

T-DAB in the UK

— overcoming the spectrum planning and interference issues

Mark Thomas

Director of Engineering, UK Radio Authority

The roll-out of T-DAB in the UK is proceeding rapidly, with a large proportion of the population now within range of a wide choice of digital radio programme services. The main drivers for reaching this stage have been a mixture of industry resolve, consensus, long-term vision and investment – catalysed by well-constructed incentives.

This article looks at the background to the UK's frequency plan, then looks more closely at two areas of work undertaken by the UK Radio Authority to control interference between the transmissions of different multiplex operators.

Another Christmas for DAB?

What will St. Nicholas bring us this year? There is another set of DAB radios in the shops, but for the average consumer, there are still not that many and they are not that cheap. However this situation is starting to change more noticeably. The number of DAB receivers sold is not sending shock waves through the industry (although falling share values are) but, as the prices steadily if slowly fall, we can expect a steady if slow increase in penetration. The last week in November has seen a press release which promises a variety of “radio-inclusive” products from the British firm, Goodmans, starting at £100 (about 160 euros). Goodmans is a mass-market rather than a niche-market manufacturer. These receivers will be available in the latter part of 2002 and it is unlikely that Goodmans’ competitors will let them have it all their own way.

So what will our lucky consumers be able to hear? Already over 45% of the GB population is covered by four DAB multiplexes:

- * one BBC national multiplex, which reaches about 65% of the population;
- * one commercial national multiplex, called *Digital One*, which reaches around 80% of the population;
- * two local/regional multiplexes, carrying both BBC and commercial T-DAB services.

Each multiplex typically carries eight or more programme services. The BBC and the commercial national services are committed to further expansion, and so too is the local/regional sector. Over the next year or two, the population coverage of the four multiplexes will reach some 63%, while 80% of the population will potentially



A stand-alone DAB radio from VideoLogic.

be able to receive at least three of the multiplexes (two national and one local).

Fig. 1 shows the current and projected coverage of local DAB services in the UK. Depending on the circumstances, it is usual for between 70 and 95% of the potential local-population coverage to be achieved by the initial networks that are built to start the services.

Regulatory issues

In the UK, as in some other countries, the regulatory framework consists of more than one body. The BBC is, up to a point, its own regulator and the Radio Authority regulates all other sound broadcasting services. The BBC and the non-BBC sectors certainly compete for the listener's ear – to his/her undoubted benefit. But the listener doesn't really care about such distinctions. Especially in matters of technical effectiveness and transparency of access to different services, listeners simply want the radio to work, and to deliver a wide range of diverse and high-quality services from which to choose.

All of this requires significant co-operation among the several players, which include two government departments. The extent and effectiveness of this co-operative approach has been a crucial factor in getting DAB onto the UK airwaves.

In particular, the Radio Authority has introduced two “new” concepts for the regulatory management of *digital frequency planning* and *interference control*. These two concepts have developed – one directly, the other indirectly – from the fact that T-DAB networks are based on the SFN approach, whereby different transmitters carrying the same multiplex may use the same frequency and, instead of interfering with each other, they mutually improve reception at the receiver (unless the transmitters are a long way apart).

