Indoor reception of DAB — consequences for planning and implementation

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NTL has conducted extensive DAB field-strength measurements in Band III inside large buildings in central London. The conclusions from this campaign are that a field strength of 71 dbμV/m is required in order to provide good indoor DAB reception to handheld devices.

NTL Broadcast provides transmission facilities for over 40 DAB multiplexes in the UK, and plans the network coverage in conjunction with the customers who own the broadcast licences. These broadcast licensees are now becoming interested in data services and the delivery of these services to handheld devices indoors. The licensees have to draw up business models based on the quality of service delivered to these devices versus the cost of the network. It is this drive for accurate business modelling which has focused NTL on the work described in this article.

To plan a broadcast network, a software field-strength prediction tool is used. This allows the number of transmitters, ERPs, antenna heights, site locations and antenna patterns to be modified until a compromise is reached on the required coverage versus cost. These statistically-based prediction tools give a good approximation over typically 100m square areas (pixels) but are not designed to do micro (sub 10 m square) planning.

To work out whether the field strength delivered into a pixel (as predicted by the planning tool) is deemed a service, the following issues need to be fully understood:

- the modulation scheme;
- codec or carousel performance;
- receiver performance including antenna gain;
- the RF channel characteristic;
- man-made noise;
- building penetration loss;
- mean value and the field-strength location variation over the pixel area being used by the tool and the interaction of the location variation in the buildings;
- time variation.

The modulation scheme

Eureka-147 DAB in mode 1 [1] comprises the following key elements of the coding and modulation scheme, shown in *Fig. 1* for an MPEG-1 layer II audio service.

1. There are 4 modes defined in the Eureka-147 specification (ETS 300 401). Mode 1 is considered in this article as it is used for large-scale SFNs in Band III which are the only types of network which have been implemented in the UK.

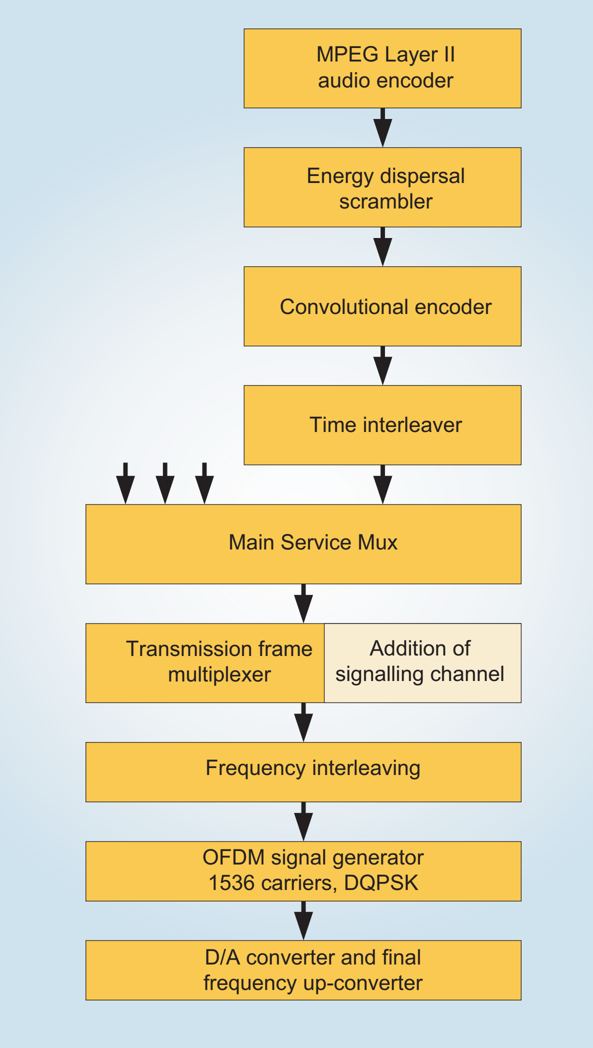

Figure 1
Eureka-147 modulation scheme

The performance of this modulation scheme in various channels is described in ETSI 101 758: *Digital Audio Broadcasting (DAB); Signal strengths and receiver parameters; Targets for typical operation*. For an MPEG-1 Layer II codec, the C/N for non-audio impairment is 14 dB for the majority of locations in urban and rural environments and at speeds below 130 km/h.

