Technical analysis of interference from mobile network base stations in the 800 MHz band to digital terrestrial television

Technical report

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Section 1

Executive summary

1.1 This document reports on the results of studies undertaken by Ofcom to investigate the impact of interference from future mobile network base stations (BSs) in the 800 MHz band to digital terrestrial television (DTT) services below 790 MHz.

1.2 The studies reported here consist of analysis and computer modelling based on the UK's DTT network planning model (UKPM), building on our past contributions to CEPT, and drawing on the results of a number of measurement programmes we have commissioned over the past two years.

1.3 The objectives of our studies have been two-fold:

i) To investigate and to quantify, where possible, the efficacy of technical measures to mitigate the impact of interference from mobile/fixed communication network (MFCN) base stations to individual households;

ii) To assess the UK-wide impact of interference from mobile network base stations by estimating the total number of households whose DTT reception might be affected.

Mitigation measures

1.4 In addressing the first objective, we have focused our analysis on the coverage area of the Oxford DTT transmitter. The conclusions of our modelling with regards to the effectiveness of various mitigation measures can be summarised as follows:

- Filtering at the DTT receiver – This is the most robust tool for mitigating the impact of interference from MFCN base stations. Simple filtering can virtually eliminate interference into channels 57 and below, and where receiver selectivity is the bottleneck, it can significantly reduce interference into channel 58. Filters at the receiver are not so effective where the spectral leakage from the base stations is the bottleneck, i.e., in channel 60, and partly in channel 59.

- Filtering at the base station transmitter – This is an effective mitigation measure where interference is otherwise lower-bounded by the spectral leakage of MFCN base stations; The case in point is interference from the upper blocks B and C of the 800 MHz band into channels 59 and 60, and where filtering is already applied at the DTT receiver. Filtering at the base station transmitter is not effective in mitigating interference from block A into channel 60, unless accompanied by high-performance filtering at the DTT receiver.

- Polarisation discrimination – The use of orthogonal-to-DTT polarisation at the MFCN base stations (as opposed to slant polarisation) reduces the number of affected households by a factor of between 3 to 4. This assumes an attenuation of 16 dB (as opposed to 3 dB) for base station signals arriving within the main beam of the TV aerial. However, measurements indicate that the degree of polarisation discrimination that can be achieved in practice is highly dependent on the local scattering environment and is difficult to predict.

- Reduction in base station power – Our modelling indicates that, for the examples considered, the number of households affected as a result of interference grows with an exponent of around 0.8 as a function of base station EIRP (in Watts). Furthermore, unless the aim is to provide deep indoor coverage in rural environments, the EIRPs of MFCN base stations (or the EIRPs of specific sectors) can be reduced substantially with modest degradation in MFCN downlink cell-edge throughput. Having said that, the mitigating efficacy of a reduction in EIRP can vary significantly from one site to another, and will depend on the local DTT field strength, DTT channels in use, radio propagation environment, and the spatial distribution of households.

- On-channel repeaters – Measurements indicate that OCRs are an effective mitigation tool when co-sited with MFCN base stations, and can operate robustly in around 85% of sites in the coverage area of the Oxford transmitter, so long as a coupling loss of 80 dB can be maintained between the OCR input and output. However, measurements also indicate that the ability to achieve the required coupling loss in a stable manner depends on the local clutter. Furthermore, many of the households affected by interference are likely to be located near the 15% of sites where the OCR cannot operate robustly (i.e., where DTT field strength is inadequate for rebroadcasting). We have noted that OCRs cannot mitigate the overloading of DTT receivers or amplifiers, since they only add to the total power received by the overloaded device. In such circumstances, overload can be eliminated by inserting an attenuator prior to the DTT receiver or amplifier. We have also noted that multi-channel OCRs would be required in circumstances where the degradation in signal-to-interference ratio affects more than a single channel. The viability of OCRs as a universal mitigation tool remains uncertain.

1.5 Our modelling has also indicated that, when aggregated across the coverage area of a DTT transmitter, a departure from site-sharing results in a modest increase of around 10% in the number of households affected. The reason for this modest increase is that the impact of interference to the DTT service is greatest at the edge of DTT coverage, where the size of the coverage holes created around the base station sites is large in comparison with typical separations between (unshared) sites.

Impact on DTT reception in the UK

1.6 In addressing the second objective, we have categorised UK households as belonging to one of the following three groups: standard domestic installations (SDI), communal aerial systems (CAS), and domestic installations with amplifiers (DIA).

1.7 In modelling of the impact of interference on the above categories of households we have taken the following approach:

a) We have used information from the UK Census with regards to communal dwellings, as well as estimates of the numbers of communal and domestic TV amplifiers, to build a picture of the geographic distribution of each of the three categories of household down to a 100 metre by 100 metre resolution.

b) We have used information from the digital switchover and clearance plan to build a picture of the distribution of the three categories of households across all DTT channels. This is important to ensure that households are analysed based on the most susceptible channel which they receive, and to avoid double-counting.

c) We have assumed a UK-wide LTE deployment of roughly 9,000 base stations per each of three licensees of 10 MHz bocks in the 800 MHz band.

d) We have used measured protection ratios to characterise the immunity of DVB-T receivers and TV amplifiers with respect to adjacent channel LTE interferers for each of the three categories of households.

e) We have performed computer simulations to model the impact of interference within the key coverage areas of 15 main and 15 relays DTT transmitters in England and Wales, and extrapolated the results to the rest of the UK.

f) We have generated results for three scenarios, namely where no mitigation measures are applied, where filtering is applied at the DTT receivers, and where filtering is applied both at the DTT receivers and the MFCN base stations.

1.8 The table below summarises the results[1] of our modelling in terms of the estimated numbers of households whose DTT service might be affected in the UK.

	Standard installations	Communal aerial systems	Domestic installations with amplifiers	Total
	Number of households served			
	16,299,699	5,213,819	5,655,629	27,169,147
	Number of households affected by interference			
No mitigation	115,212	521,619	115,058	751,889
Filtering at DTT receiver	32,942	4,128	10,260	47,329
Filtering at DTT receiver & BS transmitter	23,167	44	7,405	30,617

1.9 Since the consultation was published on 2 June some of the results of the modelling have changed as a result of final validation and checking. We consider these changes as minor and furthermore do not consider that these changes alter the policy conclusions we draw in the consultation. Specifically the first change occurs along the row labelled “No mitigation” in the above table. The differences in this row from the numbers published in the consultation are a result of final refinements to the methodology we used to balance differences between household data from the digital switchover plans and national census data. This methodology is explained in Section 7 and Annex 7. The second change occurs in the row labelled “Filtering at DTT receiver”. The differences here are due to the final verification of the post-processing of the modelling results used to generate the final output numbers in this row.

1.10 The following tables present a breakdown of the above results by DTT channel.

[1] The estimates are presented with a large number of significant figures in order to help with the traceability of the calculations. This should not be construed as an indication of the accuracy of the estimates.

No mitigation	Number of households affected by interference			
DTT channel	Standard domestic installations	Communal aerial systems	Domestic installations with amplifiers	Total
60	34,662	41,177	12,303	88,142
59	14[2]	48,335	14,085	62,434
58	5,504	16,333	3,723	25,560
57-51	25,537	23,863	7,865	57,265
≤50	49,494	391,912	77,082	518,488
Total	115,212	521,619	115,058	751,889

Filtering at DTT receiver	Number of households affected by interference			
DTT channel	Standard domestic installations	Communal aerial systems	Domestic installations with amplifiers	Total
60	28,890	2,916	8,251	40,057
59	3,654	1,201	1,952	6,807
58	189	11	45	245
57-51	79	0	11	90
≤50	131	0	0	131
Total	32,942	4,128	10,260	47,329

Filtering at DTT receiver & BS transmitter	Number of households affected by interference			
DTT channel	Standard domestic installations	Communal aerial systems	Domestic installations with amplifiers	Total
60	21,014	39	5,891	26,944
59	1,861	5	1,484	3,350
58	50	0	19	69
57-51	113	0	10	123
≤50	131	0	0	131
Total	23,167	44	7,405	30,617

The results indicate the following:

1) A large proportion of households in communal aerial systems would be affected by interference in the absence of mitigation measures. This is due to the overloading of the launch amplifier used in these systems, and the resulting (comparatively) frequency agnostic nature of the protection ratios (adjacent-channel immunity).

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[2] Households which receiver channel 59 from a main transmitter also receiver a more susceptible channel, and are therefore counted in a different row

2) A larger proportion of domestic installations with amplifiers would be affected by interference as compared to standard domestic installations. This is again due to the overloading of the domestic amplifiers, and the resulting (comparatively) frequency agnostic nature of the protection ratios.

3) Filtering at the DTT receiver (pre-amplifier) is very effective in mitigating the impact of interference in channel 58 and below. Note that we have assumed low-cost filters for domestic installations, and more costly high-performance filters for communal aerial systems.

4) The addition of filtering at the base station transmitter virtually eliminates the impact of interference to households in communal aerial systems. This is because the high-performance DTT receiver (pre-amplifier) filtering assumed in these systems fully exploits the resulting reduction in base station spectral leakage.

5) The addition of filtering at the base station transmitter is not as affective a mitigation tool for domestic installations, as is evidenced by the more modest reductions in the number of households affected in channel 59, and particularly channel 60. This is because the low-cost DTT receiver filtering assumed for these households remains the bottle-neck. Here, the observed reductions in affected households are primarily due to the mitigation of interference from blocks B and C, where the low-cost receiver filtering is effective.

Assumptions, caveats, and uncertainties

1.11 As is inevitable in any study of the type presented in this document, we have made assumptions with regards to the values of a large number of parameters. These relate to

- the quality of DTT coverage in the UK,
- the nature of the mobile network deployment,
- the characteristics of radio propagation,
- the adjacent channel immunity of DTT receivers and amplifiers,
- the numbers of households in the UK associated with each the three categories of receiver installation.

1.12 In much of our work we have adopted parameter values which we believe capture the bulk of the interference issues. Nevertheless, it is important to note the following factors in interpreting the results:

1) In relation to the quality of DTT coverage in the UK, we have based our modelling on the UK DTT planning model (UKPM). This characterises DTT coverage via roof-top reception at a height of 10 metres with a *standard* TV aerial. Absent alternative baselines, we have used the UKPM to also characterise DTT coverage for communal aerial systems. In practice, the antennas in such systems are more likely to be installed at greater heights (receive higher DTT field strengths) and may have better gain and angular discrimination than we have modelled.

2) In relation to the nature of mobile network, we have assumed deployment at roughly 9,000 sites UK-wide by each of three licensees. Full site-sharing is

assumed (i.e., 27,000 base stations in 9,000 sites). This is consistent with the deployment of an existing GSM-900 network. We have also assumed that each base station radiates at a nominal 59 dBm per 10 MHz channel. Greater powers would only be required for the provision of deep indoor coverage in rural areas. Greater numbers of base stations operating at the same nominal power would inevitably increase the number of household affected by interference. However, to the extent that higher densities of base stations would most likely be deployed for the provision of increased capacity, they can operate at reduced powers, thereby mitigating the impact of interference to the DTT service.

3) In relation to the nature of radio propagation, we have adopted the suburban extended-Hata model with a log-normal shadowing standard deviation that varies as a function of distance between the transmitter and receiver. The model is consistent with the result of our propagation measurements in Tamworth. We estimate that that roughly 3%, 70%, and 27% of the UK population reside in what can be categorised as urban, suburban, and rural radio propagation environments, respectively. The adopted suburban model over-estimates the impact of interference in urban areas, and slightly under-estimates the impact of interference in rural areas.

4) In relation to the performance of the DTT receivers, our measurements indicate a wide range of behaviours among the equipment available in the UK market. Here we have adopted a cautious approach by using MFCN-to-DTT protection ratios that are biased towards to worst-performing DTT receivers.

5) In relation to the performance of communal aerial (launch) amplifiers and domestic amplifiers, we have not had the opportunity to test a large number of these devices. As such, we are less certain of their behaviour.

6) We have used independent estimates of the number of domestic amplifiers (masthead and indoor) in the UK which serve primary DTT receivers in order to quantify the proportion of domestic installations which use an amplifier. Absent any reliable guidelines, we have applied this proportion uniformly to every 100m ×100m pixel throughout the UK. In practice, it is likely that the proportion of domestic installations with amplifiers is greater in areas with poor DTT coverage, where by implication they would also be more susceptible to interference from MFCN base stations.

1.13 Finally, note that in order for the calculations contained herein to be repeatable and transparent, we have presented certain values with up to two decimal places. This should not be construed as an indication of the accuracy of the estimates.

Section 2

Introduction

2.1 On 2 June 2011[3] we published a consultation regarding the coexistence of new services in the 800 MHz band with digital terrestrial television. In this, we described at a high level the technical work we have undertaken in investigating and considering how to manage potential interference to DTT reception. Based on the results of this work, we set out proposals on the preferred mitigation options and the implementation measures that would be needed to deliver mitigation.

2.2 This technical report sets out full details of the technical analysis and modelling that we have undertaken to inform our policy proposals. This includes an explanation of the methodology and parameters we have used and the results of the modelling.

2.3 Separate to this report, we are also publishing reports of technical studies which we commissioned in support of our internal technical work. These include:

- "The impact of LTE on Communal Aerial Systems", Mandercom,
- "Masthead and indoor amplifiers for TV signal reception and distribution", Mandercom.
- "The co-existence of LTE and DTT services at UHF: a field trial", Aegis[4].

These reports will be published on our website at: http://stakeholders.ofcom.org.uk/consultations/coexistence-with-dtt/

2.4 The rest of this document is structured as follows:

- In Section 3, we explain the background to the technical studies performed in CEPT with regards to the introduction new services in the 800 MHz band;
- In Section 4, we provide a detailed description of the methodology we have used for quantifying the effect of interference from MFCN base stations to DTT;
- In Section 5, we discuss the key parameter values that we have used for the purposes of modelling in this report (see also Annex 1);
- In Section 6, we describe and present the results of our analysis of potential mitigation measures, using the impact in the coverage area of the Oxford DTT transmitter to illustrate these;
- In Sections 7 through 10, we describe three categories of DTT receiver installations that we have investigated and set out the results of our UK-wide modelling for each category;
- In Section 11, we summarise the main conclusions of our technical analysis.

[3] http://stakeholders.ofcom.org.uk/binaries/consultations/dtt/summary/dttcondoc.pdf.
[4] We note that the field trial report is currently in preparation and may be published somewhat later than this technical report.

Section 3

Background

3.1 The switchover from analogue to digital terrestrial television (DTT), expected to be completed in Europe by the end of 2012, will free up 72 MHz of spectrum at the top of the UHF TV band. This so-called *Digital Dividend* provides a unique opportunity to meet the demand for spectrum by next generation mobile communications services.

3.2 However, the deployment of mobile networks in frequencies adjacent to those used by DTT networks is inevitably accompanied by a high risk of interference.

3.3 In recognition of this, in 2008 the European Commission (EC) issued a mandate[5] to the Conference of European Post and Telecommunications Administrations (CEPT) to define technical conditions for use of the 790-862 MHz Digital Dividend spectrum by mobile/fixed communication networks (MFCNs).

3.4 The main objective of this work was to ensure the timely development of the technical conditions required to pave the way for non-mandatory, non-exclusive, and coordinated use of the Digital Dividend in Europe.

3.5 In response to Task 1 of the EC mandate, the ECC/SE42 project team defined a set of least restrictive technical conditions (emission limits) for the use of the Digital Dividend spectrum by MFCN base stations and terminal stations. These accounted for both interference from MFCNs to DTT services, and interference among MFCNs.

3.6 In response to Task 2 of the EC mandate, the ECC/PT1 project team identified appropriate band plans for the use of the Digital Dividend spectrum by MFCNs.

3.7 In October 2009 CEPT adopted ECC Decision 09(03)[6] based on the outcome of the above studies. This work culminated in 2010 with Commission Decision 2010/267/EU[7] which includes most (but not all) of the technical conditions specified in ECC Decision 09(03).

3.8 The technical conditions contained in the Commission Decision are legally binding on all member states of the European Union (EU) who wish to free up the 790-862 MHz band for use by MFCNs.

3.9 These conditions were agreed in the knowledge that adherence to them would not completely remove the risk of interference. The Decision recognised that further measures tailored to fit the specific circumstances of Member States could be applied at a national level to mitigate this risk.

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[5] EC second mandate to CEPT on technical considerations regarding harmonisation options for the digital dividend in the European Union, Apr. 2008.

[6] ECC Decision (09)03 on harmonised conditions for Mobile/Fixed Communications Networks operating in the band 790-862 MHz, Oct. 2009, www.erodocdb.dk.

[7] Commission Decision 2010/267/EU on harmonised technical conditions of use in the 790-862 MHz frequency band for terrestrial systems capable of providing electronic communications services in the European Union, May 2010.
Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010D0267:EN:NOT.

3.10 Given the above background, the objective of the present technical report is two-fold:

1) To assess the impact of interference to the DTT service subject to adherence by MFCNs to the technical conditions set out in the Commission Decision.

2) To investigate the technical efficacy of a number of technical measures in mitigating the impact of interference.

3.11 In this section, we outline[8] the relevant band-plans and technical conditions (in-block and out-of-block emission limits) which were specified by the CEPT. For completeness, we include the emission limits for both MFCN base stations and terminal stations. These are used as a basis for the modelling reported in this document.

European harmonised band plans for the 790-862 MHz band

3.12 Figure 1 shows the European preferred harmonized frequency arrangement for MFCNs as specified by ECC/PT1. This consists of a frequency-division duplex (FDD) channelling arrangement of 2×30 MHz, based on a block size of 5 MHz, a duplex gap of 11 MHz, and a duplex spacing of 41 MHz. The FDD downlink starts at 791 MHz and the FDD uplink starts at 832 MHz (reverse duplex). This implies a 1 MHz guard band between MFCN and DTT services.

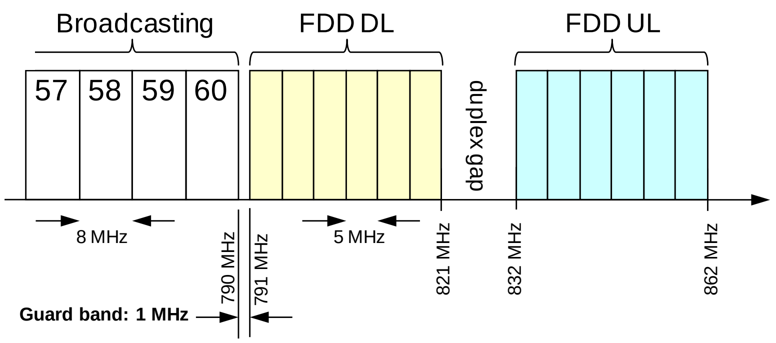

Figure 1. The European preferred (FDD) frequency arrangement.

3.13 ECC/PT1 also considered the possibility of alternative band plans for use by national administrations which do not wish to use the above preferred harmonized frequency arrangement. These alternatives include a) partial implementations of the preferred (FDD) frequency arrangement, b) frequency arrangements for time-division duplex (TDD) operation in all or part of the 790-862 MHz band, and c) frequency arrangements for mixed introduction of TDD and FDD. Specifically, the frequency arrangements for TDD operation consist of a minimum guard band of 7 MHz (from 790 to 797 MHz) for the protection of broadcasting from the MFCN uplink. This is illustrated in Figure 2.

[8] For a concise description of the underlying assumptions made in the derivation of the CEPT band-plans and technical conditions see: H.R.Karimi, M.Fenton, G.Lapierre, E.Fournier, "European harmonized technical conditions and band-plans for broadband wireless access in the 790-862 MHz Digital Dividend spectrum," in *Proc. Dynamic Spectrum Access Networks* (IEEE-DySPAN), Apr. 2010, Singapore.

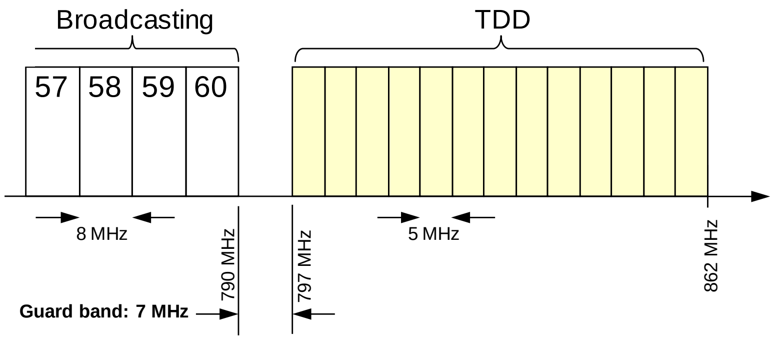

Figure 2. Frequency arrangement for TDD.

3.14 For the specific purposes of this report (and without prejudice to the eventual outcome of the UK auction) only, we consider the FDD frequency arrangement with three MFCN licensees over 791-862 MHz, each with a 10 MHz channel bandwidth. As shown in Figure 3, the 10 MHz blocks will be referred to as “A”, “B”, and “C”, respectively.

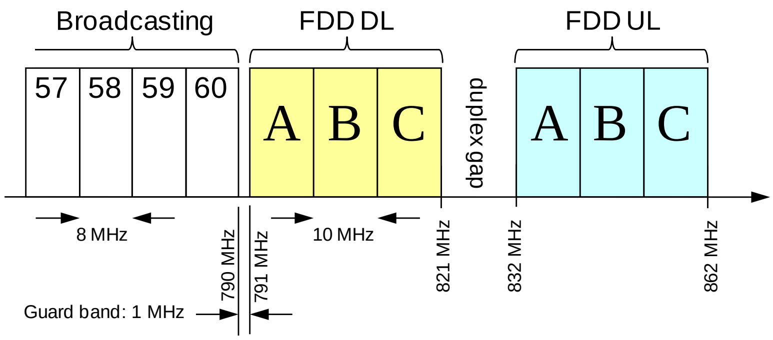

Figure 3. Frequency arrangement used in this study.

European harmonised emission limits for MFCN base stations

In-block limit

3.15 In-block power refers to the power radiated by a transmitter over its channel bandwidth. This power corresponds to that portion of the signal which is intended for reception by a specific receiver.

3.16 ECC/SE42 concluded that there is no need to specify a harmonized regulatory in-block EIRP limit for MFCN base stations. If required, such a limit may be specified by administrations in accordance with national circumstances, and is likely to range from 56 to 64 dBm/(5 MHz).

Out-of-block limits (for protection of broadcasting services)

3.17 Out-of-block power refers to the power radiated by a transmitter outside its channel bandwidth. This power corresponds to a portion of the signal that is not intended for reception by any receivers.

3.18 Table 1 presents the out-of-block *baseline* requirements for MFCN base stations over the spectrum allocated to broadcasting (DTT) services. The relationship between in-block and out-of-block EIRPs is also illustrated in Figure 4.

Table 1. Baseline requirements for base station out-of-block EIRP limits over frequencies occupied by broadcasting.

	Frequency range of out-of-block emissions	Condition on base station in-block EIRP, P dBm/(10 MHz)	Maximum mean out-of-block EIRP dBm/(8 MHz)
A	For DTT frequencies where broadcasting is protected	P ≥ 59	0
		36 ≤ P < 59	(P–59)
		P < 36	–23
B	For DTT frequencies where broadcasting is subject to an intermediate level of protection	P ≥ 59	10
		36 ≤ P < 59	(P–49)
		P < 36	–13
C	For DTT frequencies where broadcasting is not protected	No conditions	22

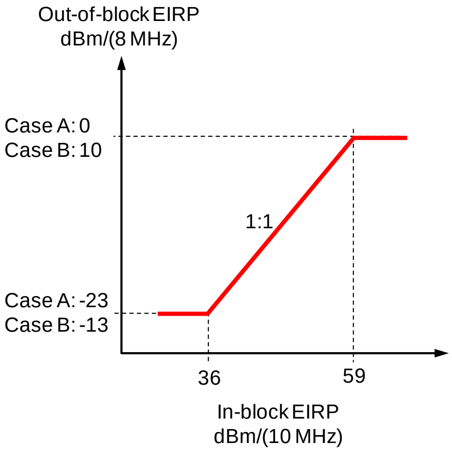

Figure 4. Relationship between base station in-block and out-of-block EIRP limits.

3.19 The three different cases A, B, and C described in Table 1 above can be applied on a per-channel and/or per-region basis. In other words, for the same DTT channel different cases can be applied in different geographic areas (e.g., based on DTT coverage), and different cases can be applied to different channels in the same geographic area.

3.20 Other baseline requirements can be applied in specific circumstances subject to agreements between the broadcasting authority, MFCN operators and the administration if required.

3.21 Given the objectives of this report, we assume that MFCN base stations comply with the out-of-block limits of case A over DTT channel 60. In practice, emission levels reduce with increasing frequency offset from the carrier. As a result, we assume that the base station out-of-block emissions over channels 59 and below are accordingly lower than those specified in Table 1 (see Sections 5 and 6).

European harmonised emission limits for MFCN terminal stations

3.22 The emission limits were specified by ECC/SE42 in terms of EIRP for those terminal stations designed to be fixed or installed, and as total radiated power[9] (TRP) for those terminal stations designed to be mobile or nomadic.

In-block limit

3.23 ECC/SE42 set the maximum value of the in-block emission level for FDD or TDD terminal stations to 23 dBm.

3.24 Administrations may relax this limit in certain situations, for example in the case of fixed terminal stations in rural areas, providing that protection of other services, networks and applications is not compromised and cross-border obligations are fulfilled.

Out-of-band limit (for protection of broadcasting services)

3.25 Table 2 presents the out-of-block baseline requirements for MFCN terminal stations over the spectrum allocated to DTT services.

Frequency range of out-of-band emissions	Maximum mean out-of-band power
Frequencies allocated to broadcasting	–65 dBm/(8 MHz)

Table 2. Baseline requirements for terminal station out-of-band emission limits over frequencies occupied by broadcasting.

[9] TRP is a measure of how much power the antenna actually radiates. The TRP is defined as the integral of the power transmitted in different directions over the entire radiation sphere. For an isotropic antenna radiation pattern, EIRP and TRP are equivalent. For a directional antenna radiation pattern, EIRP in the direction of the main beam is (by definition) greater than the TRP.

Section 4

Modelling the impact of interference

Introduction

4.1 In 2009 we specified a methodology for quantifying the impact of interference from MFCN base stations in the 800 MHz band to DTT services below 790 MHz. This built on our experience of CEPT studies[10,11] undertaken over the previous year, and was designed to account for specific aspects of the UK's DTT network.

4.2 We subsequently commissioned Arqiva to implement a software tool in order to implement our proposed modelling methodology based on the output of the UK's DTT network planning model[12] (UKPM). We refer to this modelling tool as *Punch*, in reference to the coverage holes "punched" in the vicinity of MFCN base stations.

4.3 In this section we present a detailed description of our methodology, and the internal workings of Punch:

- We first introduce the concept of DTT location probability as used for purposes of DTT network planning in the UK. We then explain how the UKPM calculates this for every 100 metre by 100 metre pixel throughout the UK.

- We then explain how the degradation in DTT location probability (caused by emissions from MFCN base stations) can be calculated for each pixel. This quantifies how interference impacts DTT coverage through a combination of degradation in signal-to-interference-plus noise ratio (SINR) and receiver overload.

- We also present an approach to calculate the probability that DTT receiver failure within a pixel is due to receiver overload only.

- We finally describe how the number of households affected (either through a combination of SINR degradation and receiver overload, or due to overload only) can be quantified via proportional counting.

4.4 The methodologies presented in this section have been used in all the computer modelling presented in this document.

[10] H.R.Karimi, G.Lapierre, Terry O'Leary, Walid Sami, "Computation of block-edge masks for mobile communication network base stations in the 790-862 MHz Digital Dividend spectrum," in *Proc. Global Mobile Congress* (GMC), Oct. 2009, Shanghai – China. Available from IEEE Explore.
[11] H.R.Karimi, G.Warren, M.Fenton, et al. "Block-edge mask baseline limits for mobile communication network base stations in the 790-862 MHz Digital Dividend spectrum," in *Proc. Dynamic Spectrum Access Networks* (IEEE-DySPAN), Apr. 2010, Singapore. Available from IEEE Explore.
[12] For the planning of coverage based on fixed roof-top reception of DTT.

Modelling of DTT reception in the UK

Probability of DTT receiver failure

4.5 Consider a noise-limited environment, where the only source of disturbance to DTT reception is additive white Gaussian thermal noise. Then, the probability of failure of a DTT receiver can be written (in the linear domain) as

$$\begin{aligned} P_{\mathrm{F}} &= \Pr\left\{\mathrm{SNR} < \mathrm{SNR}_{\min}\right\} = \Pr\left\{\frac{P_{\mathrm{S}}}{P_{\mathrm{N}}} < \mathrm{SNR}_{\min}\right\} \\ &= \Pr\left\{P_{\mathrm{S}} < \mathrm{SNR}_{\min} P_{\mathrm{N}}\right\} = \Pr\left\{P_{\mathrm{S}} < P_{\mathrm{S,min}}\right\} \end{aligned} \quad (1)$$

where $\Pr\{\mathrm{A}\}$ represents the probability of event A, SNR is the experienced signal-to-noise ratio at the DTT receiver, $\mathrm{SNR}_{\min}$ is the minimum SNR required for correct operation, P_{S} is the wanted signal power at the DTT receiver, P_{N} is the thermal noise power, and $P_{\mathrm{S,min}}$ is the minimum wanted signal power required for correct operation (reference sensitivity level).

4.6 Now consider an interference-limited environment, where the dominant source of disturbance to DTT reception is an interfering signal (co-channel or adjacent channel) received at a power level P_U. Then, the probability of failure for the DTT receiver can be written as

$$P_{\mathrm{F}} = \Pr\left\{\frac{P_{\mathrm{S}}}{P_U} < r\right\} = \Pr\left\{P_{\mathrm{S}} < r\, P_U\right\} \quad (2)$$

4.7 where the protection ratio, r, is the minimum ratio of wanted DTT signal power to interferer power required for correct operation of the DTT receiver.

4.8 In an environment where there is contribution from both thermal noise and a total of K interferers, we may extend (2) by writing

$$P_{\mathrm{F}} = \Pr\left\{P_{\mathrm{S}} < \mathrm{SNR}_{\min} P_{\mathrm{N}} + \sum_{k=1}^{K} r_{U,k}\, P_{U,k}\right\}. \quad (3)$$

4.9 The following points should be noted:

- If the k^{th} interferer is co-channel, and has a structure which is similar to additive white Gaussian noise, then we have $r_{U,k} = \mathrm{SNR}_{\min}$.
- For Equation (3) to be consistent, it is important that $\mathrm{SNR}_{\min}$ and $r_{U,k}$ both correspond to the same level of subjective degradation in DTT reception; i.e., that noise and interference are treated equally.

Definition of DTT location probability

4.10 The UKPM calculates the DTT *location probability*, q, for every 100m × 100m *pixel* across the UK. This is defined as the probability with which wanted and unwanted DTT signal powers meet the relevant criterion for the correct operation of a DTT receiver. Specifically, the location probability can be written (in the linear domain) as

$$
\begin{aligned}
q &= \Pr\left\{P_{\mathrm{S}} \geq \ \mathrm{SNR}_{\min} P_{\mathrm{N}} + \sum_{k=1}^{K} r_{U,k} P_{U,k}\right\} \\
&= \Pr\left\{P_{\mathrm{S}} \geq \ P_{\mathrm{S},\min} + \sum_{k=1}^{K} r_{U,k} P_{U,k}\right\} \\
&= \Pr\left\{P_{\mathrm{S}} \geq U\right\},
\end{aligned}
\tag{4}
$$

where

P_{S}	is the wanted signal power at the DTT receiver,
P_{N}	is the thermal noise power,
$\mathrm{SNR}_{\min}$	is the minimum SNR required for *correct* operation,
$P_{S,\min}$	is the minimum received wanted signal power required for *correct* operation in a noise-limited environment,
K	is the number of (co-channel and/or adjacent-channel) DTT interferers,
$P_{U,k}$	is the received power level of the k^{th} DTT interferer, and
$r_{U,k}$	is the minimum ratio of wanted DTT signal power to DTT interferer power required for *correct* operation (DTT-to-DTT protection ratio).

4.11 Re-writing, we have

$$
q = \Pr\left\{\frac{P_{\mathrm{S}}}{U} \geq 1\right\} = \Pr\left\{P_{\mathrm{S\,(dBm)}} - U_{\mathrm{(dBm)}} \geq 0\right\}. \tag{5}
$$

4.12 In the planning of DTT networks, $P_{\mathrm{S\,(dBm)}}$ and each of the individual terms $P_{U,k\,\mathrm{(dBm)}}$ are modelled as real Gaussian random variables. Note that in (4), the powers are summed in the linear domain. For this reason, the most accurate way of calculating the probability q is to use Monte Carlo simulations whereby a large number of trials are performed with values for each random variable generated according to their log-normal distributions and then summed.

4.13 However, the UKPM uses an approximation whereby the terms $P_{\mathrm{S\,(dBm)}}$ and $U_{\mathrm{(dBm)}}$ are approximated as Gaussian random variables with medians $m_{\mathrm{S\,(dBm)}}$ and $m_{U\,\mathrm{(dBm)}}$, and standard deviations $\sigma_{\mathrm{S\,(dB)}}$ and $\sigma_{U\,\mathrm{(dB)}}$, respectively. The terms $m_{U\,\mathrm{(dBm)}}$ and $\sigma_{U\,\mathrm{(dB)}}$ are then derived via the Schwartz-Yeh algorithm. The relationship between q, P_{S} and U in a pixel is illustrated in Figure 5 below.

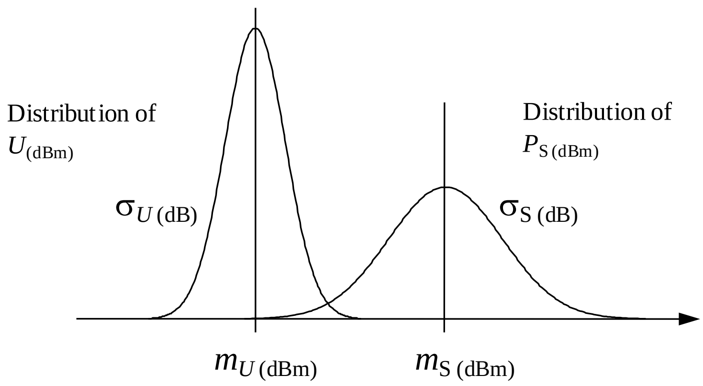

Figure 5. Distributions of wanted DTT power and DTT-to-DTT interference power in a pixel.

4.14 From Equation (5), and based on the above approximation, the location probability in each pixel can be readily expressed in closed form as

$$q = 1 - \frac{1}{2}\operatorname{erfc}\left\{ \frac{1}{\sqrt{2}} \frac{m_{\mathrm{S}\,(\mathrm{dBm})} - m_{U\,(\mathrm{dBm})}}{\sqrt{\sigma^2_{\mathrm{S}(\mathrm{dB})} + \sigma^2_{U\,(\mathrm{dB})}}} \right\}. \qquad (6)$$

4.15 In short, the UKPM derives the DTT location probability as a function of

a) the median and standard deviation of the received wanted signal power, $P_{\mathrm{S}\,(\mathrm{dBm})}$, and

b) the median and standard deviation of the wighted sum, $U_{(\mathrm{dBm})}$, of the received interferer signal powers.