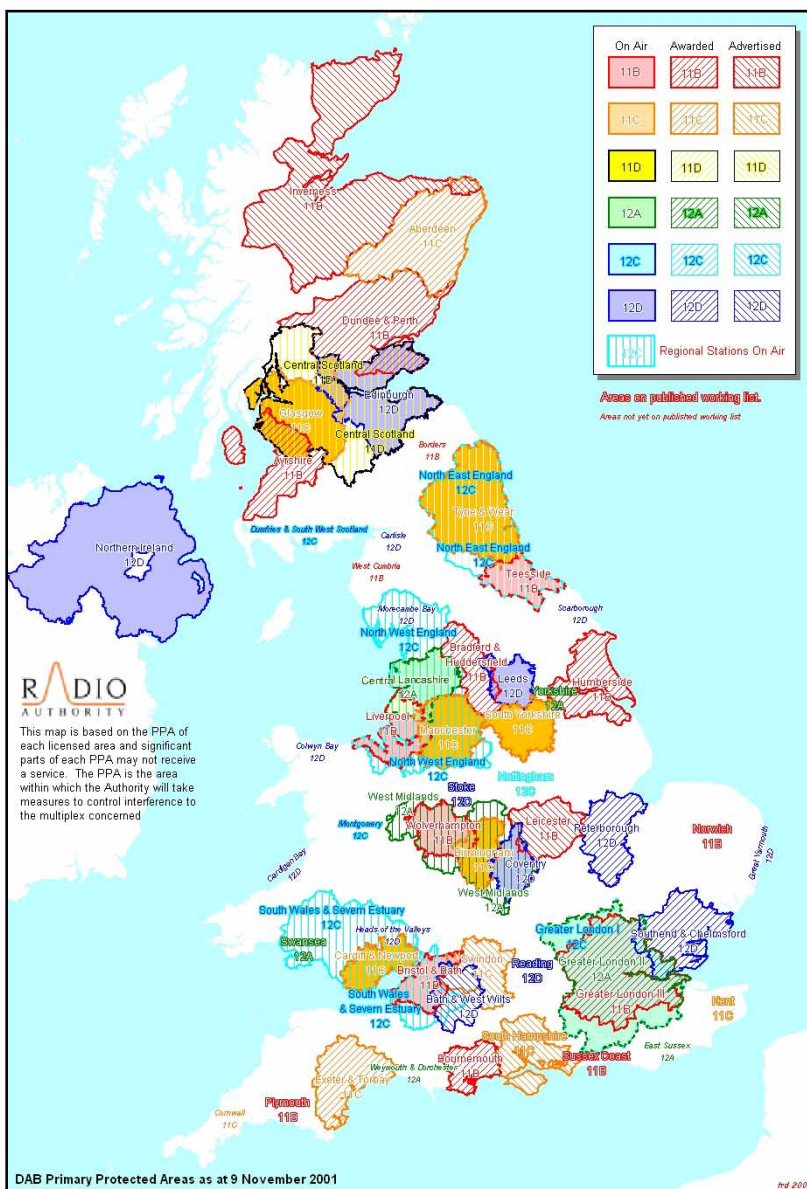


Figure 1
Local digital radio areas in the UK.

Abbreviations

AM	Amplitude Modulation	ITU-R	ITU - Radiocommunication Sector
BER	Bit Error Rate	FM	Frequency Modulation
CEPT	European Conference of Postal and Telecommunications Administrations	PPA	Primary Protected Area
DAB	Digital Audio Broadcasting (Eureka-147)	SFN	Single-Frequency Network
ITU	International Telecommunication Union	T-DAB	Terrestrial - Digital Audio Broadcasting

Strategic planning

The Radio Authority's primary interest in T-DAB is as a replacement technology for the great majority of analogue radio services. People listen to radio services, not delivery platforms, so it seems a good starting point to decide that the most popular radio services and the best delivery platforms should be natural partners.

Therefore, when the Authority started its strategic planning for T-DAB in the early part of the last decade, it decided to assume that its deployment of frequencies would need to support the market structures which the public has come to expect. The Authority initiated a discussion with its major licensees and the BBC, which led to a consensus that the initial allocation of spectrum for T-DAB in the UK should at least be capable of supporting a system based on the established structures of national and local radio, with the ability to increase the number of programme services. Indeed, this approach has the big attraction for the Authority of expanding listener choice on a major scale. Although the choice of FM and AM services has been widened very significantly in the 11 years since the Authority was established, frequency constraints have held this back to below the level which the growing advertising revenues (usually) would be able to sustain.

Table 1 shows, as an example, the pattern of analogue services in Greater Manchester, one of the UK's better-served cities. This structure is taken as a basis for the digital model, which offers simulcasts of the analogue services as well as additional new services. This is achieved by providing a regional multiplex, in this case for North West England, as well as a local multiplex for Manchester.

Table 1
Analogue listening choice in Greater Manchester (*simplified*)

National BBC	National Commercial	Local
BBC Radio 5 Live	Classic FM	Piccadilly (103 MHz)
BBC Radio 4	Virgin Radio	Kiss 102 MHz
BBC Radio 3	talkSport	BBC GMR
BBC Radio 2		Piccadilly Gold (1152 kHz)
BBC Radio 1		Century Radio (105.4 MHz): regional coverage
		Jazz FM (100.4 MHz): regional coverage
		Big AM (1458 kHz)
		Plus small-scale stations, depending on location

The split of radio listening in the UK is approximately 50-50% between the BBC and the commercially-funded services, and also 50-50% between the national and the local services. National BBC and local commercial stations make up the majority of listening, but local BBC and national commercial stations are also very significant, to the point of being indispensable in the digital ecology. In fact, both these categories of service enjoy the provision of rights of "reserved capacity" on (respectively) the national and local commercial multiplexes. This introduces local multiplexes with a mix of BBC and non-BBC services. For both types of multiplex, the promise of the extent (and timing) of coverage is one of the factors taken into account in choosing between competing applicants for multiplex licences.

