ETSI TS 101 758 V1.1.1 (2000-07)

Technical Specification

Digital Audio Broadcasting (DAB); Signal strengths and receiver parameters; Targets for typical operation

European Broadcasting Union Union Européenne de Radio-Télévision

EBU·UER

Reference

DTS/JTC-DAB-24

Keywords

Audio, broadcast, broadcasting, DAB, digital, receiver

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

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Foreword

This Technical Specification (TS) has been produced by the Joint Technical Committee (JTC) of the European Broadcasting Union (EBU), Comité Européen de Normalization ELECtrotechnique (CENELEC) and the European Telecommunications Standards Institute (ETSI), using information supplied by the Eureka Project 147 - Digital Audio Broadcasting.

NOTE 1: The EBU/ETSI JTC Broadcast was established in 1990 to co-ordinate the drafting of standards in the specific field of broadcasting and related fields. Since 1995 the JTC Broadcast became a tripartite body by including in the Memorandum of Understanding also CENELEC, which is responsible for the standardization of radio and television receivers. The EBU is a professional association of broadcasting organizations whose work includes the co-ordination of its members' activities in the technical, legal, programme-making and programme-exchange domains. The EBU has active members in about 60 countries in the European broadcasting area; its headquarters is in Geneva.

European Broadcasting Union
CH-1218 GRAND SACONNEX (Geneva)
Switzerland
Tel: +41 22 717 21 11
Fax: +41 22 717 24 81

The EUREKA Project 147 was established in 1987, with funding from the EC, to develop a system for the broadcasting of audio and data to fixed, portable or mobile receivers. Their work resulted in the publication of a European Standard, EN 300 401 [1], for DAB (note 2) which now has world-wide acceptance. The members of the Eureka 147 Project are drawn from broadcasting organizations and telecommunication providers together with companies from the professional and consumer electronics industry.

NOTE 2: DAB is a registered trademark owned by one of the EUREKA 147 partners.

Introduction

DAB is a system whose main purpose is to broadcast audio programme services [1]. The broadcaster transmits a signal, and some distance away, the listener can listen to programmes on his or her receiver. To keep the listener happy, the broadcaster has to transmit a satisfactory signal strength and the receiver has to operate well when it receives a suitable signal. The important issues are:

- how much signal is needed to be provided by the broadcaster; and
- how well should the receiver perform.

The present document describes the compromises involved.

The main objective is that sufficient signal is received to overcome the noise generated throughout the system. As there are many factors which affect the signal level, and a similar number which affect the noise levels, the calculation is complex. For an efficient DAB system, it is desirable to avoid unnecessary waste.

Experience with transmissions in Band III shows that it is possible to reach a good balance between, on the one hand, field strengths offered by the broadcaster, and the sensitivity of the receiver on the other hand.

In L-Band, operation is known to be satisfactory if all parts of the system are of high specification. If all parts of the system operate to a relaxed specification, then the coverage will be unacceptably small. Broadcasters, network operators and receiver manufacturers need to be aware of the design compromises that are part of the system. The CEPT Planning Meeting at Wiesbaden adopted parameters which are difficult to implement. The broadcast signal is relatively low in power, and this requires receivers to have a sensitivity which is difficult to provide at a low price using current receiver technology.

In the present document, the implications of different parameters will be discussed. Each has a target value, but the effects of departures from this value will be considered. It is not the intention of the present document to define the minimum requirements of the system. It is the intention to show how the parameters can be chosen for good reliable performance. It is recommended that these values, or values compatible with them, are used as a target whenever possible. In planning a service, broadcasters should seek wherever possible to base their coverage areas on the proposed target field strengths, and receiver and antenna manufacturers should provide products which are compatible with the same targets.

The present document provides guidance on the field strengths and receiver sensitivity that can be adopted in a DAB system. These are close to the parameters adopted by CEPT for planning international co-ordination. Individual broadcasters and receiver makers have the flexibility to adopt other values.

1 Scope

The specification of the system for broadcasting digital radio [1] makes no reference to the implementation of the system. The present document establishes general principles for deriving the necessary field strength and compatible receiver sensitivity for satisfactory operation of a DAB system.

2 References

The following documents contain provisions which, through reference in the present document, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.
- A non-specific reference to an ETS shall also be taken to refer to later versions published as an EN with the same number.

[1] ETSI EN 300 401: "Radio broadcasting systems; Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers".

[2] ITU-R Special Publication: "Terrestrial and satellite digital sound broadcasting to vehicular, portable and fixed receivers in the VHF/UHF bands, Geneva, 1995".