4.16 The following is an example of the output of the UKPM.

Table 3. Example of the output of the UKPM for four pixels.

Pixel location		Households per pixel, M	Wanted signal $P_{\mathrm{S}\,(\mathrm{dBm})}$		Interferers $U_{(\mathrm{dBm})}$		Location probability q
Eastings (m)	Northings (m)		Median m_{S} (dBμV/m)	Standard deviation σ_{S} (dB)	Median m_{S} (dBμV/m)	Standard deviation σ_{S} (dB)	
402000	195500	68	65.5	5.5	62	4.4	0.69
402100	195500	49	78.4	5.5	65.9	5	0.95
402200	195500	49	80.4	5.5	65.9	4.7	0.98
402300	195500	50	77.4	5.5	65.9	4.7	0.94

4.17 The following should be noted with regards to the calculations in the UKPM:

- All radio link calculations are performed subject to the assumption that the TV aerials are located at a height of 10 m at the centres of 100m ×100m pixels. Given the typically large separations between the TV aerial and the DTT transmitter, the coarse spatial granularity implied by this assumption is a reasonable approximation.

- The received power, P, for each (wanted or interferer) signal component is calculated as

$$P = G\, P_{\mathrm{EIRP}}\ ,$$

where P_{EIRP} is the EIRP of the relevant transmitter, and G is the aggregate coupling gain between the transmitter and receiver. The aggregate coupling gain is the product of the propagation gain, log-normal shadowing gain, antenna angular discrimination gains, and receiver antenna gain.

- The UKPM assumes a log-normal shadowing standard deviation of 5.5 dB. This means that the received power, $P_{(\mathrm{dBm})}$, of each (wanted or interferer) signal component has a Gaussian distribution with a standard deviation of 5.5 dB.

- The UKPM assumes that each TV aerial points directly at the serving DTT transmitter in azimuth.

- The UKPM accounts for the angular discrimination of the TV aerial in azimuth only. This is modelled according to the ITU-R Rec.419-3 pattern. The UKPM does not model angular discrimination in elevation.

- While the equations in this report are presented in terms of power received at the input of a DTT receiver, the UKPM works based on field strength at the antenna. For this reason, the TV aerial gain is actually not included in the calculations (since it is common to both the wanted signal and interferers). Furthermore, the term $P_{\mathrm{S,min}}$ is replaced with $E_{\mathrm{S,min}}$, where at 786 MHz,

$$\begin{aligned} E_{\mathrm{S,min}\,(\mathrm{dB}\mu\mathrm{v/m})} &= E_{500\,(\mathrm{dB}\mu\mathrm{v/m})} + 20\log_{10}\frac{f_{(\mathrm{MHz})}}{500} + 1 \\ &= 46.8 + 20\log_{10}\frac{786}{500} + 1 = 51.73 \quad \mathrm{dB}\mu\mathrm{v/m}. \end{aligned} \tag{7}$$

4.18 The UKPM assumes a *nominal* co-channel protection ratio of 19.8 dB, and an adjacent-channel protection ratio of -25 dB (irrespective of the interferer's frequency) for DVB-T 64-QAM with 2/3 rate coding.

Degradation in DTT location probability due to interference from MFCN base stations

4.19 Here we describe how Punch uses the output of the UKPM to evaluate the degradation in DTT coverage as a result of interference from MFCN base stations in the 800 MHz band.

4.20 We first describe the parameters involved in the computation of the received (wanted or interferer) signal powers at the input to a DTT receiver. We then explain how Punch calculates the reduced DTT location probability caused by a reduction in SINR due to MFCN base station emissions.

4.21 It should be pointed out that while Punch uses the median and standard deviation values derived by the UKPM in its calculations, Punch does not make these values available to the user. This is for reasons of commercial sensitivity.

Modelling of radio links

4.22 Figure 6 illustrates the radio link from a MFCN base station to a DTT receiver.

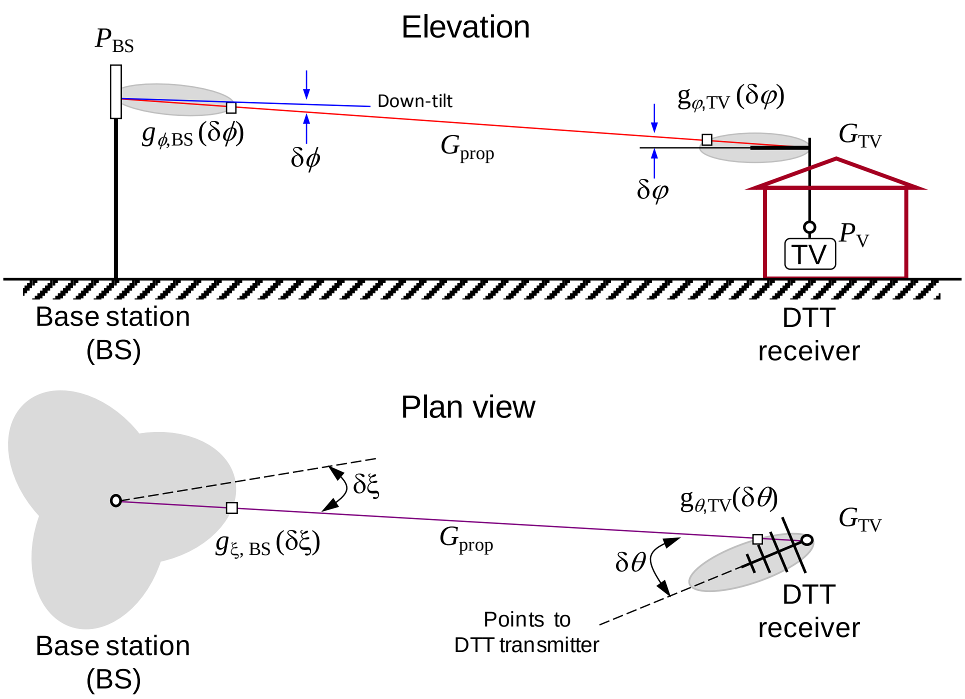

Figure 6. Geometry of base station to TV radio link.

4.23 The power of the m^{th} MFCN adjacent-channel interferer as received at the input of a DTT receiver may be written (in the linear domain) as

$$P_{V,m} = \{P_{BS,m}\}\{g_{BS}(\delta\xi_m, \delta\phi_m)\}\{G_{prop}\}$$
$$\{g_{TV}(\delta\theta_m, \delta\varphi_m)\}\{g_{p,TV}(\delta\theta_m, \delta\varphi_m)\}\{G_{TV}\} \quad (8)$$

where

$P_{BS,m}$ is the EIRP of the m^{th} MFCN base station,

$\delta\xi_m, \delta\phi_m$ are the azimuth and elevation offsets of the link with respect to the orientation and down-tilt of the MFCN base station antenna,

$g_{BS}(\,)$ is the angular discrimination gain of the MFCN base station antenna,

G_{prop} is the propagation gain (log-normal random variable),

$\delta\theta_m, \delta\varphi_m$ are the azimuth and elevation offsets of the link with respect to the the axis of the TV aerial,

$g_{TV}(\,)$ is the angular discrimination gain of the TV aerial,

$g_{p,TV}(\,)$ is the angular polar discrimination gain of the TV aerial,

G_{TV} is the TV aerial gain (including losses).

4.24 Values for the above parameters are presented in Annex 1.

Degradation in DTT location probability

4.25 Earlier we saw how the UKPM calculates the DTT location probability, q, in the presence of K (co-channel and/or adjacent-channel) DTT interferers within a $100\text{ m} \times 100\text{ m}$ pixel, by calculating the term

$$U = P_{\mathrm{S,min}} + \sum_{k=1}^{K} r_{U,k}\, P_{U,k}\ .$$

4.26 Punch operates on the output of the UKPM to calculate the DTT location probability, q', not only due to DTT self-interference, but also due to interference from adjacent-channel MFCN base stations. In each pixel this is given by

$$\begin{aligned} q' &= \Pr\left\{ P_{\mathrm{S}} \geq P_{\mathrm{S,min}} + \sum_{k=1}^{K} r_{U,k} P_{U,k} + \sum_{m=1}^{M} r_{V,m} P_{V,m} \right\} \\ &= \Pr\left\{ P_{\mathrm{S}} \geq U + V \right\} \qquad (9) \\ &= \Pr\left\{ P_{\mathrm{S}} \geq \mathrm{Z} \right\}, \end{aligned}$$

where

P_{S}	is the wanted signal power at the DTT receiver,
$P_{\mathrm{S,\,min}}$	is the minimum received wanted signal power required for *correct* operation in a noise-limited environment,
K	is the number of (co-channel and/or adjacent-channel) DTT interferers,
M	is the number of (adjacent channel) MFCN interferers,
$P_{V,\,m}$	is the received power level of the m^{th} MFCN interferer, and
$r_{V,m}$	is the minimum ratio of wanted DTT signal power to MFCN interferer power required for *correct* operation (MFCN-to-DTT protection ratio).

4.27 Note that the protection ratios $r_{V,m}$ have interferer-specific values. This is because the protection ratios are a function of the MFCN-DTT frequency separation, as well as a function of the received power of the interferer. The latter feature allow us to capture non-linear behaviours of the receiver. For this reason, the reduced location probability, q', is agnostic as to whether DTT receiver failure is caused by poor SINR or overload (see later in this section).

4.28 Re-writing as before, we have

$$q' = q - \Delta q = \Pr\left\{ \frac{P_{\mathrm{S}}}{Z} \geq 1 \right\} = \Pr\left\{ P_{\mathrm{S\,(dBm)}} - Z_{\mathrm{(dBm)}} \geq 0 \right\}. \qquad (10)$$

4.29 As explained for Equation (5), strictly speaking, q' should be computed via Monte Carlo simulations. However, as for the case of q, an approximation could be made in order to derive q' analytically.

4.30 In Punch we follow the same approach as in the UKPM, whereby the terms $P_{\mathrm{S\,(dBm)}}$ and $Z_{\mathrm{(dBm)}}$ are approximated as Gaussian random variables with medians $m_{\mathrm{S\,(dBm)}}$ and $m_{Z\,\mathrm{(dBm)}}$, and standard deviations $\sigma_{\mathrm{S\,(dB)}}$ and $\sigma_{Z\,\mathrm{(dB)}}$, respectively. The terms $m_{Z\,\mathrm{(dBm)}}$ and $\sigma_{Z\,\mathrm{(dB)}}$ are then derived via the Schwartz-Yeh algorithm.

4.31 From Equation (10), and based on the above approximation, the new location probability in each pixel can be readily expressed in closed form as

$$q' = q - \Delta q = 1 - \frac{1}{2}\operatorname{erfc}\left\{\frac{1}{\sqrt{2}}\frac{m_{\mathrm{S(dBm)}} - m_{Z\mathrm{(dBm)}}}{\sqrt{\sigma^2_{\mathrm{S(dB)}} + \sigma^2_{Z\mathrm{(dB)}}}}\right\}. \tag{11}$$

4.32 The following should be noted with regards to our modelling approach:

- All radio link calculations are performed subject to the assumption that the TV aerials are located at a height of 10 metres at the centres of 100m $\times$100m pixels. Given that in practice affected households may be located in the same pixel as the interfering base station, the coarse spatial granularity implied by this assumption appears problematic. However, large numbers of affected households are located further from the offending base stations, and for these, the assumption is a reasonable approximation. Furthermore, any errors resulting from the approximation tend to average out when aggregated over large areas (e.g., the coverage areas of DTT transmitters).

- The received power, P, for each (wanted or interferer) signal component is calculated as

$$P = G\,P_{\mathrm{EIRP}},$$

  where P_{EIRP} is the EIRP of the relevant transmitter, and G is the aggregate coupling gain between the transmitter and receiver. The aggregate coupling gain is the product of the propagation gain, log-normal shadowing gain, antenna angular discrimination gains, receiver antenna polarisation discrimination gain, and receiver antenna gain.

- The UKPM assumes a fixed log-normal shadowing standard deviation of 5.5 dB for the DTT signals. In our modelling we assume a log-normal shadowing standard deviation for the received MFCN signals that is a function of the separation between the base station and TV aerial (see Annex 2).

- We assume that each TV aerial points directly at the serving DTT transmitter in azimuth.

- We account for the angular discrimination of the TV aerial in both azimuth and elevation. This is modelled according to the ITU-R Rec.419-3 pattern.

- We account for the polarisation discrimination of the TV aerial in both the azimuth and elevation.

- We account for the angular discrimination provided by the MFCN base station transmitter antenna both in azimuth and elevation.

- While the equations in this report are presented in terms of power received at the input of a DTT receiver, Punch actually works based on field strength at the antenna. For this reason, the TV aerial gain is not actually included in the calculations.

- The adjacent-channel protection ratios used in our modelling are based of bench measurements of LTE signals interfering with DVB-T receivers and TV amplifiers.

DTT receiver overload

4.33 In this section we describe how we model the degradation in DTT coverage as a result of DTT receiver overload caused by the emissions of MFCN base stations in the 800 MHz band.

4.34 A DTT receiver is overloaded (and fails to operate) if the sum of the signal powers at its input exceeds a specific overload threshold, P_{TH}. The implication is that once a receiver fails to operate due to overloading by a strong interferer, an increase in the wanted signal level only makes matters worse. This is in contrast to the case where a receiver fails to operate due to a degraded SINR only, in which case an increase in the wanted signal level would restore operation.

4.35 Note that the output of the UKPM does not contain information on the power received from individual DTT interferers[13]. For this reason, we ignore the contribution of DTT interferers in the context of the overload issue.

4.36 We define the overload probability, P_{OV}, within a pixel as the probability that a DTT receiver located at the centre of that pixel is overloaded. Accordingly, we can write (in the linear domain)

$$\begin{aligned} P_{\mathrm{OV}} &= \Pr\left\{ w_0 P_{\mathrm{S}} + \sum_{m=1}^{M} w_m P_{V,m} > P_{\mathrm{TH}} \right\} \\ &= \Pr\left\{ B > P_{\mathrm{TH}} \right\} \end{aligned} \qquad (12)$$

where

P_{S}	is the wanted signal power at the DTT receiver,
$P_{V,m}$	is the received power level of the m^{th} MFCN interferer, and
P_{TH}	is the overload threshold at the input of the DTT receiver,
w_0	is the weight applied to the received wanted signal power,
w_m	are filter discrimination gains applied to the individual interferers.

4.37 The weights $w_m \le 1$ model the extent to which filtering at the input to the DTT receiver suppresses the interferers and mitigates overload.

4.38 Once again, P_{OV} can be computed via Monte Carlo simulations. However, as for the case of q and q' an approximation could be made in order to derive P_{OV} analytically.

[13] The UKPM outputs only the weighted sum of the received DTT interferer powers. The weights are equal to DTT-to-DTT protection ratios.

4.39 In our modelling we approximate the term $B_{(\text{dBm})}$ as a Gaussian random variable with median $m_{B\,(\text{dBm})}$, and standard deviation $\sigma_{B\,(\text{dB})}$, respectively. The terms $m_{B\,(\text{dBm})}$ and $\sigma_{B\,(\text{dB})}$ are derived via the Schwartz-Yeh algorithm.

4.40 The relationship between P_{OV}, P_{S} and B in a pixel is illustrated in Figure 7 below.

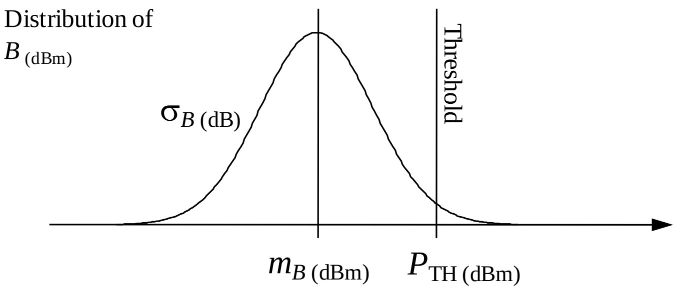

Figure 7. Distribution of interferer power
In relation to the overload threshold.

4.41 From Equation (12), and based on the above approximation, the probability of overload in each pixel can be readily expressed in closed form as

$$P_{\text{OV}} = \frac{1}{2}\text{erfc}\left\{\frac{1}{\sqrt{2}}\frac{P_{\text{TH}\,(\text{dBm})} - m_{B(\text{dBm})}}{\sigma_{B(\text{dB})}}\right\}. \tag{13}$$

4.42 For the purposes of this study we exclude the contribution of the received wanted signal power, P_{S}, to receiver overload; We consider this to be a reasonable approach for the following reasons:

- The vast majority of DTT receivers are distant from the serving DTT transmitter, and it is likely for P_{S} to be significantly lower than the overload threshold, P_{TH}. The latter is typically between -10 and 0 dBm.

- The UKPM does not model the angular discrimination of TV aerials in elevation. As such, the UKPM over-estimates P_{S} (and hence the potential for DTT receiver overload) at locations very close to the DTT transmitter.

- At locations where a DTT receiver might be overloaded due to P_{S} approaching or exceeding the overload threshold, overload would need to be mitigated (e.g., via low-gain antennas, re-orientation, or insertion of attenuators or lossy cables) even in the absence of interference from MFCN base stations.

4.43 Based on the above arguments we set $w_0 = 0\ (-\infty\ \text{dB})$.

4.44 Where no filtering is applied at the input to the DTT receiver, we set $w_m = 1$ (0 dB) $\forall m$. Where filtering is applied, the value of w_m is a function of the filter stop-band attenuation over the channel bandwidth of the m^{th} interferer.

4.45 Measurements indicate that the overload threshold, P_{TH}, can vary slightly depending on the frequency separation between the victim and interferer. Where multiple MFCN signals are present, we use the lowest (most stringent) overload threshold for the calculation of overload probability.

Counting of households

4.46 In this sub-section we explore the way in which DTT location probability and DTT receiver overload probability can be used to count the number of households affected by interference in each pixel.

70% cut-off counting

4.47 Broadcasters have traditionally used a 70% cut-off rule for the purpose of predicting DTT coverage. This means that if M is the number of households in a particular pixel, and q is the DTT location probability in that pixel, then the number of households, N_{served}, served in the pixel is given according to the following rule:

$$N_{\text{served}} = \begin{cases} 0 & \text{if } q < 0.7, \\ M & \text{if } q \geq 0.7. \end{cases} \qquad (14)$$

4.48 In other words, if location probability in a pixel is less (greater) than 70%, then we count none (all) of the households in that pixel as served. We could then aggregate the numbers over all pixels to derive the total number of households served in the UK.

4.49 Consequently, a PSB coverage target of 98.5% means that for each PSB the aggregate number of households served in those pixels across the UK where the location probability is equal to or greater than 70% is at least equal to 98.5% of the number of households in all pixels.

4.50 This so-called "70% cut-off" approach to counting served households may be adequate for purposes of DTT network planning, but has serious deficiencies in the context of assessing the impact of interference from MFCN base stations. We illustrate this via the following example.

Example

4.51 Suppose that emissions from MFCN base stations reduce the location probability in a pixel from 92% to 71%. The 70% cut-off approach to counting would indicate no affected households in the pixel. In practice many households are likely to lose DTT reception in this pixel (due to significant loss in margin above noise and/or interference).

4.52 Now suppose that emissions from MFCN base stations reduce the location probability in a pixel from 72% to 69%. The 70% cut-off approach to counting would indicate all households as having lost DTT reception. In practice only few households are likely to be affected (due to small reduction in margin above noise and/or interference).

4.53 As illustrated by the above simple example, depending on the quality of DTT coverage in a pixel, the 70% cut-off approach can grossly over-estimate <u>or</u> under-estimate the number of households affected by interference from MFCN base stations. For this reason, we use an alternative approach.

Proportional counting

4.54 To avoid the drawbacks of the 70% cut-off approach, we use *proportional counting*.

4.55 Let M be the number of households in a pixel, q be the DTT location probability in that pixel in the absence of base station emissions, and q' be the reduced DTT location probability in the presence of base station emissions. Then according to our proportional counting approach

a) the number of households, N_{served}, served in the pixel and in the absence of base station emissions is given by:

$$N_{\text{served}} = \begin{cases} 0 & \text{if } q < 0.7, \\ qM & \text{if } q \geq 0.7, \end{cases} \tag{15}$$

b) the number of households, N'_{served}, served in the pixel and in the presence of base station emissions is given by:

$$N'_{\text{served}} = \begin{cases} 0 & \text{if } q < 0.7, \\ q'M & \text{if } q \geq 0.7. \end{cases} \tag{16}$$

4.56 Note that households in pixels with "MFCN-free" location probability below 70% are considered as not served. This is consistent with the 70% cut-off rule used in DTT network planning. But where the "MFCN-free" location probability is above 70%, the number of households served is considered to be proportional to the actual prevailing location probability in the pixel (q or q').

4.57 In this way, proportional counting can more effectively capture the number of households affected, as it relates this to the extent of reduction in signal margin above noise and/or interference.

Example

4.58 If a pixel contains 100 households, and its DTT location probability drops from 80% to 75% due to interference from base stations, then proportional counting indicates that 5 households lose DTT reception.

An alternative but helpful interpretation of proportional counting is that the product of location probability and the number of households in a pixel represents the *average*[14] number of households served in the pixel.

[14] From a statistical standpoint, the product *qM* represents the *average* value of the binomially distributed number of households served in the pixel. This has a standard deviation of *Mq*(1−*q*).

If the location probability in a pixel reduces from q to q' due to interference from base stations, then the average number of households whose DTT reception might be affected in that pixel can be written as

$$round(qM) - round(q'M) . \qquad (17)$$

4.59 Note that we round the products qM and $q'M$ separately prior to subtraction to derive the number of households affected by interference. Our proportional counting approach is illustrated in the following table.

Table 4. Summary of proportional counting approach.

Pixel location		Households per pixel, M	MFCN-free location probability q	MFCN-free households served round(qM)	Reduced location probability q'	Reduced households served round($q'M$)
Eastings (m)	Northings (m)					
522000	395500	68	0.53	0	0.47	0
522100	395500	49	0.95	47	0.74	36
522200	395500	49	0.75	37	0.68	33
522300	395500	50	0.91	46	0.90	45

Proportional counting of overload

4.60 The number of households affected by overload only can also be quantified via proportional counting.

4.61 Let M be the number of households in a pixel, and P_{OV} be the probability of overload in that pixel in the presence of base station emissions. Then according to the proportional counting approach the number of households[15], N_{OV} , overloaded in the pixel is given by:

$$N_{OV} = \begin{cases} 0 & \text{if } q < 0.7, \\ P_{OV} M & \text{if } q \geq 0.7, \end{cases} \qquad (18)$$

4.62 Note that (as in the 70% cut-off rule) households in pixels with "MFCN-free" location probability, q, below 70% are considered as not served. Overloaded households in these unserved pixels are not counted. This is consistent with the 70% cut-off rule used in DTT network planning. But where the "MFCN-free" location probability is above 70%, the number of households overloaded is considered to be proportional to the prevailing overload probability in the pixel.

Conclusions

4.63 We have described in some detail our methodology for quantifying the impact of interference from MFCN base stations to the DTT service. This is implemented in our modelling tool Punch and includes

[15] Once again, from a statistical standpoint, the product $P_{OV}M$ represents the *average* value of the binomially distributed number of households overloaded in the pixel. This has a standard deviation of $MP_{OV}(1-P_{OV})$.

a) the calculation of the reduction in DTT location probability at a pixel level. This is agnostic as to whether DTT receiver failure is due to poor SINR or receiver overload;

b) the calculation of the overload probability at a pixel level, to account for cases where DTT receiver failure is due to overload only.

4.64 We have also highlighted the inadequacies of the 70% cut-off approach for the counting of served households in the context of interference from MFCN base stations, and proposed a more appropriate proportional counting approach.

Section 5

Parameters and assumptions

5.1 In this section we discuss the key parameter values that we have used for purposes of modelling in this report. A comprehensive list of parameter values is included in Annex 1.

MFCN parameters

5.2 For purposes of modelling in this report we have used the base station locations and heights of an existing UK-wide GSM-900 network as a proxy for future LTE-800 deployments.

5.3 The choice of a GSM-900 network as proxy is justified

a) due to the proximity in frequency to the 800 MHz band, and hence similar propagation characteristics, and

b) due to the mature nationwide coverage of the network with large numbers of sites in rural areas.

5.4 The choice is further justified given the huge cost-savings that can be achieved as a result of re-using existing sites for next-generation network roll-outs.

Number of sites

5.5 The GSM-900 network considered consists of a total of 10,823 sites across the UK.

5.6 We excluded from these 2012 base station sites which have a (per carrier) EIRP of less than 45 dBm, as they are not compatible with the high EIRPs we have assumed in our modelling. These base stations are primarily deployed in densely populated urban areas (city centres) for the provision of capacity and have low antenna heights See Figures 8 and 9. As such, they do not contribute significantly to the interference to the DTT service.

Site sharing

5.7 We have assumed that the licensees of the 800 MHz band share all 8811 sites, i.e., we have effectively modelled 26,433 base stations sharing 8811 sites. This was a pragmatic assumption, driven by our access to information regarding only a single UK-wide GSM-900 deployment.

5.8 In Section 6 we address the impact of a departure from full site-sharing.

Channel bandwidth

5.9 We have assumed a channel bandwidth of 10 MHz without prejudice to the eventual outcome of the UK auction of the 800 MHz band. This implies three licensees in the 2×30 MHz band, which we refer to as licensees A, B, and C.

5.10 For the full site-sharing geometries examined, the actual channel bandwidth is irrelevant in determining the impact of interference to DTT. This is because each TV aerial effectively receives 30 MHz of MFCN signal radiated from each site.

Base station antennas

5.11 We have assumed the gain and angular discrimination pattern of a Kathrein 742 265 slant polarised antenna with a 3° down-tilt. The antennas are assumed to be arranged in a conventional tri-sector formation at each site (with one sector always pointing to the East). The antenna has a gain of 15.5 dBi.

5.12 We have used the same antenna characteristics for modelling vertically polarised base station antennas.

Base station EIRP

5.13 We have assumed a per sector EIRP of 59 dBm/(10 MHz) for each base station. This is based on a power amplifier with an output rating of 46 dBm[16] feeding the 15.5 dBi Kathrein antenna through a cable loss of 2.5 dB. This value was assumed for all 8811 base stations modelled[17].

5.14 Simulations indicate that LTE downlink cell-edge throughput increases only marginally for greater EIRPs even for deep indoor coverage in rural areas (see Section 6). An EIRP of 59 dBm was also used as a reference case in the ECC/SE42 coexistence studies.

5.15 In practice, of course, base stations use a range of EIRPs depending on their deployment geometries. Figure 10 shows the distribution of (per carrier) EIRPs used by a UK mobile network operator in the 900 MHz, 1800 MHz, and 2100 MHz bands. Note that the UK regulatory limit for base station EIRP is 62 dBm in all three cases[18]. It is clear that a large proportion of UMTS-2100 base stations radiate at close to the regulatory limit, despite the wide variety of environments in which they are deployed.

5.16 The GSM-900 EIRPs appear to be more widely distributed, but this is because the EIRPs are only specified on a per carrier basis. Consequently the statistics is not indicative of the total EIRP of each GSM base station.

[16] This corresponds to a base station (10 MHz channel) transmit power of 40 W as specified in 3GPP TR 36.814.
[17] Note that in the case of dual-antenna transmission, each antenna radiates at half power, i.e., at 56 dBm/(10 MHz);
[18] This was recently increased to 65 dBm in the 2100 MHz band.

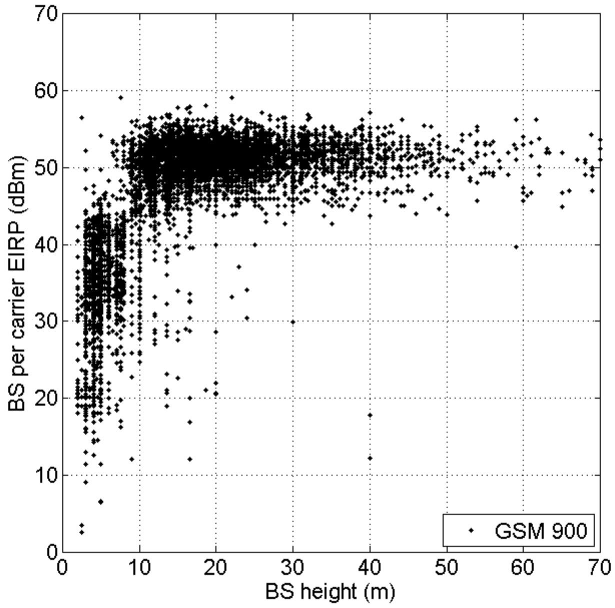

Figure 8. Correlation between GSM-900 base station EIRP(per carrier) and antenna height.

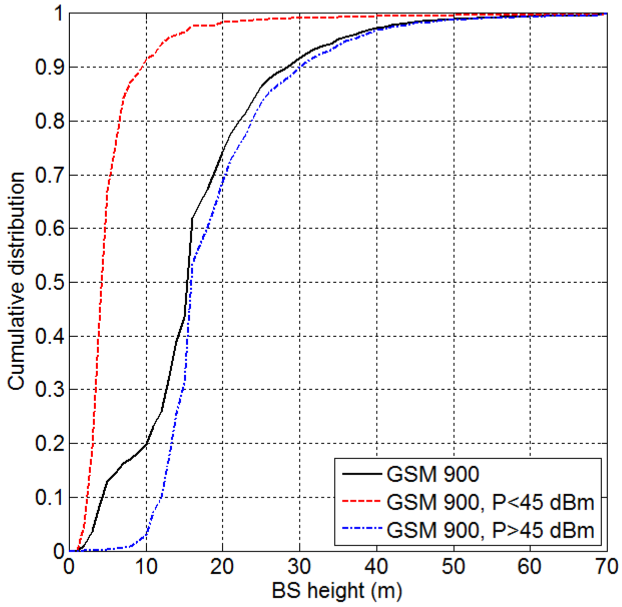

Figure 9. Distribution of MFCN base station antenna heights for a specific GSM-900 deployment.
The most popular height is 16 metres.

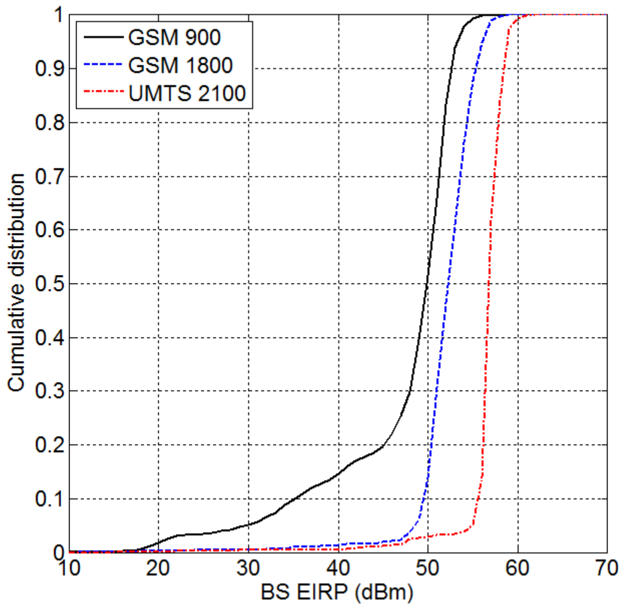

Figure 10. Distribution of MFCN base station EIRPs. Values are per carrier.

DTT parameters

5.17 All the parameters used for the purposes of modelling the DTT network in this report are “hard-coded” into the UKPM. This has the advantage of ensuring that we assess the state of the DTT network in a way that is consistent with common practices among network planners. The disadvantage is that it limits our ability to test the impact of alternative parameter values on DTT coverage.

5.18 However, we have greater freedom in selecting parameter values which relate to the impact of interference from MFCN base stations to the DTT service.

DTT coverage

5.19 The Punch modelling tool operates on the output of the UKPM (version 5.9.3), with DTT coverage for each DTT transmitter defined based on the definition of the analogue preferred service area[19] (APSA), and the pixels wherein the location probability exceeds 70% (the cut-off approach).

TV aerial

5.20 The UKPM assumes a TV aerial height of 10 m, with angular discrimination in azimuth based on the ITU-R Rec.419-3 specification.

5.21 In modelling the response of the TV aerial to interference from MFCN base stations we have also assumed the ITU-R Rec.419-3 angular discrimination pattern, but as a

[19] Analogue Preferred Service Area. This is a method for identifying which transmitter households receive from at a pixel level. APSA rather than Digital Preferred Service Area (DPSA) is used in the modelling as it is believed to more accurately reflect where viewers aerials are in practice pointing at switchover. Additionally the initial implementation of DPSA ignores some smaller relay transmitters, and does not protect national coverage – e.g. at the Welsh border.

function of angular offset (*cone* angle) from the axis of the aerial (accounting for both azimuth and elevation).

5.22 We have assumed a TV aerial gain of 9.15 dBi (consisting of a gain of 12 dBd less cable loss of 5 dB). Note that the aerial gain is relevant only in quantifying the absolute levels of interferer power for the calculation of the probability of receiver overload.

5.23 We have assumed that the TV aerials are horizontally (vertically) polarised in main (relay) DTT transmitter areas.

5.24 Where the polarisation of MFCN signals is *orthogonal* to the polarisation of DTT signals, we have modelled polarisation discrimination at the TV aerial as 16 dB within the main lobe of the ITU-R Rec.419-3 pattern. Where the MFCN signals are ±45° (slant) polarised, we have modelled polarisation discrimination at the TV aerial as 3 dB within the main lobe of the ITU-R Rec.419-3 pattern. This is the assumed default MFCN polarisation. A polarisation discrimination of 0 dB is assumed outside the main lobe. See also Section 6.

5.25 Finally, we have not accounted for aerial groupings in our analysis (i.e., we have assumed wideband antennas throughout).

TV receiver installations

5.26 As we explained earlier, the UKPM evaluates DTT coverage based on outdoor roof-top reception[20] at a height of 10 metres. We refer to this mode of reception as a *standard domestic installation*.

5.27 Absent any alternatives, we have used the UKPM output to also model DTT reception by communal aerial systems and domestic installations with amplifiers. See Section 7 for definitions of the installation categories.

5.28 The implicit assumption here is that the quality of *pre-MFCN* DTT coverage for communal aerial systems is similar to that for standard domestic installations; i.e., that a communal aerial system delivers a “standard domestic installation” quality of DTT service to each of the dwellings it serves.

Communal antenna systems

5.29 For communal aerial systems (e.g., as installed in blocks of flats), TV aerial heights are likely to be greater than 10 metres. Such systems would receive greater DTT signal strengths than those predicted by the UKPM, and may use antennas with superior gain and angular discrimination compared to those of ITU-R Rec.419-3 assumed by UKMP/Punch. This means that in practice (and not withstanding issues relating to the susceptibility of launch amplifiers) many communal aerial systems are likely to be more robust to interference from MFCN base stations than predicted by Punch. On the other hand, the coexistence of communal aerials and MFCN base stations on the same roof-tops can present challenging site-engineering issues.