Codec or carousel performance

Broadcast content can be delivered in two key ways:

- **Streaming**;
- **Store and forward**, where the content is a file and is sent via a carousel, and is stored on the receiver in memory from which the content can then be accessed at the consumer's convenience. This is shown in *Fig. 2*.

As the store-and-forward system has the advantage of repetition – so giving better error protection but with a higher latency depending on the rotation rate of the carousel – the streamed service is more difficult to deliver.

Low bit-rate codecs need BERs better than 10^{-6} and, for a reliable store-and-forward service, results so far show that a BER of 10^{-5} is what is required to keep carousel rotations to no more than three.

But the way in which these services are received also needs to be considered.

Streamed services such as video will be watched where the device is held away from the body and the device/antenna will be positioned such that the service works.

A store-and-forward service is delivered in the background. This could be when the device is in a pocket with the antenna "scrunched up": body loss will be higher than in the streamed case.

Streaming requires a better BER but, due to the way it is consumed, the antenna performance is better. The difference in BER equates to a 2.5 dB C/N change. It is more difficult to quantify the antenna performance change but some simple measurements show a loss of around 3 dB with the receiver in the pocket.

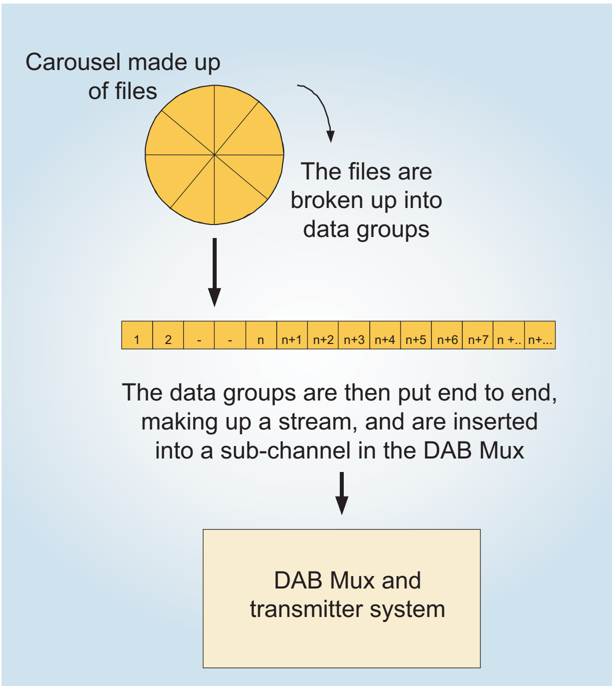

Figure 2
Carousel system

Building penetration loss

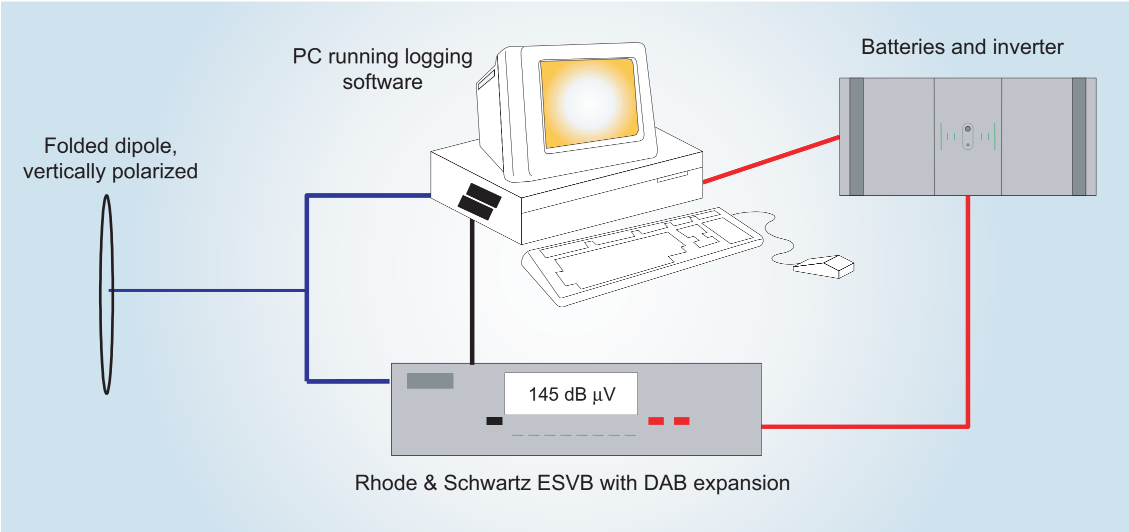