3 Symbols and abbreviations

3.1 Symbols

For the purposes of the present document, the following symbols apply:

C/N	The carrier-to-noise ratio (i.e. the ratio of the power of the received signal to that of the noise in the receiver)
f	Frequency of operation
F	The normal noise figure (i.e. as represented in dB)
F'	The noise figure in linear form (i.e. $10^{(F/10)}$)
G	Gain of an antenna (measured in dBi when referred to an isotropic antenna, or dBd when referred to a dipole)
G'	Effective antenna gain (include allowance for loss etc)
k	Boltzmann's constant
K	Degrees Kelvin
n	The overall noise factor of the receiver referred to the receiver input
N	The noise power in the receiver
T	Noise temperature of the DAB receiver
T_e	Contribution to noise temperature from surroundings
To	The reference temperature
Ta	The noise temperature of the sky
V	Received field strength
X	Loss in the cable from the antenna to the radio
α	Resistive loss in antenna cable
β	Passive loss in antenna system
Δf	Bandwidth of DAB signal (usually taken as 1 536 kHz)

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

BER	Bit-error ratio
CEPT	European Conference of Posts and Telecommunications
COST 207	Commission of the European Community's Co-operation in Scientific and Technical Research Committee project, Digital land mobile radio communications
DAB	Digital Audio Broadcasting
EMC	Electromagnetic compatibility
ETSI	European Telecommunications Standards Institute
FFT	Fast Fourier Transform
PFD	Power Flux Density
QPSK	Quaternary Phase Shift Keying

4 The desired *C/N* of the broadcast channel

The primary aim of the DAB system is to provide audio services of adequate audio quality. At the studio, audio quality is a function of the choice of bit rate. The quality may then be degraded by data errors on transmission. Measurements of subjective quality as a function of error rate and source coding have been made by Eureka 147 [2] and these show that the threshold of audibility for errors usually occurs with a Bit Error Ratio (BER) of around 5×10^{-5}. Failure occurs with a BER around 10^{-2}. An edge of service target of BER of 10^{-4} is reasonable.

DAB uses a modified version of QPSK on its carriers. This has very good noise properties, but the required *C/N* is not directly related to the BER. It depends on the propagation conditions within the broadcast channel.

The simplest of channels is one in which a perfect signal is received with the addition of a small amount of random (thermal) noise in the receiver. This is the so-called Gaussian channel. Measurements of the performance of DAB in the laboratory are close to theoretical expectations and show that the BER required for threshold of audibility and failure are about 8 dB and 6 dB respectively. Figure 1 shows typical values measured in the Eureka 147 validation trials, as reported in [2]. Unfortunately the broadcast channel rarely demonstrates a Gaussian characteristic. Figure 1 also shows that there is some sensitivity of result to the level of protection used (The measurements cited here used convolutional codes with code rates of 0,5 and 0,375). In the present document, it is assumed that level 3 protection, as defined in [1] will be used. This is appropriate for most terrestrial broadcasts of audio signals. Different values may be more suitable for satellite or cable systems, or for the transmission of data.

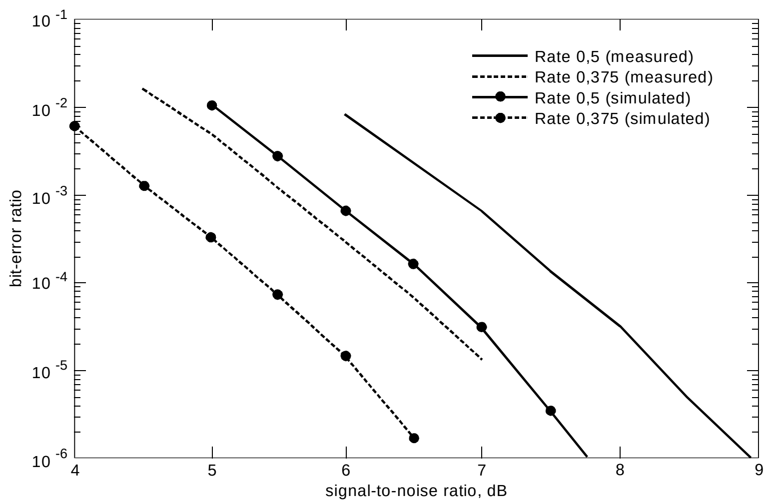

Figure 1: The performance of DAB in a Gaussian channel (Mode 1)

If the channel is subject to multipath distortion, Doppler shift etc., then the required *C/N* for a given BER is different from that of the Gaussian channel. The performance depends very much on the nature of the channel. Although DAB is often quoted as being resistant to multipath, and the guard interval provides robust performance in the presence of multipath, the *C/N* we require for good reception varies significantly with the type of channel. It is not the intention to explain the reasons in the present document, but examples are presented and the consequences considered.

