Fig. 2 shows the BER as a function of C/N as measured for different code rates with the receiver under test.

Prior to the evaluation, audio test material had been prepared by the CCETT. This comprised two recordings; one of critical musical items, glockenspiel and clarinet, and the other of English speech items. A popular music item from the Swedish group 'ABBA' was initially included as an additional item in a few of the tests, because it comprises stereo material with a number of spatially separated sound sources. It proved to be no more critical than the other items, and its use was discontinued at an early stage in the tests. The source of the programme items was the EBU SQAM Compact Disc[2] and details of the material are given in the Appendix. In each test, the programme items were repeated until the listeners had reached a decision. Significantly longer periods of listening were needed for the tests involving a Rayleigh channel than for those involving a Gaussian channel.

The DAB system is able to carry bit-rate-reduced digital audio signals at a number of different bit rates, coded as mono, stereo, joint stereo or dual channel.[3] The channel coding, based on punctured convolutional coding, affords protection against errors. The greatest protection is afforded at the lowest code rates, which have the highest proportion of redundant information.

The audio bit rates and average code rates selected for testing are shown in Table 1. The Eureka 147 Steering Committee had specifically requested that a wide range of code rates should be tested at one of the bit rates, and that a range of bit rates should be tested at one code rate. Test conditions 2 to 6 and 14 to 17 fulfil the former requirement, and conditions 4, 7, 8, 9, 10, 11, 12, 16 and 18 fulfil the latter. Condition 1, the only stereo test condition, is one of the conditions tested in the 1994 tests. Repeating the tests with this condition enables direct comparisons to be made with the earlier test results. The remaining test conditions were chosen to ensure that audio services with sampling frequencies of 48 kHz and 24 kHz were tested over a reasonable range of bit rates and, in the case of the 24 kHz-sampled service, with both equal and unequal error protection (EEP and UEP). Conditions nine and ten were chosen to enable a direct comparison to be made between 48 kHz-sampled and 24 kHz-sampled audio services at the same bit rate and code rate, with unequal error protection.

In the listening tests, the Eureka audio engineers asked for the carrier-to-noise ratio to be adjusted whilst they searched for the onset of impairment and the failure point of the received DAB signal. They defined the onset of impairment as the point where three or four error-related events could be heard in a period of about 30 seconds. The failure point was defined as the point where the error-related events occurred almost continuously, and muting took place two or three times in a period of about 30 seconds. When the appropriate condition had been reached, the r.f. engineers checked the carrier-to-noise ratio, and this was recorded by the audio engineers. The analogue audio signal at the output of the receiver was recorded on a DAT tape, before proceeding to the next test.*

Table 1: Conditions used in error-performance tests.

	Bit rate, kbit/s	Sampling frequency kHz	Mono/ stereo	UEP/ EEP	Code rate	Protection level
1	256	48	stereo	UEP	0.50	3
2	224	48	joint stereo	UEP	0.35	1
3	224	48	joint stereo	UEP	0.40	2
4	224	48	joint stereo	UEP	0.50	3
5	224	48	joint stereo	UEP	0.60	4
6	224	48	joint stereo	UEP	0.72	5
7	192	48	joint stereo	UEP	0.51	3
8	160	48	joint stereo	UEP	0.51	3
9	64	48	mono	UEP	0.50	3
10	64	24	mono	UEP	0.50	3
11	64	24	joint stereo	UEP	0.50	3
12	56	24	mono	UEP	0.50	3
13	56	24	mono	UEP	0.60	4
14	40	24	mono	EEP	0.25	1
15	40	24	mono	EEP	0.38	2
16	40	24	mono	EEP	0.50	3
17	40	24	mono	EEP	0.75	4
18	32	24	mono	UEP	0.50	3
19	24	24	mono	EEP	0.38	2
20	16	24	mono	EEP	0.38	2

As was mentioned above, two audio recordings, of 30 s duration each, were used for most of the tests. The music recording appeared to be very critical, particularly for determining the onset of impairment; the speech sequence was used mainly to assess intelligibility. However, the use of both could sometimes be avoided, when judged appropriate, thus saving time which could then be used for assessing the results from additional experiments. In particular, once it was established that there was no significant difference between the results obtained with the two recordings, especially at low bit rates, only the speech recording was then used. Speech services are the most likely ones to use the lowest bit rates.

