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Small scale DAB trials

Final report

Research report

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About this document

During 2015, Ofcom licensed and co-ordinated a trial of a new approach to DAB radio broadcasting which we are calling small scale DAB. This document reports on the outcomes of the trial so far, particularly in relation to its three primary objectives, and sets out Ofcom's conclusions. This document concludes Ofcom's reporting to the Department of Culture, Media and Sport, who initiated and made funding available for the project.

Our report concludes that the trials were generally highly successful and achieved their three objectives. The trials showed that the small scale approach to DAB transmission is technically sound, and they helped Ofcom, the triallists, and wider industry to understand the practical requirements for successfully sustaining DAB radio transmissions using the small scale approach.

In light of stakeholder and wider interest in the technical aspects of the trials, we are also publishing several separate technical documents and studies as annexes alongside this report. The technical documents contain more in-depth information on the technical development and operational aspects of the small scale trials, as well as technical studies on potential frequency availability for small scale DAB, a technical report on DAB receiver performance that we commissioned during the project, and some summary results of a survey of radio stations on small scale DAB that we carried out while preparing this report. The technical documents are available on our website at https://www.ofcom.org.uk/research-and-data/tv-radio-and-on-demand/radio-research/small-scale-dab-final-report

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Section 1

Executive summary

1.1 To date, many smaller analogue radio stations (broadcasting on FM or AM frequencies) have been unable to transmit digitally on the DAB (Digital Audio Broadcasting) radio platform. This is usually due to the relatively high transmission costs that smaller stations would have to incur for carriage on existing DAB services. This, in turn, is often related to the fact that existing DAB services usually cover much larger geographical areas than smaller stations wish to serve.

1.2 A new approach to DAB transmission, known as 'small scale DAB', can potentially provide a more cost-effective way for these stations to broadcast on DAB. Small scale DAB keeps costs low by making use of relatively inexpensive transmission equipment and the freely available 'open-source' software maintained by Open Digital Radio[1].

1.3 Small scale DAB can also achieve more 'granular' geographic coverage than existing DAB services, potentially making it more suited to smaller radio stations' needs.

1.4 To help test the practical viability of small scale DAB, the Department for Culture, Media and Sport (DCMS) made funding available for real-world trials of the technology.

1.5 Ofcom awarded trial licences for ten towns and cities across the UK during 2015. Ofcom also provided assistance with technical development and support, and supplied transmission equipment to the triallists. The trial services were initially licensed for nine months.

1.6 The three main aims of the trial were:

- to test how well the small scale DAB technology worked;
- to test how well the technology lends itself to several parties coordinating their services (this is because DAB broadcasting involves several radio stations being transmitted as part of the same signal); and
- to give the market an opportunity to learn about small scale DAB and the potential opportunities the technology affords.

1.7 We have concluded that the trials successfully achieved all three aims:

- The technology generally worked well and reliably, and technical problems identified were resolved. We are continuing work to improve the technical stability of some specific transmitter configurations.
- Coordination between service providers has generally been very effective. Across the ten trial areas, nearly 70 unique radio stations are now being carried, the majority of which are new to DAB.

[1] www.opendigitalradio.org, a non-profit organisation whose activities include maintaining open-source digital radio transmission software and tools.

- The ten trial operators have gained extensive practical experience of small scale DAB, and have also shared their experiences and technical knowledge with each other. Some operators have been directly involved in innovating further technical enhancements to the small scale concept, and the trials have prompted wider market interest.

1.8 As a result of the success of the trials, the current licences were extended for a further two years. The ten existing trial locations will remain on-air until 2018.

1.9 As part of this project, we have also looked at the availability of frequencies for small scale DAB. Our conclusion is that, when added to the spectrum available amongst the UK's existing licensed DAB multiplexes, there is sufficient spectrum to support at least one small scale multiplex in most parts of the UK.

1.10 On the basis of the trials so far and the other conclusions of this report, we believe that there is a significant level of demand from smaller radio stations for small scale DAB, and that a wider roll-out of additional small scale services into more geographic areas would be both technically possible and commercially sustainable.

Section 2

Background to the trials

Radio in the UK

2.1 The UK has a large, diverse, and vibrant broadcast radio sector, which includes both the long-established FM and AM analogue radio platforms, as well as the newer Digital Audio Broadcasting (or DAB) digital radio platform.

2.2 DAB radio services are broadcast as 'multiplexes'. This means that sound signals from a number of individual radio stations are combined together and transmitted as digital data. A DAB multiplex can be broadcast from many transmitters, all using the same transmission frequency, to cover a wide area. This is in contrast to analogue radio, where stations are simply broadcast on individual frequencies, and neighbouring transmitters cannot generally use the same frequencies as each other.

2.3 There are three 'layers' of commercial and independent radio in the UK: national radio stations, local radio stations, and community radio stations. In addition, the BBC provides its own national and local radio services.

2.4 On DAB, three national multiplexes (Digital One[2], Sound Digital[3], and the BBC's national DAB service[4]) currently broadcast between 10 and 19 stations each. These national services are available to up to 97% of the UK population in the case of the most extensive network.

2.5 There are also 58 local commercial DAB multiplexes, covering approximately county-sized areas. Each local multiplex broadcasts up to 14 commercial radio stations, as well the relevant BBC local station for the area. Over 90% of UK households should be able to receive a local DAB multiplex by the end of 2016.

2.6 However, there are up to 400 local commercial and community radio stations on analogue radio which are not currently carried on DAB. This is partly because local DAB multiplexes cover relatively large geographical areas, which can make the cost of carriage uneconomic for stations which seek to serve smaller towns or communities.

2.7 In addition, some local DAB multiplexes are already full of existing stations, meaning that new stations can't be added unless other services leave the multiplex or reduce the space they occupy (e.g. by moving from stereo to mono transmission).

Trialling an alternative approach: 'small scale' DAB

2.8 In 2012 and 2013, Ofcom engineer Rashid Mustapha carried out an initial trial in Brighton to test a new technical approach to DAB transmission. This trial took advantage of inexpensive computers, open-source software released by the Communications Research Centre in Canada, and a relatively novel 'software defined radio' module, to replace many of the dedicated hardware components used in traditional DAB transmission systems with lower cost alternatives. These initial

[2] http://www.ukdigitalradio.com/
[3] http://www.sounddigital.co.uk/
[4] http://www.bbc.co.uk/reception/radio/digitalradio/

trials showed that the new approach had the potential to significantly reduce the capital and operating costs of DAB broadcasting for smaller multiplexes.

2.9 The full report of this trial is available on the Ofcom website[5].

2.10 Following the success of the Brighton trial, the Department for Culture, Media & Sport (DCMS) asked Ofcom to further develop the small scale concept, and to carry out a series of 'real world' trials of the small scale DAB system. The DCMS also made funding available to support the trials.

The role of stakeholders in the trials

2.11 A key element in delivering this project was for radio stakeholders to be deeply engaged in trialling the small scale approach to DAB transmission. This was in order to test the longer-term reliability, capabilities, and viability of the platform when deployed in a real-world context by broadcasters.

2.12 The Brighton trial was very limited in its duration and focus, as it used only one transmitter and carried no radio stations (due to restrictions which prevent purely technical trials from carrying broadcast content). We felt that it was important to test the approach more widely, from both a technical and an implementation perspective. We also concluded that it was crucial to include as wide a range of stakeholders as possible, and to include transmissions of 'real' radio stations, in order to further develop and validate the small scale approach.

How we proposed to carry out the trials

2.13 In October 2014 Ofcom began a consultation on proposals for three trial small scale DAB multiplexes, which would be run by radio sector stakeholders. We anticipated awarding trial licences for one of each of the following trial scenarios:

- Trial Type 1: a single transmitter multiplex carrying multiple services;
- Trial Type 2: a Single Frequency Network (SFN) carrying multiple services from two transmitter sites; and
- Trial Type 3: an SFN carrying multiple services based on two transmitter sites, with one of them being an 'on-channel repeater'[6].

2.14 Following this consultation, in February 2015 we published a statement confirming the three primary objectives of the trials:

- to test the function, capability and stability of software-defined DAB multiplex technology, particularly in SFN mode;

[5] http://stakeholders.ofcom.org.uk/binaries/research/radio-research/Software-DAB-Research.pdf

[6] A DAB on-channel repeater consists of a transmitter which picks up a signal directly from another DAB transmitter, and then re-transmits it. This basic principle has been used for many decades by TV and radio 'relay' transmitters (which transmit on a different frequency to the incoming signal). However, because an on-channel repeater transmits on the *same* frequency as the incoming signal, relatively complex electronic signal processing is required (and special attention must be paid to the aerial systems) in order to make the system stable and to avoid causing interference.

- to test how well the available technology lends itself to several parties coordinating their services into the multiplex (many small scale radio services do not have experience of using multiplexing technology); and

- to give the market an opportunity to learn about the software-defined DAB platform and the potential opportunities the technology affords, particularly for those stakeholders who are not familiar with digital broadcasting.

2.15 Following high levels of demand from radio stations and other stakeholders to take part, we also increased the number of trials available from three to ten. We stated that we would seek to award one licence for trial type 3 (the on-channel repeater), two for trial type 2 (the SFN), and the remaining seven for trial type 1 (the single transmitter trials).

2.16 At the same time as this statement, we published an Invitation to Apply for trial multiplex licences.

2.17 A full set of documents about the trial consultation process can be found on the Ofcom website at http://stakeholders.ofcom.org.uk/consultations/small-scale-dab/.

Section 3

Implementing the trials

3.1 Although the trial multiplexes are operated independently by stakeholders, Ofcom played an active role in their development, particularly in the early stages. This section outlines Ofcom's involvement in the trials in terms of licensing, construction and supply of transmission equipment, compiling and configuring software modules, and technical support.

Licensing

3.2 In response to our February 2015 Invitation to Apply for trial multiplex licences, Ofcom received 51 applications for the ten available licences. The majority of these were for the single transmitter trial type. We also received ten applications for the SFN trial, and three for the on-channel repeater trial.

3.3 In June 2015 we announced the award of the ten licences. The table below shows the successful trial licensees:

Trial type	Licensee	Location
Trial type 1 (single transmitter trial)	Angel Radio	Portsmouth
	BFBS Aldershot	Woking[7]
	Brighton & Hove Radio	Brighton
	Celador Radio	Bristol
	Future Digital Norfolk	Norwich
	Niocast Digital	Manchester
	Switch Radio	Birmingham
Trial type 2 (SFN trial)	Scrimshaws Information Directories	Glasgow
	U.DAB	London
Trial type 3 (on-channel repeater)	UKRD	Cambridge

3.4 All ten successful trial licensees proposed to carry at least four radio stations, including a mix of commercial and community stations, and had access to transmitter sites that appeared to be suitable for serving the areas that they had proposed.

3.5 The full account of the award decisions, including a list of the stations that the successful trial applicants proposed to carry, is available at http://licensing.ofcom.org.uk/binaries/radio/digital/small-scale-trial-multiplex-licensing/trial_awards_statement.pdf.

3.6 Following licence award, Ofcom worked to procure, supply and integrate certain elements of the transmission chain which met each licensee's specific requirements,

[7] The Woking trial was originally intended to serve Aldershot. however due to transmitter site acquisition issues, a site serving Woking was eventually used.

and we held training sessions to familiarise licensees with configuring and operating their equipment.

3.7 The first trial multiplex came on-air during July 2015 in Brighton, with other services coming on-air through the summer of 2015. The final service to launch was in Glasgow, which went live in November 2015.