5.30 We have used census data on the number of flats at a local geographic level as a means of quantifying the distribution of communal aerial system locations down to a spatial resolution of 100m ×100m within the coverage area of the DTT transmitters

[20] We have not addressed indoor DTT reception in this report.

examined. The census data is in good agreement with our independent estimates of the total number of communal aerial systems in the UK. See Section 7.

Domestic amplifier installations

5.31 We have used independent estimates of the number of domestic (mast-head and indoor) amplifiers in the UK as a means of quantifying the overall proportion of households which use domestic amplifiers in conjunction with primary TV sets. Absent any robust guidelines, we have applied this proportion uniformly to every 100m $\times$100m pixel within the coverage areas of the transmitters examined. In practice, it is likely that the proportion of households with domestic amplifier installations is greater within pixels in poor DTT coverage areas, where by implication they would also be more susceptible to interference from MFCN base stations. We have not explored this issue further.

DTT receiver characteristics

UKPM

5.32 For DTT-to-DTT interference the UKPM uses[21] a co-channel protection ratio of 19.8 dB and an adjacent channel protection ratio of -25 dB (all for 64-QAM & 2/3 rate coding). The 19.8 dB is based on a minimum SNR of 17.1 dB for fixed reception in a Rician channel, in addition to a 2.7 dB *implementation margin*[22].

5.33 The assumed adjacent-channel protection ratio of -25 dB appears quite large.

5.34 Measurements of early commercial DVB-T receivers quoted in the Appendix of JPP/MB/1 indicate $n-1$ and $n+1$ adjacent-channel protection ratios of -30 and -26 dB respectively (DVB-T critical mask). Measurements[23] commissioned by Ofcom in 2007 suggest $n-1$ and $n+1$ adjacent-channel protection ratios of -30 to -40 dB and -26 to -35 dB, respectively (DVB-T non-critical mask, wanted signal of -73 dBm).

5.35 This implies that the UKPM under-estimates the adjacent-channel rejection performance of DTT receivers (i.e., under-estimates the extent of DTT coverage in the UK).

Standard domestic installations

5.36 We have used measured values of LTE-to-DTT protection ratios to model the immunity of DTT receivers to adjacent channel interferers in various DTT channels and for different wanted DTT signal levels. The latter characterisation allows us to model the non-linear behaviour of the receivers.

5.37 The protection ratios used in the modelling correspond to the highest values (worst performance) measured at each test point among three super-heterodyne (can) tuners and two Silicon tuners. See Annex 3.

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[21] Joint Frequency Planning Project, "Technical parameters and planning algorithms," JPP/MB/1, version 2, July 2003.

[22] Somewhat paradoxically, the UKPM model also considers a minimum SNR of 22.8 dB. This consists of a minimum SNR of 17.1 dB for fixed reception in a Rician channel, in addition to a 2.7 dB implementation margin, and in addition to a further 3 dB margin for real conditions (based on measurements of DVB-T receivers).

[23] ERA, "Conducted measurements to quantify DVB-T interference into DTT Receivers," final report, October 2007.

5.38 As part of our measurements, we have also investigated the impact of time-discontinuous or *bursty* LTE signals in relation to interference to DTT reception. Such bursty signals occur when the base station is not fully loaded with user traffic and does not transmit with all resource blocks at its disposal.

5.39 We have shown that with the exception of a few receivers which behave particularly poorly in the presence of bursty interferers, DTT receivers by and large perform better than we have assumed in our modelling. Measurements by the DTG appear to indicate that only 1% to 3% of DTT receivers in the UK market have a poorer immunity to adjacent channel interference than we have assumed. See Annex 6.

Communal antenna systems

5.40 We have measured the protection ratios corresponding to the combination of a (variable gain) launch amplifier in cascade with a Silicon tuner to characterise the immunity of communal aerial systems to adjacent channel interferers. The protection ratios were found to be greater (poorer receiver immunity) than those measured for DTT receivers alone. This is due to amplifier overload. See Annex 4.

5.41 We have not had the opportunity to test more than one launch amplifier, and in this sense, there is a greater uncertainty in our modelling results for communal aerial systems than for standard domestic installations. This uncertainty is exacerbated by the wide range of communal installation arrangements observed in practice.

Domestic installations with amplifiers

5.42 We have measured the protection ratios corresponding to the combination of a (fixed gain) domestic mast-head amplifier in cascade with a Silicon tuner to characterise the immunity of domestic amplifier installations. The protection ratios were found to be greater (poorer receiver immunity) than those measured for DTT receivers alone. This is again due to the early onset of amplifier overload.

5.43 Interestingly, the protection ratios for the domestic amplifier were found to be lower (better receiver immunity) than those measured for the communal aerial system launch amplifier.

5.44 We have not had the opportunity to test more than one domestic amplifier, and in this sense, there is a greater uncertainty associated with the results of our modelling of domestic amplifier installations than for standard domestic installations. This uncertainty is exacerbated by the wide range of amplifier installation arrangements observed in practice.

DTT receiver filtering

5.45 We have examined the use of filtering at the input of the DTT receiver (or preceding amplifier) as a robust tool for mitigating the impact of interference from MFCN base stations.

Domestic installations (with or without amplifiers)

5.46 In the context of standard domestic installations, we have used in our modelling the frequency response of a filter prototype designed and built by Technetix. See Annex 3. This is a low-cost and simple filter designed for the protection of channel 60 via a sharp roll off. When tuned for the protection of channel 58 and below, the filter exhibits a stop-band attenuation of around 20 dB over blocks A, B, and C. This is sufficient to broadly eliminate the impact of interference on households below channel 57.

5.47 Significantly greater stop-band attenuations can be achieved by filters commercially available from manufacturers such as Braun for the protection of channels 57. In these filters, large stop-band attenuations are achieved at the expense of less steep roll-offs. In the context of domestic installations with amplifiers, we have assumed the Technetix filters for protecting channels 60, 59, and 58, and the Braun filters for protecting channels 57 and below. See Annex 5.

Communal antenna systems

5.48 In the context of communal aerial systems, bulkier, more complex, and hence more costly filters are viable as a mitigation tool. Based on our discussions with manufacturer Isotek, we have assumed a filter stop-band attenuation of 45 dB for the protection of channel 60 (constrained by the required sharp roll-off), and a stop-band attenuation of 60 dB for the protection of channels 59 and below. See Annex 4.

Radio propagation parameters

MFCN-to-DTT propagation

Median path loss

5.49 We have modelled median path loss based on suburban extended-Hata[24] for all areas in the UK. This was primarily for pragmatic reasons; as the current version of Punch can only process a single path loss model.

5.50 The suburban flavour of extended-Hata was chosen since our analysis of clutter databases indicates that roughly 3%, 70%, and 27% of the UK population reside in what can be categorised as urban, suburban, and rural radio propagation environments, respectively. The suburban model also agrees well with the results of our propagation measurements in Tamworth (see Annex 2).

5.51 The implication of the use of suburban extended-Hata is that the Punch model over-estimates the number of households affected in urban areas and (slightly) under-estimates the number of households affected in rural areas. We say slightly, because the suburban model only diverges from the rural model at transmitter-receiver separations greater than 300 to 600 metres, and these are of the same order of magnitude as the dimensions of most coverage holes.

Shadowing standard deviation

5.52 We have modelled lognormal shadowing via a standard deviation which varies as a function of the separation between the transmitter and receiver.

5.53 This is the approach we had used in our studies within the ECC/SE42 project team. However, for the purposes of this report, we have revised the shape of the standard deviation profile in view of our recent propagation measurements in Tamworth. See Annex 2.

[24] See the SEAMCAT manual at http://www.ero.dk/seamcat.

DTT propagation

5.54 The UKPM uses recommendation P.1546 (multiple edge diffraction) along with a database clutter to model median propagation loss from a DTT transmitter to a TV aerial. Log-normal variability is modelled via a fixed standard deviation of 5.5 dB applied to all signals.

5.55 It is worth noting that in the UKPM, the wanted DTT signal is modelled via a *50%-time* propagation model; i.e. the resulting received signal strength is exceeded 50% of the time. However, DTT-to-DTT interference is modelled via a *1%-time* propagation model; i.e., the resulting received signal strength is exceeded 1% of the time. In short, the latter characterises *lifts* in interference due to atmospheric effects which occur 1% of the time.

5.56 As a result, the Punch model estimates the number of households affected by interference from MFCN base stations during the 1% of time when atmospheric conditions have enhanced the levels of DTT-to-DTT interference. In the remaining 99% of time the affected households are likely to be more immune to interference from MFCN base stations.

5.57 Nevertheless, since the 1% time model is used for DTT network planning in the UK, we believe it is reasonable to use this also to model the impact of interference from MFCN base stations.

Section 6

Analysis of mitigation measures

Introduction

6.1 In this section, we examine a number of measures which can be used to mitigation the impact of interference from MFCN base stations in the 800 MHz band to DTT services below 790 MHz.

6.2 These measures include the

- use of filtering at the DTT receiver,
- use of filtering at the base station transmitter,
- choice of polarisation at the base station transmitter,
- impact of site-sharing among licensees,
- impact of base station EIRP, and
- use of on-channel receivers.

6.3 We demosntrate the technical efficacy of the above techniques through computer modelling[25] of the impact of interference to households within the APSA coverage area of the Oxford DTT transmitter.

6.4 We present results for channels 60, 59, 58, and 57 to show the effect of increased frequency separation between the DTT and MFCN signals. Note that the Oxford transmitter does not actually transmit in channel 58, so these results are for illustrative purposes only. Furthermore, we treat all households as standard domestic installations (with the associated protection ratios in Annex 3).

6.5 Unless otherwise stated, the numerical results presented are based on the modelling methodologies described in Section 4 and the technical parameter values presented in Section 5 and Annex 1.

Coverage area of the Oxford DTT transmitter

6.6 Figure 11 shows the APSA coverage area of the Oxford DTT transmitter which we have examined. The Oxford transmitter is located to the north-east of the city of Oxford in Oxfordshire, and broadcasts on channels 60, 59, 57, 55, 53, and eventually 50.

6.7 The area we have examined consists of 417,263 pixels where location probability equals or exceeds 70%. These *served* pixels contain a total of 411,092 households spread across 39,364 pixels (i.e., a large majority of served pixels contain no

[25] The results presented in this section were generated via a modelling tool developed in Matlab. There are some minor differences between the results (presented in this section) generated by the Matlab tool and those generated by Punch (presented in Sections 8, 9, and 10). There are three reasons for this: 1) The Matlab tool and Punch use different versions of the UKPM, 2) The Matlab tool and Punch examine slightly different areas, and 3) The Matlab tool calculates location probabilities based on Monte Carlo trials as opposed to the Schwartz-Yeh algorithm used in Punch. To expedite the Matlab simulations, we used 1000 trials per pixel. Note that both the Matlab tool and Punch implement the precise methodology described in Section 4.

population at all). The number of households served according to the proportional counting approach (see Section 4 for definition) is equal to 404,866.

6.8 In our modelling we include the interference from base stations that are within 5 km of the outer boundary of the Oxford transmitter's coverage area. This corresponds to a total of 392 base station sites per licensee.

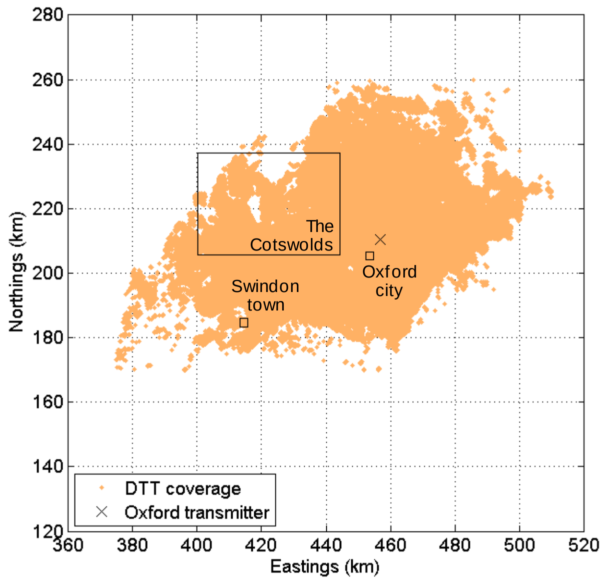

Figure 11. Coverage area of the Oxford transmitter. DTT coverage refers to pixels where the location probability is greater than 70%.

Mechanisms for mitigation

6.9 As described in Section 4, the impact of interference on a DTT receiver can be described via the adjacent channel protection ratio. This is the minimum ratio of wanted DTT signal power, P_S , to unwanted MFCN interferer power, P_V , required for correct operation of the receiver. The wanted and unwanted powers are often denoted as C and I .

6.10 It is common practice to present protection ratios in the form of *C-to-I* curves, as depicted in Figure 12. Here, the protection ratio at each point on the curve is given by the different between the coordinates, i.e., $r_{(dB)} = C_{(dBm)} - I_{(dBm)}$. For a DTT receiver to function correctly, it must operate on the left-hand-side of the C-to-I curve.

6.11 Note that for a receiver which operated linearly (cannot be overloaded), the C-to-I curve is a straight line; i.e., the protection ratio is not a function of the absolute values of C or I .

6.12 Let us consider a DTT receiver that operates at point A as a result of interference from MFCN base stations. In order to restore correct operation, a mitigation measure must shift the operating point to the left-hand-side of the C-to-I curve. This can be achieved via one of the following mechanisms:

a) A reduction in the interferer power; e.g. via filtering at the DTT receiver[26], or the use of polarisation discrimination.

b) An increase in the wanted signal power; e.g. via an on-channel repeater.

c) An increase in the wanted signal power and a simultaneous reduction in the interferer power; e.g. via high-gain highly-directional TV aerials.

6.13 Note that if a DTT receiver operates at a point B where the level of interferer power exceeds P_{TH} , then no amount of increase in the level of the wanted signal power can restore correct operation; i.e., the receiver is overloaded. It is evident that an overloaded receiver, by definition, also suffers from insufficient SINR.

6.14 However, if the wanted signal level is increased sufficiently at the input of an overloaded receiver, correct operation can be restored via the insertion of an attenuator at the input to the DTT receiver.

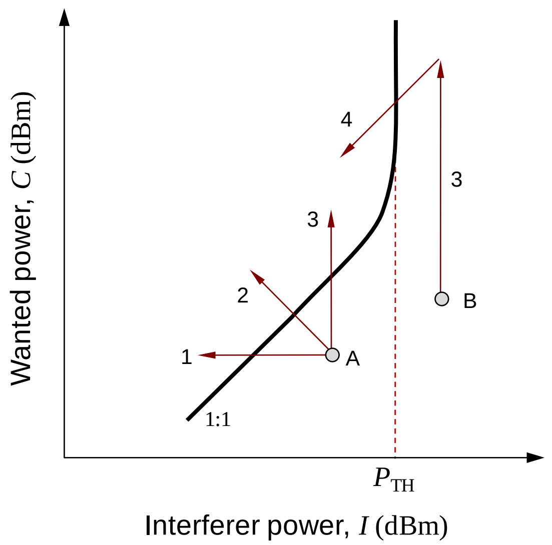

Figure 12. Examples of mitigation:
1. DTT receiver filtering or polarisation discrimination,
2. High-quality TV aerial, 3. OCR, 4. Attenuator.

6.15 We next examine a number the above mitigation measures in detail.

[26] Filtering at the DTT receiver and/or filtering at the MFCN base station transmitter can also be interpreted as changing the shape of the C-to-I curve).

Filtering at the DTT receiver

6.16 Low-pass (or alternatively, band-reject) filtering at the input of a DTT receiver is arguably the most robust technique for mitigating the impact of interference from MFCN base stations in the 800 MHz band to DTT services below 790 MHz.

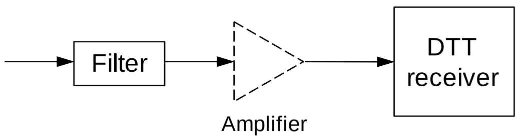

Figure 13. Filtering at the input to a DTT receiver.

6.17 In this sub-section we explain the mechanism through which filtering at the DTT receiver mitigates interference, describe how this can be modelled, and demonstrate how the efficacy of filtering at the DTT receiver is related to the spectral mask of the base station emissions.

Filtering operation

6.18 By attenuating the in-block (carrier) power received from a MFCN base station, a filter enhances the frequency selectivity of the DTT receiving system, and thereby

a) increases the DTT signal-to-interference ratio[27]; and

b) prevents the overloading of the DTT receiving equipment.

6.19 Figure 14 illustrates the typical frequency response of a filter used for protecting a receiver for which the upper-most serving DTT channel is channel *N*. We refer to this as a *type-N* filter.

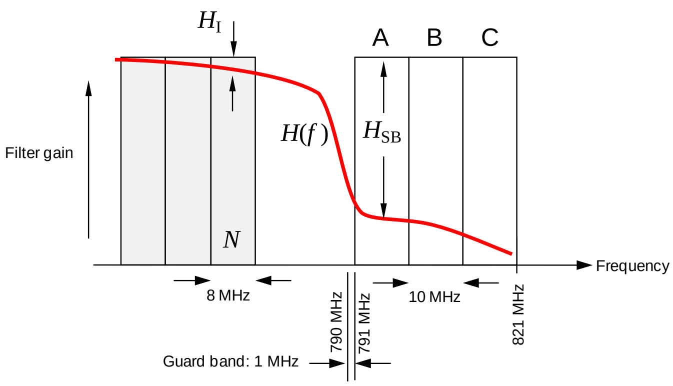

Figure 14. Typical frequency response of a type-N filter used for the protection of DTT channels N and below.

6.20 The filter is characterised by an insertion gain, $H_I < 1$ over the DTT frequencies, and a stop-band gain, $H_{SB} < 1$, over the McFCN frequencies. We define the filter's *frequency discrimination gain* as applied to the signals from an interfering base station as

[27] So long as the interference is not significantly dominated by the interferer's spectral leakage.

$$G_{\mathrm{D}}(F_0, F_{\mathrm{V}}) = \frac{H_{\mathrm{SB}}(F_0)}{H_{\mathrm{I}}(F_{\mathrm{V}})} < 1 \qquad (19)$$

where (F_0, F_{V}) are the base station and DTT carrier (victim) frequencies respectively, $H_{\mathrm{I}}(F_{\mathrm{V}})$ is the average[28] insertion gain over the DTT carrier bandwidth (i.e., over $F_{\mathrm{V}} \pm 4$ MHz), and $H_{\mathrm{SB}}(F_0)$ is the average stop-band gain over the interfering base station's carrier bandwidth (i.e., over $F_0 \pm 5$ MHz).

6.21 Unless otherwise stated, filters examined in this report have an insertion loss which does not exceed 1 dB (i.e., $H_{\mathrm{I}} \leq -1$ dB). As such, the insertion loss does not significantly affect DTT reception; but is still accounted for in the calculation of the discrimination gain. For simplicity, we assume that the insertion loss equals 1 dB at all victim frequencies F_{V}, so that

$$G_{\mathrm{D}}(F_0)_{(\mathrm{dB})} = H_{\mathrm{SB}}(F_0)_{(\mathrm{dB})} + 1. \qquad (20)$$

6.22 The frequency discrimination gain presented in Figure 15 is for a low-cost type-60 filter prototype[29] by Technetix. We assume this template (and its frequency shifted versions) for the modelling of type-*N* filters in standard domestic installations. Note that we have used the upper envelope of the measured filter gains to represent the filter's frequency response $H(f)$, thereby avoiding sensitivities with respect to the deep nulls.

6.23 As can be seen, despite the sharp roll-off achieved by the type-60 filter, base station signals from block A cannot be attenuated substantially. This is due to the conflicting requirement of low insertion loss in channel 60.

6.24 Table 5 shows the corresponding values of filter discrimination gain, $G_{\mathrm{D}}(F_0)$, for type-60 to type-53 filters. As can be seen, the discrimination gains applied to block A, B, and C do not reduce significantly for type-*N* filters where $N \leq 58$. For this reason, in our modelling of standard domestic installations, we use type-58 filters to mitigate interference to all DTT channels below channel 58.

6.25 It is worth noting that greater frequency discriminations than those shown in the above table can be achieved when the filter is designed to protect channels 57 and below (i.e., for type-*N* filters where $N \leq 57$). This is because the roll-off between pass-band and stop-band can be made less steep and traded off against increased stop-band attenuation[30]. Such filters are commercially available from Braun GmBH among others, at an increased cost.

6.26 In our modelling of DTT receiver filters for domestic installations with amplifiers, we have assumed Technetix filters for type-*N* *N*=60, 59, 58, and Braun filters for type-*N* $N \leq 57$.

[28] Averaging is performed in the linear domain.
[29] In 2009 Ofcom commissioned Technetix to design and build a type-60 DTT filter prototype. Technetix use a combination of micro-strip technology, coaxial resonator and high-Q air core inductors. In order to keep the filter price at an acceptable level, the use of (expensive) trimmer capacitors is limited to a minimum, and wherever possible fixed so-called "super high Q" ceramic capacitors are used.
[30] Stop-band attenuations of around 20, 40, and 60 dB can be achieved for a type-57 filter over blocks A, B, and C. See Annex 5.

6.27 Where filter size and cost are less of a concern, very high stop-band attenuations of 45 and 60 dB can be achieved for type-60, and type-*N* $N \leq 59$ filters, respectively, as suggested by Isotek. In our modelling of DTT receiver filters for communal aerial systems we have assumed such filters.

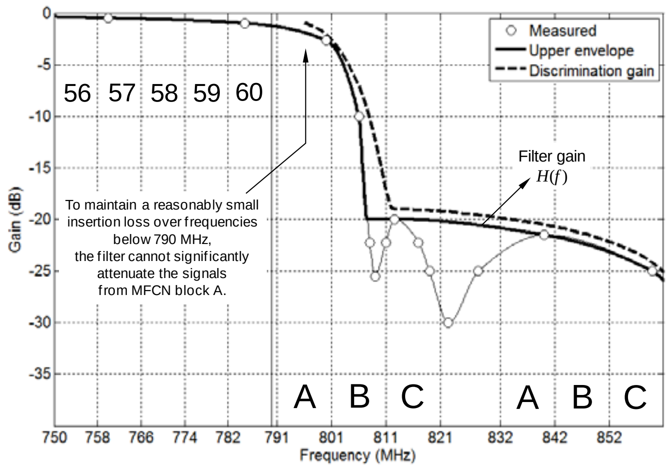

Figure 15. Frequency discrimination gain for a type-60 filter prototype by Technetix.

Table 5. Frequency discrimination gains used in this report based on the Technetix prototype.

		MFCN block		
Filter type	Filter cut-off (MHz)	A F_0 = 796 MHz	B F_0 = 806 MHz	C F_0 = 816 MHz
Type-60	790	-0.95	-7.03	-19.05
Type-59	782	-4.81	-19.02	-19.34
Type-58	774	-18.91	-19.24	-19.84
Type-57	766	-19.16	-19.70	-20.5
Type-56	758	-19.57	-20.32	-21.45
Type-55	750	-19.70	-21.17	-22.97
Type-54	742	-20.32	-22.53	-26.01
Type-53	734	-21.17	-25.01	-30.18

Modelling the behaviour of filters

6.28 In Section 4 we described our methodology for quantifying the degradation in DTT location probability and the likelihood of receiver overload. The impact of filtering can be modelled within the same framework, as described next.

6.29 The effect of filtering in mitigating interference can be modelled as an increase in the the DTT receiver's adjacent channel selectivity[31], $\mathrm{ACS}(F_0, F_\mathrm{v})$, by a factor equal to the filter's discrimination attenuation, $G_\mathrm{D}^{-1}(F_0)$; i.e.,

$$\mathrm{ACS}(F_0)_{(\mathrm{dB})} \leftarrow \mathrm{ACS}(F_0)_{(\mathrm{dB})} - G_\mathrm{D}(F_0)_{(\mathrm{dB})}. \qquad (21)$$

[31] The ACS of a receiver is defined as the ratio of the receiver's filter gain over the wanted signal's channel bandwidth (8 MHz in this case) divided by the receiver's filter gain over an adjacent channel interferer's channel bandwidth (10 MHz in this case). The ACS represents the amount by which the adjacent channel interferer is attenuated.

The corresponding protection ratio, $r(F_0, F_V)$, can then be calculated by combining the DTT receiver's increased ACS with the adjacent channel leakage ratio[32] (ACLR) of the base station (see next).

6.30 The effect of filtering in mitigating receiver overload can be modelled by setting the weights, w_m, in Equation 12 equal to $H_{SB}(F_0)$, where F_0 is the carrier frequency of the interferer. These weights then appropriately attenuate the contributions of the base station in-block emissions to receiver overload[33].

Limits of mitigation via receiver filtering only

6.31 The effectiveness of additional filtering at the DTT receiver as an interference mitigation measure is strongly linked to the spectral leakage of the MFCN base station emissions over the DTT frequencies.

6.32 This can be demonstrated by observing that the MFCN-to-DTT protection ratio, $r(F_0, F_V)$, is a function of a) the adjacent channel selectivity $\mathrm{ACS}(F_0)$ of the DTT receiver, and b) the adjacent channel leakage ratio $\mathrm{ACLR}(F_V)$ of the MFCN base station. In short,

$$r(F_0, F_V) = \frac{r_0}{\mathrm{ACIR}(F_0, F_V)} = r_0 \left\{ \mathrm{ACS}^{-1}(F_0) + \mathrm{ACLR}^{-1}(F_V) \right\} \qquad (22)$$

where r_0 is the co-channel protection ratio, and $\mathrm{ACIR}(F_0, F_V)$ is the adjacent-channel interference ratio (by definition).

6.33 It is evident that even if the ACS approaches infinity (e.g., through the use of an ideal brick-wall receiver filter), the protection ratio will still be lower-bounded (ACIR will be upper-bounded) by the interferer's finite ACLR; i.e.,

$$\lim_{\mathrm{ACS}\to\infty} r(F_0, F_V) = \frac{r_0}{\mathrm{ACIR}(F_0, F_V)} = \frac{r_0}{\mathrm{ACLR}(F_V)}. \qquad (23)$$

6.34 This indicates that indefinite attenuation of the received base station in-block power via improved filtering at the DTT receiver cannot result in an indefinite reduction of the impact of interference (unless the interferer has zero spectral leakage, i.e., where ACLR = ∞).

Numerical example

6.35 The above effects can be readily demonstrated with a numerical example of type-60 and type-57 filtering for the protection of channel 60 and 57.

6.36 Let us assume that the MFCN base stations achieve an ACLR of 59 dB over channel 60, and that this ACLR naturally increases by 10 dB for every 8 MHz increase in the interferer-victim carrier frequency separation. See Figure 16.

[32] The ACLR of an interferer is defined as the ratio of the signal's in-block power (nominally equal to the power over the signal's pass-band (10 MHz in this case), divided by the out-of-block power of the signal when measured at the output of a (nominally rectangular) receiver filter centred on an adjacent frequency channel (8 MHz in this case).
[33] Note that the overload thresholds themselves are not changed as a result of the filtering.

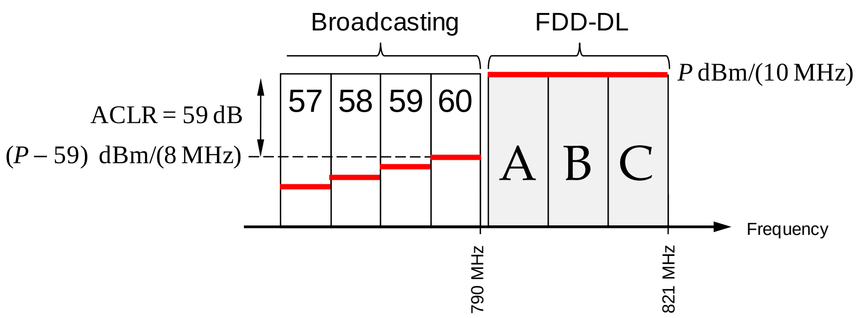

Figure 16. Assumed spectral leakage of the MFCN base stations.
The emissions comply with the EC Decision block edge mask in channel 60,
but with a roll-off of 10 dB/(8 MHz) in lower DTT channels.

6.37 Let us also assume that the DTT receiver has the ACS values presented in the following table.

Table 6. Assumed adjacent channel selectivity values.

	ACS (dB)		
	MFCN block		
DTT channel	A	B	C
60	56	60	64
57	64	65	66

6.38 The interactions between the ACLR and ACS in defining the protection ratio are presented in Table 7. A *nominal* co-channel protection ratio of 16 dB is assumed. The filter discrimination attenuation, A_F, is based on type-60 and type-57 Technetix filters.

Table 7. The impact of DTT receiver filtering on the protection ratios in channels 60 and 57.

			MFCN block A	MFCN block B	MFCN block C
DTT Channel 60	No receiver filter	ACLR (dB)	59	59	59
		$ACS_{DTT(dB)}$	56	60	64
		$A_{F(dB)}$	0	0	0
		$ACS_{(dB)} = ACS_{DTT(dB)} + A_{F(dB)}$	56	60	64
		$ACIR_{(dB)}$	54	56	58
		Protection ratio, $r_{(dB)}$	**-38**	**-40**	**-42**
	Receiver filter	ACLR (dB))	59	59	59
		$ACS_{DTT(dB)}$	56	60	64
		$A_{F(dB)}$	1	7	19
		$ACS_{(dB)} = ACS_{DTT(dB)} + A_{F(dB)}$	57	67	83
		$ACIR_{(dB)}$	55	58	59
		Protection ratio, $r_{(dB)}$	**-39**	**-42**	**-43**
DTT Channel 57	No receiver filter	ACLR (dB)	89	89	89
		$ACS_{DTT(dB)}$	64	65	66
		$A_{F(dB)}$	0	0	0
		$ACS_{(dB)} = ACS_{DTT(dB)} + A_{F(dB)}$	64	65	66
		$ACIR_{(dB)}$	64	65	66
		Protection ratio, $r_{(dB)}$	**-48**	**-49**	**-50**
	Receiver filter	ACLR (dB)	89	89	89
		$ACS_{DTT(dB)}$	64	65	66
		$A_{F(dB)}$	19	20	20
		$ACS_{(dB)} = ACS_{DTT(dB)} + A_{F(dB)}$	83	85	86
		$ACIR_{(dB)}$	82	84	84
		Protection ratio, $r_{(dB)}$	**-66**	**-68**	**-68**

6.39 The following can be observed for channel 60:

- For the case of interference from block A we have ACS < ACLR; i.e., the ACIR is upper-bounded by the limited ACS. Filtering can be helpful here. However, the small interferer-victim frequency separation means that filtering only improves the ACS by a mere 1 dB, resulting in less than 1 dB increase in the ACIR. Filtering is not effective.

- For the case of blocks B and C, we have ACLR < ACS; i.e., the ACIR is upper-bounded by the limited ALCR. Filtering cannot help here. Even through filtering significantly increases the ACS, this has no substantial impact on the ACIR.

6.40 The situation is somewhat different in channel 57. Here the ACLR of the base station is high, due the large interferer-victim frequency separation. For this reason, ACS < ACLR; i.e., the ACIR is upper-bounded by the limited ACS. Filtering can be helpful here. Given the large interferer-victim frequency separation, filtering improves the ACS by around 20 dB, with significant improvements in ACIR.

DTT receiver filtering and affected households

6.41 Table 8 presents the estimated number of affected households (standard doemstic installations) subject to the use of no mitigation measures. These are the results of computer modelling in the coverage area of the Oxford DTT transmitter.

Table 8. The impact of DTT receiver filtering on the number of households affected by interference from MFCN base stations. The total number of households served in the coverage area is 404,866.

	DTT channel	No. of households affected by interference			
		MFCN blocks			
		A	B	C	ABC
No filtering	60	7,101	2,444	2,314	9,370
	59	1,260	1,654	1,252	3,453
	58	2,281[34]	1,393	684	3,677
DTT receiver filtering	60	6,196	1,960	1,823	7,820
	59	604	306	310	1,019
	58	87	60	48	165

6.42 The results indicate significant reduction in interference to channel 58, some reduction in channel 59, and only a modest reduction in channel 60.

6.43 The reason for the modest reduction of interference in channel 60 is two-fold:

- Firstly, a type-60 filter can only slightly attenuate the immediately adjacent in-block emissions from block A.
- Secondly, although a type-60 filter can better attenuate the in-block emissions of blocks B and C, interference is still dominated by the base station out-of-block emissions. DTT receiver filtering cannot mitigate this.

6.44 The results also indicate that filtering at the DTT receiver can virtually eliminate interference to channels 57 and below.

6.45 Note that the number of households affected by interference from combined emissions from blocks A, B, and C is less than the sum of the numbers of households affected by emissions from each of the blocks individually. This is due to overlaps in the locations (*coverage holes*) wherein households are affected.

Conclusions

6.46 Filtering at the DTT receiver is an effective measure for mitigating the impact of interference from MFCN base stations in the 800 MHz band.

6.47 In this sub-section we have shown that:

[34] The number of households affected in channel 58 is greater than in channel 59. This counter-intuitive result is due to the fact that the measured protection ratios of DTT receivers do not necessarily decrease monotonically with increasing frequency separation between the interferer and victim. This feature is particularly prevalent in receivers with super-heterodyne tuners.

- Filtering at the DTT receiver virtually eliminates interference into channels 57 and below.

- Where the limited frequency selectivity of the DTT receiver is the bottleneck, filtering at the DTT receiver can significantly reduce the number of affected households. This applies to channel 58.

- Where the spectral leakage of the MFCN base station is the bottleneck, filtering at the DTT receiver cannot be very effective. This applies to channel 60, and partially to channel 59.

6.48 It should be pointed out that in installations where amplifiers are used to boost the signal level prior to a DTT receiver, the amplifier itself is also susceptible to interference from MFCN base stations. In such cases, the filtering should be applied at the input to the amplifier.

6.49 It might be envisaged that, in the long term, some filtering will be integrated within all DTT receivers and TV amplifiers.

Filtering at the MFCN base station transmitter

6.50 In the previous sub-section we addressed the use of filtering at the DTT receiver as a means for mitigating the impact of interference from the 800 MHz band. We demonstrated that filtering at the DTT receiver can only be effective in circumstances where interference is not dominated by excessive spectral leakage of MFCN base station emissions over the DTT frequencies.

6.51 In this section we show how *additional* filtering at the base station transmitter can be used to control spectral leakage over the DTT frequencies, and we demonstrate the effectiveness of the joint use of filtering at the MFCN base station transmitters and at the DTT receivers.

MFCN base station emission masks

6.52 EC Decision 2010/267/EU specifies block edge masks (BEMs) for the operation of MFCN base stations in the 800 MHz band. Details of the BEMs were presented in Section 2.

6.53 In summary, the BEMs specify that over frequencies where broadcasting is to be protected, and for in-block EIRPs of between[35] 36 and 59 dBm, the base stations must achieve a minimum ACLR of 59 dB through the use of appropriate filtering at their transmitters. The above requirement is depicted in Figure 17.