The carrier-to-noise ratios at the onset of impairment and at the failure point were found in the manner described, with a Gaussian channel (i.e. just with Gaussian noise added to the received signal) and with Rayleigh fading of the received signal (simulated using Grundig 'FADICS'**equipment).[4] The tests with a Gaussian channel represented the conditions in which a static receiver operates, and the FADICS was used to simulate two mobile reception conditions. One was reception in a vehicle moving at 15 km per hour (approximately 9.3 miles per hour) in an urban environment; the other was reception in a vehicle moving at 100 km per hour (approximately 62 miles per hour) in a rural environment. The mean carrier-to-noise ratio under Rayleigh fading conditions was measured by means of an analogue power meter, using the following method. The power in a Gaussian channel was taken as reference, and then the Rayleigh channel was programmed with the highest vehicle speed available in the simulator, in order to minimise the fluctuations of the power meter readings. The power of the Rayleigh channel was adjusted to be the same as the reference value, prior to the setting of the desired speed. The error in such a method of estimation is probably within the range ±1.0 dB.

* The analogue output was recorded because a DAT recorder with a digital signal at its input might modify the signal in such a way that impairments would be suppressed (e.g. by smoothing, during replay, timing disturbances which occur during recording) or added (e.g. when corruption of the signal causes a loss of frame alignment in the recorder).

** 'FADICS' stands for **FADI**ng **C**hannel **S**imulator.

Tests were conducted with simulated Rayleigh fading in the urban and rural conditions described above in Band III for transmision Mode I, and in L-Band for Mode II. In some of the tests with Rayleigh fading, it was found impossible to obtain error-free reception, even at high carrier-to-noise ratios. Under these circumstances, the onset of errors could not be found, but where possible an approximate indication was obtained of the point at which the rate of occurrence of error-related events ceased to fall, as the carrier-to-noise ratio was increased from the failure point. This point was termed the 'transition point' because a transition occurred from a carrier-to-noise ratio dependent impairment condition to a static condition where a steady residual (or 'background') error rate was evident.

To test every combination of bit rate, sampling frequency and channel code rate (with both of the programme items, and with both Rayleigh fading and Gaussian noise), would have been very time-consuming; this was recognised at the outset. The results presented in the first table, where Gaussian noise was added to the signal, were obtained using tests in which all of the combinations were used. In the subsequent tables, the results were obtained from tests using fewer combinations. These combinations were agreed by the panel of experts as the most important to perform in the period of time available for the tests. Attention was focussed on two aspects in particular: a comparison of the performance of the third and fourh generation receivers (with reference to the 1994 tests),[1] and the performance of the system operating with 24 kHz sampling frequency (at low bit rates) with unequal error protection (UEP) and equal error protection (EEP).

3. DISCUSSION OF RESULTS

A summary of the results of the listening tests is presented in Tables 2 to 7 *(pages 5 to 7)*. Tables 2 and 5 give the results obtained with a Gaussian channel in Mode II (L-Band) and Mode I (Band III) respectively. Tables 3 and 6 give the corresponding results obtained with simulated urban Rayleigh fading, and Tables 4 and 7 with simulated rural Rayleigh fading.