There are propagation models, many developed by the COST 207 Project (see Bibliography), which are typical of different receiving conditions. These cover a range of different types of country, from dense urban through to rural. The models cover different types of reception, from stationary to high-speed mobile. Eureka 147 has measured the performance of DAB for several of these models. The quality of reception varies with the frequency of operation and the choice of mode (see Bibliography). Representative results are shown in Figures 2, 3, 4, 5, 6 and 7.

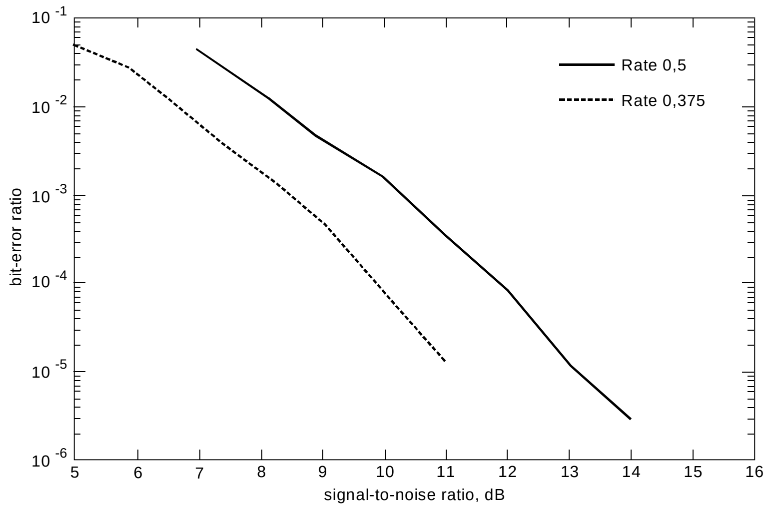

Figure 2: The performance of DAB in a simulated Raleigh Channel, Mode 1,Urban environment, 15 km/h speed, Band III

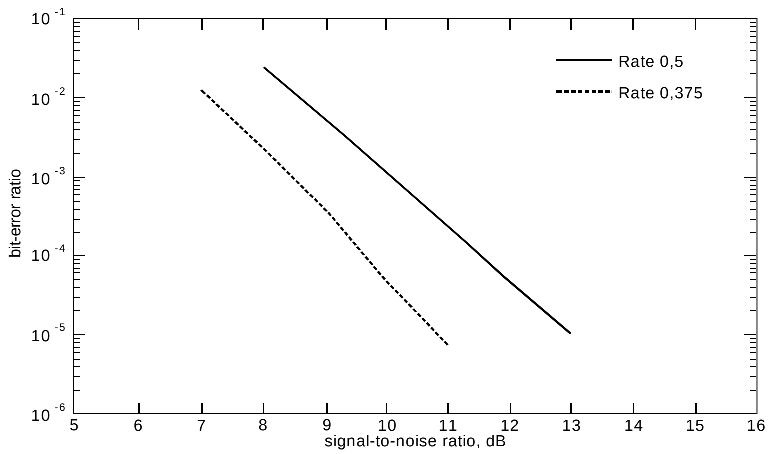

Figure 3: Performance of DAB in a simulated Raleigh Channel, Mode 2,Urban environment, 15 km/h speed, L-Band

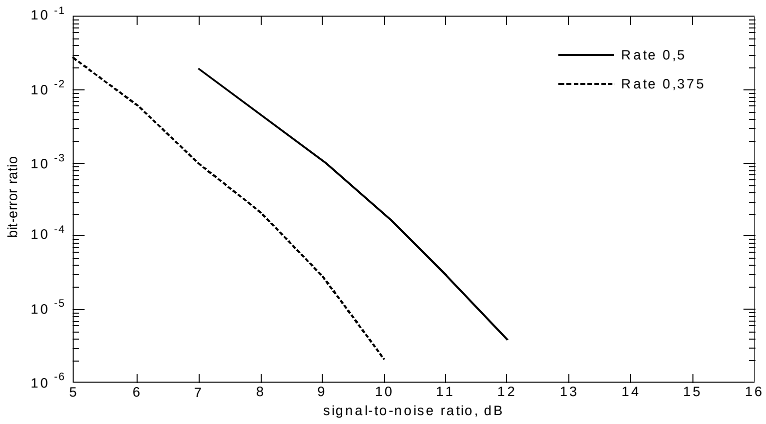

Figure 4: Performance of DAB in a simulated Raleigh Channel, Mode 3, Urban environment, 15 km/h speed, L-Band