In 1994, the government responded to the case for T-DAB frequencies, in the face of competing claims for spectrum, by allocating seven frequency blocks to it – subsidiary, of course, to the limitations due to international constraints. Tables 2a and 2b shows how these frequencies are used in Great Britain to support the local areas shown in Fig. 1.

Since this decision was taken, quite a number of new local services of smaller scale have developed on FM. These newer services have a typical coverage diameter of about 15 - 22 km, compared with 34 - 60 km (and sometimes more) in the case of the longer-established local (and regional) services, which themselves have

Table 2a
Attribution of frequencies to T-DAB in England and Wales.

Frequency block	11B	11C	11D	12A	12B	12C	12D
Attribution	Local (RAu)	Local (RAu)	National (RAu)	Local (RAu)	National (BBC)	Local (RAu)	Local (RAu)

Table 2b
Attribution of frequencies to T-DAB in Scotland.

Frequency block	11B	11C	11D	12A	12B	12C	12D
Attribution	Local (RAu)	Local (RAu)	Local (RAu)	National (RAu)	National (BBC)	Local (RAu)	Local (RAu)

Notes:

- 1) RAu = Radio Authority, which licenses these services. Most local RAu multiplexes include reserved capacity (128 kbit/s net) for the BBC.
- 2) The frequency blocks cover the range 217.5 to 230 MHz, and are standard within the framework of the 1995 CEPT Wiesbaden Special Arrangement.
- 3) In Northern Ireland, the proximity of the Irish Republic, with its own T-DAB allotments in Channel 12 and analogue TV in Channel 11, effectively limits the available blocks to 12B for the BBC multiplex, and 12D for a single Radio Authority multiplex licence.

grown in number. This new small-scale sector cannot be ignored but, given the relatively small (though important) role these services play in the radio landscape, it would not have been effective or even feasible to address the possibility of providing digital carriage for them. Apart from anything else, their coverage areas are smaller than those of other stations which overlap their coverage. To base digital coverage areas on these small-scale stations would have presented much greater economic hurdles to the radio sector as a whole.

However, the UK's plans for the 1.5 GHz range (L-Band) in the latter part of this decade do allow for the possibility that smaller-area multiplexes may be licensed.



A stand-alone DAB radio from Roberts.

The original, idealised, concept for using the seven frequencies was that four of them would support universal coverage of a single “layer” of local services. Two other frequencies would support the two national multiplexes, and the seventh frequency would allow for a fourth multiplex in the larger conurbations. It would not have been realistic to secure a larger allocation at that time. However, although the SFN approach liberates the frequency planner, regulator and broadcaster alike, economic reality limits the density of transmitter networks that can be deployed. Compromises in the network design are also needed because of adjacent-channel considerations (see later in this article). It was clear that there would not be enough frequencies to complete the local coverage.

The Authority consulted with the commercial radio industry and resolved that it would be better – although keeping to the underlying concept of the digital coverage map – to deploy frequencies into the areas of highest population density. The concept was retained of bringing a fourth multiplex to listeners in the larger conurbations, typically on a “regional” scale overlaid on contiguous adjacent local areas. This, with a relatively minor penalty in terms of the overall availability of local coverage in the UK, would allow for digital radio to offer a more

radical increase in programme services for those consumers who can receive local digital services.

Real plans

Let us now “fast-forward” to 1997. The European frequency planning meetings of Wiesbaden and Bonn had been concluded. Every country had two frequency blocks for each part of its territory. As well as the two “Wiesbaden” blocks which the UK had planned to use for national coverages, there was a good prospect that the Bonn agreement for modifications to the Wiesbaden Plan would allow the other five frequencies to be deployed, as envisaged, for local services over a large proportion of the country.

The Authority had made a plan – the *Local Frequency Plan* – for using these five frequencies. This plan was modified over time to reflect the more detailed planning work that took place, and the implications of the ongoing international frequency co-ordination process. This process is directed at protecting existing services such as analogue TV from interference, and at achieving an equitable distribution of residual frequency resources between neighbouring countries, post-Wiesbaden-95.