The listeners had similar experiences in these tests to those of the listeners during the former tests,[1]* concerning the precision with which the onset of impairment (OOI) and the point of failure (POF) could be determined subjectively. There is typically an uncertainty of about 0.5 dB in determining the failure point. When determining the onset of impairment (or the transition point, where there was a residual error rate, even at high carrier-to-noise ratios) the less critical programme items (speech) tended to mask the error-related impairments to some degree. This latter phenomenon appears to be particularly noticeable under rural Rayleigh fading conditions with Mode II transmissions at L-Band (Table 4). However, the uncertainty in determining the mean carrier-to-noise ratio for the tests with simulated Rayleigh fading (±1.0 dB, as mentioned in the previous section) is a factor to be borne in mind when examining the relevant results.

It is interesting to compare the results of the present experiment with those of 1994, for the third generation receiver.[1] Comparing the results for the DAB signal with added Gaussian noise, in Mode I and Mode II at the bit rates and code rates common to both tests, in Tables 2 and 5 of this Report and in Tables 1 and 2 of the 1994 Report, shows that any differences are very small, usually only 0.5 dB. Such differences as there are tend to indicate that the third generation receiver may have a slightly better performance than the fourth generation receiver. However, as the differences are comparable with the expected error in determining the carrier-to-noise ratio at the OOI and POF, they are probably not significant. Essentially, the two sets of results are mutually consistent.

The results of Tables 3 and 4 (urban and rural Rayleigh fading, respectively, with a Mode II L-band signal) may be compared with the results in Tables 8 and 7 in the 1994 Report.[1] There are very few results available from the earlier tests, and the only common bit rate is 224 kbit/s, at a code rate of 0.5. With urban Rayleigh fading, the OOI was in the range 13.5 to 14.0 dB C/N, compared with 11.0 to 15.0 dB C/N in 1994, and the POF 9.0 dB, compared with 7.0 dB in 1994. With rural Rayleigh fading, the OOI was in the range 15.0 to 17.0 dB C/N, compared with 19 to 20 dB C/N in 1994, and the POF 11.0 dB, compared with 10.0 dB in 1994.

When comparing the results for urban and rural Rayleigh fading (using a Mode I Band III signal) with the earlier results, similar differences are found. The results of Tables 6 and 7 (urban and rural Rayleigh fading, respectively) may be compared with the results in Tables 5 and 3 in the 1994 Report.[1] The only common bit rate is again 224 kbit/s, at a code rate of 0.5. With urban Rayleigh fading, the OOI was in the range 14.0 to 14.5 dB C/N, compared with 15.0 to 17.0 dB C/N in 1994, and the POF 10.0 to 10.5dB, compared with 9.0 dB in 1994. With rural Rayleigh fading, the OOI was in the range 15.5 to 17.0 dB C/N, compared with 16 to 18 dB C/N in 1994, and the POF 11.0 dB, compared with 10.0 dB in 1994.

* Some listeners participated in both tests.

Carrier-to-noise ratios at the onset of impairment and failure points.

Table 2: Transmission Mode II Gaussian noise added to received L-Band signal.

