Technical Parameters and Planning Algorithms for T-DAB Coverage Calculations June 2011

Document Number DAB/1

Version 1.0, 7 June 2011

Produced by

arqiva BBC Ofcom OFFICE OF COMMUNICATIONS

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1 Introduction

The purpose of this document is to summarise the planning parameters and algorithms that are being used by the BBC, Arqiva and Ofcom in the joint frequency planning work for terrestrial digital radio (T-DAB). Subject to agreement by the parties within the project, the parameters and algorithms described in the document may be updated or modified in the light of new information as it becomes available.

2 Planning Parameters

2.1 T-DAB system parameters

The T-DAB system currently used in the UK (Mode I) will be considered here. Other system variants could be investigated if requested. Five levels of Unequal Error Protection (UEP) are defined, and system parameters for each are shown in Table 1. Derivations are shown for both Gaussian and Rayleigh channels.

	UEP	**1**	**2**	**3**	**4**	**5**
Modulation		QPSK				
Error Coding Rate		0.34	0.43	0.5	0.6	0.75
Guard Interval (µs)		246				
Approximate data rate (Mbit/s)		0.78	0.99	1.15	1.38	1.73
Gaussian Channel	C/N (dB)	4.6	5.4	6.1	7.1	8.9
	Receiver Implementation Margin (dB)	1.3				
	System C/N (dB)	5.9	6.7	7.4	8.4	10.2
Rayleigh Channel	C/N (dB)	7.2	7.7	8.4	10.0	13.7
	Receiver Implementation Margin (dB)	4.6				
	System C/N (dB)	11.8	12.3	13.0	14.6	18.3

Table 1: T-DAB System Parameters

Because different segments of the data stream for each programme service have different protection levels and therefore require different code rates, it is not possible to precisely specify the overall code rate for each programme service or for the overall multiplex of programme services and data. The code rate thus depends slightly on the data rate used for each programme service (or data service).

2.2 Reception conditions

Calculations of DAB coverage are made under two separate assumptions of reception conditions: in-car (mobile) and indoor (portable). No assessment is made of reception by rooftop antennas. The principle differences between in-car and indoor reception are different assumptions on antenna gain (see section 2.4), required percentage locations (see section 2.9) and building penetration loss (see section 2.5).

2.3 Height loss

Unlike TV or FM radio planning, it is assumed that all DAB reception takes place at 1.5m above ground level. As prediction algorithms are optimised for reception at 10m above ground level, a height loss correction of 10 dB is taken into account.

2.4 Receiving antenna gain and discrimination

All predictions of T-DAB coverage will assume omni-directional vertically polarised receiving antennas. Cross-polar discrimination is not modelled as most interference (from other T-DAB networks) will also be vertically polarised.

The two types of receivers modelled have different antenna gain assumptions:

Receiver Type	Antenna Gain (dBi)
In-car	-2.9
Portable	-8.1

Table 2: Receiving Antenna Gain

2.5 Building penetration loss

For indoor reception, distinction is made between “suburban” and “dense urban” building types, based on the clutter type pertaining at a prediction pixel (see section 3.1). This is intended to make allowance for the differences in construction typically found between residential properties and more solidly constructed buildings in city centres (whether residential or commercial).

Building Type	Median Penetration Loss (dB)	Standard Deviation of Penetration Loss (dB)
Suburban	8	4.4
Dense Urban	15	5

Table 3: Building Penetration Loss

The decision of whether to use suburban or dense urban building loss figures is based on the clutter type for the pixel in question. Dense urban is indicated by the clutter classes representing the densest environments, and suburban covers all other types (including rural, open in urban etc).

2.6 Frequency dependence

All the calculations in this section are for a frequency of 220 MHz. For other frequencies, a correction term can be added as follows:

$$FS_{\min} = FS_{base} + 20\log(f/220)$$

where	$FS_{\min}$	is the minimum wanted field strength
	FS_{base}	is the base minimum field strength at 220 MHz (see below)
	f	is the centre frequency of the block

2.7 Receiver sensitivity in a Gaussian channel

Using the figures in Table 1 and the data above, it is possible to derive a theoretical sensitivity for a receiver in a Gaussian channel (such as might be encountered in a G-TEM cell). The factors that contribute to the sensitivity are thermal noise, receiver noise figure, the system C/N value, the dipole factor for the frequency in use, the antenna gain and an "implementation margin". In the example calculation below, antenna gain appropriate for a portable receiver has been used.