Equipment

3.8 Ofcom procured and provided each triallist with a largely standardised set of transmission equipment, which comprised the following main components:

- Up to six audio source encoders (comprised of single board computers and low-cost USB sound devices);
- A multiplexer (a small form factor desktop PC);
- A modulator (a 'software defined radio' peripheral);
- A linear VHF power amplifier;
- A 250 watt mask filter;
- A transmitting antenna and feeder cable;
- Other miscellaneous equipment including a network switch and an uninterruptable power supply (suitable for supporting all the electronic equipment apart from the power amplifier).

3.9 For trial type 2 (the SFNs), precision timing reference boards were added to the software defined radio modules to allow synchronisation of the transmitters within the SFN.

3.10 For trial type 3 (the on-channel repeater), a dedicated on-channel repeater unit (integrated by the manufacturer within the same chassis as a VHF power amplifier) was provided in place of one of the standard power amplifiers.

3.11 Although we sought to standardise the equipment provided to each triallist where possible, we introduced variations in some specific equipment types in order to reduce the risk of batch faults, and to provide a 'mix' of equipment for comparative evaluation during the trial. For example, we sourced power amplifiers from two separate manufacturers, and eventually deployed three models of single-board computer for the audio encoders.

3.12 Different transmitting antennas were selected based on the proposed transmission site and desired coverage. Omnidirectional antennas were used in most cases, while directional antennas were used in a few cases.

3.13 For multiplexer and modulator components, it was important to for us to supply standardised hardware and software platforms to enable on-going development and optimisation of these components during the trial. Therefore, the equipment used for these tasks – the software defined radio and desktop PC - were the same for all trials.

3.14 The approximate average cost (including VAT) of the equipment provided by Ofcom was:

- £9,000 for trial type 1 (single transmitter);
- £17,000 for trial type 2 (SFN), comprised of one set of transmitter equipment for each of the two transmitter sites within each SFN; and
- £19,000 for the type 3 (on-channel repeater) trial. As with the type 2 trials, two sets of transmitter equipment were required, of which one set included the specialised on-channel repeater unit.

3.15 Ofcom also offered to meet the costs of the internet circuits required to provide links between multiplexing sites and transmitters, and offered to provide limited support for audio contribution links (e.g. between radio station studios and the multiplexing site). Five triallists opted to use such circuits, with the remaining triallists either using existing connectivity or procuring their own circuits.

3.16 There was a relatively wide variation in the costs of the internet circuits funded by Ofcom. The circuits selected varied from standard business-grade ADSL broadband and VDSL fibre broadband (supporting single transmitter trials), to Ethernet over Fibre To The Cabinet (EoFTTC) circuits which were used in one of the SFN trials.

3.17 Licensees were responsible for meeting the cost of equipment installation, including the installation of their transmitting antennas. Licensees were also responsible for providing connectivity (usually fixed broadband circuits) where these were not funded by Ofcom.

3.18 A more detailed technical description of the equipment used in the trials is provided in Annex 2[8], and the photographs below show the main transmitter system components supplied by Ofcom.

[8] Annex 2, http://stakeholders.ofcom.org.uk/market-data-research/other/radio-research/ssdab-final-report

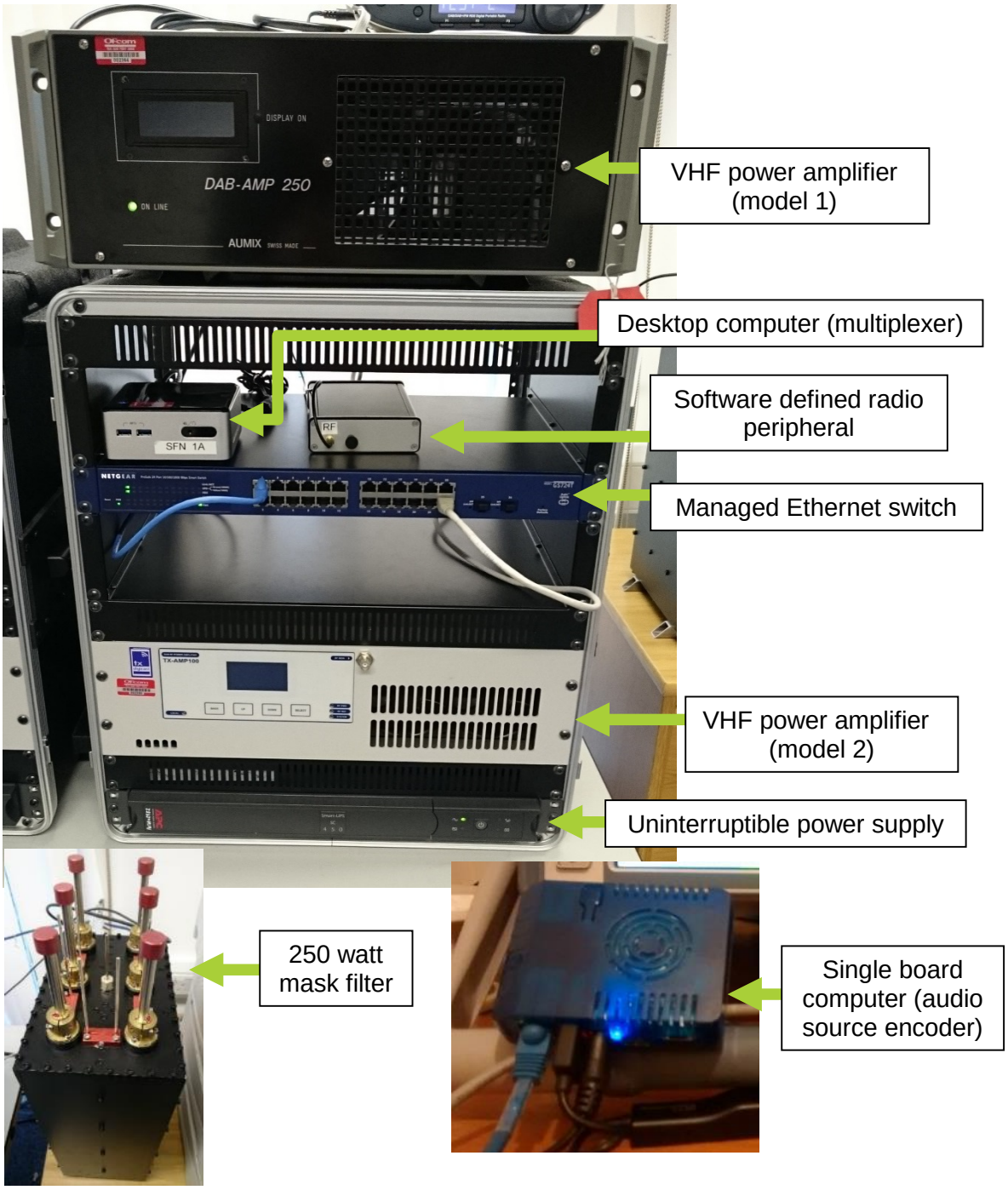


Figure 1: Trial transmitter equipment – main components

Technical support

3.19 The multiplexer and audio encoder systems provided to each triallist were developed, configured, and tested by Ofcom and ran standard software. The multiplexers used ODR-DabMux[9] software running on the Debian GNU/Linux operating system, and

[9] https://github.com/Opendigitalradio/ODR-DabMux

the source encoders used toolame-dab[10] running on the Ubuntu GNU/Linux operating system (tailored for the specific single board computer systems used).

3.20 Ofcom provided training to all triallists to help familiarise them with the operation of the equipment. During the training we helped the triallists to carry out basic configuration of their systems to suit their specific needs (e.g. configuring the multiplexer to receive the desired audio services, and to set appropriate transmission parameters).

3.21 Ofcom also provided technical support to the triallists throughout the duration of the initial nine month trial. We have now scaled back our technical support role, partly because the initial trial period has now elapsed, and partly because licensees are now more familiar with the operational aspects of their equipment. However, we are continuing to provide support on a 'reasonable endeavours' basis for urgent issues, and are continuing our collaboration with the wider Open Digital Radio project to help refine the performance of the software.

Commissioning, Adjacent Channel Interference and coverage checks

3.22 All new radio transmitter sites go through a process of engineering checks known as 'commissioning'. The main aims of this process are to ensure that the transmitted signal does not exceed the maximum power level set out in the broadcaster's licence, and that limits to the level of signals generated outside of the frequency 'block' allocated to the DAB multiplex are being properly met. This is in order to ensure that neighbouring frequency spectrum users do not suffer undue interference. Ofcom carried out commissioning of all the small scale transmitter sites, and provided support and advice on system optimisation during the commissioning process where needed.

3.23 Another important part of the commissioning process was to ensure that the small scale DAB transmitters were not causing 'ACI' (Adjacent Channel Interference) issues. ACI is an effect that can sometimes be caused when a new DAB transmitter comes into operation, and occurs when relatively high signal strengths in the immediate vicinity of the new transmitter can effectively 'block' listeners' reception of weaker signals from more distant DAB transmitters. The modest power levels used for the small scale DAB transmitters (along with careful selection of transmitting aerials) helped to avoid these problems, and no significant ACI issues were encountered during the trial.

3.24 Existing local and national multiplex operators are responsible for liaising with other multiplex operators in the areas where new transmitters are proposed in order to minimise possible ACI effects. Where required, this allows the parties involved to negotiate directly as well as enabling Ofcom to arbitrate if necessary. In the case of the small scale DAB trials, Ofcom carried out this liaison itself so that services could come on-air quickly. For any small scale DAB enhancement transmitters, or in any future permanent licensing regime, Ofcom would expect small scale multiplex operators to seek such agreements themselves. More detailed information on the commissioning and ACI aspects of the trials is available in Annex 2[11]

[10] https://github.com/Opendigitalradio/toolame-dab
[11] Annex 2, http://stakeholders.ofcom.org.uk/market-data-research/other/radio-research/ssdab-final-report

3.25 Ofcom also carried out computer modelling to predict the coverage area that each small scale transmitter was likely to achieve (see Annex 1). We validated these predictions by carrying out vehicle-based measurements of the coverage that each small scale transmitter actually achieved in practice. We found a close correlation in most cases, and where there was a significant mis-match, this was found to be due to issues with the transmitting antennas.

DAB receiver testing

3.26 Because many of the small scale trials used transmission frequencies which had not previously been used for DAB services in the UK, staff from Ofcom's spectrum engineering team carried out some initial technical testing of a range of domestic and in-car DAB receivers to ensure that the receivers would operate as expected on the new frequencies. We also carried out basic sensitivity tests on receivers operating on the new frequencies. No significant functional issues were found during this testing.

3.27 We also subsequently commissioned a more detailed study of receiver sensitivity from DTG Testing Limited[12] which is available as Annex 6[13] to this report. This found that while all the receivers tested could tune to the new frequencies, the sensitivity of individual models of DAB set varied considerably (on both the new frequencies and on existing DAB frequencies). This finding was consistent with our previous in-house basic sensitivity testing.

3.28 In general, receiver sensitivity has been improved considerably over time, and newer sets tend to provide the most reliable reception experience. This highlights the importance of the Digital Tick scheme[14]. Manufacturers must prove that their products meet (or exceed) a minimum performance specification before the Tick mark can be displayed on packaging and marketing materials for the radio set.

Reporting

3.29 Alongside providing equipment, support and commissioning, Ofcom required triallists to provide weekly reports on progress against their launch plans during the pre-launch period. This proved helpful in understanding the issues triallists were facing as they arose.

3.30 After launch, triallists had to report on a fortnightly basis, and keep a reporting log for submission to Ofcom every month. This was to ensure that all relevant information was being captured.

3.31 Triallists have now moved to reporting monthly, and will continue to do so until the end of their trial licence, so that Ofcom can continue to gather information on the long-term stability of the small scale approach, and on how the market is developing.