	Bit rate kbit/s	Sampling frequency kHz	UEP/EEP	Mono/stereo	Code rate	C/N, dB, at the onset of impairment	C/N, dB, at the point of failure
1	256	48	UEP	Stereo	0.50	Music: 8.0 Speech: 7.5	Music: 5.5 Speech: 5.5
2	224	48	UEP	Joint stereo	0.35	Music: 6.5 Speech: 6.0	Music: 4.5 Speech: 4.0
3	224	48	UEP	Joint stereo	0.40	Music: 7.0 Speech: 6.5	Music: 4.5 Speech: 4.5
4	224	48	UEP	Joint stereo	0.50	Music: 8.0 Speech: 7.5	Music: 5.5 Speech: 5.5
5	224	48	UEP	Joint stereo	0.60	Music: 9.5 Speech: 9.0	Music: 6.0 Speech: 6.5
6	224	48	UEP	Joint stereo	0.72	Music: 11.0 Speech: 10.5	Music: 7.5 Speech: 7.0
7	192	48	UEP	Joint stereo	0.51	Music: 8.0 Speech: 7.5	Music: 5.0 Speech: 5.0
8	160	48	UEP	Joint stereo	0.51	Music: 8.0 Speech: 8.0	Music: 5.0 Speech: 5.0
9	64	48	UEP	Mono	0.50	Music: 8.0 Speech: 8.0	Music: 5.0 Speech: 5.0
10	64	24	UEP	Mono	0.50	Music: 8.0 Speech: 7.5	Music: 5.0 Speech: 5.0
11	64	24	UEP	Joint stereo	0.50	Music: 8.0 Speech: 7.5	Music: 6.5 Speech: 6.5
12	56	24	UEP	Mono	0.50	Music: 8.0 Speech: 7.0	Music: 5.0 Speech: 5.5
13	56	24	UEP	Mono	0.60	Music: 9.0 Speech: 8.5	Music: 7.0 Speech: 6.5
14	40	24	EEP	Mono	0.25	Music: 5.0 Speech: 4.5	Music: 4.0 Speech: 4.5
15	40	24	EEP	Mono	0.38	Music: 6.5 Speech: 6.0	Music: 5.5 Speech: 5.5
16	40	24	EEP	Mono	0.50	Music: 7.5 Speech: 7.5	Music: 7.0 Speech: 7.0
17	40	24	EEP	Mono	0.75	Music: 11.0 Speech: 10.5	Music: 9.5 Speech: 9.5
18	32	24	UEP	Mono	0.50	Music: 8.0 Speech: 8.0	Music: 6.0 Speech: 6.0
19	24	24	EEP	Mono	0.38	Music: 5.5 Speech: 6.0	Music: 5.5 Speech: 5.5
20	16	24	EEP	Mono	0.38	Music: – Speech: 6.0	Music: – Speech: 6.0

Table 3: Transmission Mode II, L-Band signal subject to urban Rayleigh fading.

	Bit rate kbit/s	Sampling frequency kHz	UEP/EEP	Mono/stereo	Code rate	C/N, dB, at the onset of impairment	C/N, dB, at the point of failure
1	256	48	UEP	Stereo	0.50		
2	224	48	UEP	Joint stereo	0.35		
3	224	48	UEP	Joint stereo	0.40		
4	224	48	UEP	Joint stereo	0.50	Music: 14.0 Speech: 13.5	Music: 9.0 Speech: 9.0
5	224	48	UEP	Joint stereo	0.60		
6	224	48	UEP	Joint stereo	0.72		
7	192	48	UEP	Joint stereo	0.51		
8	160	48	UEP	Joint stereo	0.51		
9	64	48	UEP	Mono	0.50		
10	64	24	UEP	Mono	0.50	Speech: 12.5	Speech: 9.0
11	64	24	UEP	Joint stereo	0.50		
12	56	24	UEP	Mono	0.50		
13	56	24	UEP	Mono	0.60	Speech: 15.0	Speech: 11.0
14	40	24	EEP	Mono	0.25	Speech: 8.5	Speech: 7.5
15	40	24	EEP	Mono	0.38		
16	40	24	EEP	Mono	0.50	Speech: 13.0	Speech: 12.5
17	40	24	EEP	Mono	0.75		
18	32	24	UEP	Mono	0.50		
19	24	24	EEP	Mono	0.38		
20	16	24	EEP	Mono	0.38		

Carrier-to-noise ratios at the onset of impairment and failure points.

Table 4: Transmission Mode II, L-Band signal subject to rural Rayleigh fading.