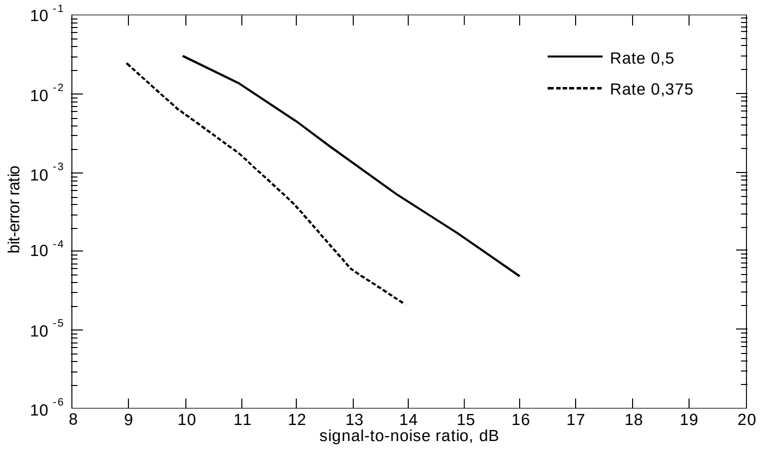

Figure 5: Performance of DAB in a simulated Raleigh Channel, Mode 1, Rural environment, 130 km/h speed, Band III

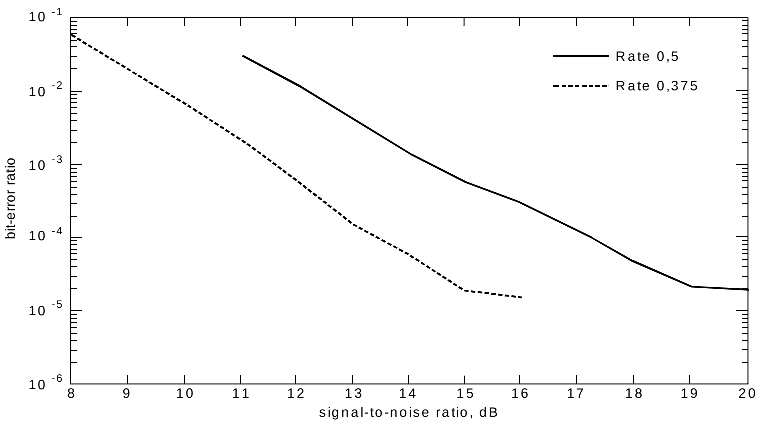

Figure 6: Performance of DAB in a simulated Raleigh Channel, Mode 2, Rural environment, 130 km/h speed, L-Band

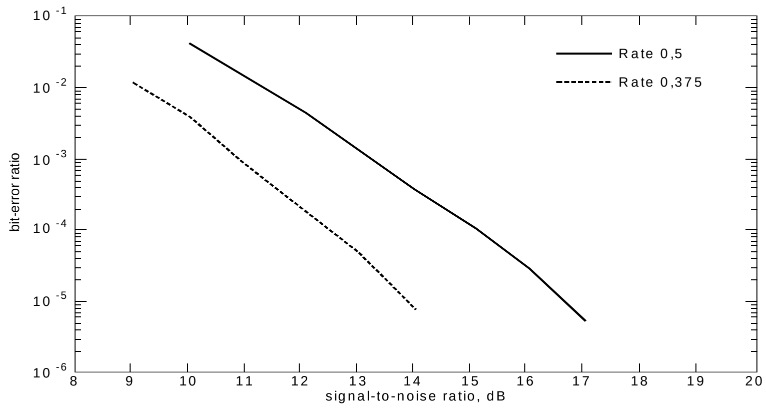

Figure 7: Performance of DAB in a simulated Raleigh Channel, Mode 3, Rural environment, 130 km/h speed, L-Band

From these results it can be seen that in some places good reception will be possible with a low *C/N* close to that of the Gaussian channel, but that in others, a much higher *C/N* is needed. For the type of channel that is both typical and extreme (the rural model) the *C/N* for acceptable reception is about 14 dB. There are other models which require a higher *C/N* perhaps up to about 20 dB, but this high *C/N* is often required because the signal suffers prolonged periods of flat fading. It is an unrealistic requirement to operate under such extreme conditions of broad area flat fading.