Allotment planning

The Wiesbaden Plan is based on the concept of *allotments*. The SFN technique allows for great flexibility in planning transmitter networks as a whole, rather than as a series of transmitters (assignments), each of which has its own frequency. It is therefore more effective to define overall rights of implementation, and protection from interference for the service as a whole, rather than by reference to the detailed characteristics of individual transmitters (which is known as *assignment* planning, as is used for analogue radio and TV and, so far, for most digital TV planning).

This is where we introduce the first of our areas of *regulatory pre-planning*. The five frequencies used for local and regional services need to be re-used around the country. A resource is being distributed between different operators, therefore the regulator needs to ensure effective management between them.

Co-channel interference management

The concept of allotment planning at the international level is used as a basis, albeit in a very different detailed form, for the Radio Authority’s control of interference between different areas which use the same frequency within the UK. The Local Frequency Plan, having been established, has to be managed in practice. Just as the Wiesbaden Agreement (as revised at Bonn in 1996) contains a procedure for converting allotments into actual transmitter assignments, so at the national level, different multiplex transmission operators need to be regulated in how they give effect in detail to the general rights and obligations of frequency use.

Within a given country, it is practical for a regulator such as the Radio Authority to use terrain-based database and propagation tools, instead of the generalised techniques used in the international context (based on the former ITU-R Recommendation 370). This is partly because a single planning tool can be used, and partly because the use of terrain shielding of signals, and knowledge of that possibility, was an integral and enabling factor in drawing up the UK’s local plan in the first place.

The allotment concept is embodied in our national planning in what we call a *Primary Protected Area* or PPA. This is an area within which the Authority, in its regulation of other multiplex operators, will seek to protect a given service from interference. *Fig. 1* shows the actual PPAs, where they have been defined.

It is impractical to base co-channel protection management on detailed predictions of interference-limited coverage from specific networks. This is because transmitter networks for different areas will develop at different times and they will be developed in progressive stages – as increased digital receiver penetration makes it more worthwhile to build more transmitters. Therefore the first element of planning to protect from co-channel interference is to define a generalised maximum level of interference at any point within the PPA. (With a Wiesbaden allotment, this consideration can be applied at test points on its boundary but in the domestic context, using terrain-based propagation algorithms, signal strengths do not decay monotonically with distance).

So, this generalised limit could be based on protecting the minimum threshold field strength of what constitutes a “service” within the PPA. (This principle is also applied to the allowable limits in managing the Wiesbaden Plan). The appropriate level of minimum wanted signal strength is debatable, and depends on service objectives and the assumptions used. The Authority considers the threshold to be a field strength of 47 dB($\mu\text{V}/\text{m}$) at a height of 1.5 metres above ground ¹. The Authority’s derived value for co-channel protection is that the difference between the median values of the wanted and interfering signals – in an area of planning of 100 metre squares – should be at or greater than 25 dB ² (see the later section, “Testing a Theory”).

This would imply that the maximum allowable interfering field strength into a co-channel PPA would be 47 – 25 = 22 dB($\mu\text{V}/\text{m}$). This approach is rational in the valid, but theoretical, world of textbooks where terrain is gently undulating and radios are miraculously everywhere all at once. Luckily, Europe is more interesting than that, as a glance from the window of EBU headquarters in Geneva will quickly confirm.

When planning with terrain-based techniques, even in less dramatic scenery, as you conceptually turn up the power of a distant interfering transmitter, you will reach the point where this “threshold-based” interference limit will be reached within the area you want to protect, but this will typically only apply on top of a hill. The vast majority of the area will still be receiving a (much) lower level of interference than this threshold-based maximum, and, over much of the area, typically on higher ground, the signal from the wanted network will be higher than the minimum, so more interference can be accepted. So there is scope to admit more interference into the area. That in turn reduces the constraints on the design and expense of transmitter networks, and so makes the local frequency plan realistic.

T-DAB

We looked at a few sample scenarios of how coverage would be maintained across a local SFN in the presence of interference from a distant transmitter (as a proxy for a network, since interference will tend to be dominated by one or two transmitters lying in similar directions). We judged that the margin of additional interference we could apply would be 10 dB. Use of this “wide area signal correlation” margin appeared adequate to maintain coverage. Some isolated areas of coverage beyond the main zone of contiguous coverage tends to be lost in applying this margin, but this should generally be acceptable.