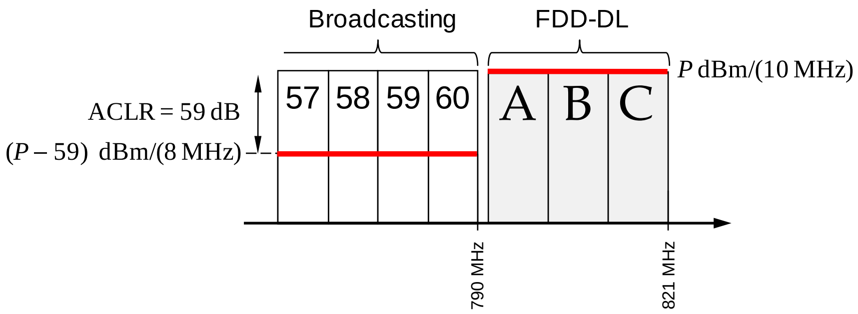

Figure 17. The EC Decision BEM for MFCN base stations, specified in relation to the 790 MHz frequency boundary. Filtering at the base station transmitters must result in a minimum ACLR of 59 dB.

6.54 It is important to note the following three key properties of the above BEM:

i) The EC Decision ACLR of 59 dB was specified[11] based on the fact that, absent any filtering at the DTT receiver, greater ACLRs would not result in a significant reduction in interference to broadcasting in channel 60. However, measurements of the actual emission masks of LTE base station equipment have indicated that an ACLR of 76 dB can be readily achieved over channel 60.

ii) The out-of block emission limits of the EC Decision are specified to be independent of frequency. In practice, the MFCN base station emission levels naturally reduce with increasing frequency separation from the base station

[35] For an EIRP that is X dB greater than 59 dBm, the ACLR must equal (59+X) dB. Furthermore, for an EIRP that is X dB smaller than 36 dBm, the ACLR must equal to (59–X) dB.

carrier. Evidence[36] suggests that a spectral gradient of around 11 dB per 8 MHz is a reasonable model for this spectral roll-off. We used a similar roll-off in the examples of the previous sub-section.

iii) The EC Decision BEM applies to MFCN base stations irrespective of whether they operate in block A, B, or C; i.e., the ACLR is specified with respect to the 790 MHz frequency boundary. This is a serious shortcoming[37] of the way in which the BEMs have been specified, and implies that the increased interferer-victim frequency separations which exist for blocks B and C cannot be fully exploited in reducing the impact of interference. In practice, so long as all licensees use similar filtering, the emission masks of base stations in blocks A, B, and C will be shifted versions of one another centred at carrier frequencies of 796, 806, and 816 MHz, respectively.

6.55 Based on the above arguments, and in the context of understanding the implications of filtering at both the MFCN base station transmitters and DTT receivers, we assume that the base station emission masks have the following characteristics:

a) An ACLR of 76 dB over frequency offsets of 6 to 14 MHz from the MFCN base station carrier.

b) An increase in ACLR of 10 dB for each additional 8 MHz of frequency offset from the MFCN base station carrier.

6.56 The resulting emissions masks for blocks A, B, and C are illustrated in Figure 18, along with the ACLRs in channel 60.

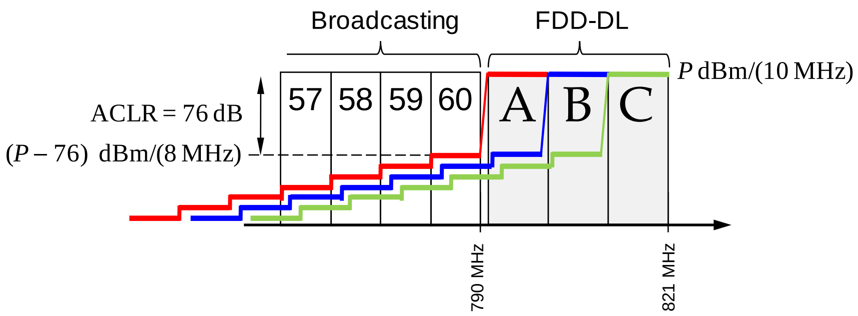

Figure 18. Assumed spectral leakage of the MFCN base stations. The emission masks are specified with reference to the carrier frequencies in blocks A, B, and C.

Table 9. Assumed ACLRs in relation to channel 60 for base stations in blocks A, B, and C.

	ACLR (dB)		
	MFCN block		
DTT channel	A	B	C
60	76	87	99

[36] This corresponds to the spectral roll-off of typical base station transmitter filters. See ECC PT1(09)048,“Guard band and duplex gap for the FDD band-plan of the 790-862 MHz band,” April 2009.

[37] We proposed a correction to this shortcoming during the deliberations of ECC/SE42. While this correction was broadly accepted, it was not finally adopted due to the challenging timescales of the SE42 studies. See “UK response to the ECC public consultation of the draft CEPT report 30 on the identification of common and minimal technical conditions for the 790-862 MHz digital dividend in the European Union,” Sep. 2009..

6.57 We next demonstrate the impact of filtering at the base station transmitters via numerical examples.

MFCN base station transmitter filtering and affected households

6.58 Table 10 presents the estimated number of affected households (standard domestic installations) subject to the use of additional base station transmitter filtering alone, and where additional base station transmitter filtering is used jointly with DTT receiver filtering. These are the results of computer modelling in the coverage area of the Oxford DTT transmitter.

Table 10. The impact of MFCN base station transmitter filtering on the number of households affected by interference. The total number of households served in the coverage area is 404,866.

	DTT channel	No. of households affected by interference			
		MFCN blocks			
		A	B	C	ABC
No filtering	60	7,101	2,444	2,314	9,370
	59	1,260	1,654	1,252	3,453
	58	2,281[34]34	1,393	684	3,677
BS transmitter filtering only	60	6,526	1,239	1,186	7,701
	59	1,142	1,524	1,134	3,180
	58	2,267	1,384	671	3,656
BS transmitter & DTT receiver filtering	60	5,559	304	25	5,711
	59	436	36	19	466
	58	55	29	11	81

6.59 The results indicate that where base station transmitter filtering is used alone, the reduction in interference is very modest. This is because interference is lower-bounded by the limited frequency selectivity of the DTT receivers despite the reduced spectral leakage of the base stations.

6.60 However, where base station transmitter filtering and DTT receiver filtering are used in combination, the levels of interference reduce considerably, particularly from blocks B and C. The exception is the case of interference from block A to channel 60. Here DTT receiver filtering is ineffective due to the immediate adjacency of the MFCN and DTT carriers, and so the interference is still lower-bounded by the DTT receiver selectivity and cannot be reduced materially with an improvement in the spectral leakage of the mobile base stations.

Conclusions

6.61 Filtering at the MFCN base station transmitter is an effective tool for the mitigation of interference in scenarios where interference is lower-bounded by the out-of-block emissions of the base station. This is particularly evident in scenarios where DTT receiver filtering is already in use.

6.62 An example of this is the case for interference from blocks B and C to channels 60 and 59, where base station transmitter filtering is very effective in reducing the impact of interference.

6.63 For the case of interference from block A to channel 60, even joint use of base station transmitter filtering and DTT receiver filtering is not very effective. This is because DTT receiver filtering fails to significantly increase the receiver's frequency selectivity, and so any reduction in base station out-of-block emissions cannot be exploited.

6.64 Consequently, mitigation of interference from block A to channel 60 calls for better DTT receiver filter characteristics than those which we have used in our modelling of domestic installations; namely a sharp roll-off from the pass-band edge at 790 MHz to a respectable stop-band attenuation of 20 dB immediately above 791 MHz.

Polarisation discrimination

6.65 In this sub-section we examine the effectiveness of polarisation discrimination as a measure for mitigating the impact of interference from MFCN base stations in the 800 MHz band to DTT services below 790 MHz.

Polarisation discrimination

6.66 Polarisation discrimination (PD) refers to the *additional* attenuation that a signal experiences when its plane of polarisation[38] differs from the plane of polarisation which an antenna is designed to optimally receive. The greatest discrimination is achieved when the polarisation of the received signal is orthogonal to that of the receiving antenna. This can be exploited to suppress interfering signals from MFCN base stations, as described next.

6.67 Main DTT transmitters typically radiate horizontally polarised signals. Accordingly, the target TV aerials are oriented horizontally in order to maximise the received power. Relay DTT transmitters, on the other hand, typically radiate vertically polarised signals, with the receiving TV aerials oriented accordingly. Consequently, if MFCN base stations radiate with a polarisation that is orthogonal to the polarisation of the serving DTT transmitter, then the base station signals will potentially experience significant attenuation upon reception by a TV aerial. See figure below.

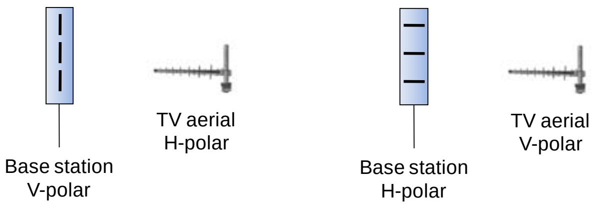

Figure 19. Orthogonal-to-DTT polarisation.

6.68 Multi-antenna transmit and receive signal processing technologies are today an established element of MFCNs. Traditionally, spatially separated[39] vertically polarised antennas were used for the implementation of multi-antenna techniques at the base stations of 2G networks (primarily in the form of receiver diversity). In recent years, however, base stations have been increasingly using co-located ±45° (slant or mixed) polarised antennas in order to reduce the amount of space required on the mast. See figure below.

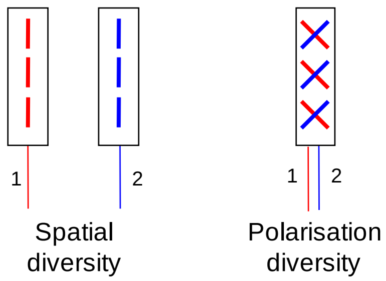

Figure 20. Spatial vs. polarisation diversity used to implement multi-antenna techniques at MFCN base stations.

[38] Direction of the electric field as the wave travels.
[39] A separation of many wavelengths is typically required to de-correlate the multi-antenna signals.

6.69 As we will see next, a ±45° (slant) polarised base station signal does not become significantly attenuated when received by a vertically or horizontally oriented TV aerial.

Modelling of TV aerial polarisation discrimination

6.70 It is common practice to model the polarisation discrimination at a TV aerial as

a) an attenuation of 16 dB[40] when the interfering signal's polarisation is orthogonal to that of the wanted DTT signal (or orientation of the TV aerial); and

b) an attenuation of 3 dB[41] when the interfering signal is ±45° (slant) polarised.

c) an attenuation of 0 dB when the interfering signal's polarisation is the same as that of the wanted DTT signal (or orientation of the TV aerial).

6.71 Note that the above attenuations apply only to interfering signal which arrive within the main beam of the TV aerial's directional gain pattern.

6.72 For the TV aerial directional gain pattern specified in ITU-R Rec.419-3, the polarisation discrimination can be modelled as shown in Figure 21 below. The resulting *net* directional gain (combination of the aerial's directional gain and polarisation discrimination) is shown in Figure 22. These are used in all our modelling.

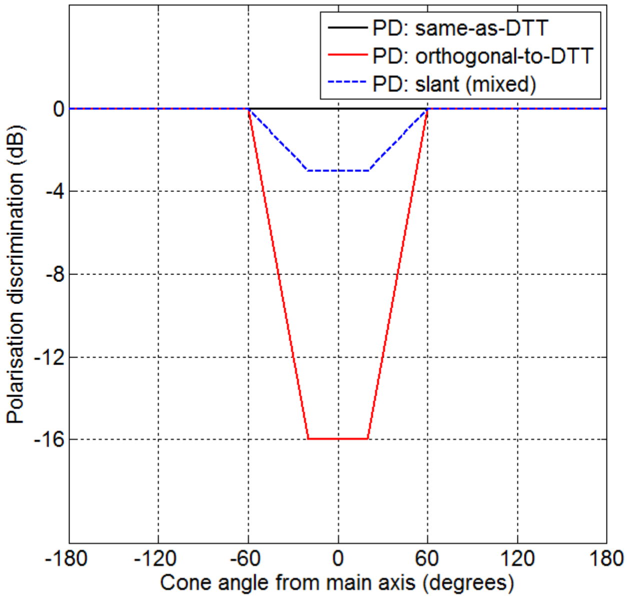

Figure 21. TV aerial polarisation discrimination as a function of *cone* angle of arrival with respect to the aerial's main axis. The corner points are at ±20° and ±60°.

[40] In principle, the attenuation would be ∞ dB if polarisations were perfectly orthogonal. In practice the attenuation is bounded by the fluctuations in the polarisation plane and the imperfections of the receiving aerial.

[41] Each of the +45° and –45° polarised components carry half the base station's EIRP, and a vertical or horizontal TV aerial captures only half of the power in each of the +45° and –45° polarisation components.

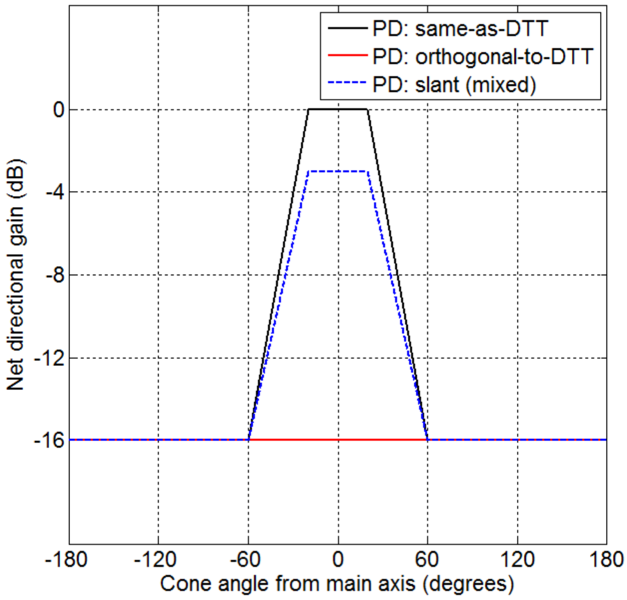

Figure 22. TV aerial net directional gain (combination of directional gain and polarisation discrimination) as a function of *cone* angle of arrival with respect to the aerial's main axis. The corner points are at ±20° and ±60°.

6.73 It is interesting that to note that in response to a base station signal with orthogonal-to-DTT polarisation, the TV aerial exhibits an omni-directional gain of –16 dB as opposed to the classical *keyhole* pattern. This is illustrated graphically below. The change in directional gain will have a corresponding impact on the shape of the coverage holes in the proximity of base stations[42].

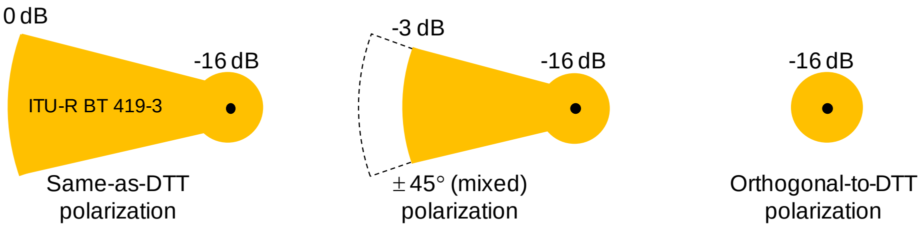

Figure 23. TV aerial net directional gain
(combination of directional gain and polarisation discrimination).

Field measurements of polarisation discrimination

6.74 We recently commissioned Aegis and ERA to undertake a programme of over-the-air measurements in relation to the potential for interference from LTE base stations in the 800 MHz band to DTT services below 790 MHz.

6.75 As part of this programme, we measured the polarisation discrimination of a domestic TV aerial (Yagi) in response to emissions in block A from a distant vertically polarised LTE base station antenna. At each test point, the TV aerial was pointed in the azimuth direction of the Lichfield DTT transmitter, and the signal power received from

42

the LTE base station was recorded with the TV aerial rotated around its main axis to a) align with the horizontal plane, and b) align with the vertical plane. The difference between the two recordings at each test point represents the polarisation discrimination of the tested TV aerial with respect to an orthogonal-to-DTT polarised signal.

6.76 The tested TV aerial has a gain of 6 to 8 dB, and its angular discrimination gain is shown in Figure 24 as a function of azimuth offset from its axis.

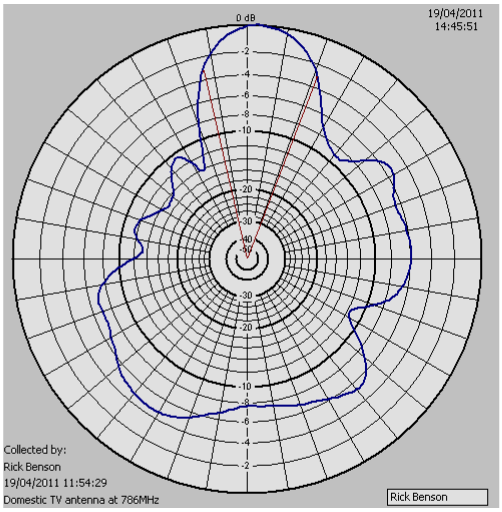

Figure 24. Angular discrimination gain of the tested domestic TV antenna.

6.77 The measured values of polarisation discrimination are shown in Figure 25 as a function of the azimuth offset of the LTE base station from the axis of the TV aerial. Also shown is the polarisation discrimination pattern we have used in our modelling (corresponding to the ITU-R Rec.419-3 angular gain pattern).

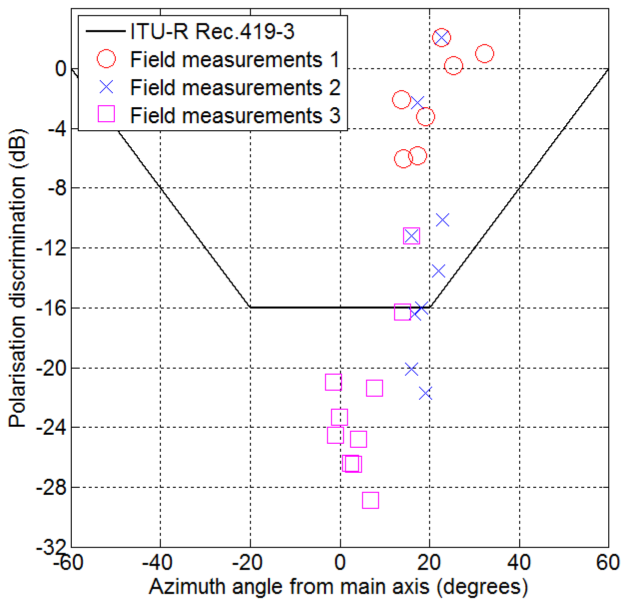

Figure 25. Measured polarisation discrimination.

6.78 The measurements indicate that the tested antenna attenuates orthogonal-to-DTT polarised signals by up to 29 dB in some locations, and by as little as 0 dB in others[43]. It appears that radio propagation and clutter in the vicinity of the TV aerial have a significant impact on the achievable polarisation discrimination.

Polarisation and affected households

6.79 Table 11 presents the estimated number of affected households (standard domestic installations) subject to the use of orthogonal-to-DTT polarisation by the MFCN base stations. These are the results of computer modelling in the coverage area of the Oxford transmitter.

6.80 Although not explicitly stated, we had assumed slant polarised base station emissions as default in the results presented previously.

6.81 Comparison with the results of Tables 8 and 10 indicates that the numbers of affected household when orthogonal-to-DTT polarisation is used at the base stations is a factor of between 3 to 4 lower than the corresponding numbers when slant polarisation is used at the base stations.

Table 11. Impact of orthogonal-to-DTT polarisation on the number of households affected by interference from MFCN base stations. The total number of households served in the coverage area is 404,866.

	DTT channel	No. of households affected			
		Mobile blocks			
		A	B	C	ABC
No filtering	60	2,379	785	763	3,291
	59	341	473	358	1,007
	58	663	381	188	1,093
DTT receiver filtering	60	2,019	676	634	2,739
	59	166	85	88	302
	58	19	12	10	43
BS transmitter filtering	60	2,083	352	339	2,516
	59	300	429	311	912
	58	656	380	182	1,083
BS transmitter & DTT receiver filtering	60	1,726	84	4	1,781
	59	110	6	3	117
	58	9	4	2	14

Conclusions

6.82 The results of modelling suggest that the use of orthogonal-to-DTT (as opposed to slant) polarisation at the MFCN base stations reduces the number of affected households by a factor of between 3 to 4. The modelling assumes a polarisation discrimination pattern which attenuates the interferer by 16 dB (as opposed to 3 dB) within the main beam of the TV aerial.

6.83 As such, the use of orthogonal-to-DTT polarisation is a technically effective tool for mitigating the impact of interference from MFCN base stations in the 800 MHz band to DTT services below 790 MHz.

[43] In certain test points, the orthogonal-to-DTT polarised signal is in fact amplified rather than attenuated.

6.84 However, the following issues may constrain their widespread deployment:

a) Vertically (or horizontally) polarised base station antennas need to be spatially separated and so require more space at the mast head as compared to ±45° polarised antennas. Such space may not be available in the smaller base station sites.

b) Orthogonal-to-DTT polarisation in the coverage area of relay DTT transmitters implies the use of horizontally polarised antennas at the MFCN base stations. Mobile communication networks have not traditionally used horizontally polarised antennas. As a result, such antennas are not widely available commercially.

c) Measurements indicate that the amount of polarisation discrimination achievable in practice is highly dependent on the nature of radio wave propagation and the extent of multipath and scattering in the vicinity of the TV aerial. This means that polarisation may not be equally effective for all households.

MFCN base station site-sharing

6.85 In deriving the results presented in this report, we have assumed that the MFCN licensees of blocks A, B, and C share their base station sites. This was a pragmatic assumption, driven by our access to detailed information regarding a single existing UK-wide deployment of GSM-900 base stations.

6.86 In this section we explore the impact on the number of households affected by interference in scenarios where site sharing does not apply.

Site sharing and coverage holes

6.87 Intuitively, one might expect the impact of interference to be reduced significantly in scenarios where licensees share their base station sites. This is because site-sharing is expected to reduce the size of the area affected surrounding the base stations. However, as shown in Figure 26, this reduction in size is not significant if the dimensions of the licensees' individual coverage holes are large in comparison with the separation between their base stations.

6.88 Even where the coverage holes are small compared to the base station separations, the size of the area affected does not necessarily reduce by a factor of ×3. This is due to the aggregation of interference from the individual licensees.

6.89 Finally, a reduction in the size of the affected area does not translate to a proportional reduction in the number of affected households (even if households had a uniform spatial distribution). This is because the *intensity* of the coverage hole created by three co-sited base stations will be greater than that of the coverage hole created by three separated base stations; resulting in a greater likelihood of receiver failure near the co-sited base stations. All this dilutes the potential benefits of site-sharing.

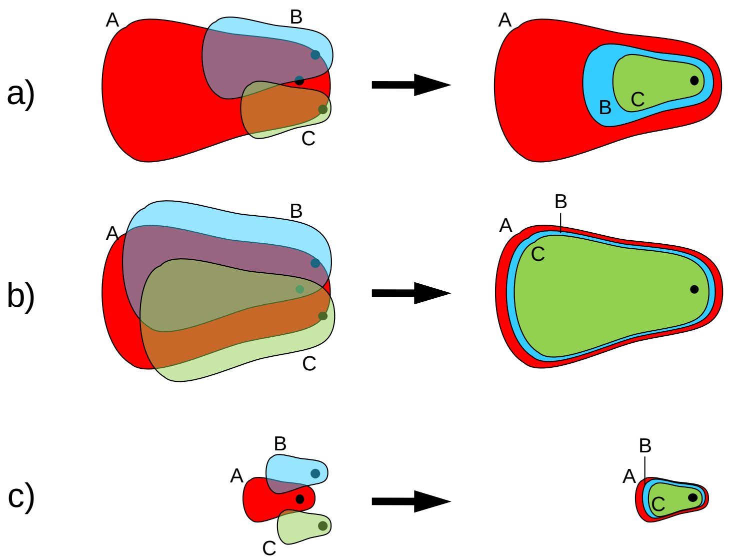

Figure 26. Site-sharing and impact on the size of the affected areas.
Note that the figures do not capture the increased *intensity* of the coverage holes near the co-sited base stations.

6.90 It is difficult to devise a rule of thumb to quantify the benefits of site sharing. However, it should be noted that the overall number of households affected across the coverage area of a DTT transmitter tends to be dominated by the number of households affected at the edge of DTT coverage. Furthermore, the dimensions of coverage holes at the edge of DTT coverage tend to be between 500 to 1000 metres in channel 60 areas, and between 200 to 400 metres in channel ≤51 areas[44]. This suggests that a departure from site-sharing does not significantly alter the impact of interference for base station separations of up to a couple of hundred metres.

Site sharing and affected households

6.91 Here, we model the departure from site-sharing by locating the base stations of licensees A, B, and C on the vertices of equilateral triangles of side d metres, where the triangle centroids coincide with the GSM-900 base station locations examined previously. This is illustrated below.

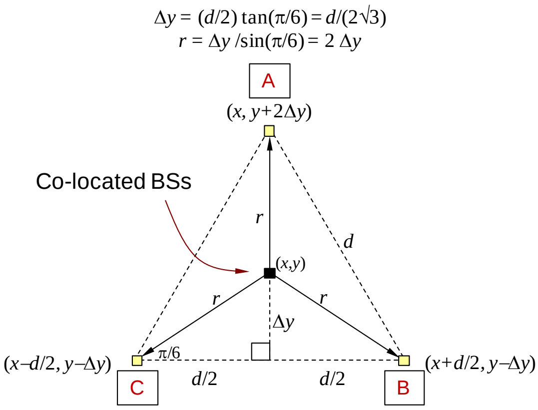

Figure 27. Departure from site-sharing: modelled geometry.

6.92 Table 12 shows the numbers of households (standard domestic installation) that are affected by interference in channel 60 for a range of values of base station separation, d. These are the results of computer modelling in the coverage area of the Oxford transmitter, and in the absence of any mitigation measures.

6.93 In this example, a departure from site-sharing increases the number of affected households by around 10%. This is because interference is dominated by emissions from block A, and – at least at the edge of DTT coverage – there remains considerable overlap between the coverage holes created by blocks A, B, and C even at a large separation of d = 200 m.

[44] Specifically, for DTT signal powers of {-70, -60} dBm, and corresponding protection ratios of {-37, -34} dB in channel 60, and {-52, -50} dB in channel 51, the largest dimension of the resulting coverage holes is roughly {1000, 600} metres in channel 60, and {400, 200} metres in channel 51. These are for a BS EIRP of 59 dBm (±45° polarised), BS antenna height of 20 m, BS antenna angular discrimination based on the 3GPP reference specifications, BS antenna down-tilt of 3°, TV aerial gain of 9.15 dBi (including cable loss), TV aerial angular discrimination based on the ITU-R Rec.419-3 specifications, TV aerial height of 10 m, TV aerial down-tilt of 0°. Suburban extended-Hata median path loss is assumed. Note that the calculation is based on median signal strengths only. The dimensions would be greater if margins were included to account for the standard deviations of the wanted and interferer signals.

Table 12. Estimated number of households affected by interference in channel 60 and in the absence of mitigation measures: impact of co-siting. The total number of households served in the coverage area is 404,866.

base station separation *d* (m)	No. of households affected by interference			
	Mobile blocks			
	A	B	C	ABC
0	7,101	2,444	2,314	9,370
25	7,102	2,449	2,321	9,383
50	7,140	2,439	2,340	9,525
100	7,109	2,428	2,354	9,755
200	7,065	2,479	2,367	10,303

6.94 Table 13 shows the corresponding numbers for channel 51. In this example, a departure from site-sharing increase the total number of affected households by around 12%. Here, blocks A, B, and C contribute more equally to interference (in the form of receiver overload). Furthermore, Secondly, the increased interferer-victim frequency separation implies smaller coverage holes in comparison with the examined values of d .

Table 13. Estimated number of households affected by interference in channel 51 and in the absence of mitigation measures: impact of co-siting. The total number of households served in the coverage area is 404,866.

base station separation *d* (m)	No. of households affected by interference			
	Mobile blocks			
	A	B	C	ABC
0	550	550	550	1,557
25	550	559	576	1,58934
50	515	551	572	1,626
100	486	557	589	1,724
200	472	591	609	1,750

6.95 Finally note that in all the above examples the number of affected households due to the emissions of each of blocks A, B, and C remain broadly unchanged as a result of the movement of the base station locations. This implies that the finite 100m × 100m spatial resolution of the UKPM is adequate for the purposes of our analysis, and that any local modelling anomalies caused by the implied coarse granularity in DTT receiver locations is averaged out when considered over a large area.

Conclusions

6.96 In this sub-section we examined the benefits of site-sharing among new licensees of the 800 MHz band in the context of reducing the number of households whose DTT service might be affected.

6.97 Our modelling indicates that, when aggregated across the coverage area of the Oxford DTT transmitter, site-sharing provides a modest reduction of around 10% (or less) in the number of households affected.

6.98 The reason for such a modest reduction is that the impact of interference from MFCN base stations is greatest at the edge of DTT coverage, where the dimensions of the coverage holes created in the vicinity of base stations are of the order of hundreds of metres; i.e., greater than the typical separation between unshared sites.

6.99 Furthermore, co-sited base stations can create more *intense* coverage hole, and this dilutes any benefits derived from a reduction in the size of the area affected.

6.100 Nevertheless, site sharing has other more significant benefits such as reducing mobile network CAPEX/ OPEX, as well as simplifying the task of coordination among the licensees.

Impact of base station EIRP

6.101 In this sub-section we investigate the effectiveness of a reduction in the in-block EIRP of MFCN base stations in the 800 MHz band as a measure for mitigating the impact of interference to DTT services below 790 MHz.

Affected households vs. base station EIRP

6.102 It is not possible to derive a simple rule of thumb to describe the relationship between the number of households affected by a base station and the base station's EIRP. This is because an increase in EIRP not only increases the area of the coverage hole surrounding a base station but it also increases the *intensity* of the coverage hole (i.e., the likelihood that households located at a certain distance from the base station might be affected)[45]. For this reason, we rely on the results of computer simulation.

6.103 Figure 28 shows the variation in the estimated number of affected households (standard installations) as a function of the EIRP of the MFCN base stations. The results are for DTT channel 60 and throughout the coverage area of the Oxford transmitter. Results are presented for the case of no filtering, and where both base station transmitter and DTT receiver filtering are used. As a benchmark, typical base stations in the 800 MHz band are likely to operate at an EIRP of around 60 dBm.

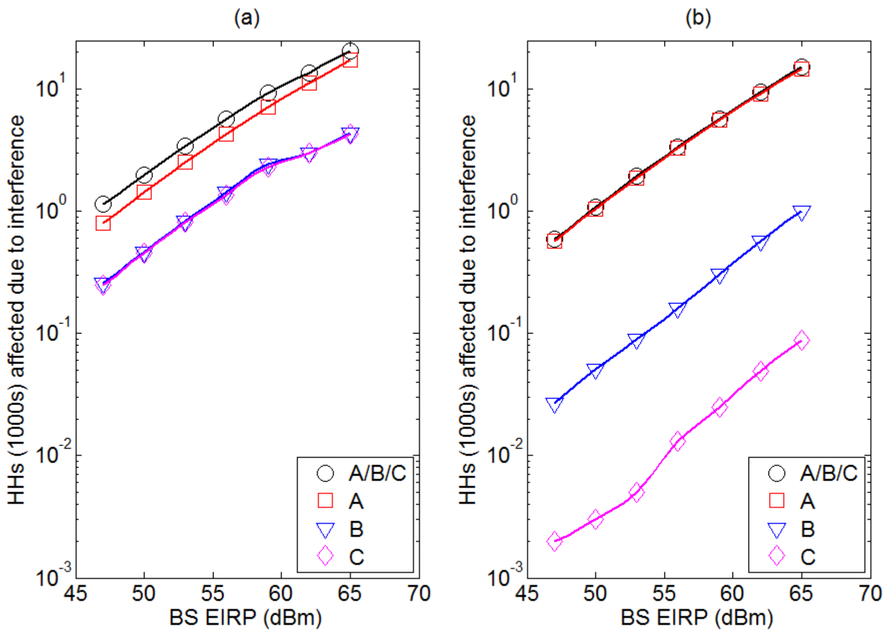

Figure 28. Variation of affected households in channel 60 as a function of base station EIRP for two cases: a) no filtering, b) filtering at the base station transmitters and DTT receivers.

6.104 The following conclusions can be drawn from the above results:

1) The number of affected households grows as an exponential function of the EIRP (in Watts) of the base stations; i.e., $N \propto P^m$. The exponent m in the presented

[45] If an increase in base station EIRP only increased the area of the coverage hole (and not its "intensity"), then assuming a uniform spatial distribution of households, the number of affected households would be proportional to $P^{2/n}$ where P is the EIRP in watts, and n is the prevalent path loss exponent.

example is roughly 0.8. Naturally, this variation cannot be sustained indefinitely, and the curves flatten out for very large EIRPs as fewer and fewer households remain unaffected.

2) For the mitigation of interference to DTT channel 60, and in terms of absolute numbers of affected households, a reduction in EIRP is a far more effective measure when applied to block A than when applied to blocks B and C. This is particularly the case when both base station transmitter filtering and DTT receiver filtering are use, in which case the emissions from blocks B and C contribute little to interference.

3) By extension, for the mitigation of interference to lower DTT channels, a reduction in EIRP is less effective and would need to be applied more equally to blocks A, B, and C.

MFCN downlink throughput vs. base station EIRP

6.105 A reduction in base station EIRP is not without implications for the mobile network, and inevitably results in degradations in the downlink quality of service.

6.106 This is illustrated in Figure 29 where we show how LTE downlink throughput at the cell-edge varies as a function of base station EIRP[46]. These are the results of computer modelling for Oxford city centre (suburban Hata), Swindon town centre (suburban Hata), and the Cotswolds (rural Hata), all in the coverage area of the Oxford transmitter (see Figure 11 for boundaries of analysed areas).

6.107 As might be expected, rural coverage requires greater base station EIRPs. In built-up areas of Oxford and Swindon, outdoor coverage is broadly insensitive to reductions in EIRP down to levels of 45 to 50 dBm; with indoor coverage broadly unchanged for EIRPs of down to 50 to 55 dBm. However, in rural areas such as the Cotswolds, while outdoor coverage is broadly unchanged for EIRPs down to 55 dBm, indoor coverage drops sharply below around 60 dBm.

[46] Here we defined cell-edge throughput as the throughput exceeded in 90% of locations. See Annex 1 for the values of the other parameters used, including the definitions of depth 1 and depth 2+ indoor coverage.