Figure 3
The logging hardware used for indoor measurements

To quantify the building penetration loss, the test equipment shown in *Fig. 3* was put on a trolley and moved around the key walkways in several London offices. The measurements were repeated outside the building at ground level to give a mean field strength for outside.

Fig. 4 shows the locations around London where the building penetration measurements were done. The buildings were chosen to give a range of construction types and general clutter around the buildings.

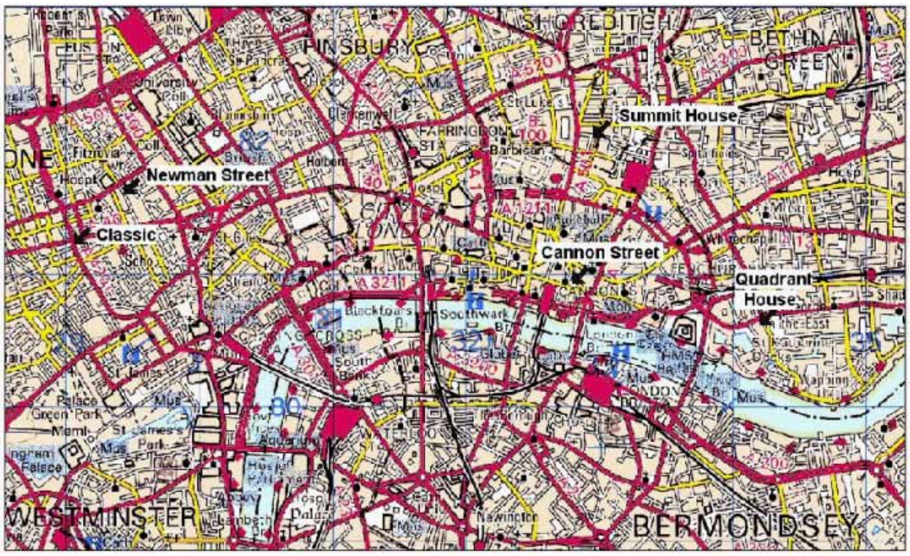

Figure 4
Location of the buildings in central London

Abbreviations

BER	Bit-Error Ratio
C/N	Carrier-to-Noise ratio
DAB	Digital Audio Broadcasting (Eureka-147)
ERP	Effective Radiated Power
ETSI	European Telecommunication Standards Institute
FS	Field Strength
OFDM	Orthogonal Frequency Division Multiplex
RF	Radio-Frequency
SFN	Single-Frequency Network
UEP	Unequal Error Protection

Location 1 – Classic FM House

Band III measurements – Classic FM Building

Location	Average signal strength (dBμV/m)	Standard deviation (dBμV/m)	Max. deviation (dBμV/m)	Min. deviation (dBμV/m)	Building penetration (dBμV/m)	Notes
Roof	78 to 82					
Floor 6	56.64	3.45	10.53	-6.73	-8.99	
Floor 5	54.76	4.8	13.71	-11.04	-10.87	
Floor 4	52.95	4.55	10.88	-9.08	-12.68	
Floor 3	61	4.45	11.12	-10.16	-4.63	Empty Floor
Floor 2	54.21	4.75	10.3	-10.09	-11.42	
Floor 1	49.61	4.39	11.18	-9.12	-16.02	
Floor 0	52.04	4.44	9.35	-12.52	-13.59	
Basement	36.29	2.57	7.93	-3.54	-29.34	
Outside	65.63	4.92	10.01	-12.06	0	
Floors 0 to 6	54.77	5.52	17.32	-15.25	-14.805	Building penetration: floors 1 & 2 only