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Fig. 2 is a sequence of three plots, showing a situation which would arise with a certain choice of transmission parameters. *Fig. 2a* shows a wanted coverage (“noise-limited”) in the absence of interference, and *Fig. 2b* shows interference coming into the area from the west. The blue area on this second map shows levels which are above the 22 dB($\mu\text{V}/\text{m}$) threshold, but within the 10 dB margin which would allow signals up to 32 dB($\mu\text{V}/\text{m}$) into the area. The yellow areas are where interference would exceed the threshold inclusive of the 10 dB margin (i.e. above 32 dB($\mu\text{V}/\text{m}$)).

It can be seen in *Fig. 2c* that the areas of coverage which are lost due to interference coincide with areas of interference above 32 dB($\mu\text{V}/\text{m}$) – note how they coincide with the areas where coverage by the wanted transmitter is only just above the threshold.

However, this 10dB margin needs to be used with care. It is not applicable to areas of flat terrain. It can be noted from *Fig. 2* that some areas to the west of the map suffer losses due to interference, with interfering levels just below the 32 dB($\mu\text{V}/\text{m}$) mark.

In practice, the effect of very high terrain (which typically is sparsely inhabited) is that some parts of a PPA need to be defined (in licence specifications) as being susceptible to higher levels than the general value. The most convenient way to express this advice is to define a reference transmitter in both the wanted PPA and the other co-channel PPAs, as a way to define maximum allowable levels of outgoing and incoming interference

1. Required field strength = (receiver threshold strength) + (50-to-99% location correction factor = 2.33 * standard deviation within prediction “pixel”(= 4.3dB))
47 dB($\mu\text{V}/\text{m}$) = 37 dB($\mu\text{V}/\text{m}$) + 10 dB.
2. Protection margin = protection ratio + $\sqrt{2}$ (50-to-99% location correction factor for both wanted and unwanted signals), where standard deviation of the signals, σ , is the same for wanted and unwanted signals (taken as 4.3 dB), and correlation between the two is taken as zero.
24 dB = 10 dB + 2.33*4.3* $\sqrt{2}$

respectively. Some subjective judgement by the regulator is needed to compare real transmitter plans with the reference transmitter, but so far this has proved quite easy to agree with the multiplex transmission operator.

Testing a theory

The other aspect of research we conducted before embarking on a programme of licensing the local multiplexes, was to examine how the theoretical planning margin between the median wanted and interfering signals (then 24 dB, as mathematically derived in *Footnote 2*, on page 5) correlated with a real-life simulation of performance in an interference-limited environment.

The Authority set up a joint research project with the BBC, and the private companies, GEC-Marconi Research (now part of BAe Systems) and NTL; the whole project received 50% funding from the UK's Department of Trade and Industry, and consultation was also made with the UK Radiocommunications Agency, and trade bodies.

In essence, the investigation involved setting up a small SFN in the area of Chelmsford, some 50 km north-east of Central London, and performing trials variously with one or more transmitters switched on. Co-channel interference was provided by a test transmitter operating in the London area. Measurements were taken within several 250 metre squares; this equated fairly closely to the anticipated granularity of planning tools. In fact, the areas analysed were slightly larger than those used in the planning tools, to enable larger statistical samples to be generated in the field work.

Levels of interference were quite high: and this provided the limiting factor for reception, rather than just the strength of the wanted signal.

NTL model coverage prediction: DAB Coverage from Croydon



Fig. 2a: Coverage without co-channel interference

NTL model coverage prediction: DAB Interference from Swindon

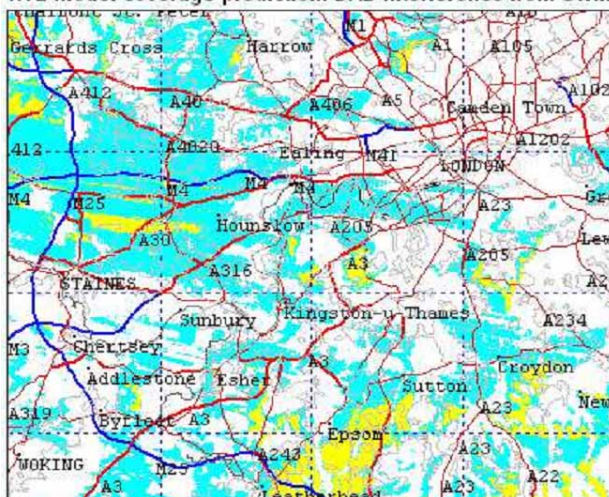


Fig. 2b: Incoming interference
(yellow areas = interference levels above standard, including margin)

NTL model carrier to interference composite: Croydon DAB minus interference



Fig. 2c: Coverage limited by interference

Figure 2
The effect of co-channel interference.