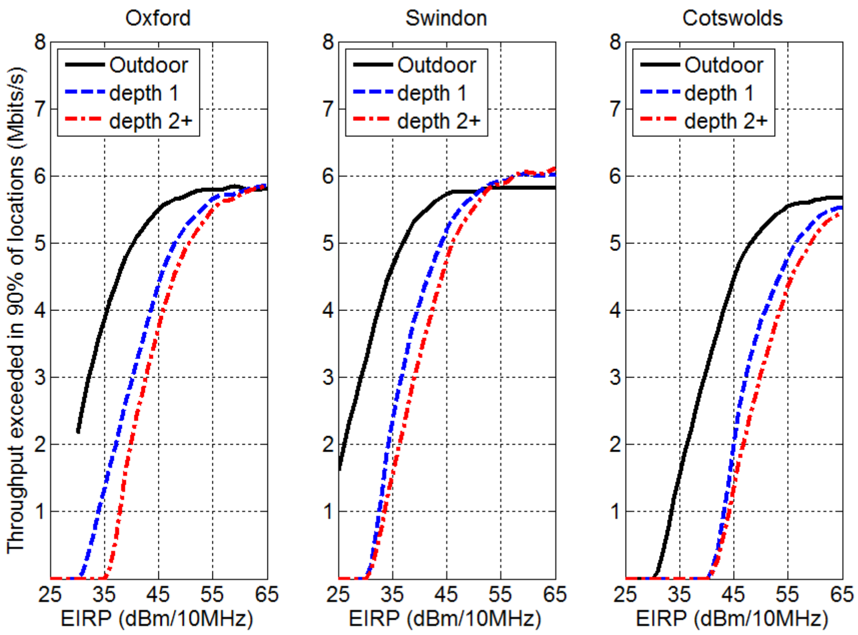

Figure 29. Variation of LTE downlink single-user throughput at cell-edge as a function of base station EIRP. MIMO: 2×2.

6.108 Note that the above results illustrate the effect of a reduction in the EIRP of all base stations in the geographical area of interest.

6.109 In practice, where the intention is to mitigate the impact of interference to the DTT service, the required amount of reduction in the EIRP of a base station will depend on the following factors[47]:

1) The household population density in the vicinity of the base station;

2) The radio propagation environment (clutter and shadowing) from the base station antenna to the TV aerials;

3) The quality of the DTT service (i.e., location probability) experienced by households located in the vicinity of the base station;

4) The MFCN-to-DTT protection ratios (functions of MFCN-to-DTT carrier separation, and received wanted DTT signal power);

5) The target degradation in DTT location probability for the households in the vicinity of the base station;

6.110 Consequently, the required reduction in EIRP will be different among different base stations, and even among different antenna sectors of the same base station. Note

[47] Interestingly, these are precisely the factors which a geolocation database for white-space devices would need to account for in its calculations when specifying the maximum permitted emission levels of the devices on a location-specific basis. See H.R.Karimi, "Geolocation databases for white space devices in the UHF TV bands: Specification of maximum permitted emission levels," in *Proc. Dynamic Spectrum Access Networks* (IEEE-DySPAN), May 2011, Aachen – Germany.

that significant reductions in EIRP are only likely to be required in one or two sectors of any base station. This is due to the directionality of TV aerials.

Conclusions

6.111 We have illustrated (via modelling in the coverage area of the Oxford DTT transmitter) that the number of households affected by interference from MFCN base stations varies exponentially with the EIRP of the base stations.

6.112 In the context of the absolute numbers of households affected, we have seen that reductions in EIRP are particularly effective in mitigating interference from block A to channel 60, and less so for blocks B and C.

6.113 We have also shown, via modelling in the same geographic area, how the cell-edge downlink throughput of a LTE network reduces as a result of reductions in base station EIRP.

6.114 We have noted that a uniform reduction in the EIRP of base stations is not a spectrally efficient approach to mitigating the impact of interference to DTT services. Where required, efficient mitigation can be achieved via judicious amounts of EIRP reduction in different sectors of different base stations.

On-channel repeaters

6.115 An on-channel repeater (OCR) receives a DTT signal from a parent transmitter through a receive antenna, amplifies this, and re-broadcasts it via a different antenna but on the same frequency.

6.116 By increasing the wanted DTT signal power received at the TV aerials, OCRs are potentially able to repair any degradation in the signal-to-interference ratio caused by adjacent-channel emissions from MFCN base stations in the 800 MHz band. Note that OCRs cannot mitigate against the overloading of DTT receivers or amplifiers, since they only add to the total power received by the overloaded device[48].

6.117 In this section we present the preferred installation options for OCRs, summarise the results of our recent measurements of an OCR, and describe a set of technical conditions under which we believe OCRs can operate in a stable manner.

OCR deployment

6.118 In principle OCRs can be installed at any location where they can receive an adequate DTT signal strength. However, co-siting of the OCRs with the MFCN base stations has the following advantages:

- Co-siting provides the greatest likelihood of repairing the DTT coverage hole created in the proximity of a MFCN base station. This is because the OCR-to-TV and BS-to-TV radio propagation conditions become similar and correlated. In other words, if the interference level is high at the TV aerial, then it will be likely that the wanted signal power is also high. This effect can be exploited most fully if the OCR and base station actually *shared* the same transmit antenna. See Figure 30.

- Co-siting minimises the power which an OCR is required to radiate. This is because by co-siting we avoid geometries where TV aerials are much closer to a base station than they are to an OCR. This means that for a protection ratio of *r* dB, the OCR EIRP can be *r* dB lower than the base station EIRP. Reduced OCR power reduces the likelihood of any adverse impact on DTT coverage from the parent transmitter (e.g., due to excessive delays), reduces the requirements for coupling loss between the OCR's transmit and receive antennas, and reduces interference to the MFCN downlink.

- Co-siting eliminates the need for TV aerials to re-point towards the OCR. This is because the rebroadcast DTT signal and the base station interfering signal are always subject to the same angular discrimination gain of the TV aerial. So re-pointing would increase the wanted and unwanted signal levels equally.

6.119 Antenna-sharing brings with it another advantage relating to the use of echo-cancellation. OCRs typically use echo-cancellation[49] in order to suppress the DTT signals that are coupled from its transmit antenna back to its receive antenna (due to a direct path or reflections from surrounding objects). Echo cancellation reduces the

[48] In such circumstances, overload can be eliminated by inserting an attenuator prior to the DTT receiver or amplifier.

[49] Echo-canceller uses the signal at the output of the OCR as a reference signal to estimate the channel state (in the form of the coefficients of a FIR filter) from the OCR output to the OCR input. Having estimated the channel, the echo-canceller can reconstruct the signal that is coupled from the OCR output and subtract it from the OCR input.

isolation between the OCR's input and output that is required for stable operation of the OCR.

6.120 If the OCR and base station feed the same transmit antenna, then the echo-canceller can be used to suppress both the fed back DTT and base station signals at the OCR input. We refer to this as external enhanced echo-cancellation. Different echo-cancellation modes are illustrated in Figure 31. External echo-cancellation can become complicated due to the need for the estimation of multiple channels where sectored antennas and/or transmission diversity is used by the base station.

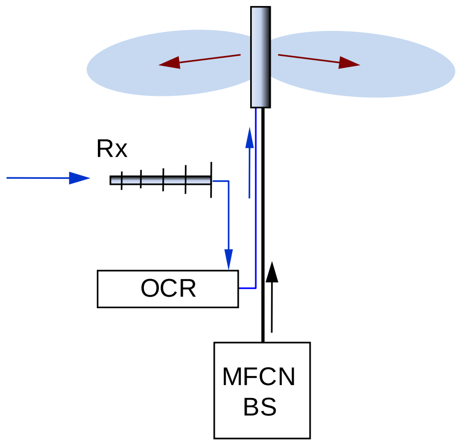

Figure 30. Antenna sharing between OCR and base station.

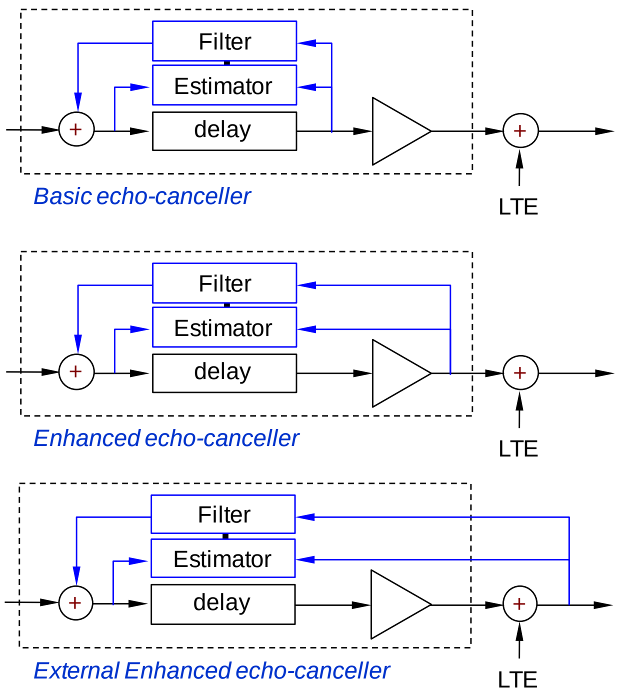

Figure 31. Echo-cancellation modes.

OCR measurements

6.121 We recently commissioned Aegis to bench-test the performance of a Rohde & Schwarz XL88000 OCR in the context of repair to DTT coverage holes caused by adjacent channel LTE emissions in the 800 MHz band. Details of the tests will be published in due course as a technical report[50].

6.122 Initial tests indicated that for a robust operation of the OCR, a DTT signal power of -60 dBm or greater is required at the OCR input. The test set-up of Figure 32 was then used to emulate the case where the OCR output is fed through the LTE base station antenna. The intention was to represent a situation in which the OCR EIRP is 10 dB lower than the base station EIRP (i.e., LTE-to-DTT protection ratio is -10 dB). The LTE power was set to +40 dBm, implying a DTT power of +30 dBm at the OCR output. The feedback attenuation was set to emulate a coupling loss of 80 dB.

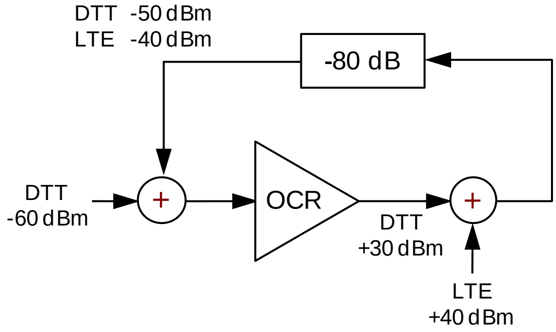

Figure 32. Bench test set-up.

6.123 Tests indicated that with a *basic* echo-cancellation, the OCR fails to operate. However with *enhanced* echo-cancellation, the OCR operates correctly and can provide a respectable modulation error-rate (MER) of around 27 dB at its output. This drops to 23 dB when the LTE power is increased to 45 dBm. *External-enhanced* echo-cancellation provides only a marginal improvement over the above performance.

6.124 The performance of the OCR degrades considerably in the presence of time-discontinuous LTE signals. Such signals would occur if the base station was lightly loaded or, in the extreme, was *idle* (i.e., transmitted no traffic other than broadcast and control signalling). Tests indicate that the performance can be recovered by inserting a modest filter at the input of the OCR. This was also demonstrated in our recent DTT protection field trials[50].

6.125 The above test set-up represents the physical arrangement shown in Figure 33. Note that assuming a base station antenna gain of 13 dBi (including 3 dB cable loss), the test set-up implies a LTE base station EIRP of 53 dBm.

6.126 For a more practical LTE EIRP of 59 dBm, the required DTT power at the input to the OCR would need to be increased by 6 dB to -54 dBm for an unchanged required coupling loss of 80 dB.

[50] R.F.Rudd, "The co-existence of LTE and DTT services at UHF: a field trial", final report by Aegis. Available at http://stakeholders.ofcom.org.uk/consultations/coexistence-with-dtt/ .

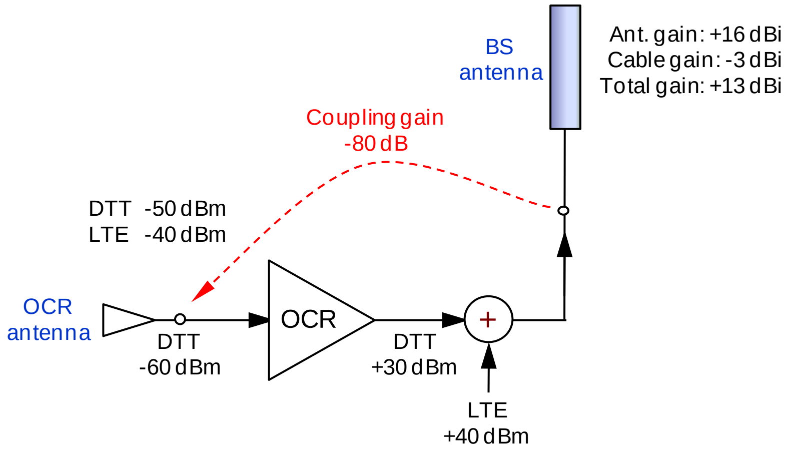

Figure 33. Physical arrangement and implications for coupling gain.

Viability as a mitigation tool

6.127 The measurement results summarised above suggest that OCRs are capable of robust operation in repairing coverage holes, subject to two requirements:

a) A DTT signal power of -54 dBm or greater at its input (for a 59 dBm EIRP base station). Assuming a signal strength standard deviation of σ = 5.5 dB, the above threshold would be achieved throughout a pixel with a probability of 95% if the median signal strength was -45 dBm (i.e., margin of 1.65σ).

b) A coupling loss of 80 dB or greater between the input and output of the OCR.

Available DTT signal power

6.128 In the context of the first condition, Figure 34 shows the distribution of DTT signal power at the locations of GSM-900 base stations belonging to a mobile operator throughout the APSA coverage area of the Oxford transmitter.

6.129 The figure indicates that the threshold of -45 dBm is exceeded in some 70% of the GSM-900 base station locations. Note that the above data is derived from the UKPM and so assumes a 9.15 dBi OCR receive antenna gain installed at a height of 10 m. Greater antennas gains and heights would increase the percentage of base station locations where the threshold is exceeded. For example, with a 14 dBi OCR receive antenna gain, the required threshold would be exceeded in ~85% of base station locations.

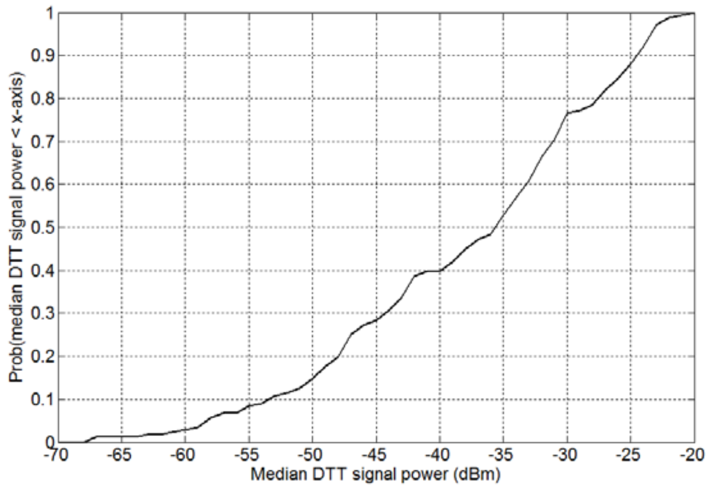

Figure 34. Distribution of DTT signal strength at the locations of an operator's GSM-900 base stations. Derived for the APSA coverage area of the Oxford transmitter, assuming a 9.15 dBi antenna gain at a height of 10 m. *Source: UKPM.*

6.130 While only a low percentage of base stations might receive insufficient DTT signal power for the operation of an OCR, it is certain that a greater percentage of households affected by interference are in the proximity of precisely these base stations; i.e., in poorer DTT coverage areas.

Achievable input-output isolation

6.131 Radiated measurements[50] performed by Aegis and Ofcom have indicated that the coupling loss achieved between the OCR input and output can take on a large range of values depending on the installation geometry, local clutter, and the movement of nearby objects.

6.132 Having said that, measurements to date have indicated that with careful site engineering, isolation losses of 80 dB or greater can be achieved in many cases.

Conclusions

6.133 In this section we have described the operation of an OCR, and explained why co-siting and antenna sharing of the OCR with the MFCN base stations is the preferred option for their deployment.

6.134 We have summarised the results of recent measurements commissioned by Ofcom. These establish that the tested OCR can operate stably and robustly so long as it can receive a DTT signal power of -54 dBm or greater, given a coupling loss of 80 dB between its input and output, and a LTE transmit power of 46 dBm (EIRP of 59 dBm for a 13 dBi net antenna gain).

6.135 The measurements also indicate that time-discontinuous LTE signals can disrupt the operation of OCRs, but that this can be readily mitigated via modest filtering at the OCR input.

6.136 Echo-cancellation with reference extracted after the addition of the LTE signal provides only marginal performance improvements over that with reference extracted internally after the OCRs amplifier. Further enhancements to commercially available OCRs will be required if echo-cancellation with external reference is to be extracted from multiple sectored or diversity antennas.

6.137 Measurements also indicate that coupling losses of 80 dB or greater can be attained in practice through careful site engineering, although their stability will depend on the nature of the local clutter.

6.138 We have also shown that only 15% of GSM-900 base stations in the coverage area of the Oxford transmitter are unable to receive sufficient median DTT signal strength for stable operation of co-sited OCRs. However, many of the households affected by interference are likely to be located in the proximity of precisely these base stations.

6.139 Based on the above arguments, we believe that the use of OCRs is a technically viable solution for mitigating against the impact of interference. However, the quality of performance of OCRs can vary widely from one location to another and across different installation geometries. Another area of uncertainty relates to the stability of operation of a network of densely deployed OCRs.

6.140 In summary, OCRs can be very effective in mitigating the impact of interference to DTT sevices from specific MFCN base stations, but their technical viability as a universal solution to the 800 MHz interference issues remains uncertain.

Section 7

Categories of DTT receiver installations

Introduction

7.1 In this section we describe three categories of DTT receiver installations, and estimate the number of households in the UK associated with each category.

7.2 In Sections 8, 9, and 10, we model in some detail the impact of interference to households in each category.

Installation categories

7.3 When assessing the impact of interference on DTT reception, it is necessary to consider the range of installation types in use in the UK. We have defined the following three categories for the purposes of modelling:

a) Standard domestic installations (SDI) – Installations which conform to the UKPM specification – i.e., a professionally installed outdoor Yagi antenna at a height of 10 m, feeding a DTT receiver through good quality coaxial cable.

b) Communal antenna systems (CAS) – Installations using a single antenna to distribute DTT signals to multiple outlets by means of a distribution or “launch” amplifier with variable gain. These are mainly used in apartment blocks, and also in hotels, hospitals etc. Communal systems are divided into two categories: Master Antenna TV (MATV) and Integrated Reception Systems (IRS). A MATV system works in the manner described above, whereas an IRS includes an integrated satellite reception and distribution system. For the purposes of modelling, these systems are considered to be equivalent as they both use similar launch amplifiers and are installed in the same manner.

c) Domestic installations with amplifiers (DIA) – Installations which employ an amplifier of some kind for use by a single household. These amplifiers are either a mast-head amplifiers (MHA), or an “indoor” amplifiers. MHAs are typically fixed-gain amplifiers professionally installed on the antenna. Indoor amplifiers are devices installed elsewhere in the DTT distribution chain, typically either in a loft or behind the TV set. These devices may be used for any of the following reasons:

- To receive DTT in an area of poor coverage;
- To obtain 6MUX coverage in a 3PSB coverage region;
- To obtain DTT services from different regions (e.g., BBC/ITV regions);
- To overcome losses due to poor cabling;
- In-home distribution to multiple outlets.

Due to the range of usage scenarios, and also the wide range in gain and performance of devices on the market, we consider MHAs and indoor amplifiers as equivalent for the purposes of modelling, and refer to them as “domestic” amplifiers.

7.4 In our modelling we are concerned with the impact of interference on a household’s *ability* to receive DTT. On this basis we do not include in our analysis households with non-standard installations where a standard installation would suffice for the reception of DTT.

7.5 As outlined earlier, there are a variety of reasons why households might use domestic amplifiers, and many amplifiers are in use where they are not strictly necessary to allow DTT reception[51]. For this reason, we include in our analysis only those households with domestic amplifier installations where the amplifiers are used for DTT reception with primary sets. As illustrated in the figure below, this avoids double counting.

7.6 We include all communal aerial systems in our analysis, as it can be assumed that this is the only option for DTT reception for households in flats/apartment blocks.

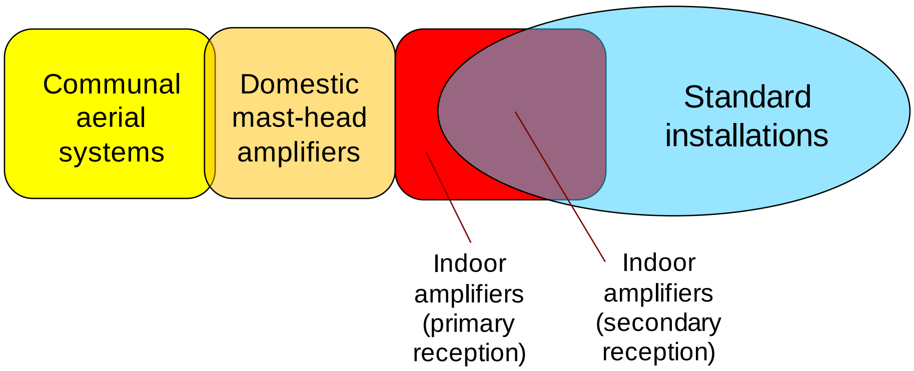

Figure 35. Venn diagram of standard and non-standard installations.

Total number of households with DTT coverage in the UK

7.7 The UKPM estimates the total number of households in the UK with DTT coverage as 27.2m based on APSA. This includes all addresses, i.e., it does not distinguish between residential and business addresses. DTT coverage is defined as 98.5%[52] of all households. The remaining 1.5% of households are not considered as part of this analysis.

7.8 The 2001 Census estimates the total number of households in the UK as 25.4m.

7.9 As our modelling of interference is based on the UKPM/APSA figures, for consistency the 27.2m total figure will be used when determining the number of households in each of the three categories listed above.

[51] For example, indoor amplifiers may be used on a significant number of “secondary” DTT sets (i.e., additional TV sets in bedrooms etc.). In many such cases, the indoor amplifier may be used in conjunction with an indoor set-top antenna, while the primary DTT set uses a standard installation. Such households will be considered as a standard installation for the purposes of our analysis.
[52] Using the 70% cut-off counting approach.

Number of UK households with DTT coverage in each category of installation

7.10 We have commissioned two separate studies[53] by consultants Mandercom to determine the likely number of “non-standard” installations (categories b and c) in use in the UK. These reports give estimates of total numbers of communal aerial systems and domestic amplifiers in use in the UK, based on consultation with the industry. These are discussed next.

Communal antenna systems

7.11 The following table shows the estimated total numbers of UK households which use communal aerial systems.

System	Number of households (millions)
Integrated reception System (IRS)	3.5
Master antenna TV (MATV) system	1.5

Table 14: Number of households using communal aerial systems.
Source: Mandercom

7.12 As stated previously, MATV and IRS are considered as equivalent for modelling purposes. We therefore estimate there to be a total of 5 million households within communal aerial systems throughout the UK.

7.13 2001 Census figures show that 5.2 million households in the UK are communal dwellings of some kind. This figure correlates quite well with the estimates in the above table.

7.14 We therefore propose to use Census data to determine the geographic distribution of communal aerial systems up to a spatial resolution of groups of pixels (referred to as *output areas* in the Census). This approach is described in some detail in Annex 7.

Domestic installations with amplifiers

7.15 The following table shows the estimated total number of MHAs and indoor amplifiers in use throughout the UK:

Device	Number of amplifiers (millions)
Masthead amplifier (MHA)	4
Indoor amplifier	5

Table 15: Number of mast-head and indoor amplifiers. Note that these are absolute numbers of devices, and not numbers of households.
Source: Mandercom

7.16 As stated earlier, we only model indoor amplifiers where the amplifier is used for DTT reception with primary DTT sets. As an approximation, we assume a uniform distribution of indoor amplifiers across both primary and secondary DTT sets to

[53] http://stakeholders.ofcom.org.uk/binaries/research/tv-research/tv-data/dig-tv-updates/charts-q4-2010.pdf .

obtain the total number of households which use indoor amplifiers with primary DTT sets.

7.17 According to the latest Ofcom figures on Digital TV, there are currently 10 million primary DTT sets in use, and 30.2 million DTT sets in total. Assuming the same proportion of primary sets when switchover is completed, then approximately 33% of the 5 million indoor amplifiers, or 1.7 million, can be estimated to be in use with primary DTT sets.

7.18 MHAs can be considered to be for primary DTT reception by definition, as they are installed on the main roof-top antenna. Therefore, all 4 million MHAs are included in our analysus. The combined figure for households with domestic amplifier installations used in our modelling is then 1.7 + 4 = 5.7 million.

7.19 It should be noted that this total figure is an estimate based on the best available information. It is difficult to estimate, with a high degree of certainty, the actual numbers of domestic amplifier installations used for primary DTT reception.

7.20 It would certainly be unreasonable to assume that 9 million domestic amplifiers are used for primary DTT reception, as this would imply that there are more non-standard installations in use than standard installations. Additionally, the following points should also be considered:

a) As noted in the Mandercom reports, there is likely to be some degree of overlap between the survey figures for communal systems (5m) and MHAs (4m), as some communal systems could be using a MHA instead of a launch amplifier. It is difficult to estimate this overlap in practice.

b) Some indoor amplifiers will be in use in conjunction with indoor antennas (i.e., in the loft or on the TV set-top). Our current modelling tool is unable to assess the impact of interference on indoor reception.

7.21 Taking these uncertainties into account, we believe 5.7 million to be a reasonable estimate of the total number of UK households with domestic amplifiers used for primary DTT reception.

Standard installations

7.22 The total number of standard installations in use can be calculated by subtracting the 10.9 million non-standard installations derived in the previous section (5.2 million communal plus 5.7 million domestic) from the 27.2 million APSA households to obtain 16.3 million.

Conclusions

7.23 Using a combination of data from the UK Census, the UKPM, and the results of studies which we have commissioned, we estimate that there are

a) a total of 5.2 million UK households within communal aerial systems with the ability to receive DTT based on APSA,

b) a total of 5.7 million UK households with domestic installed amplifiers which receive DTT, and

c) a total of 16.3 million UK households with standard installations with the ability to receive DTT.

7.24 This is illustrated in the figure below, with unrounded values in the following table.

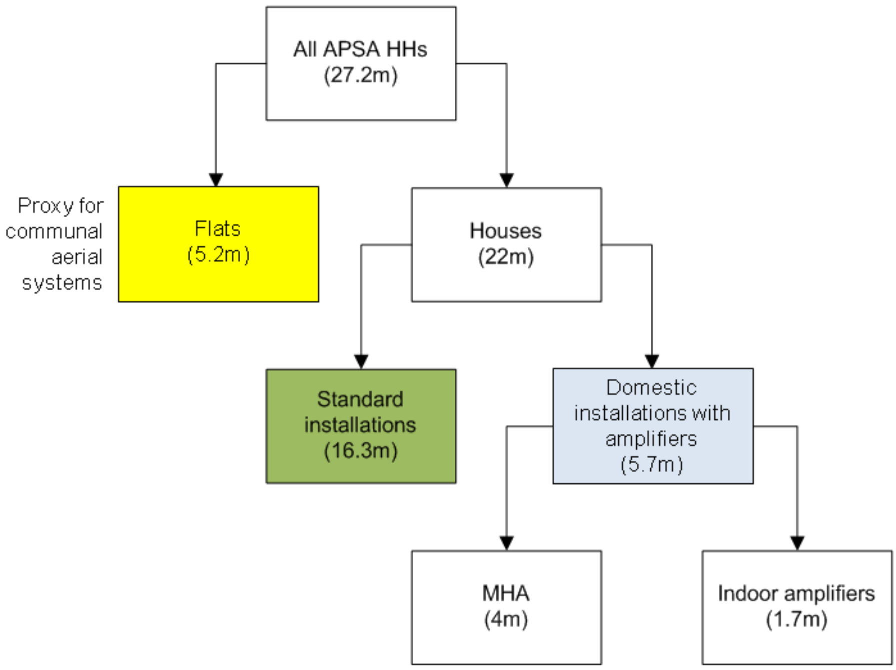

Figure 36. Breakdown of DTT installations.
The three main categories are shaded.

Table 16. Breakdown of DTT installations.
Unrounded figures.

Installation type	Number of UK households
Standard	16,299,699
Communal aerial systems	5,213,819
Domestic installations with amplifiers	5,655,629

Section 8

Impact of interference on the DTT service in the UK: Standard domestic installations

Introduction

8.1 In this section we describe our approach for estimating the total number of households with *standard* domestic DTT receiver installations which might be affected throughout the UK as a result of interference from MFCN base stations in the 800 MHz band.

8.2 A “standard” domestic installation (SDI) refers to the set-up assumed by broadcasters for purposes of network planning via the UKPM. This involves the use of a TV aerial with a net gain[54] of 9.15 dBi, and an angular discrimination pattern as described in the ITU-R Rec.419-3 specifications.

8.3 An exhaustive analysis of the number of households affected would involve the computer modelling of the degradation in DTT location probability at the *most susceptible* DTT channel in every pixel within the coverage area of every DTT transmitter in the UK. Such an analysis is feasible, but is demanding in computation time primarily due to the large numbers of DTT transmitters involved (77 main, and 1040 relay).

8.4 In order to make the analysis more tractable, and for the purposes of this technical report, we use an alternative approach whereby the total number of affected households is calculated as,

$$N = \sum_{i=21}^{60} N_i = \sum_{i=21}^{60} F_i \, M_i \,, \qquad (24)$$

where i is the DTT channel index, M_i is the number of UK households served via channel i, and F_i is the fraction of corresponding households whose DTT reception is affected as a result of interference. The fractions F_i are derived via computer modelling of the coverage areas of a total of 15 main and 15 relay transmitters.

8.5 The material in this section is organised as follows:

- We first present the *relevant* numbers of households , M_i. Details of how these are extracted from the Digital Switchover plan and census data are presented in Annex 7.

- We then describe how the fractions F_i can be estimated via computer modelling of the impact of interference on the coverage of a limited number of DTT channels and DTT transmitters. This approach significantly reduces the computational effort associated with the analysis, yet provides a good indication of the scale of the interference issue.

- We finally present our estimates of N_i. We address three specific cases of interest: a) where no mitigation measures are applied, b) where filtering is applied

[54] This includes an actual aerial gain of 12 dBd, and a feeder loss of 5 dB, resulting in a net gain of 7 dBd or 9.15 dBi.

at the DTT receivers, and c) where filtering is used both at the base station transmitters and DTT receivers.

8.6 For the case of standard domestic installations, our computer modelling uses measured protection ratios corresponding to the worst performance among three super-heterodyne and two Silicon tuners. See Annex 3.

8.7 As a refinement, we treat main and relay DTT coverage separately by expanding Equation (24) as

$$N = \sum_{i=21}^{60} F_{main,i}\, M_{main,i} + \sum_{i=21}^{60} F_{relay,i}\, M_{relay,i} \quad . \qquad (25)$$

Distribution of UK households across DTT channels 21 to 60

8.8 In this sub-section we present the distribution of the numbers, M_i, of UK households served via DTT channel i, where i = 21 … 60. The term "served" here refers to the number of households in pixels where DTT location probability is greater[55] than 70%.

8.9 Let us first consider a scenario where the MFCN-to-DTT protection ratios decreased monotonically with increasing frequency separation between the MFCN and DTT signals. Then, for a specific DTT signal quality, reception in DTT channel n would be more susceptible to interference than in channel m, if $n > m$; i.e., the higher-frequency DTT channel would also be the more susceptible.

8.10 The impact of interference might then be assessed by calculating the numbers, M_i, of UK households with standard domestic installations which receive channel i as their *highest frequency* DTT channel, where i = 21 … 60.

8.11 These can be extracted from the Digital Switchover plan, by excluding the numbers of households which are within communal aerial systems (based on census data) and those which use domestically installed amplifiers. See Annex 7 for details of calculations. The resulting values are shown in the following table. Note the large populations in channels 60, 59, 58, 54, and 52.

8.12 However, in practice, MFCN-to-DTT protection ratios do not decrease monotonically with increasing frequency separation between the MFCN and DTT signals[56]. The implication of this is that the highest-frequency DTT channels are not necessarily the most susceptible to interference from MFCN base stations.

8.13 This is illustrated in Table 17, where we present the measured[57] MFCN-to-DTT protection ratios (at wanted DTT signal power of -70 dBm[58]) and for each of the

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55 In other words, based on the 70% cut-off approach for counting served households.

56 An example of this is observed in DTT receivers which are based on a traditional super-heterodyne tuner and are particularly susceptible to interference from specific adjacent channel frequencies. This is the so-called *N+9 image channel susceptibility*, and implies a significant rise in the protection ratios at frequency offsets of around 72 MHz from the DTT carrier. See Annex 3 for examples.

57 These measurements were commissioned by Ofcom in 2009. See also Annex 3. The protection ratios we have used in this report correspond to the worst performance among three super-heterodyne and two Silicon tuners at each test point. Silicon tuners exhibit a more-or-less monotonic reduction in protection ratios with increasing interferer-victim frequency separations.

58 The lowest DTT signal level used in the measurements was -70 dBm. The total number of households affected is dominated by those affected in area of poor DTT coverage. It follows that the susceptibility of the DTT channels is primarily determined by the values of the protection ratios at low DTT signal levels.

MFCN blocks A, B, and C. Note, for example, that channel 52 is more susceptible than channel 59 with respect to interference from MFCN block A.

Table 17. Distribution of SDI households in the UK partitioned in terms of the highest frequency DTT channel which they receive.

DTT channel i	Number of SDI HHs served*, M_i		Number of DTT transmitters	
	Main	Relay	Main	Relay
60	1,402,756	409,712	13	111
59	2,669,253	260,622	11	118
58	1,034,123	181,852	3	85
57	0	3,581	0	1
56	163	51,269	2	37
55	0	2,030	0	3
54	141,618	4,622	1	2
53	0	6,924	0	1
52	1,996,994	142,393	6	14
51	0	3,979	0	2
≤50	6,489,473	1,498,334	41	666
Total	13,734,379	2,565,320	77	1040

* Derived from census data and the DSO plan based on the 70% cut-off counting approach (APSA).

8.14 Also shown are the protection ratios for co-located emissions from blocks A/B/C. These are given by the summation (in the linear domain) of the protection ratios for individual blocks A, B, and C. The combined protection ratios indicate that channel 55 is more susceptible than channel 59 with respect to co-located emissions from blocks A/B/C.

8.15 The left-most column indicates the *susceptibility rank* of the various DTT channels, as defined by the combined protection ratios for blocks A/B/C. A channel with a lower rank is more susceptible to interference. This ranking order has a profound impact on the way we calculate the distribution of UK households across the channels.

8.16 Here the relevant parameter is the number, M_i, of UK households which receive channel i as their *most susceptible* (rather than highest frequency) DTT channel. Values of M_i are shown in Table 18, and are derived via the following sequence of steps:

M_{60} = No. of HHs which receive Ch. 60,
M_{55} = No. of HHs which receive Ch. 55 (excluding those counted in earlier steps),
M_{59} = No. of HHs which receive Ch. 59 (excluding those counted in earlier steps),
M_{52} = No. of HHs which receive Ch. 52 (excluding those counted in earlier steps),

and so forth, where the most susceptible channels are treated first. Note that there are no households for which channel 59 is the most susceptible DTT channel from a main transmitter. This is correct, and simply means that all households which receiver channel 59 from a main transmitter also receiver a more susceptible channel, and are therefore counted in a different row. The sum total of households served across all channels is the same as that presented in Table 17.