Figure 8 shows a distribution typical of the minimum field strength that is required for error free reception in Band III as a function of position over a very wide area. It can be seen that there is a range of over 10 dB in necessary field strength. In practice the places that require unrealistically high values of field strength are likely to be labelled as "unserved" by the broadcaster.

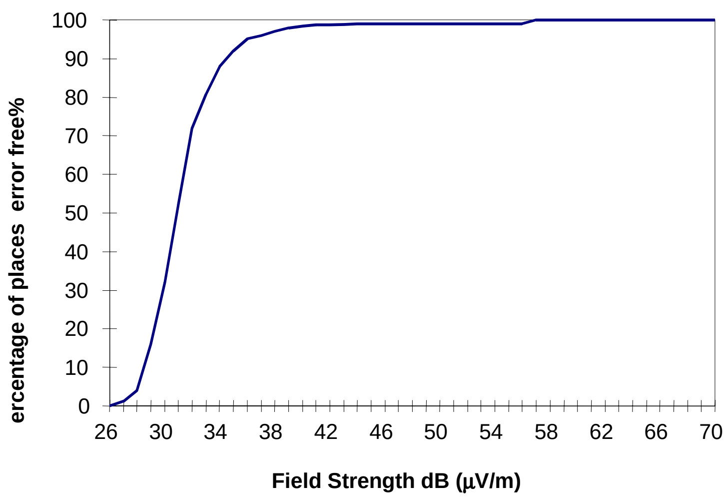

Figure 8: Example distribution of the minimum field strength that is required for error free reception

Most broadcasters accept that the most extreme conditions that the system should be expected to work is that described as URBAN. For this, Figures 1 through 7 show a *C/N* of 14 dB is an appropriate compromise. This does not mean that a system designed to operate with a *C/N* of 14 dB will work everywhere, but it will work in an acceptably high proportion of situations.

If the value of *C/I* of 14 dB is used in planning the system, there is always a chance that this will be a pessimistic value. In such a case, reception outside the nominal service area will be possible. On the other hand, the reverse is also true.

For services which are targeted at geographical areas which are not going to demonstrate extreme channel conditions (this is a matter for propagation experts to determine) lower target values of *C/N* could be suitable.

5 Permissible noise levels

Once a target value of *C/N* has been chosen, the level of noise in the system defines the level of signal that is needed.

Noise has several sources. The most obvious is the noise introduced by the input stages of the receiver where the signal is weakest. The receiver is likely to introduce noise in other places too. Typical sources of noise are:

- black body radiation from everything around the receiver. In the case of satellite reception this is relatively small (about 50 K), but normal reception with terrestrial sources is likely to have a noise contribution between 150 K and 300 K. It will be at the higher end of this range if the antenna "sees" a lot of buildings etc., but at the lower end if there is a significant part of the antenna pointing towards the sky;
- thermal noise from any lossy process (such as the cable between the antenna and the receiver front end);
- the normal shot/thermal processes in the receiver;
- interference from the digital to the analogue stages;
- additional noise from the analogue to digital conversion process before the FFT calculations in the receiver;
- noise-like errors in the signal processing in the receiver.

Revisions of EMC guidelines, indicate that there may also be high levels of external man-made noise. This noise could be broadband and random, but it is more likely to be impulsive or narrow band in nature. It is very difficult to predict the performance of DAB in the presence of such imperfectly defined noise. It is important to ensure that man-made noise is not the dominant source of degradation in the frequency bands used for broadcasting.

All these processes contribute to the noise of the system. In practice many of the contributions can be kept to relatively low levels. The receiver front end and the antenna noise tend to dominate the calculations.

The receiver noise figure can be made extremely low. For example satellite receivers offer noise figures of the order of 1 dB. However these operate at relatively low input powers. If we want a receiver with a wide dynamic range, so that it will work both at the edge of the service area and close to the transmitter, then we have to be more careful in our design. For normal production processes, it is difficult to offer both the ultimate in noise figure and a wide dynamic range. If we wish a dynamic range of the order of 90 dB, then a receiver noise figure of 6 dB is more usual. Between the performance of the satellite system and this last compromise there are various combinations. Figure 9 shows a typical example. Any low noise system requires the input power to be maintained below about -35 dBm for acceptable linearity.