	UEP	1	2	3	4	5
Noise bandwidth	(MHz)	1.536	1.536	1.536	1.536	1.536
Thermal noise	(dBm)	-112.11	-112.11	-112.11	-112.11	-112.11
Required C/N	(dB)	4.6	5.4	6.1	7.1	8.9
Receiver noise figure	(dB)	7	7	7	7	7
Gaussian implementation margin	(dB)	1.3	1.3	1.3	1.3	1.3
Minimum receiver signal level	(dBm)	-99.2	-98.4	-97.7	-96.7	-94.9
Frequency	(MHz)	220	220	220	220	220
Receiving antenna gain	(dBi)	-8.1	-8.1	-8.1	-8.1	-8.1
Required field strength	(μV/m)	44.4	48.7	52.8	59.2	72.8
Minimum required field strength	(dBμV/m)	32.9	33.7	34.4	35.4	37.2

Table 4: Derivation of minimum field strength at 220 MHz in Gaussian Channel

Any difference between measured sensitivity and the above figures (corrected for frequency) is accounted for by either different antenna gain, some degree of self-interference within the receiver, or a different implementation margin.

2.8 Receiver sensitivity in a Rayleigh channel

In contrast to a Gaussian channel, most receivers are in practice used in a Rayleigh channel; that is, one where no direct signal is received, but multiple reflections (or, in an SFN, signals from multiple transmitters) effectively contribute to the total signal at the receiver.

Such a channel has a higher theoretical C/N requirement, and in practice, receivers are found to have a higher implementation margin. Again, a portable receiver antenna gain is used in this example.

UEP		1	2	3	4	5
Noise bandwidth	(MHz)	1.536	1.536	1.536	1.536	1.536
Thermal noise	(dBm)	-112.2	-112.2	-112.2	-112.2	-112.2
Required C/N	(dB)	7.2	7.7	8.4	10	13.7
Receiver noise figure	(dB)	7	7	7	7	7
Rayleigh implementation margin	(dB)	4.6	4.6	4.6	4.6	4.6
Minimum receiver signal level	(dBm)	-93.4	-92.9	-92.2	-90.6	-86.9
Frequency	(MHz)	220	220	220	220	220
Receiving antenna gain	(dBi)	-8.1	-8.1	-8.1	-8.1	-8.1
Required field strength	(μV/m)	86.5	91.7	99.4	119.5	182.9
Minimum required field strength	(dBμV/m)	38.7	39.2	39.9	41.5	45.2

Table 5: Derivation of minimum field strength at 220 MHz in Rayleigh Channel

The calculations in Tables 4 and 5 give the minimum equivalent field strengths required at the receiving antenna at each location for the systems described in Section 2.1. Further correction factors for location and time variation are required for planning purposes.

Within a Rayleigh channel; the differences between the C/N required for each UEP is constant. It is convenient, from now on in this document, to refer only to UEP3. Values for other UEP modes can be derived by adding the correction shown below:

UEP	Correction (dB)
1	-1.2
2	-0.7
3	0
4	1.6
5	5.3

Table 6: Correction values, relative to UEP3, for other UEP modes in a Rayleigh channel.

2.9 Location variation

Measurements have shown that within a sufficiently small area, field strengths are normally distributed around a median value. Thus, if coverage is required at more than 50% of locations within a prediction pixel, additional field strength is required. This increase, called the location correction, can be calculated as:

$$LC = \mu\sigma$$

where	*LC*	is the location correction to be applied (dB)
	μ	is the inverse normal distribution function for the percentage of locations required
	σ	is the total standard deviation relevant to that pixel (known as the location variability) (dB)

Values of μ commonly used in DAB planning are tabulated below.

Percentage of locations	**μ**
50	0
80	0.84
95	1.64
99	2.33

Table 7: Common values of the inverse normal distribution function

Therefore, to achieve 99% of locations in a pixel where the location variability is 5.5 dB, additional field strength of 2.33 x 5.5 = 12.8 dB is required.

When combining signal distributions, for example when considering location variation indoors, the total standard deviation of the resultant distribution is the root mean square sum of the individual standard deviations.

T-DAB predictions are done at a resolution of 100m (see Section 3), and measurements across the UK have shown that the average standard deviation of the distribution of signal strength outdoors in such an areas is 5.5 dB.

2.9.1 Mobile

For mobile (in-car) reception, a minimum of 99% locations covered is specified to give reliable interruption-free reception. As in-car reception is outdoors, the outdoors location variability of 5.5 dB applies.