The percentage of locations where service was achieved for each square was derived and plotted against the key parameters of measured signal strength, (mean and standard deviation). “Service” here means that the audio channel BER was low enough to correspond to negligible subjective degradation of the audio.

The value of standard deviations was typically smaller than that assumed in our standard prediction work (4.3 dB) although, in a reasonable proportion of cases, it was larger. This is consistent with our perception that the value used is prudently conservative for general application. More significantly, taking all sample areas, including those with the larger standard deviations, a high availability of 99% locations could be assured, provided the difference between the mean values of the wanted and interfering signals was 25 dB or greater (although significantly lower values, even 18 dB, would suffice in some cases) (see Fig. 3).

This seems to correlate well with the previous working assumption that, in planning directed at interference control using terrain-based techniques, a margin of 24 dB would be appropriate for most cases.

Only time will tell how effective are these techniques for co-channel interference management. But two years after the first “tightly-planned” co-channel areas (Manchester and Birmingham) came on-air, there is little if any evidence of a problem.

Adjacent-channel interference management

Despite the attractions of a greater devolution of responsibility from the regulator to the broadcaster with DAB, this is evidently a partial rather than a complete transfer. With adjacent-channel interference management, the level of regulatory involvement needs in some respects to include an even more detailed level of planning than for co-channel management. This is to make feasible the use of adjacent frequency channels in the same area, which is an important requirement for the sake of efficient use of the spectrum. Given that DAB is a new service trying to squeeze its way onto an already-busy area of spectrum, it is a requirement which is unavoidable. In general, unless transmitters on adjacent frequencies are sited at or near the same place, the very high field strengths around the transmitter will interfere with the ability of a receiver trying to abstract a signal on the adjacent channel at a lower strength. With digital, the receiver’s “adjacent-channel” protection ratio must be achieved in a very high percentage of locations in order to maintain an acceptable level of service.

Compromises need to be made in the design of transmitter networks. All networks require frequencies to be re-used over a certain distance beyond the edge of their coverage, as we have seen above. This requirement tends to limit the powers and heights of transmitters, but this effect is less influential the further you are from the edge of the coverage area. Therefore this constraint will, for purely statistical and geometric reasons, tend to impinge more on local than national networks. A similar if less dramatic constraint on network design is the fact that DAB signals from distant transmitters (outside the so-called “guard interval”) – even in the same multiplex’s network – act as interference rather than as wanted signals.

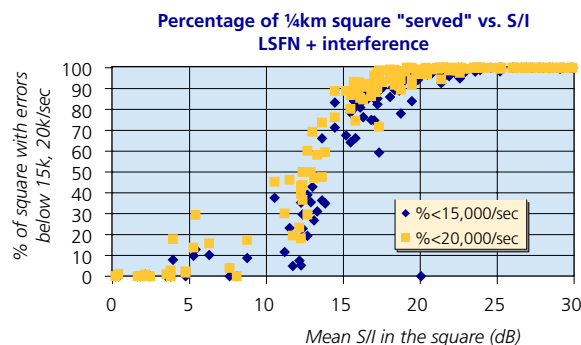


Fig. 3a: Within an SFN

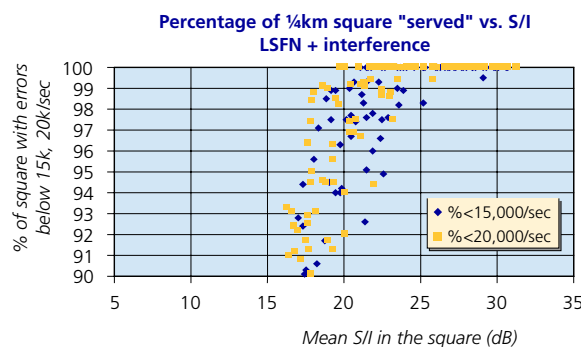


Fig. 3b: Within an SFN
(scale zoomed in to high-availability cases)