[12] DTG Testing (www.dtgtesting.com) is a UKAS accredited test facility whose services include testing DAB radios for compliance with the 'digital tick'. DTG Testing also carries out performance and functional testing of digital television equipment.
[13] Annex 6, http://stakeholders.ofcom.org.uk/market-data-research/other/radio-research/ssdab-final-report
[14] www.getdigitalradio.com/industry/what-is-the-tick-mark, a scheme which allows radio receivers meeting specified minimum performance standards to display the 'digital tick' certification mark.

3.32 We also invited the trial multiplex operators and stations on small scale DAB to complete internet surveys during August 2016. This was primarily in order to gain further insights into their experiences of small scale DAB for this report

3.33 The reporting we have received, as well as the survey results, have contributed to this report, which also draws on Ofcom's own observations and analysis. We are grateful for the useful information we have received from triallists over the course of the trials.

Section 4

On-air technical experiences

Background

4.1 The main technical objective of the trials was to test the function, capability and stability of software defined DAB multiplex services, particularly in single frequency network (SFN) mode.

4.2 The small scale DAB approach has never been trialled over an extended period in the UK, nor in so many trial areas, and we wanted to test whether it could perform reliably in a range of circumstances. At the start of the trial, it was also unknown whether the small scale approach would operate reliably in SFN configuration.

4.3 In the ten trials, we planned at the outset to award licences for seven single transmitter multiplexes, two two-site single frequency network multiplexes, and one two-site multiplex using an on-channel repeater.

4.4 The on-channel repeater trial took place in Cambridge, while a two-site SFN trial took place in London. As of August 2016, two trials are in the process of adding second transmitters, effectively turning these multiplexes into SFNs. The Glasgow trial was originally intended as a two-site SFN, but the operator experienced delays in bringing the second site into operation, and the SFN did not become fully operational until May 2016.

4.5 This section provides a high-level summary of the technical approach to the trials, and the lessons we learnt. A more detailed account of the trials' technical architecture, performance, and issues encountered is available in Annex 2[15].

Hardware

4.6 The trial transmission hardware generally worked well and proved extremely reliable. The most significant issues encountered were related to hardware failures rather than the small scale architecture itself.

Software

4.7 The multiplexing and audio encoding software proved highly reliable during the course of the trials for most operators. Some single-transmitter trial operators reported occasional instances where equipment needed to be restarted, but these were generally restricted to early stages of the trial, and no definitive cause was identified. In other trials, the software operated reliably throughout and required no user intervention except to implement service reconfigurations (such as adding new stations to the multiplex).

4.8 The most significant software issue was a problem related to the synchronisation of the transmitters in the SFN trials. Transmitters in an SFN need to be precisely synchronised together so as not to cause interference to each another, and to provide the coverage enhancing effect which is one of the main advantages of DAB

[15] Annex 2, https://www.ofcom.org.uk/research-and-data/tv-radio-and-on-demand/radio-research/small-scale-dab-final-report

operating in SFN mode. However, we found that the trial SFN transmitters would periodically experience timing issues, and the modulators needed to be reset by remote control to clear the problem. We carried out extensive technical investigations to understand and rectify this issue.

4.9 We believe that the root cause of the problem has been identified, and as the timing problem appears to have been resolved we will be issuing updated software to the two SFN triallists during September 2016.

4.10 The main focus of our technical development work on the trials was to provide core software and equipment functionality to enable the trials to go ahead. Therefore 'ease of use' issues were not a primary objective, and we did not provide graphical or web interfaces for the multiplexing or encoding software. Configuring the equipment therefore required relatively advanced IT skills. While the majority of the triallists' organisations included suitably skilled engineers or technical staff (and Ofcom was able to offer support in other cases), any wider roll-out of small scale DAB would benefit from more user-friendly configuration, operational, and monitoring tools being available. The software development community and market are now beginning to deliver these.

Single transmitter trials – Technical experiences

4.11 The coverage of the single transmitter trials closely matched our predictions, though we noted the following issues.

4.12 The coverage predicted and achieved by one of the single-transmitter trials was relatively limited. This was due to the use of a less than ideal transmitter site, and emphasises the need for good transmitter site selection.

4.13 During the course of the trial, one multiplex identified and moved to a better transmitter site and used a different aerial configuration. This improved coverage of their target area considerably.

4.14 One single transmitter trial initially had poorer coverage than expected towards the edge of its coverage area. We found that this was due to a fault with the transmitting antenna. The antenna was replaced, which significantly improved the coverage achieved within the target area.

4.15 One other single transmitter triallist reported that the coverage they were achieving fell short of their expectations, and received listener feedback to that effect. However, the coverage achieved was consistent with our coverage predictions. Serving a significantly wider area was not possible within the parameters of the single transmitter trial type.

4.16 The single transmitter trials generally proved very reliable in service. Some triallists initially experienced occasional reliability problems with the audio encoders, which were restricted to a single type of encoder computer. These encoders were replaced as required.

4.17 Licensees also generally found the equipment straightforward to use, but some degree of command line computer experience was necessary. At least two licensees developed their own web interfaces for controlling the multiplexer.

4.18 Some triallists indicated a wish to add an additional 'enhancement' transmitter site at their own expense. The enhancement sites are intended to improve building

penetration and therefore to aid indoor reception, and in one case, to better serve the primary target area (as the original site was located some distance away). We will consider requests for additional transmitters on case-by-case basis, with a primary consideration being that new transmitters should not materially expand the overall coverage area of the multiplex.

4.19 The addition of enhancement transmitters involves updating software and the provision of GPS timing references and aerials. A feed between the multiplexer and the remote site is also needed, which can be a private data link or public internet connection.

4.20 Reception of the single transmitter trial multiplexes has been mostly in-line with the predicted coverage. Due to the temporary nature of the trials, operators tended to select transmitter sites to which they were able to gain easy access at low cost, rather than ones optimally placed to serve the target areas. Should small scale DAB services roll-out more widely, we expect that operators would be able to select more suitable sites.

4.21 The relatively low power levels used in the trials did also highlight that there is a large variation in sensitivity between different models of receiver: some reports of poor reception were from within areas which we had determined to be well-served through data collected from the driven field strength measurement campaigns. This variation in receiver sensitivity was also confirmed by the technical testing mentioned in sections 3.26 to 3.28.

Single frequency network (SFN) trials - Technical experiences

4.22 The coverage of one of the two SFN trials was broadly as predicted by computer modelling. However, the distance between the two trial transmitters was relatively large, and reception around the mid-point between the transmitters was more ‘marginal’ than expected: this area happened to fall into a densely built-up city centre, which is also likely to have contributed to the issue.

4.23 There was also evidence of reception blocking caused by other DAB transmitters, and a particular business radio system with many mobile stations. A moderate increase in transmitter power from 100W ERP to 200W ERP was implemented which improved the situation subjectively, though we believe that a significant increase in the reliability of reception is only likely to be achieved by adding a third transmitter (which would add cost) to the SFN, or by bringing the two existing transmitters closer together (which would have the side-effect of shrinking the overall coverage area). The use of DAB+ may also help to increase the area in which reliable in-building reception is possible due to its lower carrier-to-noise requirement, and because DAB+ sets are generally of more recent design (and therefore often provide better performance than older receivers).

4.24 The other SFN trial experienced several problems and protracted delays in establishing and maintaining their service, and was operating with only a single transmitter in non-SFN mode for several months. The transmitting antennas that were initially installed were found to be defective and were replaced. Availability of internet connectivity at one transmitter site was found to be of prohibitively high cost, resulting in a need to change site. Ongoing reliability problems have been experienced, which are likely to be due to poor internet connectivity. We do not believe these experiences are indicative of wider flaws with the small scale concept, but rather of issues specific to that trial multiplex.

4.25 As mentioned above, achieving fully reliable synchronisation between the SFN transmitters has proved to be an ongoing issue, and has been a focal point of our continuing technical work over the duration of the trial. In service and in lab testing, the SFN transmitters would operate satisfactorily for some days or weeks, but would eventually lose synchronisation. The time-dependent nature of the effect made identifying the root cause particularly challenging, and various potential software and hardware issues were explored. We now believe we have identified an underlying software issue, and are in the process of issuing updated software builds to the two SFN triallists.

4.26 Again, licensees generally found the SFN transmitter equipment straightforward to use, but some degree of command line computer experience was necessary.

4.27 At the time of writing there is no working 'Transmitter Identification Information' (TII) functionality in the software. TII enables the signals from individual transmitters in an SFN to be monitored. Once TII has been implemented it will become much easier to monitor the stability of SFN operation.

On-channel repeater trial - Technical experiences

4.28 The Cambridge on-channel repeater trial used a primary transmitter site which was around 6km outside the city centre. The DAB signal from this site was picked up and re-transmitted by an on-channel repeater (OCR) which was located on a church within the city centre.

4.29 A process of iterative technical refinement and experimentation was required for the on-channel repeater to achieve stable operation, while also transmitting at a high enough power level to provide a useful enhancement to city-centre coverage. The receive aerial system originally planned for the repeater site needed to be replaced by a smaller type because of aesthetic concerns. The smaller aerial exhibited much lower gain than the originally-specified aerial, and could therefore only provide a proportionally lower level of signal to the on-channel repeater unit.

4.30 Achieving the required high level of radio frequency isolation between the transmit and receive aerials at the OCR site proved to be difficult due to the constraints of the building construction. The transmitting aerial was also found to have a defect which further reduced isolation between the two aerials. These aerials were replaced but the isolation achievable resulted in the repeater being operated at 50 watts ERP instead of the originally-intended 100 watts ERP. It is reasonable to expect that this restriction would be eased if aerials with characteristics closer to those originally specified could be used.

4.31 Although the planning of an on-channel repeater can be more complex, and the installation more demanding, than a standard transmitter, once installed they require very little attention. Repeaters do not require GPS references or broadband circuits associated with a conventional SFN. The higher unit cost of a repeater would also be offset by the cost savings of not requiring a broadband circuit to feed it.

4.32 The predicted coverage of the repeater station indicated that it would enhance reception in the north of the city. While a field strength survey indicated that the unit does indeed enhance the field strength within the city without causing any reception issues, the site operator does not believe the repeater provided any significant extension to the overall multiplex coverage area.

4.33 On-channel repeaters are a cost-effective and attractive solution for enhancing or extending coverage. However, as a function of their design, on-channel repeaters are best suited to situations where a directional transmitting pattern is desirable. They also require a good quality incoming signal from a favourable bearing, and can only be used where the sufficient radio frequency isolation between the receive and transmit aerial is achievable.

General technical experiences – DAB+

4.34 Reception reports and anecdotal evidence indicate that the use of DAB+, which was adopted by some triallists, has helped in providing satisfactory reception in some 'fringe' coverage areas where conventional (MPEG-1 Layer 2) DAB services in the same multiplex could not be decoded.

Section 5

Services, coordination and sustainability

Background

5.1 The second main objective for the trials was to test how well the small scale DAB technology lends itself to several parties co-ordinating their services to form a multiplex, particularly when many participants will not have had experience of being carried on the DAB platform.

5.2 Unlike an analogue radio station, which is a single service carried on its own transmitter and frequency, a DAB multiplex consists of a number of stations which all share the same 'pool' of broadcasting capacity. They also share a common transmission infrastructure. The multiplex operator is responsible for managing the multiplex, including deciding which stations it should carry, and on what commercial terms.

5.3 Because Ofcom was not part of the commercial negotiations between the trial multiplex operators and radio stations, nor to any subsequent discussions between them, we have only a limited pool of direct evidence about the effectiveness of cooperation during the trial.