The following table combines all the above to show the required minimum median field strength (MMFS) at 10 m above ground level to achieve reception in-car at 99% of locations within a pixel. For simplicity, the calculations are shown at UEP3 only. Field strengths required for other UEPs can be obtained by applying the correction factor shown in Table 6.

	UEP	3
Noise bandwidth	(MHz)	1.536
Thermal noise	(dBm)	-112.22
Required C/N	(dB)	8.4
Receiver noise figure	(dB)	7
Rayleigh implementation margin	(dB)	4.6
Minimum receiver signal level	(dBm)	-92.2
Frequency	(MHz)	220
Receiving antenna gain	(dBi)	-2.9
Required field strength	(mV/m)	54.6
Required field strength	(dBμV/m)	34.7
Height Gain	(dB)	10
Required percentage of locations	(%)	99
Inverse Normal function (from Table 7)		2.33
Outdoor Location Variation	(dB)	5.5
Additional field strength required	(dB)	22.8
Minimum Median Field Strength	(dBμV/m)	57.5

Table 8: Derivation of Minimum Median Field Strength for In-Car Reception

2.9.2 Indoor

For portable indoor reception, account needs to be taken of indoor signal variation, which is assumed to be a combination of the outdoor location variability and the variation associated with building penetration.

As seen in Section 2.5, two different values for building penetration loss (and its associated standard deviation) are used, depending on the clutter for the location. This results in two different location variability values for indoor coverage.

In addition, two different percentage locations are used for indoor coverage:

- 80% locations, representing a useful service; and
- 95% locations, representing a robust service.

There are, therefore, four different minimum median field strengths for indoor reception, depending on desired reception quality and on an assumption of building type.

UEP		3			
Reception environment		**Suburban**		**Dense Urban**	
Reception quality		**Useful**	**Robust**	**Useful**	**Robust**
Noise bandwidth	(MHz)	1.536	1.536	1.536	1.536
Thermal noise	(dBm)	-112.22	-112.22	-112.22	-112.22
Required C/N	(dB)	8.4	8.4	8.4	8.4
Receiver noise figure	(dB)	7	7	7	7
Rayleigh implementation margin	(dB)	4.6	4.6	4.6	4.6
Minimum receiver signal level	(dBm)	-92.2	-92.2	-92.2	-92.2
Frequency	(MHz)	220	220	220	220
Wavelength	(m)	1.36	1.36	1.36	1.36
Receiving antenna gain	(dBi)	-8.1	-8.1	-8.1	-8.1
Required field strength	(mV/m)	99.4	99.4	99.4	99.4
Required field strength	(dBµV/m)	39.9	39.9	39.9	39.9
Building Penetration Loss	(dB)	8	8	15	15
Height Gain	(dB)	10	10	10	10
Required percentage of locations	(%)	80	95	80	95
Inverse Normal function (from Table 7)		0.84	1.64	0.84	1.64
Outdoor Location Variation	(dB)	5.5	5.5	5.5	5.5
Building Penetration Loss SD	(dB)	4.4	4.4	5	5
Composite Location variation	(dB)	7.04	7.04	7.43	7.43
Additional field strength required	(dB)	23.9	29.6	31.3	37.2
Minimum Median Field Strength	(dBµV/m)	63.9	69.5	71.2	77.2

Table 9: Derivation of Minimum Median Field Strength for Indoor Reception

2.10 Percentage of time for protection from interference

It has been agreed that interference predictions should assume that wanted tranmissions are protected from interference for 99% of the time.

2.11 Protection ratios

2.11.1 Co-block protection ratios

For T-DAB to T-DAB interference, the protection ratio used is taken to be the same as the Rayleigh C/N value for the interfered mode.

For interference from DVB-T to T-DAB, the same applies, with a correction of -6 dB applied to the DVB-T interfering field strength to account for the wider bandwidth of the interfering system.

2.11.2 Adjacent block protection ratios

The UK DAB multiplex operators have previously agreed how adjacent-block interference should be assessed and, if necessary, remedied.

The planning project team needs to consider how best to incorporate these algorithms into its calculations of coverage, specifically whether they need to be extended to include non-adjacent frequency blocks.

3 Planning Algorithms

Over the course of nearly fifteen years, the organisations involved in T-DAB planning have been working together to create a new set of planning algorithms. Initially developed for Television planning, it has recently been adapted for T-DAB. Together, these are known as the UK Planning Model (UKPM). An outline of the model and its principal features can be found in a paper given to IBC in 2002.