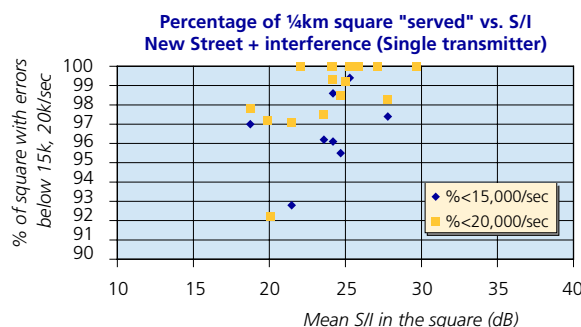


Fig. 3c: At the edge of network coverage
(one transmitter only provides the wanted coverage)

Figure 3
Location availability as a function of the margin between median signal levels.

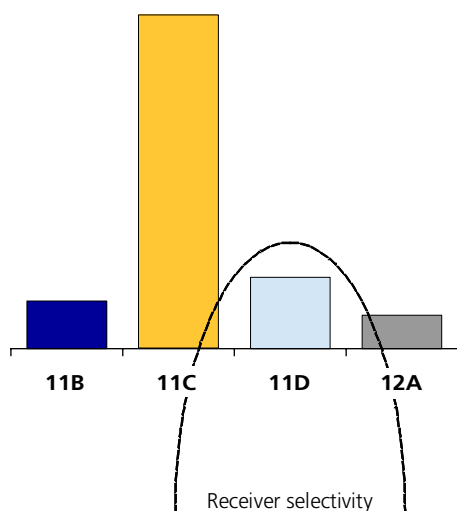


Fig. 4a: Reception of the wanted channel is subject to adjacent-channel interference

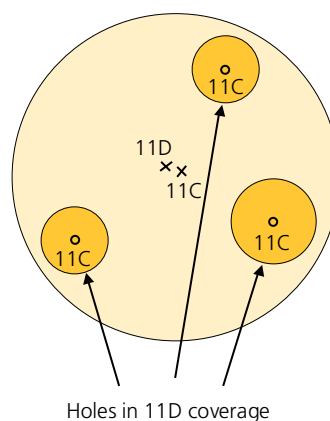


Fig. 4b: Adjacent-channel transmitters – creation of “holes” in the coverage

× 11D

Figure 4 Adjacent-channel interference.

This poses a problem. The first operator to develop services in a given area would, in effect, impose an insurmountable constraint on the ability of other broadcasters (with differing co-channel constraints) to use the adjacent channel in the same area. The other operators would be prevented (by the regulator) from introducing the transmitters necessary to achieve a credible coverage, as these would interfere with reception of the first operator’s service.

The “Reserved Assignments List”

The response to this problem in the UK has been to construct, some years ago, a table of *Reserved Transmitter Assignments*. The understanding – which applies to the BBC and, in its licensing activity, the Radio Authority – is that a broadcaster with a licence to serve a given area will be allowed to implement transmissions from sites which are at or very close to locations on the list of “reserved assignments”, within the maximum parameters specified. This allows broadcasters to establish at least a basic level of coverage, and also to anticipate where, in the absence of their own transmitter at that location, “holes” in the coverage might occur due to adjacent-channel interference.

Where more than two adjacent frequencies are planned for use in the same area, consideration must be given to the interests of all the broadcasters concerned, even future ones.

The reserved assignments system has served the UK well. In England and Wales, three of the five frequency blocks used for local and regional multiplexes are adjacent to national multiplex frequencies. The BBC rolled out its network to over 60% of the population coverage over the period 1995-7, some three years ahead of parallel developments by the commercial operator *Digital One* which, in turn, is ahead of the programme of local network development (now over half-way to completion of its first and most significant phase). Quite simply, without the reserved assignments system, the local radio coverage would be so limited as to have been not worth doing at all. Some 50% of all (analogue) radio listening in the UK is to local or regional services (i.e. not wholly “national” services). To have restricted DAB to carrying just national services only would surely have kept it below the critical threshold of relevance as a technology.

And now, in some places the local multiplexes are being developed slightly ahead of the national ones, notably in Scotland. So, here, the reserved assignment system can enable national radio!

Of course, the reserved assignments list is only a basic framework for network development. It has its limitations, partly because it includes an element of compromise between conflicting objectives, and partly because



Mark Thomas completed an Honours Degree in Physics at Exeter College, Oxford, in 1980. He gained his engineering training at the BBC, where he continued to work until 1985. Then came over two years at the then-new Mercury Communications Ltd. (a Public Telephone Operator), in the systems technology and microwave engineering departments. From 1988 to 1990, he worked at the telecommunications consultants, WS Atkins, including a year on secondment to DGXIII of the Commission of the European Communities.