	Bit rate kbit/s	Sampling frequency kHz	UEP/EEP	Mono/stereo	Code rate	C/N, dB, at the onset of impairment	C/N, dB, at the point of failure
1	256	48	UEP	Stereo	0.50		
2	224	48	UEP	Joint stereo	0.35		
3	224	48	UEP	Joint stereo	0.40		
4	224	48	UEP	Joint stereo	0.50	Music: 17.0* Speech: 15.0*	Music: 11.0 Speech: 11.0
5	224	48	UEP	Joint stereo	0.60		
6	224	48	UEP	Joint stereo	0.72		
7	192	48	UEP	Joint stereo	0.51		
8	160	48	UEP	Joint stereo	0.51		
9	64	48	UEP	Mono	0.50		
10	64	24	UEP	Mono	0.50	Speech: 15.0*	Speech: 10.0
11	64	24	UEP	Joint stereo	0.50		
12	56	24	UEP	Mono	0.50		
13	56	24	UEP	Mono	0.60	Speech: 19.0*	Speech: 15.5
14	40	24	EEP	Mono	0.25	Speech: 8.5	Speech: 7.5
15	40	24	EEP	Mono	0.38		
16	40	24	EEP	Mono	0.50	Speech: 16.5	Speech: 13.5
17	40	24	EEP	Mono	0.75		
18	32	24	UEP	Mono	0.50		
19	24	24	EEP	Mono	0.38		
20	16	24	EEP	Mono	0.38		

The signal suffered from errors even at relatively high carrier-to-noise ratios (above 20 dB). The C/N values marked with an asterisk are for the point where there was a transition between the 'back-ground' error rate and an error rate which varied with changes in the C/N.

Table 5: Transmission Mode I, Gaussian noise added to received Band III signal.

	Bit rate kbit/s	Sampling frequency kHz	UEP/EEP	Mono/stereo	Code rate	C/N, dB, at the onset of impairment	C/N, dB, at the point of failure
1	256	48	UEP	Stereo	0.50		
2	224	48	UEP	Joint stereo	0.35		
3	224	48	UEP	Joint stereo	0.40		
4	224	48	UEP	Joint stereo	0.50	Music: 7.5 Speech: 6.5	Music: 4.5 Speech: 4.5
5	224	48	UEP	Joint stereo	0.60		
6	224	48	UEP	Joint stereo	0.72		
7	192	48	UEP	Joint stereo	0.51		
8	160	48	UEP	Joint stereo	0.51		
9	64	48	UEP	Mono	0.50		
10	64	24	UEP	Mono	0.50	Speech: 7.5	Speech: 5.0
11	64	24	UEP	Joint stereo	0.50		
12	56	24	UEP	Mono	0.50		
13	56	24	UEP	Mono	0.60	Speech: 8.5	Speech: 6.5
14	40	24	EEP	Mono	0.25	Speech: 4.5	Speech: 4.0
15	40	24	EEP	Mono	0.38	Speech: 6.0	Speech: 5.5
16	40	24	EEP	Mono	0.50	Speech: 7.5	Speech: 7.0
17	40	24	EEP	Mono	0.75		
18	32	24	UEP	Mono	0.50		
19	24	24	EEP	Mono	0.38		
20	16	24	EEP	Mono	0.38		

Carrier-to-noise ratios at the onset of impairment and failure points.

Table 6: Transmission Mode I, Band III signal subject to urban Rayleigh fading.

	Bit rate kbit/s	Sampling frequency kHz	UEP/EEP	Mono/stereo	Code rate	C/N, dB, at the onset of impairment	C/N, dB, at the point of failure
1	256	48	UEP	Stereo	0.50		
2	224	48	UEP	Joint stereo	0.35		
3	224	48	UEP	Joint stereo	0.40		
4	224	48	UEP	Joint stereo	0.50	Music: 14.5 Speech: 14.0	Music: 10.5 Speech: 10.0
5	224	48	UEP	Joint stereo	0.60		
6	224	48	UEP	Joint stereo	0.72		
7	192	48	UEP	Joint stereo	0.51		
8	160	48	UEP	Joint stereo	0.51		
9	64	48	UEP	Mono	0.50		
10	64	24	UEP	Mono	0.50	Speech: 13.0	Speech: 9.5
11	64	24	UEP	Joint stereo	0.50		
12	56	24	UEP	Mono	0.50		
13	56	24	UEP	Mono	0.60	Speech: 15.0	Speech: 12.5
14	40	24	EEP	Mono	0.25	Speech: 9.5	Speech: 8.0
15	40	24	EEP	Mono	0.38		
16	40	24	EEP	Mono	0.50	Speech: 14.0	Speech: 12.5
17	40	24	EEP	Mono	0.75		
18	32	24	UEP	Mono	0.50		
19	24	24	EEP	Mono	0.38		
20	16	24	EEP	Mono	0.38		