5.4 We have drawn on the regular multiplex operator reports that we received during the trial, as well as an overview of the evolving composition and status of the small scale DAB services.

5.5 We felt that it was important to gain some structured feedback directly from the radio stations involved in the trials. We therefore invited all current and former stations on small scale DAB multiplexes to complete an online survey which asked about their experiences, and their views on the future prospects for small scale DAB. Of the 69 stations invited to complete the survey, 40 did so, a response rate of 58%.

5.6 We also carried out a similar survey of trial multiplex operators. Nine out of the ten multiplex operators responded to the multiplex operator survey, a 90% response rate.

5.7 We are publishing a sub-set of the service providers' survey responses as Annex 5[16]. In order to preserve respondent confidentiality, we are not publishing survey responses which could be personally identifiable, or which may be commercially sensitive. Due to the small sample size and confidentiality issues, we are not publishing separate response summaries for the multiplex operator survey.

Limits on the ability of the trial to predict future behaviour

5.8 When considering the operators' and stations' experiences of co-operation during the small scale trial, we are mindful that the scale, nature, and duration of the trial means that it is unlikely to fully reflect the financial, commercial, and behavioural aspects of any future permanently-licensed services. There are several reasons for this.

5.9 Firstly, the bulk of the transmitter and ancillary equipment was provided to the triallists, meaning that start-up capital costs for the multiplexes were lower than they

[16] Annex 5, https://www.ofcom.org.uk/research-and-data/tv-radio-and-on-demand/radio-research/small-scale-dab-final-report

would have been in an operator-funded situation. Telecoms circuit costs were also met by trial funding for some multiplexes.

5.10 The initial nine month trial licences were of a very short duration in comparison to conventional broadcast services.

5.11 For a variety of reasons, several multiplexes charged no, or minimal, carriage fees to the stations on their multiplexes. We also understand that most multiplexes did not agree contractual terms, such as standards of service availability and reliability, which normally form part of commercial radio carriage agreements.

5.12 For these reasons, some of the outcomes of the initial trial period must be viewed as indicative.

5.13 However, the behaviours and commercial relationships of the trial participants may well evolve over the remaining extended trial period to more closely match those that might be experienced in possible future permanent deployments. As part of our surveys, we therefore also asked multiplex operators and service providers about any changes they intend to make during the extended trial licence period.

Demand for small scale DAB from a range of different stations

5.14 The trials suggest there is a significant level of demand from potential multiplex operators and service providers for small-scale DAB.

5.15 We received 51 applications for ten trial multiplex licences. The trials indicated that there is likely to be a mix of operating models for multiplexes. Multiplexes were operated by existing commercial broadcasters, community radio services, and some non-broadcasting (multiplex only) operators.

5.16 At launch, the 10 trial multiplexes contained 72 stations, including 9 stations which were carried in more than one trial area.

5.17 The number of services rose over the course of the trial. By the end of the initial nine-month trial, 92 services (audio components) were being carried, of which 18 were services that were simulcast on more than one multiplex (and which were carried on between two and four multiplexes each).

5.18 Over the course of the initial nine month trial, four multiplexes had sufficient demand to adopt DAB+ for some services, and 27 DAB+ services are being carried (including some simulcasts) at the time of writing.

5.19 Several multiplexes, most notably Manchester and Portsmouth, saw a notable increase in the number of services carried during the trial, indicating a particularly strong demand from stations for an opportunity to join the DAB platform in these areas.

5.20 Of the 67 unique radio stations currently[17] on small scale DAB, 12 are simulcasts of existing licensed commercial radio stations (meaning they are carried on either existing analogue or existing commercial DAB multiplexes), and 33 stations are new to terrestrial broadcast radio in the UK. The remaining 22 services are simulcasts of existing Ofcom-licensed analogue community radio services.

[17] As of the end of August 2016

5.21 While there are fewer community radio simulcasts (22) than other services (45) currently on small scale DAB, a number of the 'non-community' services do have many of the characteristics of community radio, despite not holding an Ofcom Community Radio licence. For example, the 45 services include web broadcasters targeting specific communities, and 'spin off' or 'time shift' versions of existing licensed community radio stations.

Coordination and carriage charges

5.22 Overall, the coordination aspects of the trials appear to have worked positively. Multiplex operators and station operators generally worked efficiently together to establish the necessary agreements and technical arrangements for carriage of their services on the trial multiplexes. A majority of the service providers, 27 out of 37 respondents to our survey, claimed negotiating carriage on a multiplex was easy.

5.23 One objective factor which can help us to gauge the effectiveness of cooperation between service providers and multiplex holders is the terms (such as carriage fees) on which multiplexes carry services, and on service providers' intentions for the future.

5.24 The trial multiplexes sometimes offered free carriage to services, as the multiplex was a relatively cheap means of additional distribution for their existing radio stations, not a core revenue stream. In other cases, stations on the multiplexes provided 'in kind' assistance (such as access to transmitter sites) to the multiplex operator in lieu of carriage fees. In other cases, the multiplex operator absorbed the running costs of the multiplex and did not charge carriage fees.

5.25 During the initial nine month trial, the nine multiplex operators who responded to our survey indicated that their primary approach to charging stations for carriage on the multiplex was either on a cost-recovery basis (five multiplexes) or that carriage fees were not generally charged (four multiplexes).

5.26 Service providers told us that, where carriage fees were being charged, the most common level of fees, for a third of the providers, during the initial trial period was between £200 and £499 per month.

5.27 For the reasons outlined above, the multiplex operators' approach to charging for capacity during the initial trial period is unlikely to be extended to a wider or longer-term roll-out of small scale DAB. In our survey, all nine operators who responded have made, or plan to make, changes to the way they charge existing stations for carriage on their multiplexes during the remaining extended trial licence period. Four of the nine respondents have moved (or plan to move) to a more 'commercial' basis for carriage charges, with the remainder moving to - or planning to adopt - cost-recovery or other approaches.

5.28 Similarly, our survey of service providers indicated that while the majority (23 out of 27 respondents) expect carriage costs to remain the same or increase during the extended trial period, most service providers (27 out of 37 respondents) intend to remain on the small scale DAB platform. Where carriage fees are increasing, the survey responses indicate that, for half of the respondents, the most common level of increase in carriage fees per service is between £51 and £100 per month.

Views on the commercial sustainability of future small scale DAB services

5.29 We asked the multiplex operators and service providers whether they felt that a wider roll-out of small scale services would be financially sustainable.

5.30 The majority of multiplex operators (5 of the 8 respondents who answered this question) said they felt that small scale DAB would be commercially sustainable for new entrant multiplexes even where the multiplex operator was responsible for covering all equipment costs as well as running costs. The remainder answered "don't know".

5.31 21 respondents out of 37 service providers who answered a similar question felt that a wider roll-out of small scale DAB would offer a commercially sustainable method of distribution for their service, with 11 answering "don't know", and 5 answering "no".

5.32 A relatively higher number of Community Radio service providers felt that small scale DAB would provide a commercially sustainable distribution method for their service: 8 out of the 10 Community Radio services who answered this question did so positively. Service providers noted that the relatively lower costs of carriage compared to other DAB platforms was important to this.

5.33 From follow-up questions, we noted that the uncertainty of "don't know" respondents primarily stemmed from issues such as concerns around reported shortfalls in the coverage and reception experienced compared to that predicted, to other issues unrelated to the trial itself e.g. lack of audience impact (and corresponding difficulties in measuring their DAB audiences), and the level of licence fees required for playing recorded music.

5.34 Those service providers who felt that small scale DAB would not offer a viable platform for them also cited concerns that the size of their coverage area was too small, and of 'patchy' reception (on one of the single transmitter trials). Another service provider cited poor reliability of the transmitter (on one of the SFN trials).

5.35 The survey results, along with our previous feedback from small scale DAB providers, suggest there is also a high level of uncertainty about the carriage fees that might be charged in any permanent multiplex deployment. Multiplex operators have told us that it is very difficult to predict the level of fees as much will depend on factors such as the business model of the multiplex operator, the technical architecture of the service, and the location of the multiplex.

5.36 We expect that multiplex operators in any permanent deployment would be innovative when designing their services – for example, 'single ended' transmission systems (i.e. systems with little or no backup equipment in case of equipment failure) may well be acceptable in some circumstances - and therefore the carriage costs may vary between multiplexes.

5.37 While we note these uncertainties, we believe it is credible that carriage costs on small scale DAB might be, at most, comparable to FM transmission costs for most services. Furthermore, depending on the multiplex business model, and possible use of transmission modes which demand less capacity (e.g. DAB+), it could be possible for 'real world' costs to be significantly less than for FM.

Section 6

Lessons for the wider market

Background

6.1 Our third key objective for the trials was to give the market an opportunity to learn about the software defined approach to DAB and its opportunities, particularly for those stakeholders not familiar with DAB broadcasting.

6.2 The main Ofcom-licensed trials were operated by 10 different companies, ranging from existing commercial and community radio broadcasters to 'new entrant' providers, giving groups from a wide range of backgrounds the opportunity to gain valuable experience of operating a DAB multiplex.

6.3 The trials also provided an opportunity for over 70 community and commercial radio stations to join one or more trial multiplexes: the majority of these services have never been broadcast on DAB before.

Innovations during the trials

6.4 While Ofcom designed the trial transmitter systems to transmit standard DAB services, we left the option open for triallists to adopt the newer DAB+ audio encoding standard, subject to them obtaining suitable technology licensing rights. Some triallists did subsequently adopt DAB+, which allowed additional services to be carried on their multiplexes. Further information on the DAB+ services and their role in the trials is available in Annex 2[18].

6.5 Some trial operators supported each other on technical matters and common issues by communicating through an online forum. They also set up a software repository to share software developments specific to the UK trials. Others have also joined the Google group 'mmbtools'[19] which is the official user forum operated by Open Digital Radio.

6.6 Some triallists implemented DAB 'Slideshow' transmissions on their multiplexes. This allows compatible receivers to display multimedia objects such as programme-related graphics, weather forecasts, or track information.

6.7 One triallist implemented an Electronic Programme Guide (EPG). This allows compatible receivers to display information about upcoming programmes on the multiplex.

6.8 In addition to the main ten trial multiplexes, an independent multiplex began operating while the trial was taking place, with interest having been stimulated by the trials. This service used similar techniques and equipment to the main small scale trials, and was self-funded by the operator. This multiplex was licensed under a non-operational 'test and development' Wireless Telegraphy Act licence (as the original 2012/13 Brighton trial had been). This meant that it could only transmit test audio

[18] Annex 2, https://www.ofcom.org.uk/research-and-data/tv-radio-and-on-demand/radio-research/small-scale-dab-final-report

[19] https://groups.google.com/forum/#!forum/crc-mmbtools

rather than radio programming. Ofcom is also aware that several other users have been testing self-built systems under suppressed radiation conditions.

6.9 Ofcom staff have followed these developments and we noted the enthusiasm and resourcefulness of the operators in successfully applying small scale techniques outside the main trial.

Equipment commercialisation and software enhancements

6.10 To date, small scale DAB transmission hardware has not been extensively commercially integrated or marketed, but this is already under way as the open-source nature of the software enables products to be rapidly developed to complement the pre-existing software building blocks (providing that the code base is used in accordance with the GNU General Public Licence). Those who are experimenting with the technology have integrated their own systems from commodity or general purpose equipment (as we have done in the UK). If a permanent licensing framework were to be established in the UK and/or in other countries, more equipment vendors may well begin to offer pre-built systems that are easier to set-up and configure than the current tools.

6.11 As mentioned in section 4.10, it is possible for the core open-source software used in small scale DAB to be supplemented by additional open-source 'front end' configuration tools and interfaces. This has already happened, albeit to a limited extent, in the UK trials.