Location 2 – Quadrant House

Band III measurements – Quadrant House

Location	Average signal strength (dBµV/m)	Standard deviation (dBµV/m)	Max. deviation (dBµV/m)	Min. deviation (dBµV/m)	Building penetration (dBµV/m)	Notes
Floor 8	67.4	6.58	18.67	-19.62	2.95	
Floor 7	59.81	7.98	5.71	-14.73	-4.64	
Floor 6	57.08	5.81	14.39	-24.17	-7.37	
Floor 5	No access allowed					
Floor 4	54.4	4.58	10.58	-13.97	-10.05	
Floor 3	54.83	4.12	8.56	-11.07	-9.62	Empty Floor
Floor 2	53.61	4.65	12.31	-15.82	-10.84	Empty Floor
Floor 1 (Entrance)	48.16	5.1	10.91	-14.13	-16.29	No south windows
Outside at ground level	64.45	4.68	10.35	-13.03	0	
Floors 0 to 8	56.47	5.12	11.59	-16.22	-13.57	Building penetration loss: average of floors 1 & 2

Location 3 – Summit House

Band III measurements – Summit House

Location	Average signal strength (dBµV/m)	Standard deviation (dBµV/m)	Max. deviation (dBµV/m)	Min. deviation (dBµV/m)	Building penetration (dBµV/m)	Notes
Roof	57 to 63				10.35	
Floor 4	No access allowed (rented out)					
Floor 3	47.47	2.04	5.67	-6.97	-5.18	
Floor 2	42.36	2.72	5.78	-7.6	-10.29	
Floor 1	40.59	3.58	6.8	-7.27	-12.06	
Floor 0	44.91	2.68	5.07	-6.08	-7.74	
Basement	35.16	1.04	2.72	-2	-17.49	
Outside ground floor	52.65	1.72	4.92	-5.82	0	
	43.83	2.76	5.83	-6.98	-11.18	Building penetration loss: average of floors 1 & 2

Location 4 – Newman Street

Band III measurements – Newman Street

Location	Average signal strength (dBµV/m)	Standard deviation (dBµV/m)	Max. deviation (dBµV/m)	Min. deviation (dBµV/m)	Building penetration (dBµV/m)	Notes
Roof	71.93	1.74	3.29	-5.23	13.8	
Floor 5	55.34	3.4	8.86	-8.92	-2.79	
Floor 4	51.45	4.42	8.28	-7.82	-6.68	
Floor 3	46.89	3.72	12.44	-9.76	-11.24	
Floor 2	No access allowed					
Floor 1	No access allowed					
Floor 0	39.01	3.19	6.01	-4.62	-19.12	Not a typical ground floor
Basement	41.24	3.59	6.92	-7.62	-16.89	
Outside ground floor	58.13	2.62	6.1	-6.95	0	
	52.924	3.294	7.776	-7.27	-8.96	

Location 5 – Cannon St

NB: This building had metallized windows on all floors except maybe the ground floor

Band III measurements – Cannon Street

Location	Average signal strength (dBμV/m)	Standard deviation (dBμV/m)	Max. deviation (dBμV/m)	Min. deviation (dBμV/m)	Building penetration (dBμV/m)	Notes
Roof	73-78					Line of sight
Floor 12						Line of sight
Floor 11						Open
Floor 10						Open
Floor 9						Open
Floor 8						Obstructed
Floor 7	42.38	3.54	10.7	-7.33	-10.06	Obstructed
Floor 6	40.67	3.25	11.42	-7.33	-11.77	Obstructed
Floor 5	38.51	4.74	13.27	-7.49	-13.93	Obstructed
Floor 4	36.26	3.23	10.9	-5.5	-16.18	Obstructed
Floor 3	33.7	2.58	7.7	-4.08	-18.74	Obstructed
Floor 2	32.65	2.4	7.84	-4.4	-19.79	Obstructed
Floor 1	No access allowed					Obstructed
Floor 0	39.39	5.41	13.83	-9.11	-13.05	Obstructed
Basement	32.56	2.13	7.46	-4.67	-19.88	Obstructed
Outside	52.44	3.6	9.78	-8.15	0	Obstructed
Floors 0 to 7	37.45	4.99	15.77	-9.20	-16.42	