The following description is largely taken from the television Joint Planning Project's Technical Parameters document, but has been edited where necessary to remove ambiguity that might affect understanding of T-DAB calculations.

3.1 Field strength calculations from individual transmitters in the UK

The UKPM is used to calculate the wanted and interfering field strength distributions to and from each UK transmitting site. These field strengths are calculated for all cases at the centre frequency of the DAB block in question. Although the frequency of operation was previously not thought to have a significant effect on predicted signal strengths, studies showed that the population counting method could be sensitive to very small changes in the predicted levels linked with a different frequency.

In summary, the main features of the UKPM are:

- the use of a terrain database with a resolution of 50 m (although predictions are currently made at a resolution of 100 m);

- the use of a real clutter database with a base resolution of 25 m in dense urban areas (although this is now converted to 50 m to expedite calculations) and 50 m elsewhere;

- the use of a common database of domestic and, where applicable, continental transmitting stations;

- where available, high resolution HRP information for UK T-DAB stations, extracted from *in situ* measurements made by the BBC using a helicopter-based measuring system;

- regular sampling of the terrain profile between transmitting and receiving locations at twice the prediction resolution;

- radial scanning and re-using of profiles already extracted, in order to increase computation speed.

3.2 Selection of interferers

One of the most critical decisions that has to be made when determining the service area of a station, is the identification of the interfering transmitters, as well as the total amount of interference caused by these interferers at each location of interest. The following section is a brief description of how these two tasks are performed in the UKPM.

For a given wanted station, frequency and ERP, we must:

- Determine the bounding box for the wanted station.

- Compile a list of all co-channel and adjacent channel stations.

- Generate bounding boxes for the interfering stations, modifying the ERP as appropriate. The ERP is modified to take into account protection ratio and cross-polar discrimination if appropriate. For T-DAB, where no use is made of polarisation or directional discrimination, no such modification is used.

- Eliminate all interfering stations whose bounding box does not intersect the bounding box of the wanted station.

For each location within the bounding box find the value of the highest interferer, including receive antenna HRP discrimination, if any. This value should not be lower than the noise level.

For each location within the bounding box carry out a Schwartz and Yeh summation of all interferers at that location, including receive antenna HRP discrimination (if applicable). If an interferer is more than 45 dB below the highest value identified, it is not included within the summation. Interferers should be sorted by the "Site ID" field in the station database, with UK stations first followed by Continental stations.

3.3 Signal combination

A method of assessing the combined effects of multiple interferers is needed for computing digital T-DAB coverage. The log-normal location variation of field strength must be taken into account. The combined effect of noise, co-channel and adjacent-channel incoming interference to T-DAB signals will be assessed using the following method.

The distribution of the power sum of a number of log-normally distributed signals can be approximated to a sufficient degree of accuracy by another log-normal distribution function. Various methods have been developed for estimating the mean and standard deviation of this log-normal distribution: the one developed by Schwartz and Yeh is used for field strength combination in this model.

The field strength combination routine will apply the appropriate receiving antenna pattern or polarisation corrections (if any) to each mean field strength. This produces an array of mean interfering field strengths. Small interfering field strengths may then be discarded by selecting those more than the specified filter range (as given in Section 3.2 above) below the wanted field strength. This is done both to speed up the field strength combination and to reduce the possibility of errors arising from the combination of a very large number of individual sources.

The log-normal method requires a value for the standard deviation of the location variation of each individual signal. The standard deviation of each individual signal is given in Section 2.9. A correlation coefficient of zero is assumed between all signals.

In calculating the interfering fields, 1% of time field strengths will be used to ensure protection for 99% of time. 50% of time fields are used in calculating the contributing fields. This effectively assumes that the fields from all the interfering transmitters are at their 1% of time values for the same 1% of time.

The effect of noise can also be taken into account using this method. The standard deviation of the noise is zero because it is assumed to be constant at all locations. The mean field strength used for the noise is the field strength that would produce the receiver thermal noise voltage. This is given in Tables 4 and 5. With these values, the effect of noise can be combined with the interfering field strengths using the Schwartz and Yeh method.

Different types of interference will be subject to different protection ratios. The mean field strengths need to be scaled before combination so that a single protection ratio can be used. An offset can be calculated between the minimum C/N and the appropriate protection ratio for the interfering transmitter. The offset should then be added to all the mean field strengths from that transmitter. This will scale all field strengths in the interference power sum to have a protection ratio equal to the minimum C/N.