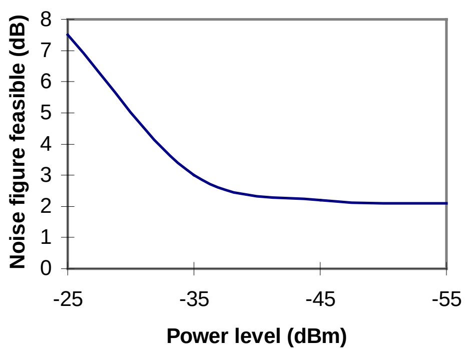

Figure 9: Variation of maximum noise figure of amplifier with power handling capability

6 The level of noise in the receiver

If we take a receiver with a given noise figure, it is possible to calculate the noise power.

This is given by:

$$N = k\, T_o\, F'\, \Delta f$$

Where:

N is the noise power;

T_o is the reference noise temperature (usually taken as 290 K);

F is the normal noise figure in dB;

F' is the linear noise figure $10^{(F/10)}$;

k is Boltzmann's constant = 1.38 exp-23;

Δf is the bandwidth of the receiver (usually taken as 1 536 kHz).

NOTE: The noise temperature, $T = (F' - 1)*290$ K.

There will of course be other contributions to the total noise, but they will be considered later.

Using a representative value of F of 3,5 dB, gives a value for the noise power of -111 dBm. If this were the only source of noise, for a representative requirement of 14 dB C/N, this receiver requires an input power of - 97 dBm.

More often, there is some contribution to the noise from the atmosphere and the loss mechanism in the antenna. It is possible to take these into account using the well known formula:

$$T = \alpha T_a + (1-\alpha)T_o + (n-1)T_o$$

Where:

T is the Total noise temperature;

T_o is the reference temperature;

T_a is the sky contribution;

α is the loss of the coupling;

n is the overall noise factor of the receiver referred to the receiver input.

Typical examples of noise powers are demonstrated in Tables 1 through 4.

7 The antenna

The antenna is a vital component in the DAB system. A good antenna can easily provide 20 dB more signal than a bad one.

In broadcasting, in the bands in question, antennas are usually characterized by their gain which is measured in dB. The gain is relative either to a dipole or to an isotropic antenna. The difference between the two is 2,1 dB (the dipole has the higher gain).

A standard dipole is a little impractical for a band III receiver. More often the antenna will be a whip. The performance of a whip depends very much on its length and the type of counterpoise or ground plane available. There will be a difference in performance between car and portable radio antennas. Typical measurements on a range of receivers shows gains of between -6 dBd and -2 dBd are reasonable assumptions.

At L-Band, the physical size of the antenna is naturally smaller. It is this which has caused much of the problem in understanding how to achieve good coverage. A smaller antenna picks up less signal, and so requires a more sensitive receiver, or more signal to be broadcast. If we can provide something which offers a little more gain than the standard $\lambda/4$ whip, then this will lead to a more optimistic view of the gain.

The radiation pattern of the antenna is not necessarily uniform. Ideally the pattern would be omni-directional, with its plane of maximum gain in the horizontal direction. Car antennas are often far from perfect in this respect. Antennas on portable radios appear to be better matched to the purpose, although body-portable receivers often have degraded performance because the antenna is affected by the body itself.

The radiation pattern of the antenna may also vary with frequency. There may be considerable variation over the wide range of frequencies allocated to DAB. We have no information about the variation of gain over the band. Also, the impedance match of the antenna is likely to vary over the band. This will also cause some loss of signal into the receiver.

Of course, the antenna has to be connected to the receiver. In a portable radio, this link is short, and so it has little bearing on the performance. In a car, we often have several meters of thin cable, which can introduce a lot of attenuation, especially at L-Band. Figures as high as 4 dB at L-Band have been suggested, but in the present document we will take 2,5 dB as a representative figure (achievable in theory with a 1,5 mm diameter copper co-axial cable). Of course, Band III systems are significantly better because the frequency is so much lower.

When calculating accurate power budgets, this loss and the thermal power introduced by the loss process, both need to be accurately calculated.

8 Signal strength required to deliver target *C/N*

Using some appropriate estimates of the parameters for the system, we can derive the received *C/N*.

If we assume Band III reception, then Table 1 shows that a good *C/N* is available using a field strength of 37 dBµV/m, with typical values of antenna gain around -6 dBd and noise figure of 6 dB. This field strength is typical of the values used in the UK for example.