Mr Thomas joined the Radio Authority at its foundation in 1990 as its Head of Engineering. Since then, his department has undertaken the frequency planning and concomitant technical regulation of the independent radio sector in the UK, at the strategic and practical levels. This period has seen a major expansion of analogue services, and the introduction and fast roll-out of T-DAB services in the UK.

it cannot benefit from the hindsight (or clairvoyance) of operators' more detailed experiences with planning and implementation, including the commercial judgements which are integral to this process. The list is modified from time to time where this would clearly carry an overall benefit to operators, but this must always be done without impacting unreasonably on the existing position of operators who have already invested in coverage of a given area.

Quite often, an operator will wish to deploy a transmitter somewhere which is not a reserved assignment location. Although this may cause interference to coverage of the adjacent-channel service, that service may also have significant deficiencies in coverage which would be filled by a transmitter at the proposed location. Under these circumstances, it may be appropriate to add this transmitter location to the reserved assignment list, although consultation with operators should be an important part of the decision-making process. It can also be a good idea to defer the inclusion of such an assignment on the reserved list to a future date. This may make the new transmitter more cost-effective for the operator who is partly needing to make up for coverage lost due to interference, and partly benefiting from additional coverage.

The BBC and the Radio Authority are now concluding an agreement on the procedures and technical criteria for the assessment of proposals for transmitters which do not conform to the reserved assignment list (where this is relevant; obviously where services are not overlapping in area or adjacent in frequency, there is no problem). This anticipates that transmitters for just one service in built-up areas would be unacceptable while, in sparsely populated rural areas, they would be acceptable. But much of the UK is less clearly defined. Here, prediction tools will be used, despite their limitations, to assess the size of the population, or the length of important road routes, whose service availability would be degraded significantly below 90 - 99% of locations. The margin of mean signal strength which would cause availability to be unacceptable would be in the order of -22 dB where predictions are to a granularity of 250m, and slightly larger, say -26 dB, where the granularity is more like 50 - 100m³. One of the largest limitations of the technique as currently practised is in short-range field strength prediction, especially given that the information on local ground cover (clutter), to the detail that is really needed for accurate work, is either not available or very very expensive!

These figures have been derived in the first instance from theory on the statistical distribution of signals, and also from measurements taken where adjacent-channel interference has been expected to occur, e.g. where one of the adjacent-channel operators has not implemented its transmitter at a reserved assignment location. The agreement between theory and practice is very good. The impact of adjacent-channel transmitters was generally less than might be predicted because of two factors. Firstly, the signal strengths varied less with location than the slightly conservative assumptions used in the predictions. Secondly, receiver adjacent-channel rejection performance was also better. Obviously these factors will not always apply. Standards are always a compromise between conflicting factors and there is never a "right answer"!

3. The receiver protection ratio is taken as -35 dB (compared with the CENELEC minimum recommended performance of -30 dB, though most receivers seem to perform at -35 to -40dB); to ensure this is met at 99% of locations within a prediction pixel of, say 200m, the standard deviation of the difference of levels between wanted and unwanted signals is taken as:

$$\sigma_{\text{diff}} = \sqrt{(\sigma_{\text{wanted}}^2 + \sigma_{\text{unwanted}}^2 - 2\rho\sigma_{\text{wanted}}\sigma_{\text{unwanted}})} = 5.6 \text{ dB}$$

and the correction factor of 2.33 times standard deviation to achieve 99% location probability is given by

$$-22 \text{ dB} = -35 \text{ dB} + (2.33 * 5.6)$$

Conclusion

Although the key components to digital uptake are the relationships between consumers, receiver manufacturers and broadcasters, careful work is needed before these relationships can start. This article has looked at just two matters; there are many others, some also involving the regulator. The greatest sense of achievement will be in the acceptance of the technology by a public that is largely unaware of how the coherent establishment of compatible services has been made.

Acknowledgement

The author would like to thank his colleagues at the Radio Authority, especially Nigel Green, for their significant contributions to the work described in this article, and to colleagues on the former EBU Project Team B/TAPI (and its successor and predecessor groups) whose development of planning concepts for DAB has been pivotal to its success.