Table 7: Transmission Mode I, Band III signal subject to rural Rayleigh fading.

	Bit rate kbit/s	Sampling frequency kHz	UEP/EEP	Mono/stereo	Code rate	C/N, dB, at the onset of impairment	C/N, dB, at the point of failure
1	256	48	UEP	Stereo	0.50		
2	224	48	UEP	Joint stereo	0.35		
3	224	48	UEP	Joint stereo	0.40		
4	224	48	UEP	Joint stereo	0.50	Music: 17.0 Speech: 15.5	Music: 11.0 Speech: 11.0
5	224	48	UEP	Joint stereo	0.60		
6	224	48	UEP	Joint stereo	0.72		
7	192	48	UEP	Joint stereo	0.51		
8	160	48	UEP	Joint stereo	0.51		
9	64	48	UEP	Mono	0.50		
10	64	24	UEP	Mono	0.50	Speech: 14.5	Speech: 10.5
11	64	24	UEP	Joint stereo	0.50		
12	56	24	UEP	Mono	0.50		
13	56	24	UEP	Mono	0.60	Speech: 19.0	Speech: 14.0
14	40	24	EEP	Mono	0.25	Speech: 9.0	Speech: 8.5
15	40	24	EEP	Mono	0.38	Speech: 12.0	Speech: 10.5
16	40	24	EEP	Mono	0.50	Speech: 15.5	Speech: 13.5
17	40	24	EEP	Mono	0.75		
18	32	24	UEP	Mono	0.50		
19	24	24	EEP	Mono	0.38		
20	16	24	EEP	Mono	0.38		

The audio coding in the 1994 tests used in the comparisons given on page 4 for Rayleigh fading, was stereo; the results of the latest tests were obtained with joint stereo coding. However, comparisons between stereo and joint stereo using the 1994 results reveal no consistent differences between the two types of coding. The error in determining the carrier-to-noise ratio for Rayleigh fading in the present tests was estimated to be up to 1.0 dB, and for the 1994 tests up to 2.0 dB. An additional error, equivalent to about 0.5 dB in carrier-to-noise ratio, exists when determining the onset of impairment (OOI) and the point of failure (POF). It therefore seems unwise to attach any particular significance to the differences in the carrier-to-noise ratios at the points of failure for the present tests. These differences correspond to 2.0 dB for urban conditions and 1.0 dB for rural conditions at L-band, with Mode II; they are 1.0 to 1.5 dB for urban conditions and 1.0 dB for rural conditions at Band II, with Mode I. The somewhat larger differences in the carrier-to-noise obtained at the onset of impairment with the rural Rayleigh fading in L-band with Mode II are also unlikely to be significant.

The measurements of the bit-error ratio (BER) performed during the tests were used to confirm the carrier-to-noise ratios shown in the Tables. It is possible, too, to confirm other aspects of the results. For example, in Mode II with Gaussian noise, a BER of approximately 5×10^{-5} was measured at the OOI in many conditions. At this BER value, Fig. 2 shows a difference of 1.5 dB in the carrier-to-noise ratio between code rates 1/4 and 3/8. The same difference in the carrier-to-noise ratios at these two code rates was obtained subjectively, as can be seen in Table 2 (in rows 14 and 15). The same BER occurs with code rates 1/2 and 3/4 at carrier-to-noise ratios which differ by between 3.0 to 3.5 dB. Rows 16 and 17 in the same table show a similar change in the carrier-to-noise ratio for the change in code rate. The same applies also when considering the POF, typically reached at a measured BER of 1×10^{-2}.