Table 1: Band III Analysis

Variable	Symbol	Value	Unit
Antenna Gain			
with respect to dipole	G	-6,0	dBd
with respect to isotropic		-3,9	dBi
with respect to isotropic, linear		0,4	Linear
Contribution to noise of surroundings	T_e	290,0	K
Loss of antenna and cable			
Resistive	α	1,0	dB
		0,8	Linear
Passive	β	0,0	dB
		1,0	Linear
Reference temperature	T_o	290,0	K
Noise figure of receiver	F	6,0	dB
		4,0	
Bandwidth of system	Δf	1,5	MHz
Boltzmann's constant	k	1,38E-23	
Effective antenna gain	G'	0,3	Linear
		-4,9	dB
Effective noise temperature	T'	1 154,5	
Incoming signal strength	V	37,0	dBµV/m
Power flux density	PFD	13,3	pW/m^2
Frequency	f	225,0	MHz
Active area of dipole	A(ref)	0,1415	m^2
Received power into receiver	C	-92,2	dBm
Noise power	N	2,4E-14	W
		-106,1	dBm
C/N (Rayleigh channel)	*C/N*	14,0	dB

Moving to L-Band, we see from Table 2 that there is a real problem with L-Band reception using an extension of the Band III figures. The *C/N* is much too low.

Table 2: Unsuitable combination of L-Band parameters

Variable	Symbol	Value	Unit
Antenna Gain			
with respect to dipole	*G*	-6,0	dBd
with respect to isotropic		-3,9	dBi
with respect to isotropic, linear		0,4	Linear
Contribution to noise of surroundings	T_e	290,0	K
Loss of antenna and cable			
resistive	α	4,0	dB
		0,4	Linear
passive	β	0,0	dB
		1,0	linear
Reference temperature	T_o	290,0	K
Noise figure of receiver	*F*	6,0	dB
		4,0	
Bandwidth of system	Δf	1,5	MHz
Boltzmann's constant	k	1,38E-23	
Effective antenna gain	*G'*	0,2	Linear
		-7,9	dB
Effective noise temperature	*T'*	1 154,5	
Incoming signal strength	*V*	43,0	dBµV/m
Power flux density	*PFD*	52,9	pW/m^2
Frequency	*f*	1470,0	MHz
Active area of dipole	*A*(ref)	0,0033	m^2
Received power into receiver	*C*	-105,5	dBm
Noise power	*N*	2,4E-14	W
		-106,1	dBm
C/N (Rayleigh channel)	*C/N*	0,7	dB

Table 2 shows that for a field strength of 43 dBµV/m (which was proposed by the CEPT at the Wiesbaden Planning Meeting in 1995) and a receiver noise figure of 6 dB no adequate C/N can be reached.

Only by optimizing the system can we derive a suitable compromise. In Table 3 we see that a higher signal strength and better receiver parameters are needed. This compromise in performance appears to be the optimum for L-Band. Nevertheless, it is still somewhat optimistic in the requirements of noise figure and cable loss in particular. The cable loss from the antenna will be greater in car radios, and there is likely to be additional noise as a consequence. For car receivers which are designed for good reception, it is likely that an antenna head amplifier will be needed.

Table 3: L-Band analysis (Optimized)

Variable	Symbol	Value	Unit
Antenna Gain			
with respect to dipole	*G*	-1,0	dBd
with respect to isotropic		1,1	dBi
with respect to isotropic, linear		1,3	Linear
Contribution to noise of surroundings	T_e	200,0	K
Loss of antenna and cable			
resistive	α	2,5	dB
		0,6	linear
passive	β	0,0	dB
		1,0	linear
Reference temperature	T_o	290,0	K
Noise figure of receiver	*F*	3,5	dB
		2,2	
Bandwidth of system	Δf	1,5	MHz
Boltzmann's constant	k	1,38E-23	
Effective antenna gain	*G'*	0,7	Linear
		-1,4	dB
Effective noise temperature	*T'*	598,6	
Incoming signal strength	*V*	47,0	dBµV/m
Power flux density	*PFD*	132,9	pW/m^2
Frequency	*f*	1470,0	MHz
Active area of dipole	*A*(ref)	0,0033	m^2
Received power into receiver	*C*	-95,0	dBm
Noise power	*N*	1,26E-14	W
		-109,0	dBm
C/N (Rayleigh channel)	*C/N*	14,0	dB

9 Antenna Head Amplifiers

An amplifier at the base of the antenna can improve the noise figure of the complete system.