3.4 Coverage criteria

Given values for the mean and standard deviation of the wanted and interfering field strengths in a coverage cell, it is possible to calculate the mean and standard deviation of their ratio. The probability of a receiver in the cell being served can then be determined.

The location variation in the ratio of wanted and unwanted power will be log-normally distributed. The mean and standard deviation of this distribution are given by:

$$m_{R_{dB}} = m_{C_{dB}} - m_{(N+I)_{dB}}$$

$$\sigma_{R_{dB}} = \sqrt{\sigma^2_{C_{dB}} + \sigma^2_{(N+I)_{dB}}}$$

where:

m_R	is the mean of the ratio (dB),
m_C	is the mean field strength from the wanted transmitter (dBμV/m),
$m_{(N+I)}$	is the mean effective field strength due to noise and interference (dBμV/m),
σ_R	is the standard deviation of the location variation in the ratio (dB),
σ_C	is the standard deviation of the location variation in the field strength from the wanted transmitter (dB),
$\sigma_{(N+I)}$	is the standard deviation of the location variation in the effective field strength due to noise and interference (dB).

The proportional coverage is the proportion of points in this distribution where the ratio is greater than required. This can be calculated using standard methods from the normal distribution for each cell.

3.5 Calculation of gross coverages

This section outlines the method for calculation of gross coverages for each multiplex from each transmitter. In an SFN, of course, the idea of gross coverage for an individual transmitter is probably not meaningful, except in the case of a single-transmitter network.

Gross population coverage assessments are currently based on the predicted wanted and interfering field strength level in each 100 m square.

For mobile in-car coverage, gross coverage sums the total length of all motorways, trunk roads and A-roads in pixels where at least 99% of locations are predicted to be served.

For indoor coverage, gross coverage counts all households within pixels where at least 95% of the locations are predicted to be served, plus the proportion of households in pixels where between 80% and 95% of locations are predicted to be served.

When counting the number of households served by a transmitter, it is very important that a sufficiently large area is selected over which to perform the calculation. Otherwise, not all of the coverage area will be included and some of the households will not be counted. In practice, the coverage of a transmitter is calculated over an area defined in a way similar to those areas defined as the bounding boxes of interferers. The method for this is given in Section 3.2.1, assuming an unmodified ERP and that the wanted system is T-DAB.

With access to the common transmitter, terrain, clutter and population databases, it is not impossible for all of the UK planning organisations to produce identical coverage predictions using the UKPM. Any minor differences that might arise are likely to be due to the individual implementations and computing platforms chosen by the organisation.

3.6 Single frequency networks

Although all the above applies to the general case of transmitters operating individually or in a multi-frequency network (MFN) environment, most UK T-DAB transmitters operate as part of single-frequency networks (SFNs). In such cases, the following algorithms are used to calculate coverage.

3.6.1 Receiving aerial pointing

No T-DAB calculations use any receiving antenna polarisation or directional discrimination.

3.6.2 Receiver synchronisation strategy

In considering the receiver synchronisation strategy it is assumed that the FFT and equalisation windows are aligned. The receiver is assumed to lock (align the start of the FFT window) to the first signal above the receiver noise threshold (thermal noise + receiver noise figure).

3.6.3 Out of guard interval performance

We assume the characteristics of T-DAB receivers are as described in the EBU Technical Review of July 2003.

$$w_i = \begin{cases} 0 & if \quad t < T_u \\ \left(\frac{\left(T_u + G_{eff}\Delta\right) - t}{T_u} \right)^2 & if \quad T_u < t < 0 \\ 1 & if \quad 0 \le t \le \Delta \\ \left(\frac{\left(T_u + G_{eff}\Delta\right) - t}{T_u} \right)^2 & if \quad \Delta < t \le T_u \\ 0 & if \quad T_u < t \end{cases}$$

$$C = \sum_i w_i C_i$$

$$I = \sum_i \left(1 - W_i\right) C_i$$

where:

C_i	=the power contribution from the i-th signal at the receiver input
C	= the total power of the effective useful signal
I	= the total effective interfering power
w_i	= the weighting coefficient for the i-th component
T_u	= the useful symbol length
Δ	= the guard interval length
t	= the signal arrival time
T_{Pstop}	= the interval after the guard during which signals usefully contribute

Guard interval and symbol period are specified by the T-DAB system mode (see Table 1).

3.6.4 Power sum

Stations' wanted components are power summed using the Schwarz and Yeh methodology, as are – separately - all interfering components. Following the summation, coverage of an SFN is calculated on the basis of the ratio of the summed wanted and interfering signal levels and their associated standard deviations.