Table 2 contains a number of results for DAB signals with different code rates, at a common bit rate and with joint stereo coding. Rows 2 to 6 inclusive contain results covering the whole range of code rates available for DAB signals at 224 kbit/s. As expected, the performance improves with decreasing code rate. The graphs of Fig. 3 show the relationship between the carrier-to-noise ratio at the OOI and POF as a function of the code rate.

Many of the results in Table 2 (for Mode II signals in L-band with Gaussian noise added) were obtained with DAB signals at the same code rate (0.5), unequal error protection (UEP) and at a number of bit rates (224 kbit/s joint stereo, 192 kbit/s joint stereo, 160 kbit/s joint stereo, 64 kbit/s joint stereo, 64 kbit/s

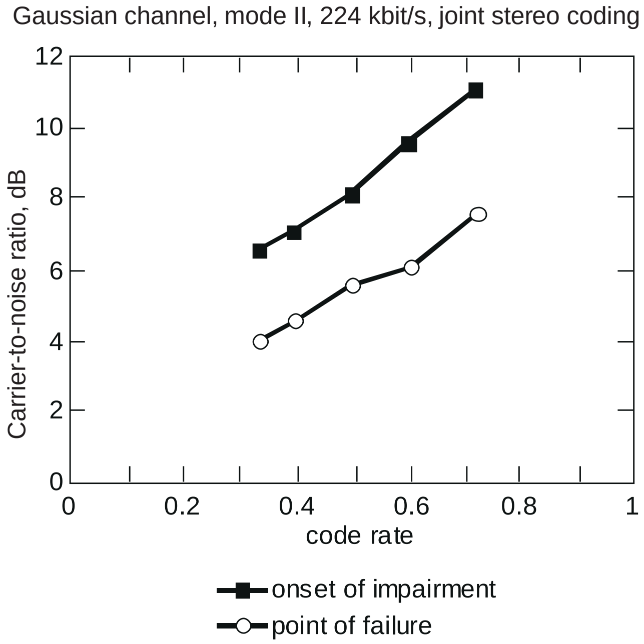

Fig. 3 - Carrier-to-noise ratio (C/N) at the onset of impairment and at the point of failure, as a function of the code rate.

mono, 56 kbit/s mono and 32 kbit/s mono). A sampling frequency of 48 kHz was used at 64 kbit/s and above; a sampling frequency of 24 kHz was used at 64 kbit/s and below. In all cases the onset of impairment occurred at carrier-to-noise ratios in the region of 7.0 to 8.0 dB. The point of failure occurred at carrier-to-noise ratios in the region of 5.0 to 6.0 dB for all results except for those of joint stereo coding at 64 kbit/s (POF at 6.5 dB, but in this case the protection profile is less suitable for stereo than for mono). These results show that the bit rate and whether the audio is coded as mono, stereo or joint stereo have little, if any, effect upon the performance of the receiver at low carrier-to-noise ratios; this is consistent with the results obtained in 1994.[1] They show, too, that reducing the audio sampling frequency to 24 kHz has no effect upon performance. The results for Rayleigh fading, in Tables 3, 4, 6 and 7, do not include examples of signals sampled at 48 kHz and 24 kHz at the same bit rate. Making the comparison at bit rates of 224 kbit/s for 48 kHz-sampled signals and at 64 kbit/s for 24 kHz-sampled signals (rows 4 and 10 of the Tables), the differences in performance are very small (never more than 1.0 dB) and always in favour of 24 kHz sampling.