International market developments

6.12 Permanent radio services based on the software defined approach used in the UK's small scale trials are already on-air in Switzerland and France, with trials taking place in a growing number of European countries. Other regulators in Europe have approached Ofcom to express their interest in the small scale approach, and to find out more about our trials.

6.13 This suggests there are potentially opportunities for small scale DAB to be deployed in several more countries, which may for example stimulate integration and commercialisation of software-defined DAB hardware.

Triallists

6.14 As mentioned earlier in this report, the triallists come from a wide range of backgrounds. Several trial groups included experienced broadcast industry engineers as part of their teams. Some groups were able to call on such expertise for some or all of the tasks required when setting up and running their multiplexes. Others were less well-resourced.

6.15 Groups with specialists on-hand required less technical support from Ofcom than groups with less broadcast engineering experience or skills. We believe however that all triallists gained valuable knowledge and experience of small scale systems.

Wider industry awareness

6.16 The small scale DAB trials have provoked a significant amount of interest in the concept from both industry and the public.

6.17 The trials have been recognised by industry to be an incubator for both innovative broadcast radio services and digital radio technology. The first regular service to use DAB+ in the UK was by a small scale trial, and some trial multiplexes already carry rich multimedia content including logos, slideshow and EPG which can be displayed by some newer receivers such as car infotainment systems, and a growing number of handheld and portable receivers.

Section 7

Technical scope for wider roll-out

Introduction

7.1 One of the key technical requirements for any future wider roll-out of small scale DAB services is the availability of sufficient transmission frequencies to enable a range of multiplexes to launch, and to enable the multiplexes to achieve desired levels of coverage.

7.2 This section sets out the main conclusions of technical work and studies that Ofcom has carried out which look at frequency availability for small scale DAB. We first considered the frequencies needed to support the small scale trials themselves, and then carried out a theoretical study looking at the potential availability of frequencies for any future small scale DAB roll-out. A summary of these studies is available as Annex 3 to this document, and the main technical study itself is available as Annex 4[20]. Please note that this work is purely indicative, and was solely intended to assist with assessing the potential for wider deployment of small scale DAB. Further technical planning work would be required in order to develop a detailed practical frequency plan.

Frequencies used in the small scale trials

7.3 DAB transmitters in the UK currently use VHF (Band III) frequency 'blocks' which range from approximately 211 MHz to 229 MHz (known as blocks 10 to 13). These frequencies provide sufficient spectrum to support three national DAB multiplexes and the current 58 local commercial DAB multiplexes.

7.4 However, when we initially looked at the prospects for the small scale DAB trials, it was clear that additional spectrum would be required. Because DAB radio receivers can also tune into lower frequencies than those currently used in the UK, we examined the availability of frequencies below 211 MHz for use during the trials.

7.5 Much of this part of the VHF frequency band has until recently been used by private business radio services in the UK. However, as part of international re-planning of frequency use, business radio users on some of these lower frequencies have generally migrated their services to other frequencies.

7.6 This provided an opportunity for additional spectrum to be used for the small scale DAB trials in a part of the VHF band known as 'sub-band II' (blocks 7, 8 and 9). Careful frequency planning was still required in order to avoid interference with the remaining business radio users in the band, and some frequencies needed to be avoided altogether.

7.7 Eight of the small scale trial multiplexes therefore shared two of the sub-band II frequencies (on approximately 194 MHz and 203 MHz – or block 7D and block 9A). The remaining two small scale DAB trials used existing DAB frequencies on an 'interleaved' basis where those frequencies were not used by other DAB multiplexes.

[20] Annexes 3 & 4, https://www.ofcom.org.uk/research-and-data/tv-radio-and-on-demand/radio-research/small-scale-dab-final-report

Future frequency availability

7.8 The remaining business radio users in sub-band II will be migrating to other frequencies over the next few years. This will potentially make six sub-band II frequencies available for DAB use across much of the UK in future. The frequencies comprise blocks 7D, 8A, 8B, 9A, 9B and 9C.

7.9 While the migration of business radio will remove many of the current constraints on the use of these frequencies for any future small scale DAB services, some neighbouring countries also have established international rights to use these frequencies. This may limit the extent to which the sub-band II frequencies could be used in some areas of the UK.

7.10 However, initial indications are that the six sub-band II frequency 'blocks' would be sufficient to enable the deployment of small scale DAB across much of the UK. Where required and feasible, unused 'gaps' in the existing DAB frequency allocations could also be used on an interleaved basis (as they were in the trial).

DAB frequencies that might accommodate existing analogue radio services

7.11 We also carried out an initial study looking at whether it would be technically feasible to develop a future frequency plan for small scale DAB that might provide an opportunity for those small commercial and community stations currently transmitting on analogue radio only to be carried on DAB.

7.12 We concluded that in most areas of the UK, it should be technically possible to develop a frequency plan for small scale DAB which might accommodate those stations. However much more detailed planning and optimisation work would be required to develop a frequency plan which could be implemented in practice.

7.13 Because the UK's neighbours have established rights to use the sub-band II frequencies (and some are already doing so), we would also need to negotiate the use of these frequencies for small scale DAB with neighbouring countries.

7.14 As mentioned above, another important (though temporary) technical constraint is that in some areas of the UK business radio services are currently using part of the VHF band identified for possible future use by small scale DAB. Our study indicates that this is likely to cause a shortage of frequencies until the business radio services migrate to other frequencies (which is due to happen by 2020). The areas most likely to be affected by these interim restrictions are north Somerset & south east Wales, the East Midlands, and areas to the south of Manchester.

Annex 1

Predicted coverage maps for the small scale DAB trials

A1.1 The maps below show coverage predictions for the small scale DAB trial multiplexes. The predictions were produced using the ATDI ICS telecom radio propagation modelling tool, and were validated with drive measurements.

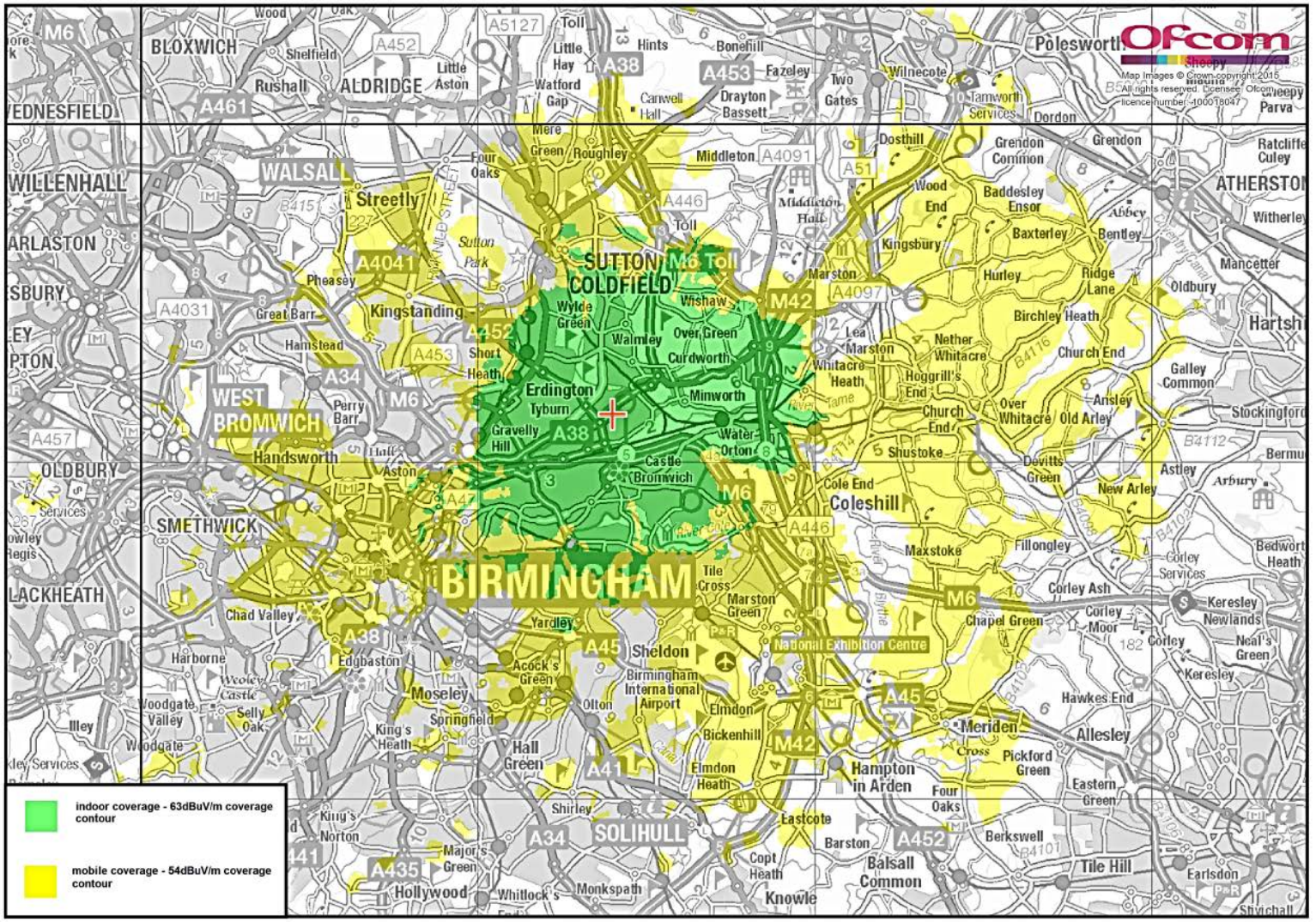
A1.2 The wanted DAB coverage predictions for individual transmitters were carried out using our standard Fresnel / Deygout propagation model and Infoterra clutter model for 99% mobile locations and 80% indoor locations.

A1.3 Outdoor mobile coverage has been based on a minimum field strength of 54dBuV/m, and indoor portable coverage has been based upon a minimum field strength of 63dBuV/m.

A1.4 For the SFN and on-channel repeater trials (London, Glasgow and Cambridge) any overlapping coverage is power summed, giving an overall increase in field strength within the overlapping coverage area.