8.17 Tables 19 and 20 show the corresponding values of M_i for the two cases where a) filtering is used at the DTT receivers, and b) filtering is used both at the base station transmitters and DTT receivers. The mitigating impact of filtering at large frequency separations means that channel 59 is now more susceptible than channel 55, hence the swap in the values M_{55} and M_{59} when compared with Table 18.

8.18 We will use the distribution of households outlined in Tables 18, 19, and 20 in conjunction with Equation (24) to calculate the total number of households affected as a result of interference. Note the significance of channels 60, 59, 58, 55, 54, 52, and ≤ 50 in terms of the large populations served. In the next sub-section we explain how computer modelling results for the above key channels can serve as proxies for other DTT channels.

Table 18. Distribution of SDI households in the UK partitioned in terms of the most susceptible DTT channel which they receive (in the absence of mitigation measures).

Rank	DTT channel i	Protection ratio (dB)				Number of SDI HHs served*, M_i		Number of DTT transmitters	
		A	B	C	A/B/C	Main	Relay	Main	Relay
1	60	-37.1	-39.8	-40.2	-34.0	1,386,555	409,972	13	111
3	59	-45.8	-46.2	-47.0	-41.5	0	6,624	0	6
5	58	-47.1	-48.0	-48.7	-43.1	531,956	164,345	2	83
6	57	-48.0	-48.7	-49.6	-43.9	0	3,583	0	1
9	56	-48.6	-49.4	-50.6	-44.7	0	498	0	1
2	55	-49.3	-50.1	-41.6	-40.4	2,820,362	254,492	11	116
7	54	-49.9	-46.8	-52.0	-44.3	139,960	3,181	1	2
8	53	-52.1	-46.1	-52.0	-44.3	0	11,157	0	3
4	52	-42.9	-52.0	-52.0	-42.0	2,461,687	208,321	9	49
10	51	-52.0	-52.0	-52.0	-47.2	0	3,982	0	2
11	≤ 50	-52.0	-52.0	-52.0	-47.2	6,393,859	1,499,167	41	666
	Total					13,734,379	2,565,320	77	1040

* Derived from census data and the DSO plan, based on the 70% cut-off counting approach (APSA).

Table 19. Distribution of SDI households in the UK partitioned in terms of the most susceptible DTT channel which they receive (with DTT receiver filtering).

Rank	DTT channel i	Protection ratio (dB)				Number of SDI HHs served*, M_i		Number of DTT transmitters	
		A	B	C	A/B/C	Main	Relay	Main	Relay
1	60	-37.7	-40.2	-40.3	-34.5	1,386,298	409,929	13	111
2	59	-48.7	-50.3	-50.3	-44.9	2,820,543	257,936	11	118
3	58	-60.1	-60.3	-60.3	-55.5	1,021,865	181,937	3	85
6	57	-65.9	-66.7	-67.7	-61.9	0	3,583	0	1
9	56	-67.4	-68.5	-70.2	-63.8	0	498	0	1
4	55	-68.2	-69.4	-61.4	-60.0	0	2,052	0	3
7	54	-68.8	-66.0	-71.9	-63.5	139,934	3,180	1	2
8	53	-71.0	-65.3	-71.8	-63.6	0	11,156	0	3
5	52	-61.8	-71.2	-71.8	-61.0	1,973,393	192,037	8	48
10	51	-70.9	-71.2	-71.8	-66.5	0	3,981	0	2
11	≤ 50	-70.9	-71.2	-71.8	-66.5	6,392,346	1,499,032	41	666
	Total					13,734,379	2,565,320	77	1040

* Derived from census data and the DSO plan, based on the 70% cut-off counting approach (APSA).

Table 20. Distribution of SDI households in the UK partitioned in terms of the most susceptible DTT channel which they receive
(with filtering at both BS transmitter and DTT receiver).

Rank	DTT channel i	Protection ratio (dB)				Number of SDI HHs served*, M_i		Number of DTT transmitters	
		A	B	C	A/B/C	Main	Relay	Main	Relay
1	60	-39.7	-51.4	-66.3	-39.4	1,386,491	410,009	13	111
2	59	-51.5	-66.2	-67.7	-51.3	2,820,949	257,983	11	118
5	58	-66.0	-67.4	-68.7	-62.4	531,932	164,358	2	83
6	57	-66.9	-67.9	-69.4	-63.2	0	3,583	0	1
9	56	-67.5	-68.7	-70.4	-63.9	0	498	0	1
3	55	-68.2	-69.4	-61.4	-60.0	0	2,943	0	4
7	54	-68.8	-66.0	-71.9	-63.5	139,954	3,181	1	2
8	53	-71.0	-65.3	-71.8	-63.6	0	11,158	0	3
4	52	-61.8	-71.2	-71.8	-61.0	2,461,572	208,338	9	49
10	51	-70.9	-71.2	-71.8	-66.5	0	3,982	0	2
11	≤ 50	-70.9	-71.2	-71.8	-66.5	6,393,482	1,499,287	41	666
	Total					13,734,379	2,565,320	77	1040

* Derived from census data and the DSO plan, based on the 70% cut-off counting approach (APSA).

Use of key DTT channels as proxies

8.19 An exhaustive analysis of interference to DTT reception would involve the evaluation of the fractions of households affected in each of DTT channels 21 to 60. However, such an exhaustive analysis is not strictly necessary.

8.20 Measured MFCN-to-DTT protection ratios indicate that the immunity of DVB receivers with respect to LTE base station interferers in blocks A, B, and C remains broadly constant for DTT channels below 51. See Tables 18 to 20. In other words, all else being equal[59], the impact of interference in *any* channel below 51 can be used as a proxy for the impact of interference in all channels below 51. To this end, we use as proxy the results of computer modelling for a limited number of channels below 51 which serve large populations.

8.21 Of the remaining DTT channels 51 to 60, we explicitly evaluate (via computer modelling) the fractions F_i of affected households in channels i = 60, 59, 58, 55, 54[60], and 52. These are *key* channels because they are associated with high protection ratios, and/or because they are used to serve large populations.

8.22 Instead of performing computer simulations for the remaining DTT channels 57, 56, 54[60], 53 and 51 (only used by relay transmitters), we use as proxy the results of simulations performed for relay transmitters in channels 60, 59, 58, 55, and 52. The proxy procedure involves two steps:

1) Identifying those channels among 60, 59, 58, 55, and 52 where the protection ratio is within ±0.5 dB of the protection ratio for the channel of interest;

[59] The implicit assumption here is that the quality of DTT coverage and the nature of MFCN base station deployment are broadly similar in the geographical areas served by the channel of interest and the channels used as proxies.
[60] We did not model any relay transmitters in channel 54. We used proxies instead.

2) Averaging the computer modelled values of F_i for the channels identified in step-1, and using this average as a proxy for the channel of interest.

8.23 The above can best be explained via an example.

Example

8.24 The proxy process is illustrated in Table 21. As can be seen, the combined protection ratio for MFCN blocks A/B/C into channel 51 is within ±0.5 dB of the protection ratios of block A into channels 59 and 58, B into 59 and 58, and C into 59. This suggests that, all else being equal, the fractions of households affected in the latter scenarios can be used as proxies for the fraction of households affected in the former scenario.

Table 21. The use of protection ratios for selecting appropriate proxies.for channels 57, 56, 54, 53 and 51 (relays). Channels marked in grey are those where the fractions of households affected are calculated via computer modelling. Boxed cells are valid proxies for interference from A/B/C to channel 51.

DTT channel	Protection ratio (dB)				
	A	B	C	A/B/C	B/C
60	-37	-40	-40	-34	-37
59	-46	-46	-47	-42	-44
58	-47	-48	-49	-43	-45
57	-48	-49	-50	-44	-46
56	-49	-49	-51	-45	-47
55	-49	-50	-42	-40	-41
54	-50	-47	-52	-44	-46
53	-52	-46	-52	-44	-45
52	-43	-52	-52	-42	-49
51	-52	-52	-52	-47	-49
≤ 50	-52	-52	-52	-47	-49

8.25 This use of proxies for relay transmitters in channels 57, 56, 54, 53, and 51 introduces some inaccuracies in the estimated fractions of households affected. However, this does not materially impact the estimates of the total number of households affected, because the number of relevant UK households served by relays in channels 57, 56, 54, 53 and 51 are relatively small.

Extrapolation of results across DTT transmitters

8.26 Equation (24) presented earlier describes our approach for calculating the total number of households affected as a result of interference. This involves a sum of products of two sets of terms:

1) The estimated fractions, F_i, of UK households affected in channel i.

2) The relevant numbers, M_i, of UK households served in channel i.

8.27 Earlier we explained how the values of M_i can be calculated. We then explained how the computer modelling of F_i in channels i = 60, 59, 58, 55, 54[60], and 52 can be used as proxies for deriving F_i in channels i = 57, 56, 53, and 51.

8.28 Here we describe our approach to computer modelling of F_i in channels i = 60, 59, 58, 55, 54, 52, and ≤50.

8.29 In principle, F_i can be derived by calculating the degradation in location probability in each pixel within the coverage area of every DTT transmitter which serves the household populations set out in Tables 18, 19 or 20.

8.30 In order to reduce the complexity of the calculations, we examine only the three main or relay transmitters with the most populated coverage areas for each of channels 60, 59, 58, 55, 54, 52 and ≤ 50. These are listed in Table 22.

Table 22. Examined DTT transmitters for the analysis of SDI households. The DTT channels considered for each transmitter are highlighted in red.

k	Main transmitters	Number of SDI HHs, served*, m_k	DTT Channels
1	Belmont	450,398	22/25/28/30/53/**60**
2	Oxford	256,752	50/53/55/57/59/**60**
3	Sudbury	220,644	41/44/47/56/58/**60**
4	Winter Hill	1,648,209	49/50/54/**55**/58/**59****
5	Pontop Pike	419,981	49/50/54/**55**/58/**59****
6	Tacolneston	213,364	39/42/45/50/**55**/**59****
7	Emley Moor	976,095	41/44/47/48/51/**52**
8	Sandy Heath	568,203	21/24/27/48/51/**52**
9	Mendip	442,215	48/49/52/54/56/**58**
10	Waltham	482,021	29/49/54/56/57/**58**
11	Plympton	19,452	42/45/49/54/56/**58**
12	Bluebell Hill	128,498	39/40/43/45/46/**54**
13	Crystal Palace	1,951,265	22/23/25/26/28/**30**
14	Sutton Coldfield	1,143,589	39/40/42/43/45/**46**
15	Rowridge	275,310	21/22/24/25/27/**28**

k	Relay transmitters	Number of SDI HHs, served*, m_k	DTT channels
1	Whitehawk Hill	53,729	48/51/53/56/57/**60**
2	Brierley Hill	50,957	50/53/55/57/59/**60**
3	Reigate	40,041	21/24/27/53/57/**60**
4	Hemel Hempstead	41,793	41/44/47/50/**55**/**59****
5	Luton	15,409	50/**55**/**59****
6	Beecroft Hill	12,622	50/**55**/**59****
7	Nottingham	43,079	21/24/27/48/51/**52**
8	Tunbridge Wells	30,412	41/42/44/47/49/**52**
9	Guildford	25,828	40/43/46/48/49/**52**
10	Kidderminster	20,706	49/54/**58**
11	Hertford	12,410	49/54/**58**
12	Workington	5,778	49/54/**58**
13	Fenton	77,932	21/22/24/25/27/**28**
14	Kilvey Hill	73,777	22/23/25/26/28/**29**
15	Sheffield	61,792	21/24/27/39/42/**45**

* Based on the proportional counting approach (APSA).
** Channel 55 or 59 is used depending on filtering mode.

8.31 It is a given that the impact of interference on the coverage of each DTT transmitter in the UK will be different. However, we can develop a broad picture of the impact throughout the UK by focusing on transmitters which serve the largest populations. For example, note that the Belmont, Oxford, and Sudbury transmitters investigated for channel 60 account for approximately 80% of UK households which receive DTT service on channel 60. Our computer modelling includes approximately 65% of UK households within DTT coverage.

8.32 In combining the results of the impact on the DTT coverage of individual DTT transmitters, it is logical to account for the household population served by each transmitter. This is to ensure that transmitters with very low served populations do not skew the results disproportionately. We do this by performing a *weighted averaging*, where the weighting relates to the proportion of households served by each transmitter in the absence of MFCN interference.

8.33 This can best be explained via an example.

Example

8.34 Consider DTT channel i = 60, and assume that the impact of interference on DTT coverage in this channel is calculated via computer modelling for a total of six DTT transmitters. Let the population of HHs served[61] by the six transmitters be $m_1 \dots m_6$ in the absence of interference from MFCNs. Also, let the calculated fractions of HHs which lose DTT reception be $p_1 \dots p_6$, respectively. Here, $p_k = n_k / m_k$, where n_k is the calculated number of HHs which lose[61] DTT reception. Without loss of generality, let transmitters 1 to 3 represent main transmitters, and transmitters 4 to 6 represent relay transmitters. The weighted-averaged fractions of households affected in main and relay coverage areas are then given by

$$F_{main,60} = \frac{n_1 + n_2 + n_3}{m_1 + m_2 + m_3} \equiv \frac{m_1 p_1 + m_2 p_2 + m_3 p_3}{m_1 + m_2 + m_3}, \qquad (26)$$

$$F_{relay,60} = \frac{n_4 + n_5 + n_6}{m_4 + m_5 + m_6} = \frac{m_4 p_4 + m_5 p_5 + m_6 p_6}{m_4 + m_5 + m_6}. \qquad (27)$$

8.35 We can generally write that for a total of K examined transmitters in channel i,

$$F_{\text{main},i} = \frac{\sum_{k=1}^{K} n_{\text{main},k,i}}{\sum_{k=1}^{K} m_{\text{main},k,i}}, \qquad F_{\text{relay},i} = \frac{\sum_{k=1}^{K} n_{\text{relay},k,i}}{\sum_{k=1}^{K} m_{\text{relay},k,i}}. \qquad (28)$$

8.36 The calculated fractions $F_{\text{main},i}$ and $F_{\text{relay},i}$ for $i = 21 \cdots 60$ are then substituted in Equation (24) for the calculation of the total number, N, of affected households.

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[61] Based on the proportional approach for counting served households.

Summary of approach

8.37 Our approach for evaluating the number of households with standard domestic installation affected as a result of interference from MFCN base stations involves the following steps.

1) For a specific DTT channel, i, use Punch to calculate the number of *generic* households which are served and affected (proportional count) within each pixel in the coverage area of a DTT transmitter. See methodology in Section 4. Use measured MFCN-to-DTT protection ratios for DTT receivers as presented in Annex 3.

2) For each pixel in the coverage area of the examined DTT transmitter in step 1, determine[62] the number of households with standard domestic installation that are served and affected (proportional count). See Annex 7 for a detailed description of this process. Aggregate across the coverage area of the transmitter.

3) Repeat steps 1 and 2 for a number of DTT transmitters in channel i. Combine the results from the individual transmitters to derive a weighted-averaged fraction, F_i, of households with standard domestic installation that are affected in channel i throughout the UK.

4) From the numbers of households with standard domestic installation served by the DTT transmitters examined in step 3, extrapolate to derive the number, M_i, of households with standard domestic installation served (cut-off counting) in channel i throughout the UK. This somewhat involved process is described in Annex 7.

5) The product $N_i = F_i M_i$ represents the number of households with standard domestic installation affected in channel i throughout the UK. Repeat[63] steps 1 to 4 to derive $N_i = F_i M_i$ for channels i = 69 …51 and ≤50. Aggregate over the DTT channels to derive the total number, N, of households with standard domestic installation that are affected throughout the UK.

8.38 The following tables in this section present the calculated values of M_i and N_i. Also presented are the corresponding values for receiver overload only.

8.39 Results for the specific transmitters examined (main and relay) are presented in Annex 8.

[62] Using census data and information on the number of domestic amplifiers in the UK.
[63] Using proxies where necessary.

Estimated numbers of affected households (standard domestic installations)

Households affected in the absence of mitigation measures

Table 23. Estimated number of SDI households affected due to interference throughout the UK in the absence of mitigation.

DTT channel, *i*	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i , affected due to interference MFCN blocks A/B/C	B/C	C	B	A
60	1,796,526	34,662	13,512	7,677	8,101	26,802
59	6,624	14	20	15	10	10
58	696,302	5,504	2,576	779	1,904	3,343
57**	3,583	11	5	11	6	6
56**	498	1	2	0	1	1
55	3,074,854	14,358	11,440	9,206	3,039	3,170
54	143,141	338	251	105	157	101
53**	11,157	34	26	11	16	11
52	2,670,008	10,782	5,035	2,455	2,447	6,242
51**	3,982	13	7	4	4	4
≤50***	7,893,026	49,494	32,918	15,105	15,063	14,995
Total	**16,299,699**	**115,212**	**65,793**	**35,369**	**30,749**	**54,684**

Table 24. Estimated number of SDI households affected due to overload only throughout the UK in the absence of mitigation.

DTT channel, *i*	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i , affected due to overload MFCN blocks A/B/C	B/C	C	B	A
60	1,796,526	1,418	216	58	84	312
59	6,624	0	0	1	0	0
58	696,302	221	85	41	41	45
57**	3,583	3	2	1	1	1
56**	498	0	0	0	0	0
55	3,074,854	1,132	707	148	83	103
54	143,141	73	45	11	12	9
53**	11,157	1	2	1	1	1
52	2,670,008	855	398	140	142	196
51**	3,982	2	0	0	0	0
≤50***	7,893,026	2,634	1,627	517	546	577
Total	**16,299,699**	**6,339**	**3,082**	**916**	**909**	**1,243**

* Derived from census data, amplifier numbers, and the DSO plan, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for channels 60, 59, 58, 55, 54, and 52.
*** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Households affected subject to DTT receiver filtering

Table 25. Estimated number of SDI households affected due to interference throughout the UK with DTT receiver filtering.

DTT channel, i	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i , affected due to interference MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,796,228	28,890	10,293	5,863	6,390	23,413
59	3,078,478	3,654	1,588	905	893	2,231
58	1,203,802	189	89	32	48	83
57**	3,583	0	0	0	0	0
56**	498	0	0	0	0	0
55	2,052	0	0	0	0	0
54	143,114	2	2	1	2	2
53**	11,156	0	0	0	0	0
52	2,165,430	77	33	28	28	60
51**	3,981	0	0	0	0	0
≤50***	7,891,378	131	77	31	31	31
Total	**16,299,699**	**32,942**	**12,082**	**6,860**	**7,392**	**25,820**

Table 26. Estimated number of SDI households affected due to overload only throughout the UK with DTT receiver filtering.

DTT channel, i	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i , affected due to overload MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,796,228	0	0	0	0	0
59	3,078,478	0	0	0	0	0
58	1,203,802	45	45	45	45	45
57**	3,583	1	1	1	1	1
56**	498	0	0	0	0	0
55	2,052	0	0	0	0	1
54	143,114	0	0	0	0	1
53**	11,156	1	0	0	0	1
52	2,165,430	22	22	22	22	22
51**	3,981	0	0	0	0	0
≤50***	7,891,378	74	74	74	74	74
Total	**16,299,699**	**145**	**143**	**143**	**143**	**145**

* Derived from census data, amplifier numbers, and the DSO plan, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for channels 60, 59, 58, 55, 54, and 52.
*** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Households affected subject to filtering at the base station transmitter and DTT receivers

Table 27. Estimated number of SDI households affected due to interference throughout the UK with base station transmitter filtering and DTT receiver filtering.

DTT channel, *i*	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i, affected due to interference MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,796,500	21,014	913	42	885	20,590
59	3,078,932	1,861	92	30	51	1,725
58	696,290	50	18	5	13	31
57**	3,583	0	0	0	0	0
56**	498	0	0	0	0	0
55	2,943	0	0	0	0	0
54	143,134	2	2	1	2	2
53**	11,158	1	0	0	0	0
52	2,669,910	110	47	35	35	84
51**	3,982	0	0	0	0	0
≤50***	7,892,770	131	77	31	31	31
Total	**16,299,699**	**23,167**	**1,150**	**144**	**1,017**	**22,463**

Table 28. Estimated number of SDI households affected due to overload only throughout the UK with base station transmitter filtering and DTT receiver filtering.

DTT channel, *i*	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i, affected due to overload MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,796,500	301	2	0	0	236
59	3,078,932	10	0	0	0	10
58	696,290	41	41	41	41	41
57**	3,583	1	1	0	1	1
56**	498	0	0	0	0	0
55	2,943	0	0	0	0	1
54	143,134	0	0	0	0	1
53**	11,158	0	0	0	0	0
52	2,669,910	28	28	28	28	28
51**	3,982	0	0	0	0	0
≤50***	7,892,770	74	74	74	74	74
Total	**16,299,699**	**456**	**146**	**143**	**144**	**392**

* Derived from census data, amplifier numbers, and the DSO plan, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for channels 60, 59, 58, 55, 54, and 52.
*** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Section 9

Impact of interference on the DTT service in the UK: Communal aerial systems

Introduction

9.1 In this section we describe our approach for estimating the total number of households within communal aerial TV systems which might be affected throughout the UK as a result of interference from MFCN base stations in the 800 MHz band.

9.2 By communal aerial systems (CASs) we refer to installations where multiple dwellings are supplied via a single TV aerial in conjunction with an amplifier.

9.3 Our approach to calculating the number of households affected is similar to that set out in Section 8 in the context of standard domestic installations. This involves calculation of the numbers, M_i , of UK households within communal aerial systems that are served via channel i , and the fractions, F_i , of corresponding households whose DTT reception is affected as a result of interference.

9.4 The material in this section is organised as follows:

- We first present the *relevant* numbers of households , M_i . Details of how these are extracted from the Digital Switchover plan and census data are presented in Annex 7.

- We then describe how the fractions F_i can be estimated via computer modelling of the impact of interference on the coverage of a limited number of DTT channels and DTT transmitters.

- We finally present our estimates , N_i , of the number of households affected in each DTT channel i . We address three specific cases of interest: a) where no mitigation measures are applied, b) where filtering is applied at the DTT receivers, and c) where filtering is used both at the base station transmitters and DTT receivers.

Distribution of UK households across DTT channels 21 to 60

9.5 In this sub-section we present the distribution of the numbers, M_i , of UK households within communal aerial systems that are served via DTT channel i , where i = 21 … 60. The term “served” here refers to the number of households in pixels where DTT location probability is greater than 70%[64].

9.6 We have performed measurements of MFCN-to-DTT protection ratios involving a CAS launch amplifier feeding a DTT receiver (Silicon tuner). These are presented in Annex 4. The measurements indicate that the protection ratios decrease

[64] In other words, based on the 70% cut-off approach for counting served HHs.

monotonically with increasing frequency separation between the MFCN and DTT signals[65].

9.7 This means that, for a specific DTT signal quality, reception in DTT channel n would be more susceptible to interference than in channel m, if $n > m$; i.e., the higher-frequency DTT channel would also be the more susceptible.

9.8 The impact of interference can then be assessed by calculating the numbers, M_i, of UK households within community antenna systems which receive channel i as their *highest frequency* DTT channel, where i = 21 … 60.

9.9 These can be extracted from the Digital Switchover plan, and by excluding the numbers of households with standard domestic installations and those with domestically installed amplifiers (see Annex 7 for details of calculations). The resulting values are shown in the following table. Note the large populations in channels 60, 59, 58, and 52.

9.10 The same partitioning applies when filtering is used, since the protection ratios continue to decrease monotonically with increasing frequency separation between the MFCN and DTT signals.

Table 29. Distribution of CAS households in the UK partitioned in terms of the highest frequency DTT channel which they receive.

DTT channel i	Number of CAS HHs served*, M_i		Number of DTT transmitters	
	Main	Relay	Main	Relay
60	157,326	202,117	13	111
59	474,245	98,656	11	118
58	143,444	49,150	3	85
57	0	1,302	0	1
56	44	18,636	2	37
55	0	746	0	3
54	18,651	1,680	1	2
53	0	2,517	0	1
52	261,128	44,128	6	14
51	0	1,446	0	2
≤50	3,338,406	400,197	41	666
Total	4,393,244	820,574	77	1040

* Derived from census data and the DSO plan based on the 70% cut-off counting approach (APSA).

Use of key DTT channels as proxies

9.11 We follow the same procedure outlined in Section 8 in the context of households with standard domestic installations.

9.12 Specifically, we

- use the results of computer simulations for a number of highly populated channels below 51 as proxies for all channels below 51.

[65] Admittedly, this is partly due to the fact that the tested DTT receiver incorporates a Silicon tuner which does not suffer from the N+9 image problem.

- use the results of computer simulations in channels 60, 59, 58, 54 and 52 as proxies for channels 57, 56, 55, 53, and 51.

9.13 The identities of the proxies are selected according to similarities in protection ratios.

Extrapolation of results across DTT transmitters

9.14 Once again we follow the same procedure described in Section 8 in the context of households with standard domestic installations.

9.15 Specifically, we perform computer modelling of only the three main or relay transmitters with the most populated coverage areas for each of channels 60, 59, 58, 54, 52 and $\leq$ 50. These are listed in Table 30.

9.16 We then calculate the fractions, F_i, of household affected by performing a weighted averaging over the of the examined transmitters in channel i.

Table 30. Examined DTT transmitters for the analysis of CAS households. The DTT channels considered for each transmitter are highlighted in red.

k	Main transmitters	Number of CAS HHs, served*, m_k	DTT Channels
1	Belmont	60,473	22/25/28/30/53/**60**
2	Oxford	42,701	50/53/55/57/59/**60**
3	Sudbury	36,016	41/44/47/56/58/**60**
4	Winter Hill	342,720	49/50/54/55/58/**59**
5	Pontop Pike	104,152	49/50/54/55/58/**59**
6	Tacolneston	28,789	39/42/45/50/55/**59**
7	Waltham	77,061	29/49/54/56/57/**58**
8	Mendip	86,010	48/49/52/54/56/**58**
9	Plympton	6,206	42/45/49/54/56/**58**
10	Bluebell Hill	21,950	39/40/43/45/46/**54**
11	Emley Moor	159,194	41/44/47/48/51/**52**
12	Sandy Heath	98,158	21/24/27/48/51/**52**
13	Heathfield	21,974	41/42/44/47/49/**52**
14	Crystal Palace	1,618,276	22/23/25/26/28/**30**
15	Sutton Coldfield	246,900	39/40/42/43/45/**46**
16	Rowridge	97,112	21/22/24/25/27/**28**

k	Relay transmitters	Number of CAS HHs, served*, m_k	DTT channels
1	Whitehawk Hill	43,185	48/51/53/56/57/**60**
2	Brierley Hill	9,062	50/53/55/57/59/**60**
3	Reigate	11,835	21/24/27/53/57/**60**
4	Hemel Hempstead	14,604	41/44/47/50/55/**59**
5	Luton	6,334	50/55/**59**
6	Beecroft Hill	2,862	50/55/**59**
7	Kidderminster	3,366	49/54/**58**
8	Hertford	4,521	49/54/**58**
9	Workington	1,110	49/54/**58**
10	Nottingham	9,077	21/24/27/48/51/**52**
11	Tunbridge Wells	9,076	41/42/44/47/49/**52**
12	Guildford	8,563	40/43/46/48/49/**52**
13	Fenton	11,321	21/22/24/25/27/**28**
14	Kilvey Hill	13,567	22/23/25/26/28/**29**
15	Sheffield	23,853	21/24/27/39/42/45

* Based on the proportional counting approach (APSA).

Summary of approach

9.17 Our approach for evaluating the number of households within communal aerial systems affected as a result of interference from MFCN base stations involves the following steps.

1) For a specific DTT channel, i, use Punch to calculate the number of *generic* households which are served and affected (proportional count) within each pixel in the coverage area of a DTT transmitter. See methodology in Section 4. Use measured MFCN-to-DTT protection ratios for a CAS launch amplifier as presented in Annex 4.

2) For each pixel in the coverage area of the examined DTT transmitter in step 1, determine[66] the number of households within communal aerial systems that are served and affected (proportional count). See Annex 7 for a detailed description of this process. Aggregate across the coverage area of the transmitter.

3) Repeat steps 1 and 2 for a number of DTT transmitters in channel i . Combine the results from the individual transmitters to derive a weighted-averaged fraction, F_i , of households within communal aerial systems that are affected in channel i throughout the UK.

4) From the numbers of households within communal aerial systems served by the DTT transmitters examined in step 3, extrapolate to derive the number, M_i , of households within communal aerial systems served (cut-off counting) in channel i throughout the UK. This somewhat involved process is described in Annex 7.

5) The product $N_i = F_i M_i$ represents the number of households within communal aerial systems affected in channel i throughout the UK. Repeat[67] steps 1 to 4 to derive $N_i = F_i M_i$ for channels $i = 69 \ldots 51$ and ≤ 50. Aggregate over the DTT channels to derive the total number, N , of households within communal aerial systems that are affected throughout the UK.

9.18 The remaining tables in this section present the calculated values of M_i and N_i .

9.19 Results for the specific transmitters examined (main and relay) are presented in Annex 8.

[66] Using census data and information on the number of domestic amplifiers in the UK.
[67] Using proxies where necessary.

Estimated numbers of affected households (communal aerial systems)

Households affected in the absence of mitigation measures

Table 31. Estimated number of affected CAS households throughout the UK in the absence of mitigation.

DTT channel, i	Number of CAS HHs served*, M_i	Number of CAS HHs, N_i , affected due to interference MFCN blocks				
		A/B/C	B/C	C	B	A
60	359,443	41,177	23,345	12,876	15,219	29,853
59	572,901	48,335	35,953	21,789	24,080	28,329
58	192,594	16,333	11,855	6,924	7,025	8,301
57	1,302	72	54	48	49	49
56	18,681	1,290	920	749	687	706
55	746	52	37	30	30	27
54	20,331	1,137	876	558	550	545
53	2,517	174	124	101	101	101
52	305,256	21,038	16,509	10,307	10,013	9,818
51	1,446	100	71	58	58	58
≤50**	3,738,602	391,912	313,558	201,182	200,425	199,641
Total	**5,213,819**	**521,619**	**403,302**	**254,621**	**258,237**	**277,430**

Households affected subject to DTT receiver filtering

Table 32. Estimated number of affected CAS households throughout the UK with DTT receiver filtering.

DTT channel, i	Number of CAS HHs served*, M_i	Number of CAS HHs, N_i , affected due to interference MFCN blocks				
		A/B/C	B/C	C	B	A
60	359,443	2,916	2,217	1,307	1,302	1,303
59	572,901	1,201	858	474	474	474
58	192,594	11	7	3	3	3
57	1,302	0	0	0	0	0
56	18,681	0	0	0	0	0
55	746	0	0	0	0	0
54	20,331	0	0	0	0	0
53	2,517	0	0	0	0	0
52	305,256	0	0	0	0	0
51	1,446	0	0	0	0	0
≤50**	3,738,602	0	0	0	0	0
Total	**5,213,819**	**4,128**	**3,081**	**1,784**	**1,780**	**1,781**

* Derived from census data, amplifier numbers, and the DSO plan, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Households affected subject to filtering at the base station transmitter and DTT receivers

Table 33. Estimated number of affected CAS households throughout the UK and with base station transmitter filtering and DTT receiver filtering).

DTT channel, i	Number of CAS HHs Served*, M_i	Number of CAS HHs, N_i , affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	359,443	39	1	0	1	36
59	572,901	5	0	0	0	5
58	192,594	0	0	0	0	0
57	1,302	0	0	0	0	0
56	18,681	0	0	0	0	0
55	746	0	0	0	0	0
54	20,331	0	0	0	0	0
53	2,517	0	0	0	0	0
52	305,256	0	0	0	0	0
51	1,446	0	0	0	0	0
≤50**	3,738,602	0	0	0	0	0
Total	5,213,819	44	1	0	1	41

* Derived from census data, amplifier numbers, and the DSO plan, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Section 10

Impact of interference on the DTT service in the UK: Domestic installations with amplifiers

Introduction

10.1 In this section we describe our approach for estimating the total number of households which use domestically installed amplifiers and which might be affected throughout the UK as a result of interference from MFCN base stations in the 800 MHz band.

10.2 By domestically installed amplifiers (DIAs) we refer to cases where consumers deploy amplifiers in order a) to improve their reception of the DTT service in areas of poor coverage, and/or b) to distribute DTT signals to multiple receivers within the home.

10.3 Such amplifiers may be in the form of mast-head amplifiers (MHAs) located with the TV aerial, may be installed in the loft, or inside the home near the receiver. For the purposes of this analysis, we draw no distinction between the above installation varieties.

10.4 Our approach to calculating the number of households affected is similar to that set out in Section 8 in the context of standard domestic installations. This involves calculation of the numbers, M_i , of UK households with domestically installed amplifiers that are served via channel i , and the fractions, F_i , of corresponding households whose DTT reception is affected as a result of interference.

10.5 The material in this section is organised as follows:

- We first present the *relevant* numbers of households , M_i . Details of how these are extracted from the Digital Switchover plan and census data are presented in Annex 7.

- We then describe how the fractions F_i can be estimated via computer modelling of the impact of interference on the coverage of a limited number of DTT channels and DTT transmitters.

- We finally present our estimates , N_i , of the number of households affected in each DTT channel i . We address three specific cases of interest: a) where no mitigation measures are applied, b) where filtering is applied at the DTT receivers, and c) where filtering is used both at the base station transmitters and DTT receivers.

Distribution of UK households across DTT channels 21 to 60

10.6 In this sub-section we present the distribution of the numbers, M_i , of UK households with domestically installed amplifiers that are served via DTT channel i , where i =

21 … 60. The term "served" here refers to the number of households in pixels where DTT location probability is greater than 70%[68].

10.7 We have performed measurements of MFCN-to-DTT protection ratios involving a domestic amplifier feeding a DTT receiver (Silicon tuner). These are presented in Annex 5. The measurements indicate that the protection ratios decrease *monotonically* with increasing frequency separation between the MFCN and DTT signals[69].

10.8 This means that, a specific DTT signal quality, reception in DTT channel n would be more susceptible to interference than in channel m, if $n > m$; i.e., the higher-frequency DTT channel would also be the more susceptible.

10.9 The impact of interference can then be assessed by calculating the numbers, M_i, of UK households with domestically installed amplifiers which receive channel i as their *highest frequency* DTT channel, where i = 21 … 60.

10.10 These can be extracted from the Digital Switchover plan, and by excluding the numbers of households with standard domestic installations and those within community antenna systems (see Annex 7 for details of calculations). The resulting values are shown in the following table. Note the large populations in channels 60, 59, 58, and 52.

10.11 The same partitioning applies when filtering is used, since the protection ratios continue to decrease monotonically with increasing frequency separation between the MFCN and DTT signals.

Table 34. Distribution of DIA households in the UK partitioned in terms of the highest frequency DTT channel which they receive.