Changing from unequal error protection (UEP) to equal error protection (EEP) at the same code rate causes reception to fail at a carrier-to-noise ratio between 1.0 and 2.0 dB higher, according to the results in rows 4, 7, 8, 9, 10, 11, 12, 16 and 18 in Table 2. The results in Table 5 (for Mode I signals in Band III with Gaussian noise added) show that UEP lowers carrier-to-noise ratio at the point of failure by 2.0 to 2.5 dB. The results for Rayleigh fading, in Tables 3, 4, 6 and 7, show that UEP lowers carrier-to-noise ratio at the point of failure by 2.0 to 3.5 dB. No significant effect upon the onset of impairment was observed when the type of error protection was changed. Thus, one effect of changing from UEP to EEP is to bring the failure point closer to the onset of impairment. In some cases, where using EEP, failure occurs very quickly as the carrier-to-noise ratio is reduced below the onset of impairment. For example, the carrier-to-noise ratio changes only 0.5 dB from the onset of impairment to the point of failure for the results in row 16 of Tables 2, 3, and 5.

As a general rule, it seems that UEP gives an improvement in performance equivalent to between 1.0 and 3.5 in the carrier-to-noise ratio relative to EEP, at a code rate of 0.5.

It may be of interest to compare the results for Mode I transmission in Band III and Mode II transmission in L-band. Comparing all relevant results in Table 2 and Table 5 (with Gaussian noise added to the signal) shows that the greatest differences are only 1.0 dB; many of the results are closer, being either identical or only 0.5 dB different. If the same comparison is made between the results for the Rayleigh channels, the results are again very similar. Both rural and urban Rayleigh channel results show differences of up to 1.5 dB, again with many identical results. It is important to remember that, with Mode II transmission in L-band, with the rural Rayleigh channel, the reception is never completely error-free; in this case, the onset of impairment is taken as the point where the rate at which errors are perceived to occur increases above the background rate, as the carrier-to-noise ratio is reduced.

4. CONCLUSIONS

Listening tests have been used to assess the error performance of the Eureka 147 DAB system while using a fourth generation receiver; this received audio programmes which were sampled at the normal frequency of 48 kHz in some of the tests, and at half-sampling frequency of 24 kHz in others. The tests involved a number of listeners (who were aware of the conditions under which the system was operating) making a collaborative decision. Adjustments were then made to the carrier-to-noise ratio for the DAB signal at the input to the receiver, in order to find the onset of impairment the failure point of the system.

Similar tests have been conducted in the past using a third generation receiver,[1] and an analysis of the results obtained here show reasonably good consistency between both sets of results. In particular, the performance of the fourth generation receiver appears, from the results of the tests described in this Report, to be equivalent to that of the third generation receiver.

As expected, reducing the code rate improved the reception quality at low carrier-to-noise ratios; this expectation had been verified during the 1994 tests, too. Most of the results show that the bit rate and whether the audio is coded as mono, stereo or joint stereo have little, if any, effect upon the performance of the receiver; this, too, is consistent with the results obtained in 1994.

Possibly the most important conclusion to be drawn from the results is that there is no change in the receiver performance at low carrier-to-noise ratios when the sampling frequency is reduced to 24 kHz.

The use of equal or unequal error protection (EEP or UEP) is determined by the bit rate of the service. The results of the tests described in this Report show that UEP gives an improvement in receiver performance at the point of failure equivalent to between 1.0 and 3.5 dB in the carrier-to-noise ratio, at a code rate of 0.5.

No significant differences were found in performance when comparing Mode I Band III transmission and Mode II L-band transmission.

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APPENDIX

Details of the Recordings Used in the Tests

EBU SQAM Compact Disc *(track and index numbers in brackets)*

1.	Clarinet tune	(16 : 2)
2.	Glockenspiel tune	(35 : 2)
3.	Female speech (English)	(49 : 1)
4.	Male speech (English)	(50 : 1)
5.	ABBA	(69 : 1)

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