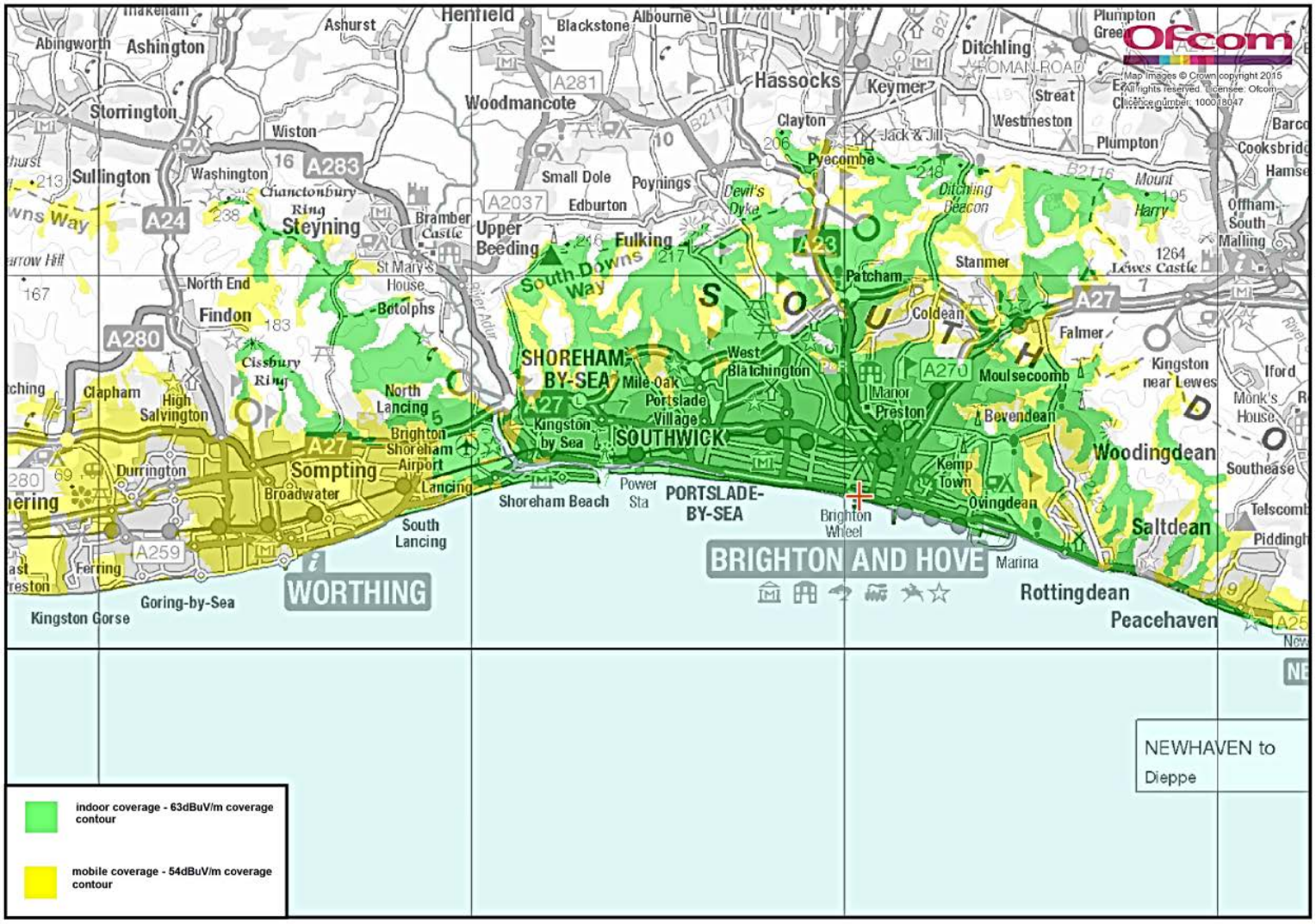
A1.5 Ofcom and the broadcasters normally carry out DAB coverage planning using the UK Planning Model (UKPM) prediction software. Predicted coverage maps for the small scale DAB trials using UKPM are available on our website at http://licensing.ofcom.org.uk/radio-broadcast-licensing/digital-radio/mux-licensing/small-scale-trial-multiplex-licensing/coverage/, and these will be kept up-to-date with any future transmitter changes.

A1.6 Coverage maps produced in UKPM do differ from those produced in ICS telecom below. However, it is not possible to correlate UKPM maps with drive measurement data, therefore ICS telecom maps are provided here for reference.



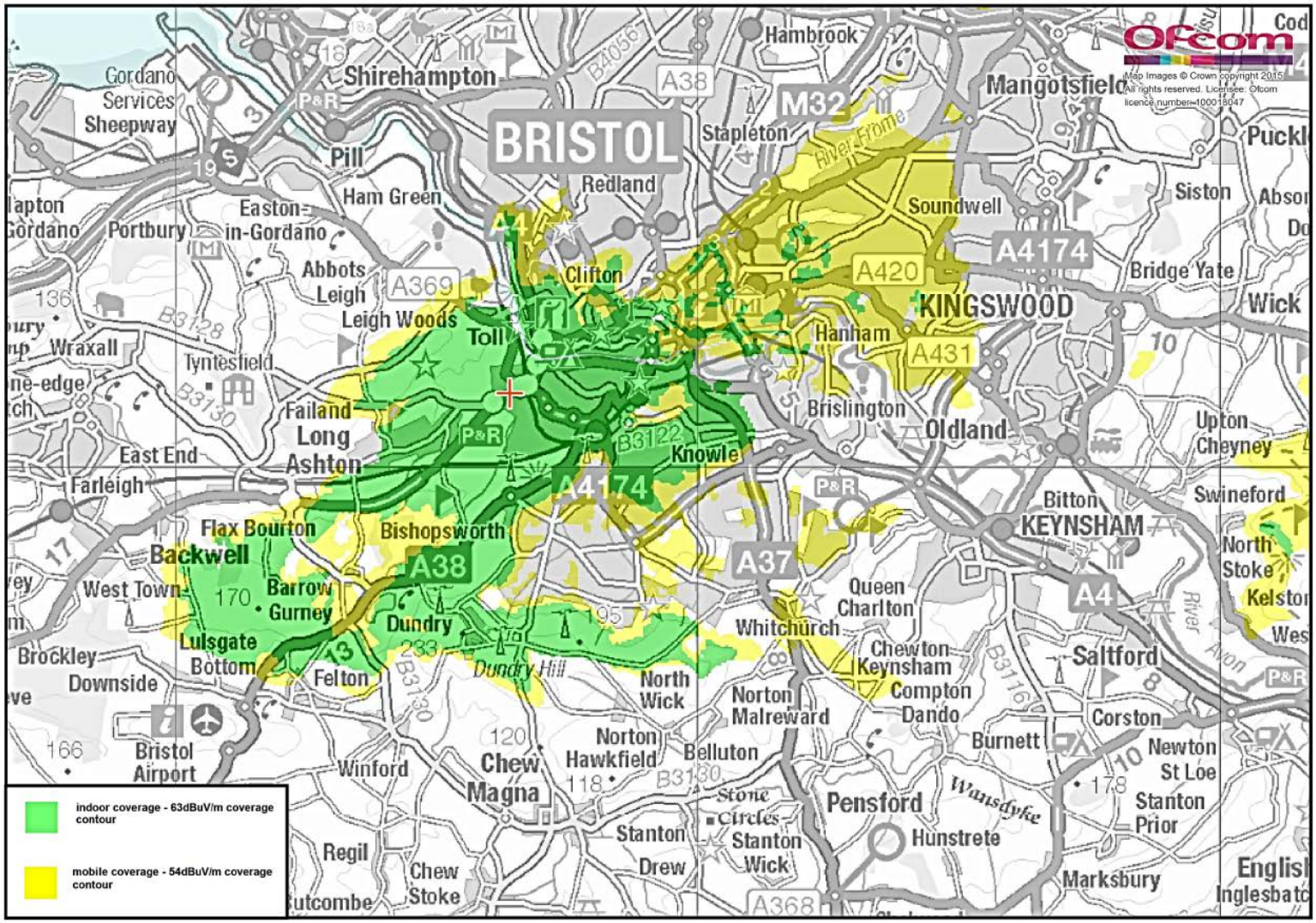
SSDAB Birmingham - Predicted coverage - in use parameters 100W ERP - 16 November 2015

Figure A1: Birmingham



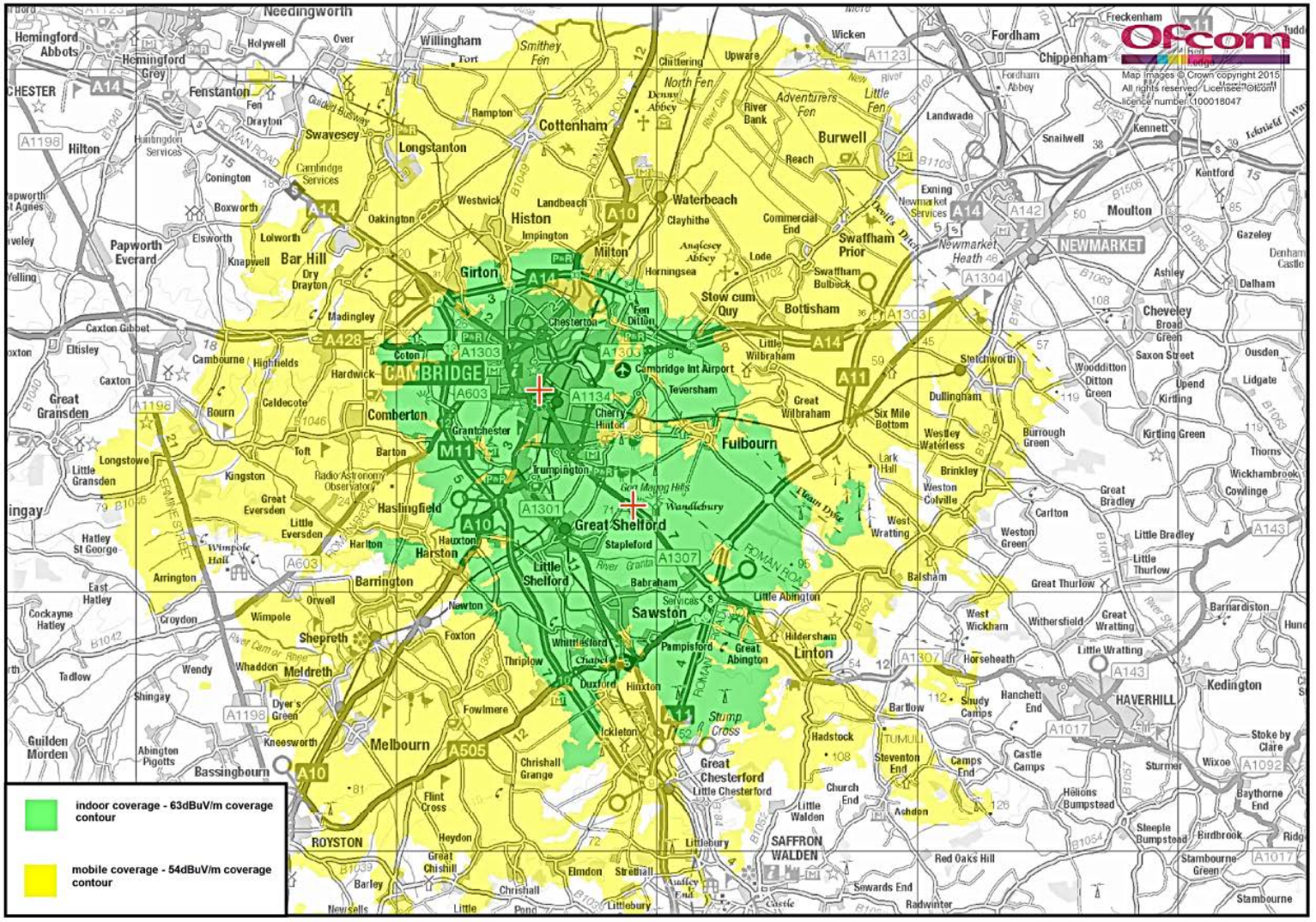
SSDAB Brighton - Predicted coverage - in use parameters 100W ERP - 16 November 2015