DTT channel i	Number of DIA HHs served*, M_i		Number of DTT transmitters	
	Main	Relay	Main	Relay
60	481,148	142,332	13	111
59	978,947	89,555	11	118
58	351,604	63,165	3	85
57	0	1,244	0	1
56	56	17,809	2	37
55	0	712	0	3
54	48,568	1,606	1	2
53	0	2,405	0	1
52	686,410	49,461	6	14
51	0	1,382	0	2
≤50	2,218,788	520,437	41	666
Total	4,765,521	890,108	77	1040

* Derived from census data and the DSO plan based on the 70% cut-off counting approach (APSA).

[68] In other words, based on the 70% cut-off approach for counting served HHs.
[69] Admittedly, this is partly due to the fact that the tested DTT receiver incorporates a Silicon tuner which does not suffer from the N+9 image problem.

Use of key DTT channels as proxies

10.12 We follow the same procedure outlined in Section 8 in the context of households with standard domestic installations.

10.13 Specifically, we

- use the results of computer simulations for a number of highly populated channels below 51 as proxies for all channels below 51.
- use the results of computer simulations in channels 60, 59, 58, 54 and 52 as proxies for channels 57, 55, 53, and 51.

10.14 The identities of the proxies are selected according to similarities in protection ratios.

Extrapolation of results across DTT transmitters

10.15 Once again we follow the same procedure described in Section 8 in the context of households with standard domestic installations.

10.16 Specifically, we perform computer modelling of only the three main or relay transmitters with the most populated coverage areas for each of channels 60, 59, 58, 55, 54, 52 and $\leq$ 50. These are listed in Table 35.

10.17 We then calculate the fractions of household affected, F_i , by performing a weighted averaging over the of the examined transmitters in channel i .

Table 35. Examined DTT transmitters for the analysis of DIA households. The DTT channels considered for each transmitter are highlighted in red.

k	Main transmitters	Number of DIA HHs, served*, m_k	DTT channels
1	Belmont	156,278	22/25/28/30/53/**60**
2	Oxford	89,087	50/53/55/57/59/**60**
3	Sudbury	76,558	41/44/47/56/58/**60**
4	Winter Hill	571,773	49/50/54/55/58/**59**
5	Pontop Pike	145,695	49/50/54/55/58/**59**
6	Tacolneston	78,040	39/42/45/50/55/**59**
7	Waltham	167,250	29/49/54/56/57/**58**
8	Mendip	153,113	48/49/52/54/56/**58**
9	Plympton	6,749	42/45/49/54/56/**58**
10	Bluebell Hill	44,586	39/40/43/45/46/**54**
11	Emley Moor	338,683	41/44/47/48/51/**52**
12	Sandy Heath	197,153	21/24/27/48/51/**52**
13	Heathfield	35,936	41/42/44/47/49/**52**
14	Crystal Palace	677,045	22/23/25/26/28/**30**
15	Sutton Coldfield	396,799	39/40/42/43/45/**46**
16	Rowridge	95,527	21/22/24/25/27/**28**

k	Relay transmitters	Number of DIA HHs, served*, m_k	DTT channels
1	Whitehawk Hill	18,643	48/51/53/56/57/**60**
2	Brierley Hill	17,681	50/53/55/57/59/**60**
3	Reigate	13,894	21/24/27/53/57/**60**
4	Hemel Hempstead	14,680	41/44/47/50/55/**59**
5	Luton	5,368	50/55/**59**
6	Beecroft Hill	4,379	50/55/**59**
7	Kidderminster	7,184	49/54/**58**
8	Hertford	4,306	49/54/**58**
9	Workington	2,005	49/54/**58**
10	Nottingham	14,947	21/24/27/48/51/**52**
11	Tunbridge Wells	10,552	41/42/44/47/49/**52**
12	Guildford	8,962	40/43/46/48/49/**52**
13	Fenton	27,041	21/22/24/25/27/**28**
14	Kilvey Hill	25,599	22/23/25/26/28/**29**
15	Sheffield	21,441	21/24/27/39/42/45

* Based on the proportional counting approach (APSA).

Summary of approach

10.18 Our approach for evaluating the number of households with domestically installed amplifiers affected as a result of interference from MFCN base stations involves the following steps.

1) For a specific DTT channel, i, use Punch to calculate the number of *generic* households which are served and affected (proportional count) within each pixel in the coverage area of a DTT transmitter. See methodology in Section 4. Use measured MFCN-to-DTT protection ratios for domestic amplifiers as presented in Annex 5.

2) For each pixel in the coverage area of the examined DTT transmitter in step 1, determine[70] the number of households with domestically installed amplifiers that are served and affected (proportional count). See Annex 7 for a detailed description of this process. Aggregate across the coverage area of the transmitter.

3) Repeat steps 1 and 2 for a number of DTT transmitters in channel i. Combine the results from the individual transmitters to derive a weighted-averaged fraction, F_i, of households with domestically installed amplifiers that are affected in channel i throughout the UK.

4) From the numbers of households with domestically installed amplifiers served by the DTT transmitters examined in step 3, extrapolate to derive the number, M_i, of households with domestically installed amplifiers served (cut-off counting) in channel i throughout the UK. This somewhat involved process is described in Annex 7.

5) The product $N_i = F_i M_i$ represents the number of households with domestically installed amplifiers affected in channel i throughout the UK. Repeat[71] steps 1 to 4 to derive $N_i = F_i M_i$ for channels i = 69 …51 and ≤50. Aggregate over the DTT channels to derive the total number, N, of households with domestically installed amplifiers that are affected throughout the UK.

10.19 The remaining tables in this section present the calculated values of M_i and N_i.

10.20 Results for the specific transmitters examined (main and relay) are presented in Annex 8.

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[70] Using census data and information on the number of domestic amplifiers in the UK.
[71] Using proxies where necessary.

Estimated numbers of affected households (domestic amplifier installations)

Households affected in the absence of mitigation measures

Table 36. Estimated number of affected DIA households throughout the UK in the absence of mitigation.

DTT channel, i	Number of DIA HHs served*, M_i	Number of DIA HHs, N_i , affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	623,480	12,303	6,013	3,069	3,342	7,824
59	1,068,501	14,085	9,290	4,638	4,494	5,312
58	414,769	3,723	2,520	1,239	1,259	1,321
57	1,244	8	13	13	8	8
56	17,865	184	290	184	196	116
55	712	7	5	5	7	8
54	50,173	495	350	181	180	184
53	2,405	39	26	16	15	17
52	735,871	7,115	4,981	2,507	2,477	2,464
51	1,382	16	15	9	9	9
≤50**	2,739,226	77,082	54,014	27,223	27,111	26,999
Total	**5,655,629**	**115,058**	**77,517**	**39,084**	**39,099**	**44,263**

Households affected subject to DTT receiver filtering

Table 37. Estimated number of affected DIA households throughout the UK with DTT receiver filtering.

DTT channel, i	Number of DIA HHs served*, M_i	Number of DIA HHs, N_i , affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	623,480	8,251	2,536	1,289	1,633	6,575
59	1,068,501	1,952	353	182	182	1,585
58	414,769	45	29	11	15	14
57	1,244	0	0	0	0	0
56	17,865	2	2	2	2	2
55	712	0	0	0	0	0
54	50,173	0	0	0	0	0
53	2,405	0	0	0	0	0
52	735,871	9	9	9	9	9
51	1,382	0	0	0	0	0
≤50**	2,739,226	0	0	0	0	0
Total	**5,655,629**	**10,260**	**2,929**	**1,493**	**1,841**	**8,186**

* Derived from census data, amplifier numbers, and the DSO plan, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Households affected subject to filtering at the base station transmitter and DTT receivers

Table 38. Estimated number of affected DIA households throughout the UK and with base station transmitter filtering and DTT receiver filtering.

DTT channel, i	Number of DIA HHs served*, M_i	Number of DIA HHs, N_i , affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	623,480	5,891	365	11	346	5,553
59	1,068,501	1,484	24	8	9	1,389
58	414,769	19	12	2	7	8
57	1,244	0	0	0	0	0
56	17,865	1	0	0	0	1
55	712	0	0	0	0	0
54	50,173	0	0	0	0	0
53	2,405	0	0	0	0	0
52	735,871	9	9	9	9	9
51	1,382	0	0	0	0	0
≤50**	2,739,226	0	0	0	0	0
Total	**5,655,629**	**7,405**	**411**	**31**	**373**	**6,961**

* Derived from census data, amplifier numbers, and the DSO plan, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Section 11

Conclusions

11.1 The objectives of the studies reported in this document have been two-fold:

i) To investigate and to quantify, where possible, the efficacy of technical measures to mitigate the impact of interference from mobile/fixed communication network (MFCN) base stations to individual households;

ii) To assess the UK-wide impact of interference from mobile network base stations by estimating the total number of households whose DTT reception might be affected.

11.2 In addressing the first objective, we have demonstrated the effectiveness of various mitigation measures by examining the coverage area of the Oxford DTT transmitter. The conclusions of our modelling can be summarised as follows:

- Filtering at the DTT receiver – This is the most robust tool for mitigating the impact of interference from MFCN base stations and can virtually eliminate interference into channels 57 and below.

- Filtering at the base station transmitter – This is an effective mitigation measure where interference is dominated by the spectral leakage of MFCN base stations.

- Polarisation discrimination – The use of orthogonal-to-DTT polarisation at the MFCN base stations (as opposed to slant polarisation) can be very effective under ideal scenarios. However, measurements indicate that the degree of polarisation discrimination that can be achieved in practice is difficult to predict.

- Reduction in base station power – The mitigating efficacy of a reduction in EIRP can vary significantly from one site to another, and will depend on the local DTT field strength, DTT channels in use, radio propagation environment, and the spatial distribution of households.

- On-channel repeaters – Measurements indicate that OCRs are an effective mitigation tool when co-sited with MFCN base stations. Analysis suggests that OCRs can operate robustly in around 85% of base stations sites so long as sufficient coupling loss can be maintained between the OCR input and output. However, the ability to achieve the required coupling loss in a stable manner depends on the local clutter. The viability of OCRs as a universal mitigation tool remains uncertain.

- Modelling has also indicated that, when aggregated across the coverage area of a DTT transmitter, a departure from site-sharing results only in modest increases in the number of households affected.

11.3 In addressing the second objective, we have categorised UK households as belonging to one of the following three groups: standard domestic installations (SDI), communal aerial systems (CAS), and domestic installations with amplifiers (DIA).

11.4 The results indicate the following:

1) A large proportion of households in communal aerial systems would be affected by interference in the absence of mitigation measures. This is due to the overloading of the launch amplifier used in these systems, and the resulting (comparatively) frequency agnostic nature of the protection ratios (adjacent-channel immunity).

2) A larger proportion of domestic installations with amplifiers would be affected by interference as compared to standard domestic installations. This is again due to the overloading of the domestic amplifiers, and the resulting (comparatively) frequency agnostic nature of the protection ratios. Interestingly, the domestic amplifier that we have tested performed better than the communal aerial launch amplifier.

3) Filtering at the DTT receiver (pre-amplifier) is very effective in mitigating the impact of interference in channel 58 and below. Note that we have assumed low-cost filters for domestic installations, and more costly high-performance filters for communal aerial systems.

4) The addition of filtering at the base station transmitter virtually eliminates the impact of interference to households in communal aerial systems. This is because the high-performance DTT receiver (pre-amplifier) filtering assumed in these systems fully exploits the resulting reduction in base station spectral leakage.

5) The addition of filtering at the base station transmitter is not as affective a mitigation tool for domestic installations. This is because the low-cost DTT receiver filtering assumed for these households remains the bottle-neck. Here, the observed reductions in affected households are primarily due to the mitigation of interference from blocks B and C, where the low-cost receiver filtering is effective.

Annex 1

Parameter values and definitions

A1.1 In this annex we present the parameter values used for purposes of modelling in this report. Note that the protection ratios used for each DTT receiver installation category are presented in detail in Annexes 3 to 5. The MFCN-to-DTT channel models are also described in detail in Annex 2.

MFCN Parameters

Parameter	Value
Total number of GSM-900 sites	12,056.
GSM-900 sites with EIRP ≥ 45 dBm	8,811.
Licensees per site (site-sharing)	3 with carriers at 796, 806, 816 MHz.
Base station EIRP (per licensee)	59 dBm.
Base station channel bandwidth	10 MHz.
Base station emission mask	Default: ACLR of 59 dB in channel 60 with a spectral roll-off of 10 dB/(8MHz). With transmitter filtering: ACLR of 76 dB in adjacent 8 MHz channel with a spectral roll-off of 10 dB/(8MHz),
Base station antennas	Kathrein Scala 742 265. Frequency 824 MHz. Gain: 15.5 dBi. Down-tilt: 3°. Three sectors (first sector points east). See figures in this annex for description of angular discrimination.

DTT Parameters

Parameter	Value
UKPM version	5.9.3.
Preferred server	APSA.
Pixel dimensions	100m ×100m.
TV aerial	Gain: 9.15 dBi (12 dBd with 5 dB feeder loss). Angular discrimination: ITU Rec.419-3 (see also see Section 6).
Filtering at the DTT receiver	Standard domestic installations: Technetix type-60, type-59, and type-58. Type-57 does not provide substantial benefits over type-58. Domestic amplifier installations: Technetix type-60, type-59, type-58. Braun type-N for N≤57.

	Communal aerial systems: Isotek type-N for N≤60. Type-60: 45 dB stop-band attenuation. Type-N N≤59: 60 dB stop-band attenuation. See also Sections 5, 6 and Annexes 3,4,5.
DTT receiver performance (protection ratios)	Standard domestic installations: Worst performance measured over five super-heterodyne receivers and three Silicon tuners. See Annex 3. Communal aerial systems: Measured performance of a launch amplifier with a Silicon tuner. See Annex 4. Domestic amplifier installations: Measured performance of a domestic mast-head amplifier with a Silicon tuner. See Annex 5. Overload thresholds for DTT receivers are derived from the “vertical” portions of the C-to-I curves. Examples: Block A to channel 60: -5 dBm. Block A to channel 59: -1 dBm.

Propagation models

Parameter	Value
DTT-to-DTT (UKPM)	Multiple edge diffraction model with clutter database. Lognormal shadowing standard deviation of 5.5. dB.
DTT-to-MFCN	Median path loss: Suburban extended-Hata (SEAMCAT). Log-normal shadowing: Standard deviation σ = 1 dB for separation ≤ 100 m, σ = 5.5 dB for separation ≥ 1000 m, with linear interpolation for intermediate (horizontal) separations.

MFCN-to-MFCN parameters
(for calculations of LTE downlink throughput in Section 6)

Parameter	Value
Channel bandwidth	10 MHz.
Carrier frequency	796 MHz.
Path loss	Extended-Hata (SEAMCAT), rural (open), suburban, and urban models.
Noise figure	10 dB at 800 MHz.
Shadowing loss	Lognormal N(m, σ). Correlation = 0.5. (m, σ) = (0, 6.9) dB for the 800 MHz band.
Building penetration loss	Lognormal N(m, σ). Correlation = 0.5. Rural/Suburban (depth-1/depth-2+): (m, σ) = (7.2,6)/(9.6,7) dB for 800 MHz.
Body loss	5 dB.
Base station antennas	3GPP antenna patterns: $G_A(\text{dB}) = -\min\{12\ (\Delta a / \Delta a_{3dB})^2,\ A\}$ where Δa is angle in degrees, and $\Delta a_{3dB} = 68$ A = 25 Horizontal $\Delta a_{3dB} = 10.5$ A = 20 Vertical Three sectors (first sector points east) Vertical down-tilt of 3 degrees.
Terminal station antennas	Omni-directional with 0 dBi gain.
Spectral efficiency	A frequency re-use of 1 is assumed. Radiation is at full power for each resource block. Interference is experienced from all base stations. Throughput is modelled as follows: 2×2 MIMO C = 2 × 0.6 × 0.8 log2(1+SINR). C ≤ 8.8 bits/s/Hz. C = 0 for SINR < –10 dB.

Miscellaneous

A1.2 Conversion of field strength (dBμv/m) to power (dB)

$$E_{(\text{dB}\mu\text{v/m})} = P_{(\text{dBm})} + 20\log_{10} f_{(\text{MHz})} + 75.1 - G_{(\text{dBd})}, \qquad (29)$$

where $f_{(\text{MHz})}$ is the operating frequency (MHz),
and $G_{(\text{dBd})}$ is the DTT receiver antenna gain (dBd).

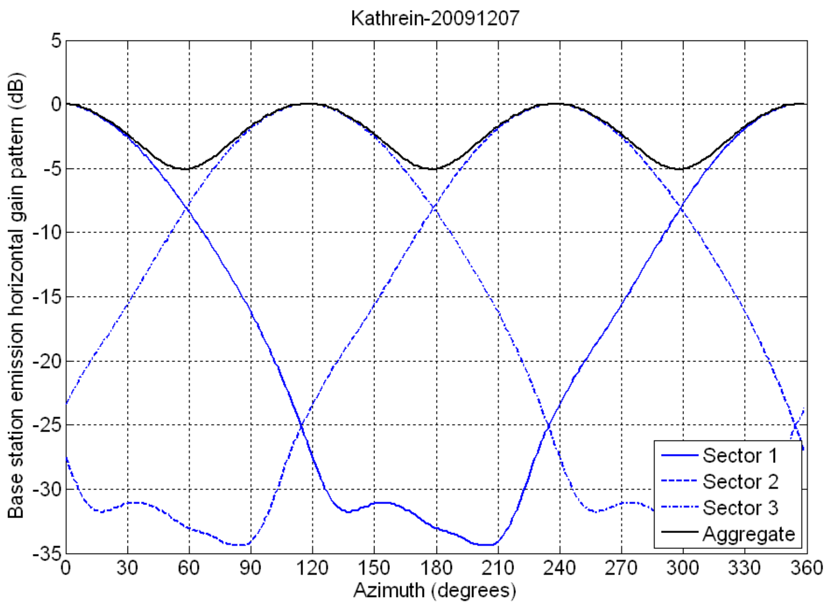

Figure 37. Kathrein antenna angular discrimination in azimuth.

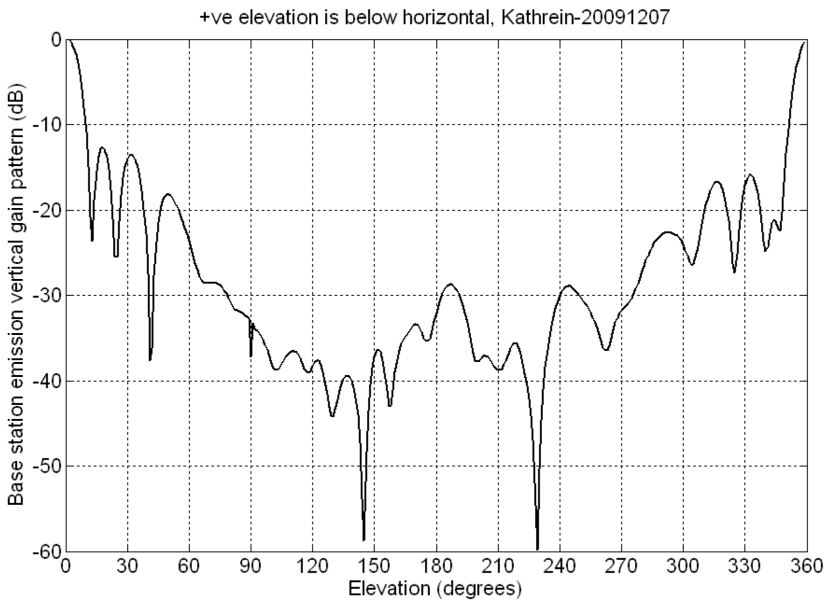

Figure 38. Kathrein antenna angular discrimination in elevation.
Positive elevations represents angles below the horizon.

Annex 2

Propagation model

A2.1 In this annex we explore the issue of propagation loss between MFCN base stations in the 800 MHz band and TV aerials receiving DTT services below 790 MHz.

A2.2 We recently commissioned a field trial programme to investigate the impact of MFCN base station emissions on DTT reception. In fulfilment of a secondary goal of this programme, we also performed a number of propagation measurements. The objective was to better understand the suitability (or otherwise) of the propagation models we had used so far in our computer simulations.

A2.3 Early measurements suggested that the propagation loss from a base station antenna to a TV aerial exhibits characteristics indicative of a two-ray propagation mechanism.

A2.4 Accordingly, we revisited and revised our propagation models to ensure that they are not contradictory to the predictions presented by a two-ray propagation mechanism. The revised model was subsequently seen to be broadly in line with further measurement results.

A2.5 In this annex we describe the two-ray path model, describe the revisions to our propagation model, and compare these with the reported measurements from the field trial.

Two-ray propagation

A2.6 Figure 39 below shows the geometry of two-ray propagation. We assume that the TV aerial points at the MFCN base station in the horizontal plane (i.e., in azimuth). Note the phase change at the ground reflection

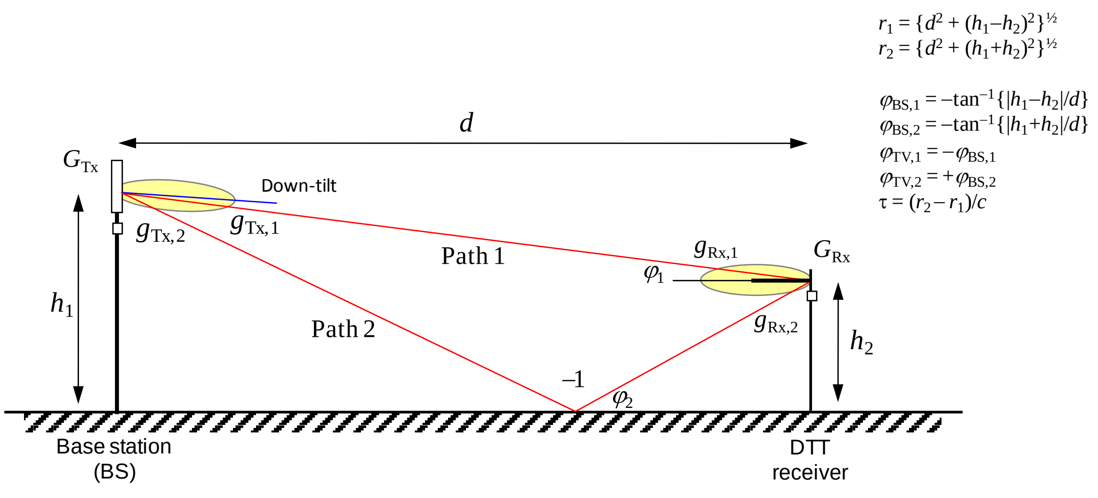

Figure 39. Two-ray propagation: geometry.

A2.7 The resulting coupling gain G_C can be written as[72]

$$G_C = | \sqrt{G_1} + a \sqrt{G_2} \exp(-j2\pi f_0 \tau) |^2 , \quad (30)$$

where

$$a = -1,$$

$$G_{i\,(dB)} = G_{FS,i\,(dB)} + \{ G_{Tx\,(dB)} + g_{Tx,i\,(dB)} + G_{Rx\,(dB)} + g_{Rx,i\,(dB)} + g_{pol,i\,(dB)} \}$$

$$i = 1, 2 \text{ (path index)},$$

and

$G_{FS,i}$ = Free-space[73] path gain (function of path length r_i),
G_{Tx} = BS antenna gain,
G_{Rx} = TV aerial antenna gain,
$g_{Tx,i}$ = BS antenna angular discrimination gain (function of φ_i),
$g_{Rx,i}$ = TV aerial angular discrimination gain (function of φ_i),
$g_{pol,i}$ = TV aerial polarisation discrimination gain (function of φ_i),
φ_i = Elevation angle of path i,
f_0 = Frequency (Hz),
τ = Time delay between path 1 and path 2 (sec).

A2.8 The coupling gain is depicted in Figure 40 as a function of horizontal separation and for the case of omni-directional transmitter and receiver antennas of 0 dBi gain at heights of 20 and 10 metres, respectively. Since the antennas have unity gain, the path gain and coupling gain are the same.

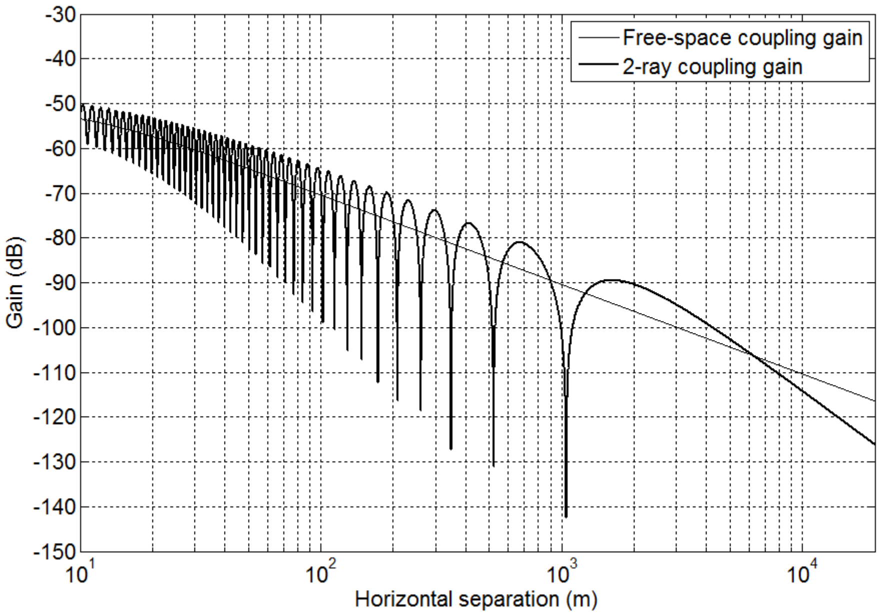

Figure 40. Free-space and two-ray coupling gains.
Omni-directional antennas (unit gain).
Transmitter height of 20 m. Receiver height of 10 m.

[72] Note the distinction between additions in the linear domain, and additions in dB.
[73] $G_{FS}(d) = +147.56 - 20\log(f) - 20\log(d)$ dB, where f is frequency in Hz, d is separation in metres.

A2.9 The pattern of peaks and nulls is due to constructive and destructive combining of signals from the two paths. The two-ray path gain is at most 6 dB above the free-space path gain.

Effective path gain

A2.10 In our computer modelling, we use an *effective* path gain in combination with the angular discrimination gains of the transmitter and receiver antennas (calculated for the angle of the direct path) to model radio propagation from the base stations to the DTT receivers.

A2.11 For our model to be consistent with two-ray propagation, the effective path gain added (in dB) to the angular discrimination gains of the transmitter and receiver antennas (calculated for the angle of the direct path) should result in a coupling gain which is equivalent to that of Equation (30) and Figure 40. This is illustrated below.

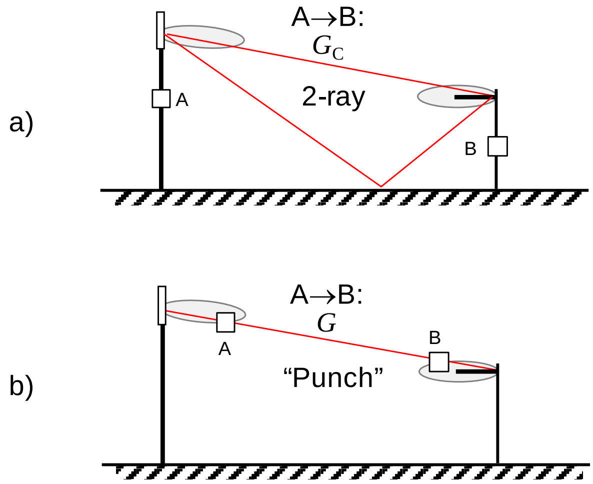

Figure 41. "Effective" path-gain.
a) Directional antennas and two-ray propagation result in coupling gain G_c.
b) Punch uses directional antennas and an effective path gain, G.

A2.12 In short, the effective path gain, G, is given by

$$G_{(dB)} = G_{C\,(dB)} - \{ G_{Tx\,(dB)} + g_{Tx,1\,(dB)} + G_{Rx\,(dB)} + g_{Rx,1\,(dB)} + g_{pol,1\,(dB)} \} \quad (31)$$

A2.13 Figure 42 shows an effective path gain that is consistent with a single-ray propagation from a 20 m high (slant polarised) directional base station transmit antenna to a 10 m high (horizontally polarised) directional TV aerial. Here the effective path gain is equal to free-space path gain. Figure 43 shows an effective path gain that is consistent with a two-ray propagation for the same geometries. Without loss of generality, we have normalised the transmitter and receiver antenna gains to unity in both examples; i.e., $G_{Tx} = G_{Rx} = 1$.

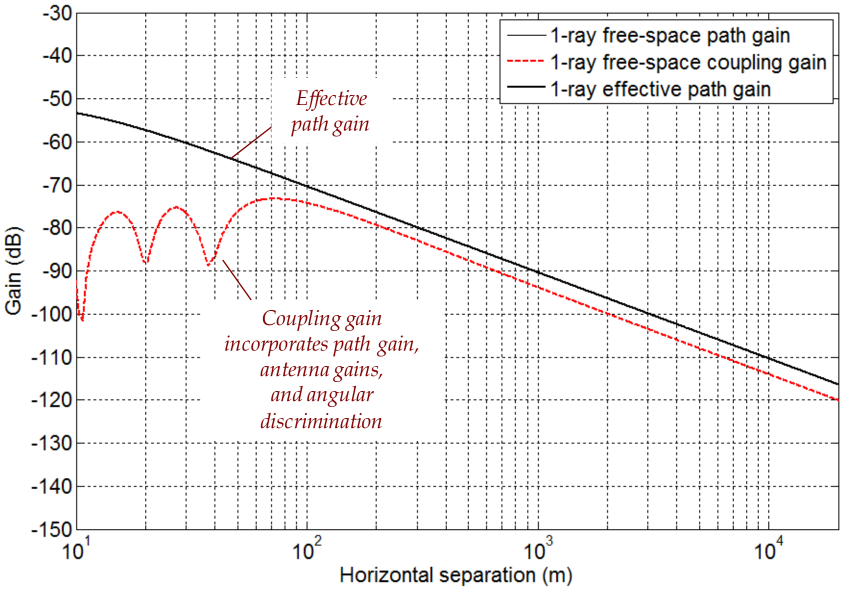

Figure 42. Effective path gain consistent with single-ray propagation.
Base station antenna: Kathrein 742265 (slant polar), –2° vertical tilt, height of 20 m.
TV aerial (H polar): ITU-R Rec.419-3, 0° vertical tilt, height of 10 m.
Polar discrimination of 3 dB. Frequency of 786 MHz.
Antenna gains are normalized to unity.

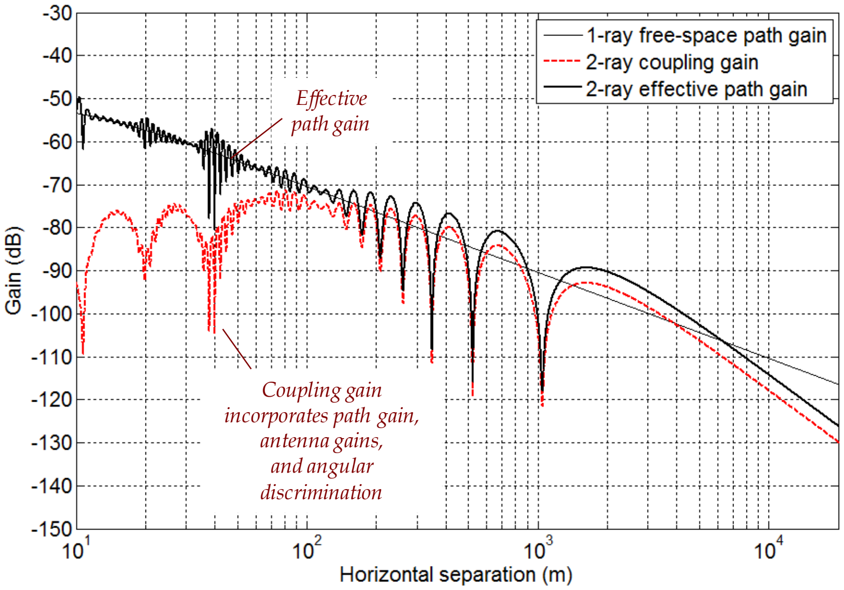

Figure 43. Two Effective path gain consistent with two-ray propagation.
Base station antenna: Kathrein 742265 (slant polar), –2° vertical tilt, height of 20 m.
TV aerial (H polar): ITU-R Rec.419-3, 0° vertical tilt, height of 10 m.
Polar discrimination of 3 dB. Frequency of 786 MHz.
Antenna gains are normalized to unity.

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A2.14 In the studies presented in this report we have used the suburban extended-Hata model[74] for median path gain. Figure 44 compares the urban, suburban, and rural extended-Hata models with the effective path gain consistent with two-ray propagation.

A2.15 It can be seen that the rural Hata median path gain tracks well with the effective path gain of a two-ray model. The urban and suburban Hata median path gains are lower (particularly at large separations), and are intended to account for physical obstructions. We conclude that extended-Hata is a plausible model for median path gain.

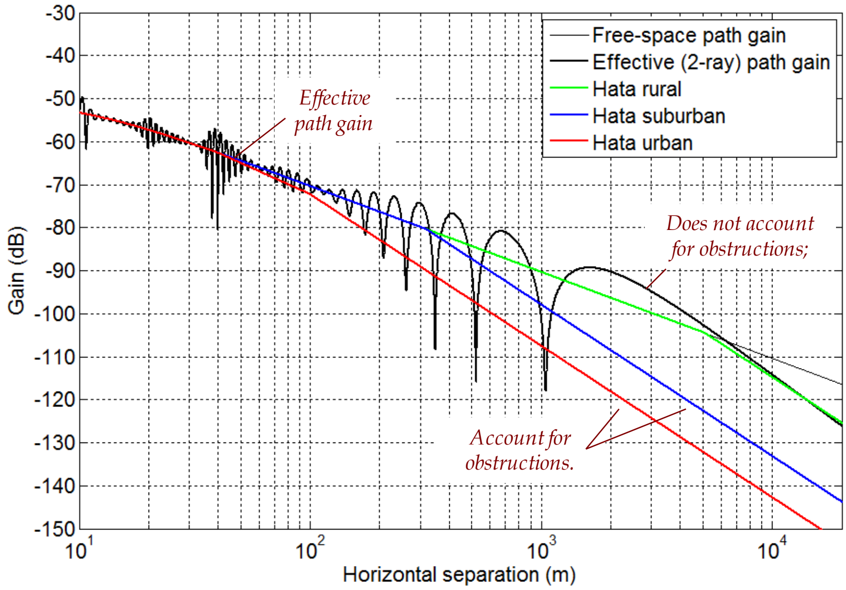


Figure 44. Comparison of effective (two-ray) path gain and extended-Hata models.
Base station antenna: Kathrein 742265 (slant polar), –2° vertical tilt, height of 20 m.
TV aerial (H polar): ITU-R Rec.419-3, 0° vertical tilt, height of 10 m.
Polar discrimination of 3 dB. Frequency of 786 MHz.
Antenna gains are normalized to unity.

log-normal shadowing

A2.16 It is common practice to model propagation via a log-normal random variable added (in dB) to a median path gain. The former accounts for prediction uncertainties caused by reflections and obstructions (sometimes referred to as shadowing).