Summary of results

	SD (dB)	BP (dB)
Cannon Street	4.99	-16.42
Newman St	3.29	-8.96
Summit House	2.76	-11.18
Quadrant House	5.12	-13.57
Classic FM House	5.52	-15.25

Conclusions

DAB indoor reception (on band III) has been measured inside a number of large buildings in central London. The worse reception areas were, in every case, on the ground and first floors. Moving up through these buildings, the field strengths invariably increased, both inside and outside the building. To achieve good DAB coverage on the majority of floors (>95% of locations), a building penetration loss value of 15 dB is adopted in this article.

A typical standard deviation for indoors – and this depends on the amount of "clutter" in the office – is 5.0 dB and it is reasonable to plan for 95% of locations indoors. NTL is planning the national multiplexes on the basis of 500 m by 500 m pixels and, in the case of outdoor reception, is using a standard deviation of 5.5 dB and a location coverage of 99%.

Using the combined indoor and outdoor standard deviations, a value of 12 dB location variation for 95% of indoor locations is derived.

	Outdoors	Indoors	Combined
% of locations	99.00%	95.00%	95.00%
SD (dB)	5.5	5.0	7.1
Location variation (dB)	12.8	8.2	12.2

The table on the next page shows how the results of the measurements combine into a link budget for streaming and "store and forward", for both indoor and outdoor environments. In these results, UEP level 3 has been assumed; by using different UEPs of an outer code, the field strength requirement could be reduced.

Simon Mason read Electronic Engineering at the University of Bradford (where the course was sponsored by Plessey Telecommunications). In 1984 he joined the BBC as an engineer in network radio and gained invaluable experience whilst working at BBC Transmission (now CCI) to roll out Radio One across the UK on FM. In 1991, at BBC Research Department, he worked on the Eureka-147 DAB specification and, later, the first high-power trial of a DAB network in London. He went on to project-lead the rollout of the BBC's national DAB network.

Mr Mason joined NTL Broadcast in 1997 to lead its digital radio development team and has since become the Head of New Product Development, where he spearheads a dynamic team within NTL's media solutions group.

	Handheld data device streamed		Handheld device store and forward		Notes
	Outdoor	Indoor	Outdoor	Indoor	
Modulation	T-DAB	T-DAB	T-DAB	T-DAB	
Code rate	UEP 3 (~0.5)	UEP 3 (~0.5)	UEP 3 (~0.5)	UEP 3 (~0.5)	
Guard interval	1/4 (246μs)	1/4 (246μs)	1/4 (246μs)	1/4 (246μs)	
Receiver noise figure (dB)	6	6	6	6	ETSI TR 101 758 V2.1.1
C/N (dB)	16.5	16.5	14	14	ETSI TR 101 758 V2.1.1 with 2.5 dB for higher BER for streamed service
Bit rate (Mbit/s)	1.15	1.15	1.15	1.15	
Feeder loss (dB)	0	0	0	0	
Allowance for man-made noise	1	1	1	1	ETSI TR 101 758 V2.1.1
Antenna Gain (dBd)	-10	-10	-13	-13	ETSI TR 101 758 V2.1.1 uses -6, increased to -4 for stream with small handheld device and -7 for store and for-ward due to crunched antenna in pocket
Min FS (dBμV/m)	43.5	43.5	44	44	
% locations	99	95	99	95	
Rx height (m)	1.5	1.5	1.5	1.5	
Building penetra-tion loss (dB)	-	15	-	15	
Location Corr. (dB)	13	12	13	12	
Minimum median FS at 1.5m (dBμV/m)	56.5	70.5	57	71	

The conclusion drawn from this work is that, in order to make Eureka-147 DAB work on a handheld device indoors, a planning field strength of 71 dBμV/m is required.