Figure A2: Brighton



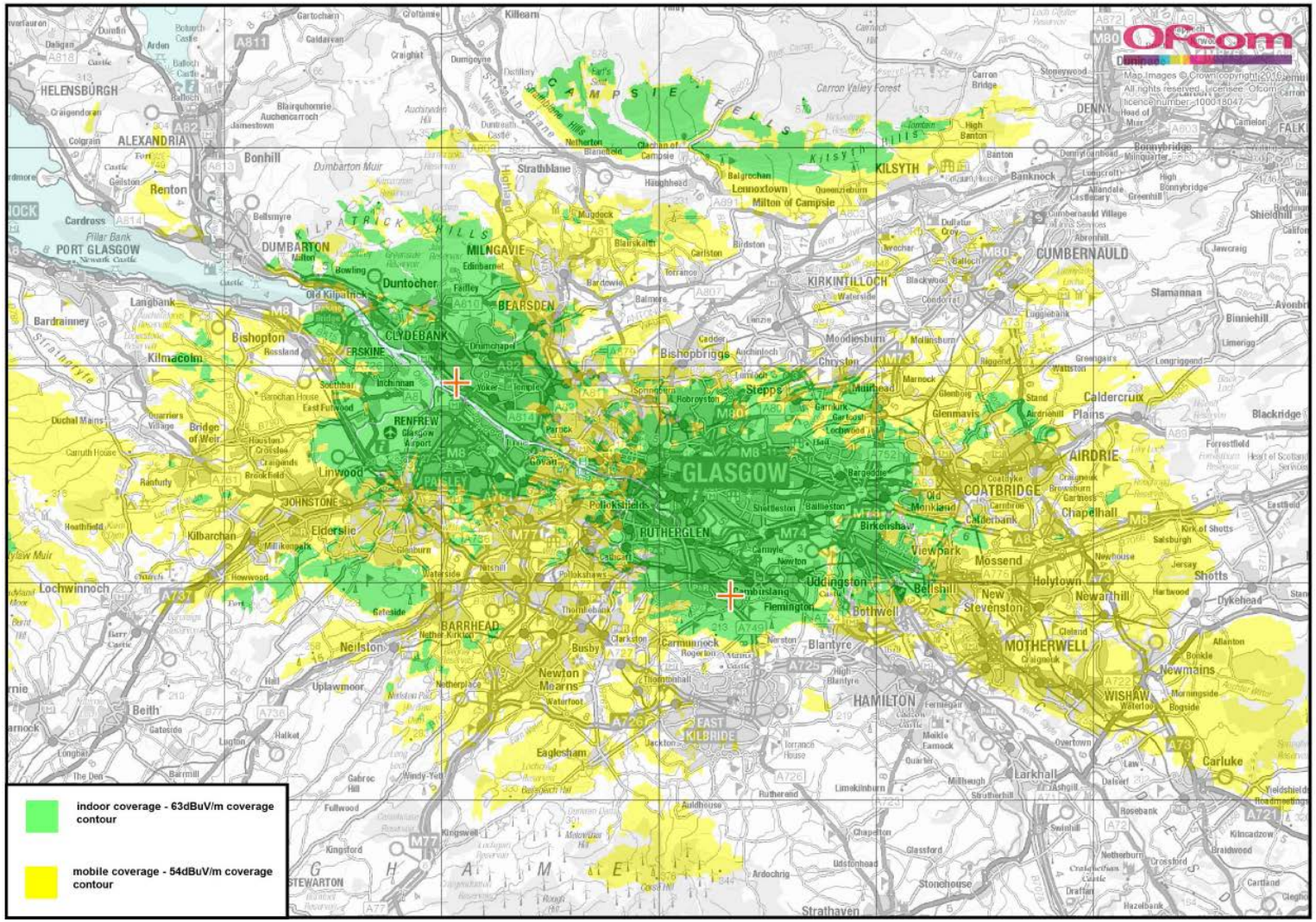
SSDAB Bristol - Predicted coverage - in use parameters 70W ERP - 16 November 2015

Figure A3: Bristol



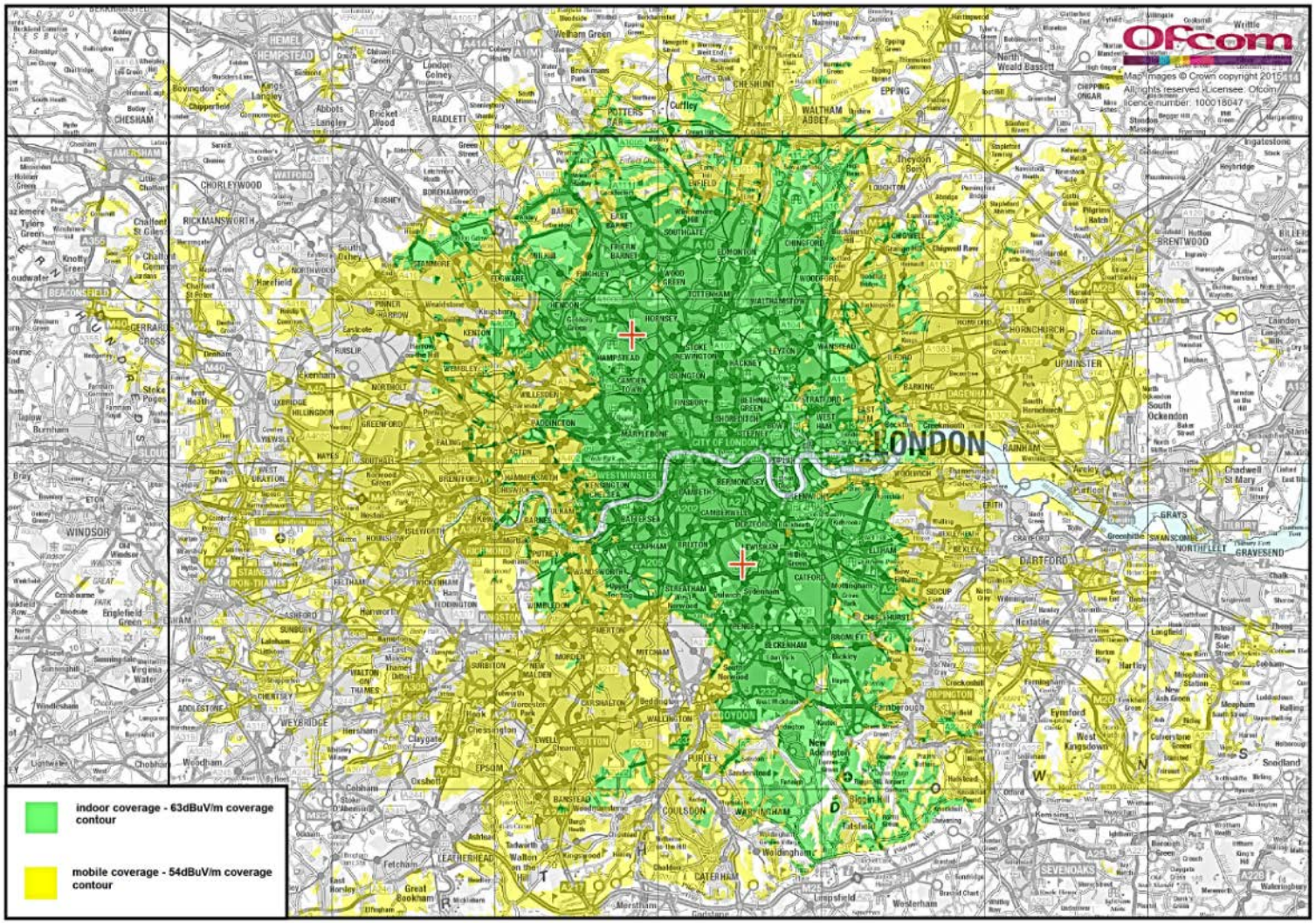
SSDAB Cambridge SFN - Predicted coverage - in use parameters 50W ERP TL455577, 100W ERP TL491533 - 17 November 2015

Figure A4: Cambridge



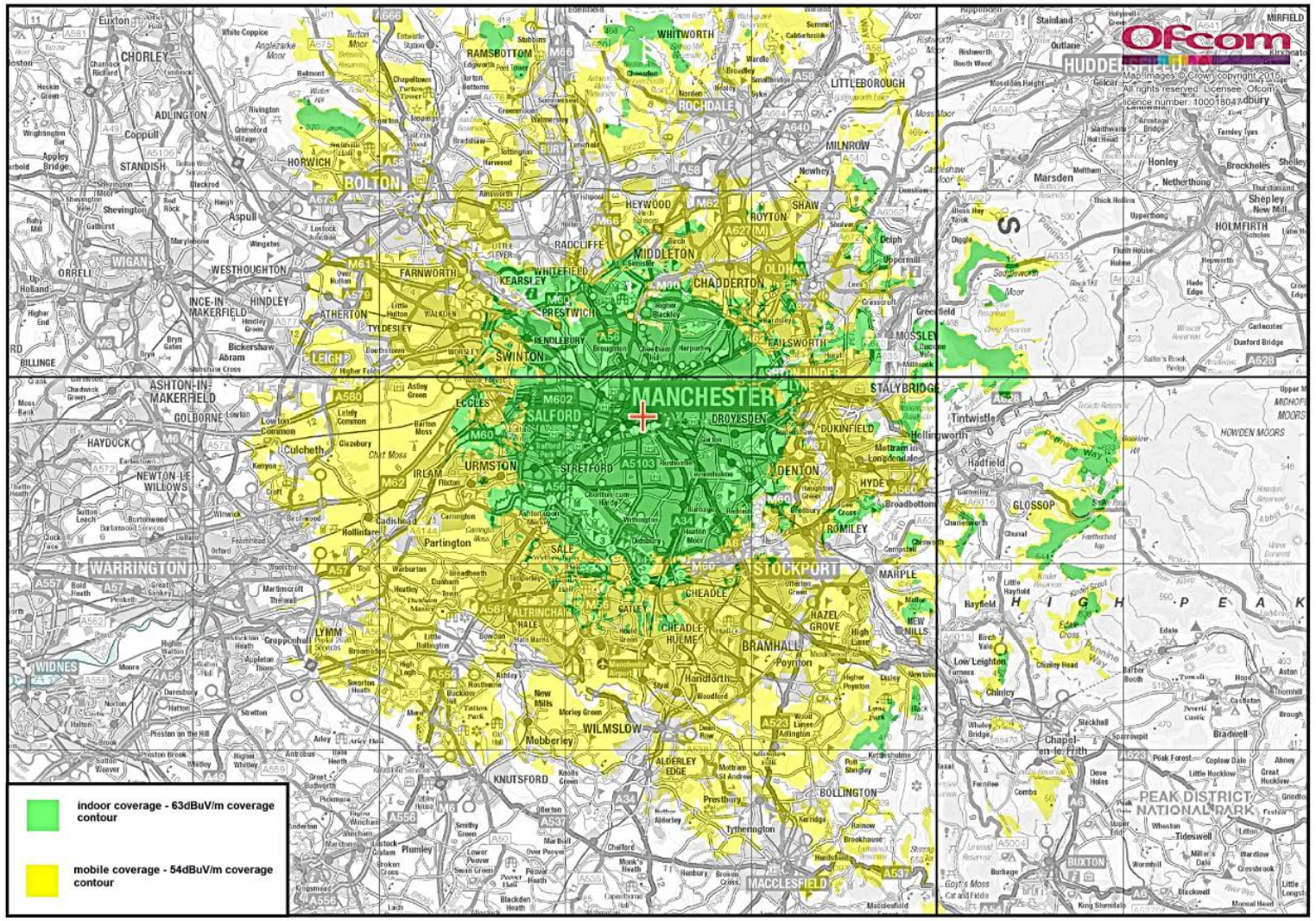
SSDAB Glasgow - Predicted coverage - 100W ERP NS 507 692 (Edmonstone Court) 52m agl and NS 633 594 (Cathkin Braes) 45m agl - omni antennas - 10 May 2016