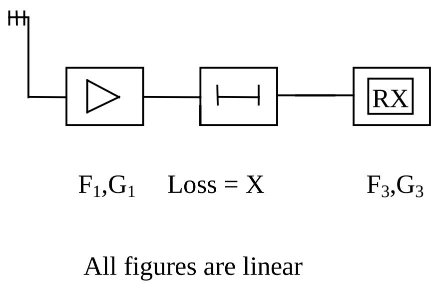

Figure 10: Configuration with an antenna amplifier

The lossy cable provides a noise contribution of noise temperature 290*(1-*X*)/*X* (Kelvin), corresponding to a noise figure of 10 log (1/*X*) dB.

We can calculate the combination of factors using the well known formula:

$$F=F_1 + ((1/X)-1)/G_1 + (F_3-1)/(G_1*G_2)$$

If we accept the figures assumed in Table 2, namely a noise figure for the receiver of 6 dB (i.e. $F_3 = 4$), and 4 dB loss in the cable ($X = 0,4$), then a preamplifier gain of 10 dB and noise figure of 2,3 dB lead to an overall figure for the receiving system of 4 dB.

It is possible to manipulate the link budget to produce Table 4. Here we have a much more achievable set of parameters. They may not be the same as used by CEPT, but they may be adequate for in-car reception.

Table 4: L-Band analysis (with pre-amplifier)

Variable	Symbol	Value	Unit
Antenna Gain			
with respect to dipole	*G*	-3,0	dBd
with respect to isotropic		-0,9	dBi
with respect to isotropic, linear		0,8	Linear
Contribution to noise of surroundings	T_e	200,0	K
Reference temperature	T_o	290,0	K
Noise figure of receiver system (including antenna amplifier and cable loss)	*F*	4,0	dB
		2,5	
Bandwidth of system	Δf	1,5	MHz
Boltzmann's constant	k	1,38E-23	
Effective antenna gain	*G'*	0,8	Linear
		-0,9	dB
Effective noise temperature	*T'*	638,4	
Incoming signal strength	*V*	47,0	dBµV/m
Power flux density	*PFD*	132,9	pW/m^2
Frequency	*f*	1470,0	MHz
Active area of dipole	*A*(ref)	0,0033	m^2
Received power into receiver	*C*	-94,5	dBm
Noise power	*N*	1,3533E-14	W
		-108,7	dBm
C/N (Rayleigh channel)	*C/N*	14,2	dB

10 Linearity

The need for a low noise figure front end is incompatible with high dynamic range for cheap domestic receivers. There is a desire to receive signals at about the -95 dBm level. We also see from Figure 8 that the maximum input power to retain linearity is likely to be around -35 dBm. This gives a 60 dB dynamic range. The receiver is therefore likely to suffer linearity problems when the field strength exceeds around 105 dBµV/m.

Care will have to be taken to balance the need for high transmit powers with the need to avoid excessive field strengths near the transmitter. It is desirable to shape the radiation pattern of the transmit antenna to ensure that this happens.

11 Conclusions

Good quality reception of DAB is feasible in Band III without difficult compromises between field strengths and receiver performance.

In L-Band, the parameters adopted by CEPT in the Wiesbaden Planning Meeting are not easy to implement, especially for car radios. Low field strengths were assumed and these lead to a need for receivers with good noise figures, which may not be easy to provide in a mass-produced set. It is strongly recommended that car radio installations intended for reception of L-Band signals use an antenna with a head amplifier which is optimized for low noise, but which also respects the wide dynamic range of signals that may be encountered.

From the analysis listed in Tables 1, 3 and 4, we can derive some preferred system parameters. These are summarized in Table 5. Although these values were derived for car reception, they can be used as a basis for other types of receivers too.

Wherever possible, broadcasters should adopt a higher power level, and care should be taken with the receiver technology to maximize antenna performance and the overall noise figure. This is particularly necessary for L-Band operation.

Table 5: Proposed target values for DAB systems

Parameter	Band III	L-Band	L-Band Pre-amp	
Field Strength (min)	37	47	47	dBμV/m
C/N in receiver (assuming Raleigh fading)	14	14	14	dB
Receiver noise figure	6	3.5	6	
Antenna gain	-6	-1	-3	dBd
Antenna amplifier gain			10	dB
Antenna amplifier noise figure			2,3	dB
Loss in antenna circuit (max)	1	2.5	4	dB

Bibliography

The following material, though not specifically referenced in the body of the present document (or not publicly available), gives supporting information.

- Failli, M.: "COST 207, Digital land mobile radio communications. Final Report. Commission of the European Communities, European Co-operation in Scientific and Technical Research Committee. 1989".

History

Document history		
V1.1.1	July 2000	Publication