Figure A5: Glasgow



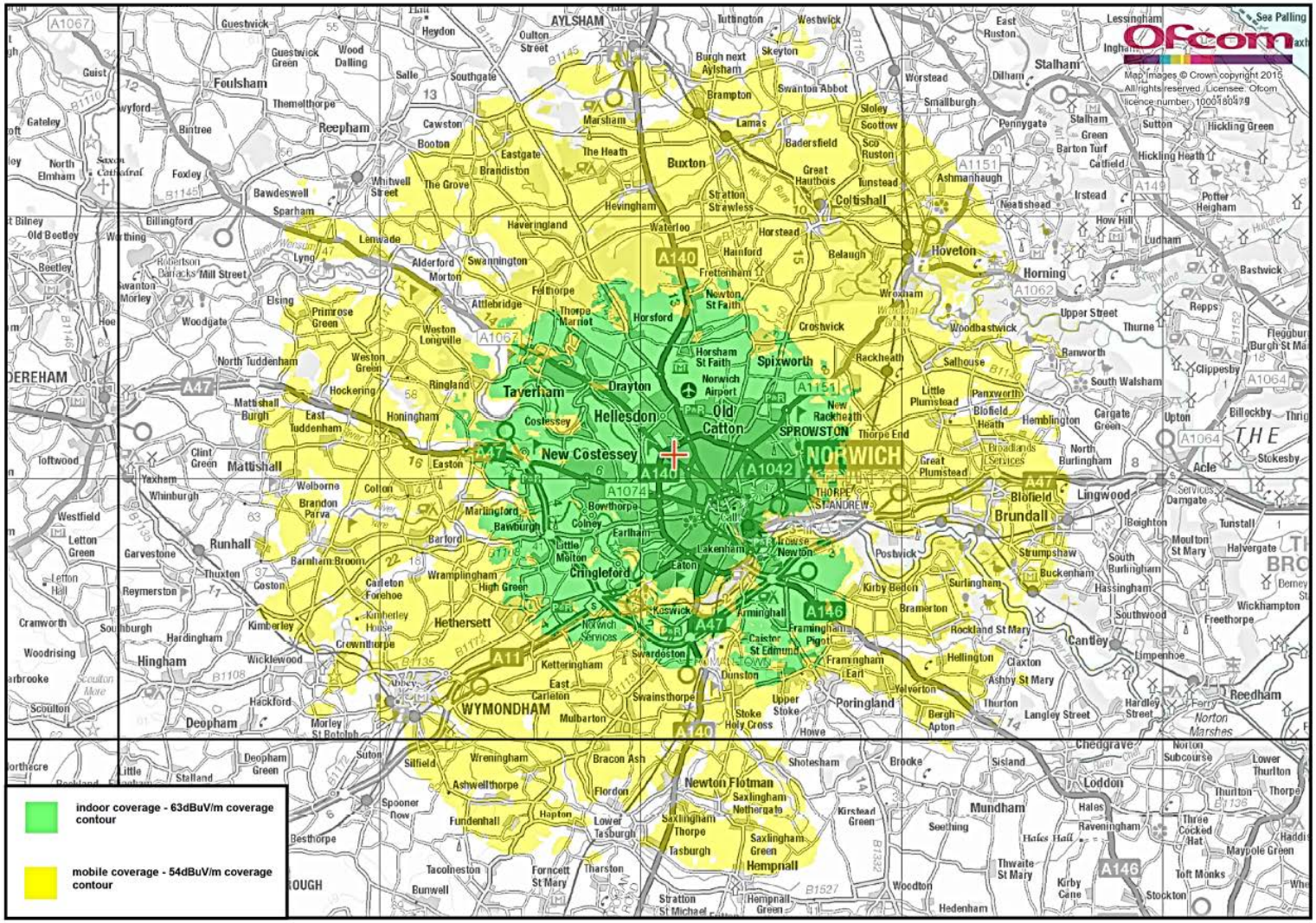
SSDAB London SFN - Predicted power summed coverage - in use parameters 200W ERP TQ352738, 200W ERP TQ284878 - 17 November 2015

Figure A6: London



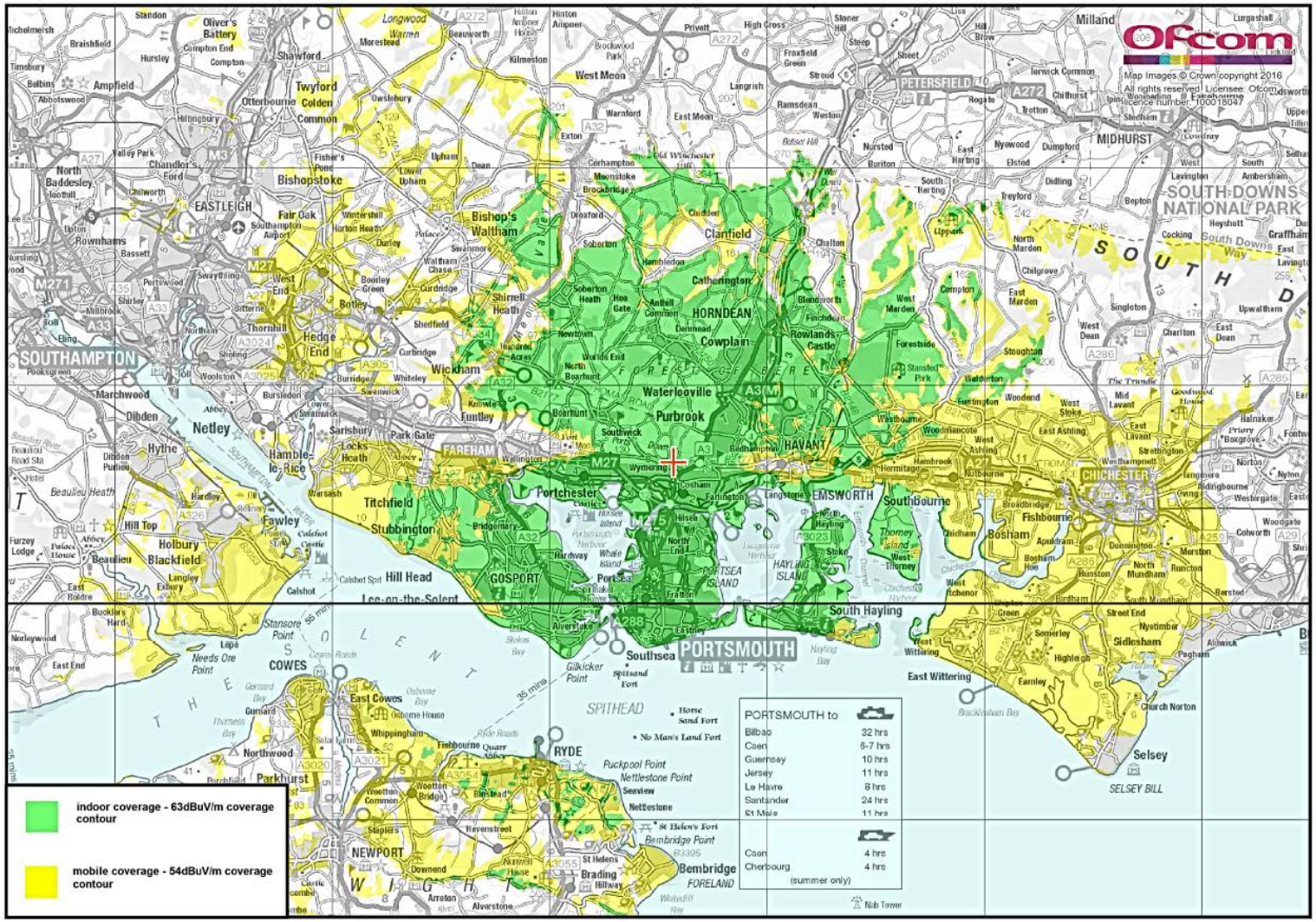
SSDAB Manchester - Predicted coverage - in use parameters 100W ERP - 17 November 2015

Figure A7: Manchester



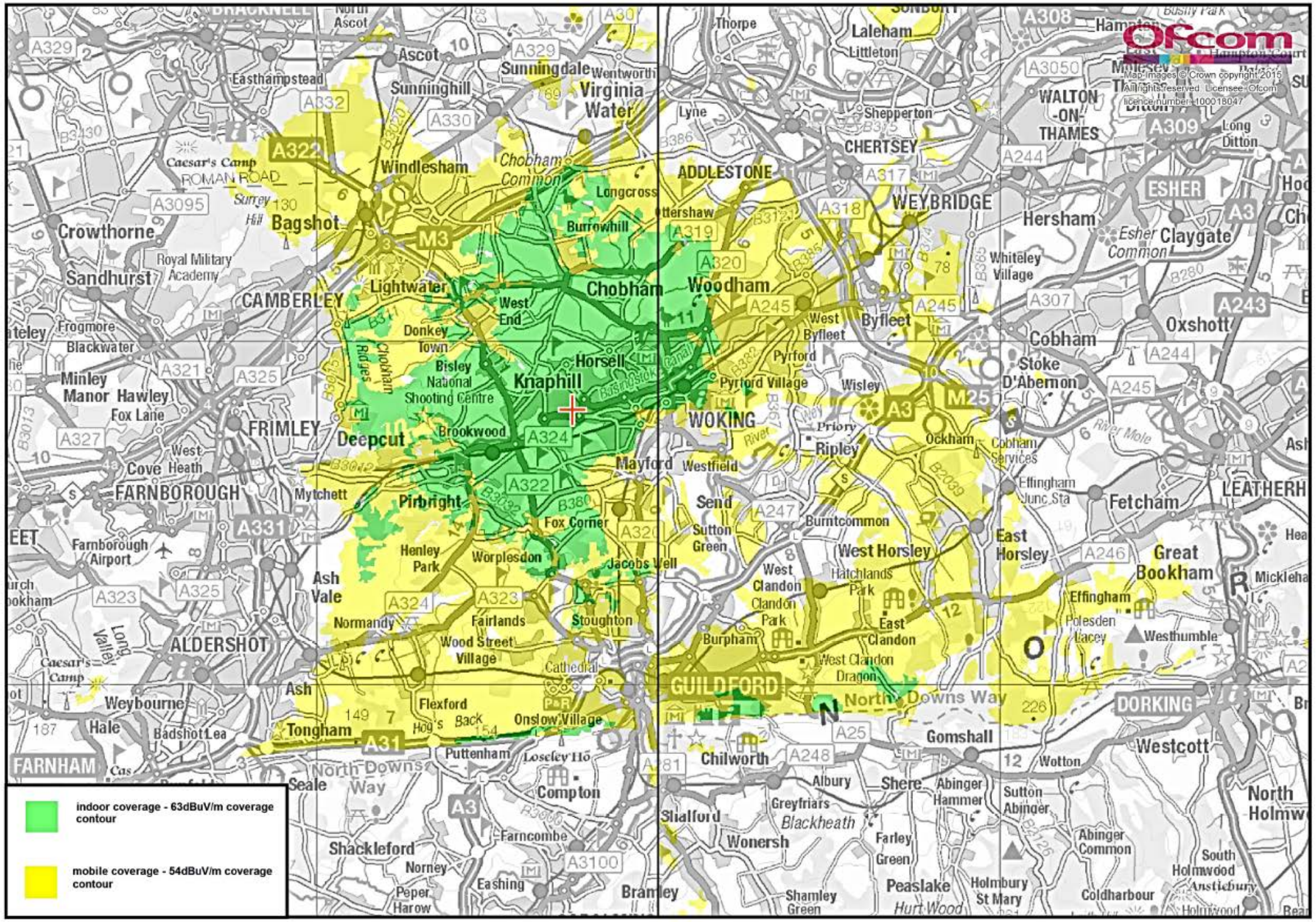
SSDAB Norwich - Predicted coverage - in use parameters 100W ERP - 16 November 2015

Figure A8: Norwich



SSDAB Portsmouth - Predicted coverage - proposed parameters 200W ERP SU 657 065 (Fort Widley) omni antenna 28m agl - 01 February 2016

Figure A9: Portsmouth



SSDAB Woking - Predicted coverage - in use parameters 100W ERP - 17 November 2015

Figure A10: Woking