A2.17 This is the approach adopted in the UKPM, and was also used in our analysis of interference from MFCN base stations to the DTT service (both within ECC/SE42 [75] and in our UK studies).

A2.18 In our UK studies and Punch we have used the suburban extended-Hata model for median path gain along with a separation-dependent standard deviation for log-normal shadowing. We initially used a standard deviation profile similar to that agreed in SE42. See Figure 45.

[74] See the SEAMCAT manual at http://www.ero.dk/seamcat .
[75] CEPT Report 30, "The identification of common and minimal (least restrictive) technical conditions for 790-862 MHz for the digital dividend in the European Union," Oct. 2009, www.erodocdb.dk.

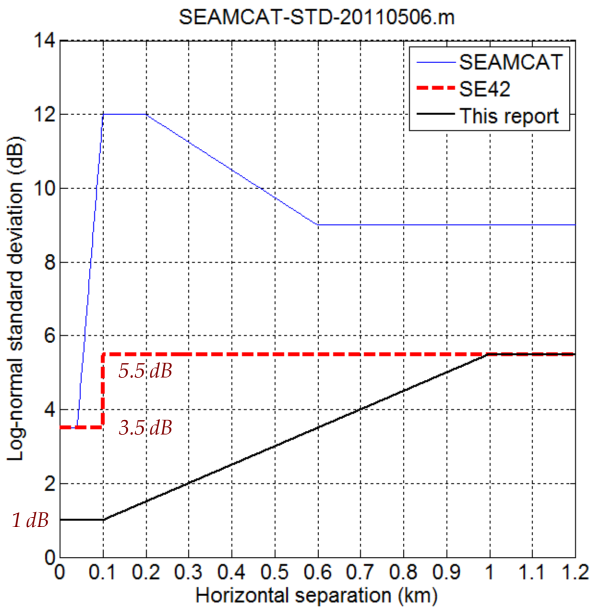


Figure 45. Standard deviation of log-normal shadowing.

A2.19 In SE42 we had originally considered the standard deviation profile suggested in SEAMCAT (a simulation tool developed by the European Communications Office). The standard deviation values quoted in the SEAMCAT manual are very large at large separations. Furthermore, the manual cites no references for the origins of these values. Dependence on antenna heights and frequency are also unknown.

A2.20 We discarded the SEAMCAT values early on in the SE42 studies, in favour of a standard deviation of σ = 3.5 dB for separations of less than 100 m, and σ = 5.5 dB for separations of greater than 100 m. The 5.5 dB was chosen as it is consistent with the value used in broadcasting. There was no specific logic behind the choice of σ =3.5 dB other than the fact that it was consistent with the SEAMCAT manual.

A2.21 Figure 46 shows the suburban extended-Hata model along with log-normal variability based on the aforementioned standard deviation profile, and compares this with the effective two-ray path gain.

A2.22 It is immediately evident that

- The standard deviation of σ = 3.5 dB is excessive at low separations below 100 m;
- The standard deviation of σ = 5.5 dB is excessive at separations of between 100 and 1000 m.

A2.23 Consequently, we adopted the following revised profile

σ = 1 dB for separation $\leq$ 100 m,
σ = 5.5 dB for separation $\geq$ 1000 m,

with linear interpolation for intermediate (horizontal) separations. These values were derived based on a visual fit to the effective two-ray path gain. Figure 47 shows the suburban extended-Hata model along with the above revised standard deviation profile.

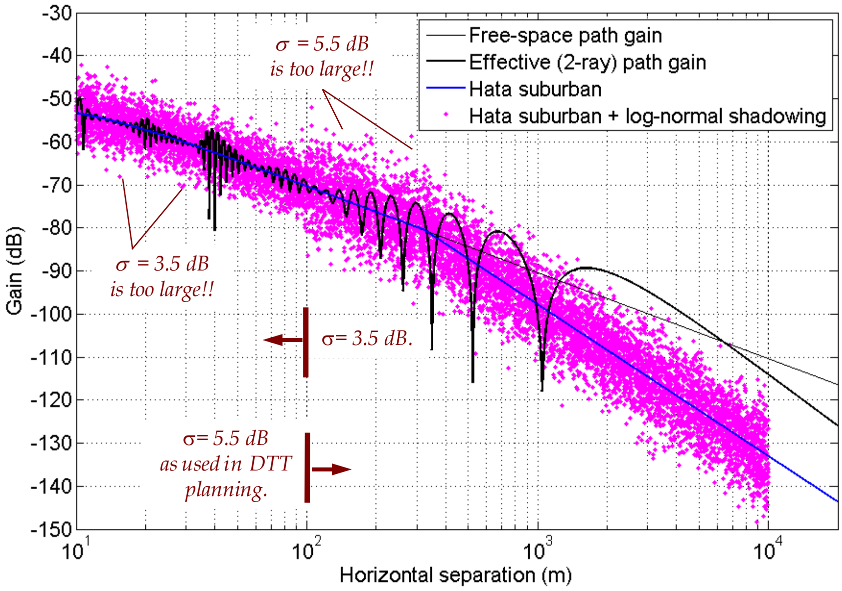


Figure 46. Comparison of effective two-ray path-gain
and suburban-Hata with the SE42 log-normal standard deviation profile.
Transmitter height of 20 m. Receiver height of 10 m.

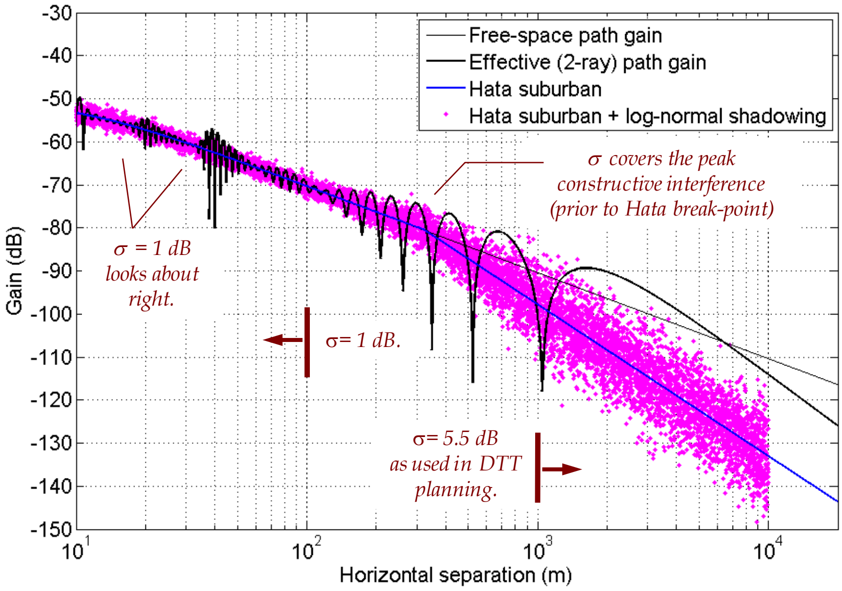


Figure 47. Comparison of effective two-ray path-gain
and suburban-Hata with the revised log-normal standard deviation profile.
Transmitter height of 20 m. Receiver height of 10 m.

Field measurements

A2.24 In our field trial we performed propagation measurements at four base station sites with the antenna arrangements presented below.

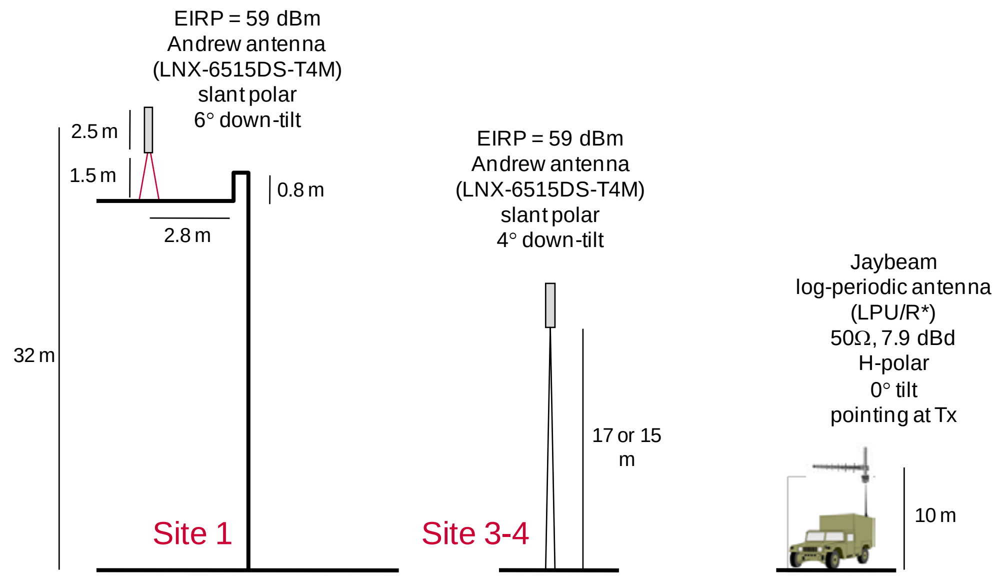


Figure 48. Field trial antenna arrangements.

A2.25 A calibrated (horizontally polarised) log-periodic antenna was pointed (in azimuth) towards a test LTE base station (slant polarised). Propagation loss was then calculated by subtracting the measured received signal power from the radiated base station power, taking into account of the antenna gains, antenna angular discrimination (in azimuth and elevation[76]), and a 3 dB polarisation discrimination.

A2.26 Figures 49 to 53 show the measures propagation gains reported by Aegis, plotted along with the suburban Hata model and the revised log-normal shadowing standard deviation profile of Figure 45.

[76] The TV aerial has little angular discrimination in elevation.

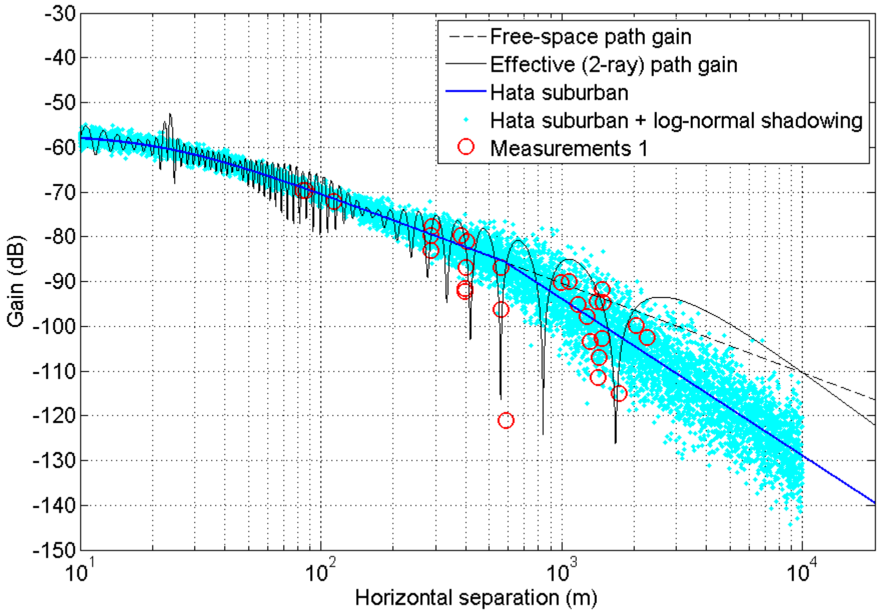


Figure 49. Comparison of field measurements with propagation model used in this report.
Base station antenna height of 32 m (Council building).
Measured path loss aligns reasonably well with two-ray null pattern.
Measured path loss aligns well with free-space path loss at ~100 m.

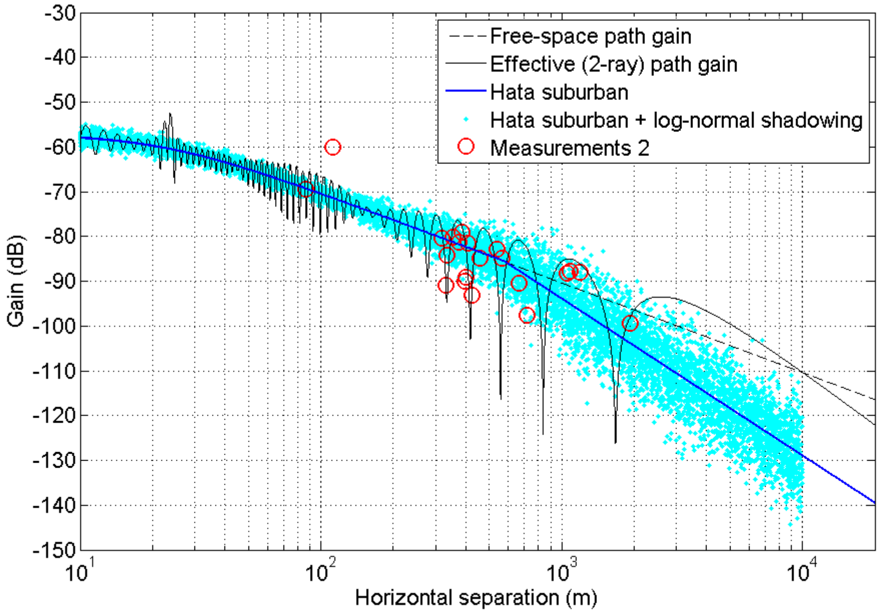


Figure 50. Comparison of field measurements with the propagation model used in this report.
Base station antenna height of 32 m (Council building).
Measured path loss aligns reasonably well with two-ray null pattern.
Unexplained low path loss measured at ~100 m.

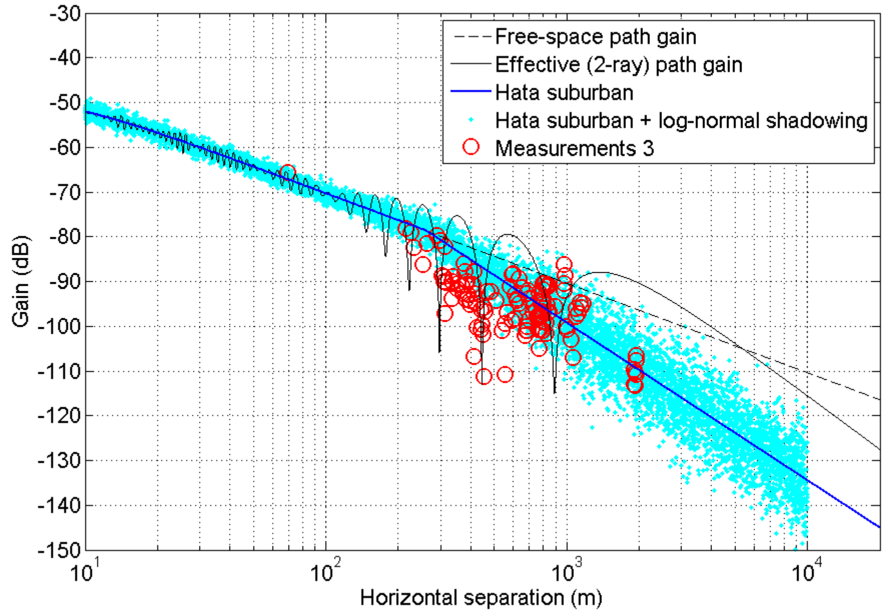


Figure 51. Comparison of field measurements with the propagation model used in this report.
Base station antenna height of 17 m (Two gates).
Measured path loss is higher than predicted by two-ray null pattern.
Reduced antenna height increases the likelihood of obstructions.
Measured path loss aligns well with free-space path loss below 100 m.

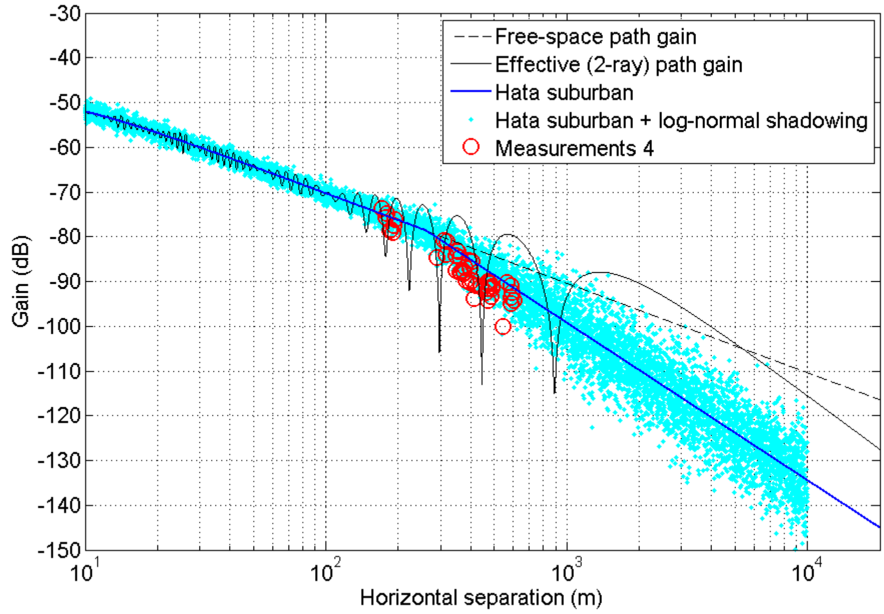


Figure 52. Comparison of field measurements with the propagation model used in this report.
Base station antenna height of 17 m (Stoneydelph).
Measured path loss is higher than predicted by two-ray null pattern.
Reduced antenna height increases the likelihood of obstructions.

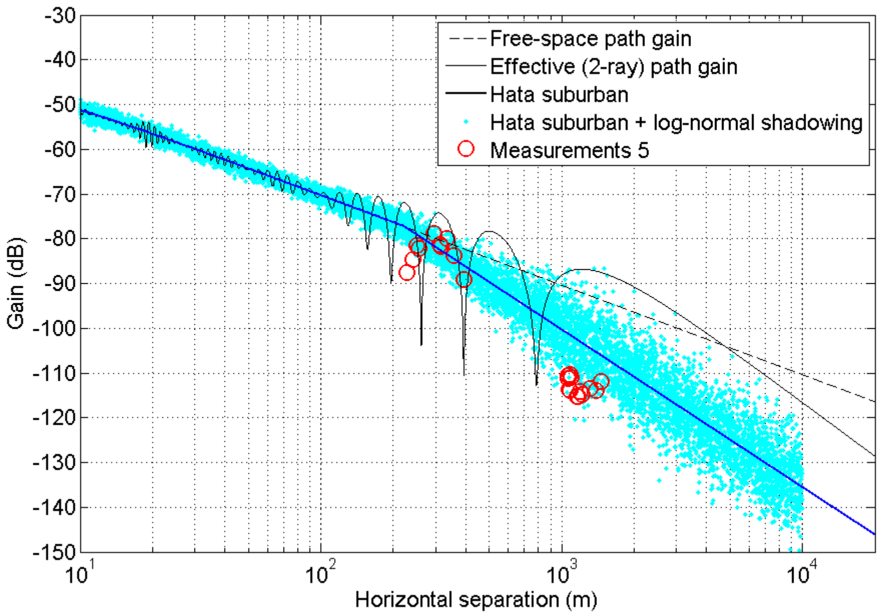


Figure 53. Comparison of field measurements with the propagation model used in this report. Base station antenna height of 15 m (Snowdome). Lobe at 0.3 – 0.4 km suggests constructive ground reflection. Measured path loss at larger separations are far greater than predicted by two-ray null pattern. This is possibly due to the low base station antenna height (below local tree line).

Conclusions

A2.27 We have reported on the results of our field trial propagation measurements. Propagation measurement was always intended to be a secondary objective of the field trial, and as such, the limited of number of measurements does not represent a statistically significant sample. However, what the results do indicate is that the measured propagation losses exhibit characteristics that suggest a two-ray radio propagation mechanism, notwithstanding local clutter and obstructions.

A2.28 We have also shown that the suburban extended-Hata median path gain tracks the two-ray path gain quite well for the antenna heights and distances of interest. We have adopted the suburban[77] extended-Hata median path gain in all the modelling presented in this report.

A2.29 As commonly practiced, we also model the deviations of propagation loss from the median path loss as a lognormal random variable. For consistency with the variations observed in two-ray propagation, we have adopted the following profile for the standard deviation of the lognormal shadowing:

σ = 1 dB for separation $\leq$ 100 m,
σ = 5.5 dB for separation $\geq$ 1000 m,

A2.30 with linear interpolation for intermediate (horizontal) separations. The adopted median path loss and lognormal shadowing model broadly captures the reported measurements, and if anything, under-estimates the losses.

[77] According to our estimates, roughly 3%, 70%, and 30% of the UK population reside in what can be categorised as urban, suburban, and rural radio propagation environments, respectively.

Annex 3

Measurements of protection ratios: DTT receivers

A3.1 In 2009 we commissioned ERA Technology to perform measurements of MFCN-to-DTT protection ratios for 5 DTT receivers, 3 of which had super-heterodyne (“can”) tuners, and 2 of which had Silicon tuners.

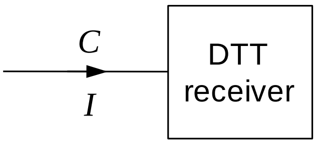
A3.2 We have used the highest values of the measured protection ratios in our modelling of the impact of interference from MFCN base stations in the 800 MHz to broadcasting services (standard installations).

A3.3 In this annex we first describe the measurement set-up and methodology. We then present the raw measurements results provided by ERA, as well as the post-processed protection ratios ultimately used in our modelling.

Set-up and assumptions

A3.4 Figure 54 shows the measurement set-up we have used for measuring the protection ratios of a DTT receiver. The variable C is the (wanted) DTT carrier power, while I is the (unwanted) MFCN carrier power.

Figure 54. DTT receiver test set-up.



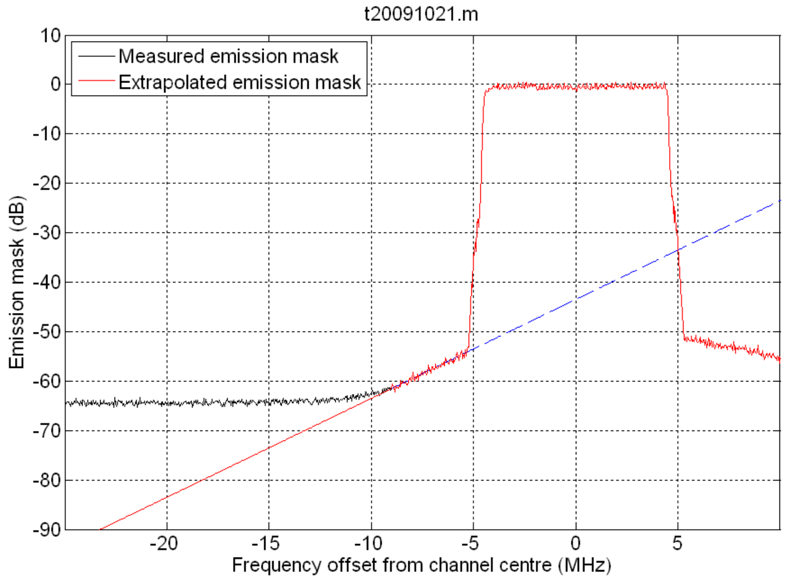
A3.5 For each test point, characterised by a value of C and an interferer-victim frequency separation, a LTE signal (from a signal generator) is applied at the input to the receiver as a proxy for an MFCN base station interferer. The interferer carrier power, I, is then recorded at the point of failure (onset of pixelation). The MFCN-to-DTT protection ratio is then given by the ratio of C to I.

A3.6 Figure (55) illustrates the measured emission mask, $P_{\mathrm{M}}(\Delta f)$, of the LTE test interferer. For purposes of analysis, the mask is extrapolated linearly for frequency offsets that are greater than -9 MHz from the carrier frequency (i.e., where the measurements are limited by the dynamic range of the spectrum analyser).

A3.7 The adjacent channel leakage ratio, $\mathrm{ACLR}_{\mathrm{M}}(\Delta f_0)$, of the test interferer can be derived[78] for any interferer-victim frequency separation Δf_0 from the emission mask, $P_{\mathrm{M}}(\Delta f)$.

[78] The ACLR at a separation of, say, 10 MHz is equal to the ratio of the test interferer’s in-block power (integrated over 10 MHz centred around the carrier) divided by the interferer’s out-of-block power (integrated over 8 MHz centred around an offset of 10 MHz away from the interferer’s carrier frequency).

Figure 55. Measured mask of the test interferer.
The roll-off is modelled as a straight line with
a gradient of -2 dB/MHz and an intercept of -43.5 dB.



Raw measurements

A3.8 Tables 39 to 43 present the measured values of protection ratio, $r_M(\Delta f)$, for five DTT receivers. Note that the wanted DTT signal power, C , and the test interferer power, I , were measured over bandwidths of 7.6 MHz and 9 MHz respectively. For this reason, the signal-to-interference ratio, SIR_M , at the point of failure can be derived by adding $10\log_{10}(9/7.6)$ = 0.73 dB (correcting for the interferer-victim bandwidth mismatch) to the co-channel protection ratios $r_M(0)$.

Table 39. Measured protection ratios for super-heterodyne receiver #1.

r_M (dB)	DTT signal power, C (dBm)				
Carrier separation Δf (MHz)	-70	-50	-30	-20	-12
0	16.88	16.13	15.12	15.96	16.39
10	-41.55	-34.55	-22.44	-16.36	-9.51
15	-49.45	-43.09	-28.41	-18.13	-10.89
20	-50.09	-45.73	-29.12	-19.53	-12.26
25	-56.38	-48.82	-31.52	-20.53	-12.75
30	-59.56	-47.01	-32.41	-21.55	-13.09
35	-63.55	-44.26	-33.41	-22.38	-13.87
46	-64.94	-46.99	-33.97	-22.85	-14.86
51	-65.43	-47.47	-34.22	-23.08	-15.09
56	-68.78	-48.61	-34.56	-23.4	-15.42
61	-69.43	-49.04	-34.92	-22.87	-16.17
66	-64.06	-48.97	-34.69	-23.52	-15.32
71	-53.08	-48.72	-34.59	-23.44	-16.22
76	-56.04	-49.04	-34.88	-23.52	-15.82
81	-70.75	-49.49	-35.59	-24.25	-15.63

Table 40. Measured protection ratios for super-heterodyne receiver #2.

r_M (dB)	DTT signal power, C (dBm)				
Carrier separation Δf (MHz)	-70	-50	-30	-20	-12
0	15.15	13.83	14	14.27	15.49
10	-38.82	-36.63	-25.47	-19.54	-13.88
15	-45.13	-44.31	-30.92	-22.02	-14.6
20	-52.06	-49.82	-31.64	-21.73	-14.45
25	-52.52	-49.54	-32.43	-22.34	-14.78
30	-58.48	-42.81	-34.47	-22.68	-15.16
35	-60.29	-43.56	-34.54	-23.54	-15.63
46	-66.89	-49.29	-36.01	-25.05	-17.12
51	-68.24	-50.52	-36.18	-25.2	-17.59
56	-70.02	-50.84	-36.61	-25.66	-17.02
61	-69.39	-51.57	-36.09	-25.28	-17.62
66	-54.18	-50.03	-35.86	-25.97	-17.31
71	-41.83	-40.84	-35.72	-25.72	-17.12
76	-47.18	-48.19	-35.92	-25.92	-17.18
81	-71.63	-53.58	-36.56	-25.62	-17.69

Table 41. Measured protection ratios for super-heterodyne DTT receiver #3.

r_M (dB)	DTT signal power, C (dBm)				
Carrier separation Δf (MHz)	-70	-50	-30	-20	-12
0	12.97	14.21	14.18	15.41	15.55
10	-41.54	-33.24	-21.34	-14.44	-8.36
15	-52.22	-42.64	-26.76	-20.03	-12.03
20	-45.51	-44.5	-30.47	-19.74	-12.68
25	-50.93	-37.16	-31.78	-22.08	-13.91
30	-60.91	-42.87	-33.09	-22.77	-14.81
35	-59.35	-41.19	-31.18	-22.04	-14.13
46	-69.02	-51.87	-33.79	-23.99	-16.61
51	-69.48	-53.16	-34.31	-24.51	-16.32
56	-70.08	-53.96	-34.93	-24.99	-16.94
61	-70.56	-54.52	-34.58	-24.63	-17.67
66	-69.41	-54.32	-35.23	-25.43	-17.36
71	-58.31	-54.28	-35.11	-25.18	-17.17
76	-61.29	-54.26	-36.15	-25.23	-17.23
81	-73.04	-54.92	-35.81	-25.58	-17.61

Table 42. Measured protection ratios for Silicon tuner DTT receiver #1.

r_M (dB)	DTT signal power, C (dBm)				
Carrier separation Δf (MHz)	-70	-50	-30	-20	-12
0	15.66	14.29	14.33	14.49	15.73
10	-41.53	-36.41	-25.34	-20.23	-14.36
15	-48.97	-42.74	-30.76	-22.61	-16.88
20	-51.66	-45.43	-32.42	-24.22	-17.38
25	-51.29	-47.02	-33.96	-24.89	-16.77
30	-51.73	-49.46	-34.4	-24.13	-16.72
35	-52.73	-50.3	-33.37	-23.26	-14.95
46	-53.46	-51.18	-32.39	-22.14	-14.74
51	-54.95	-51.61	-31.73	-22.48	-14.41
56	-54.46	-50.96	-31.16	-22.05	-14.02
61	-54.97	-50.56	-30.86	-20.75	-12.76
66	-55.68	-49.49	-30.62	-20.55	-12.32
71	-56.43	-49.29	-29.43	-19.35	-12.06
76	-57.28	-49.31	-29.33	-19.28	-12.28
81	-57.52	-48.55	-29.6	-19.44	-12.65

Table 43. Measured protection ratios for Silicon tuner DTT receiver #2.

r_M (dB)	DTT signal power, C (dBm)				
Carrier separation Δf (MHz)	-70	-50	-30	-20	-12
0	14.49	14.16	14.18	14.74	15.47
10	-39.78	-38.79	-29.61	-19.79	-13.69
15	-47.43	-44.35	-30.21	-22.59	-16.36
20	-47.87	-45.87	-31.74	-24.28	-17.95
25	-48.29	-48.27	-33.06	-25.55	-20.24
30	-48.45	-48.49	-34.29	-26.29	-20.28
35	-49.2	-49.22	-35.19	-26.06	-17.98
46	-49.96	-48.92	-34.95	-24.69	-16.83
51	-50.45	-50.37	-34.34	-24.32	-16.15
56	-50.85	-50.52	-34.02	-23.75	-16.68
61	-51.38	-50.31	-34.51	-24.38	-16.42
66	-53.23	-50.08	-34.44	-24.15	-16.24
71	-53.04	-49.83	-34.42	-23.92	-15.94
76	-53.15	-51	-34.08	-24.07	-16.14
81	-53.07	-50.55	-34.4	-23.75	-15.71

Post-processed protection ratios

A3.9 In this sub-section we present the protection ratios derived via post-processing of the raw measurements of Table 39 to 43. The post-processing involves the following:

a) Interpolation in frequency to account for the multitude of interferer-victim frequency separations. This is required since the interferer-victim frequency separations used for the measurements do not readily line up with the channel raster of the EU harmonised 800 MHz band-plan (measurements were performed prior to finalisation of the band-plan).

b) Mathematical manipulation[79] to account for the ACLR of actual LTE base station equipment.

c) Accounting for the impact of filtering through an increase (equal to the filter's stop-band attenuation) in the frequency selectivity of the receiver.

A3.10 In summary, in order to calculate the protection ratio at a given interferer-victim carrier separation Δf_0, we perform the following sequence of operations. We first interpolate the measured protection ratios to derive $r_{\mathrm{M}}(\Delta f_0)$. We also use the test interferer's emission mask to calculate $\mathrm{ACLR}_{\mathrm{M}}(\Delta f_0)$. From these two figures, and using mathematical manipulation, we derive the receiver's selectivity $\mathrm{ACS}_{\mathrm{M}}(\Delta f_0)$. We add to this the relevant filter stop-band attenuation, and then combine with the ACLR of actual base station equipment, $\mathrm{ACLR}(\Delta f_0)$, to calculate the correct protection ratio $r(\Delta f_0)$.

A3.11 The measurements of protection ratio undertaken by ERA were performed for a Gaussian channel. For purposes of consistency with the UKPM, we add a margin of 1.1 dB[80] to the post-processed protection ratios to account for Rician channels.

A3.12 At each test-point we post-process the protection ratios measured for each of the 5 devices tested. We then use the *largest* value for purposes of modelling.

A3.13 The protection ratios tend to remain constant below channel 51. For this reason, we use the channel 51 protection ratios as proxies for channels 50 and below.

<u>EC BEM with roll-off</u>

A3.14 Table 45 shows post-processed protection ratios based on the scenario where the base station emissions from blocks A, B, and C each achieve an ACLR of (59+10*n*) dB over DTT channel (60–*n*).

[79] If r_1 is the protection ratio corresponding to an interferer with ACLR_1, then the protection ratio r_2 corresponding to the same interferer but with ACLR_2 can be computed as:
$\mathrm{ACIR}_1 = r(0)/r_1$, $\mathrm{ACIR}_1 = (1/\mathrm{ACLR}_1 + 1/\mathrm{ACS})^{-1}$, $\mathrm{ACIR}_2 = (1/\mathrm{ACLR}_2 + 1/\mathrm{ACS})^{-1}$
then $r_2 = r(0)/\mathrm{ACIR}_2$ where $r(0)$ is the co-channel protection ratio, ACIR is the adjacent-channel interference ratio, and ACS is adjacent channel selectivity.
[80] As recommended in ECC Report 138, for the case of fixed reception (64-QAM and 2/3 rate coding). We have not applied this additional margin to the measurements of protection ratio presented in Annexes 4 and 5.

EC BEM with roll-off and Rx filtering

A3.15 Table 46 shows post-processed protection ratios based on the scenario where the base station emissions from blocks A, B, and C each achieve an ACLR of (59+10*n*) dB over DTT channel (60–*n*).

A3.16 Receiver filtering is modelled via the stop-band attenuations (or more precisely, filter discrimination gains) presented in the table below. These are based on a filter prototype designed and built for Ofcom by Technetix. The filters provide a sharp roll-off immediately beyond the cut-off frequency[81]. Insertion loss is of the order of 1 dB.

Table 44. Filter discrimination gains assumed for standard installations.

Protected channel	Filter cut-off (MHz)	Rx filter discrimination gain G_D (dB)		
		Block A f_0 = 796 MHz	Block B f_0 = 806 MHz	Block C f_0 = 816 MHz
60	790	-1	-7	-19
59	782	-5	-19	-19
58	774	-19	-19	-20
≤ 57	766	-19	-20	-21

Measured LTE base station emission mask and Rx filtering

A3.17 Table 47 shows post-processed protection ratios based on the scenario where the base station emissions from block A achieve an ACLR of (76+10*n*) dB over DTT channel (60–*n*). Base station emissions from blocks B and C follow a similar mask but shifted in frequency by +10 MHz and +20 MHz, respectively.

A3.18 Receiver filtering is modelled via the stop-band attenuations shown in 44.

[81] Greater stop-band attenuations (than those shown in the table) can be achieved when the filter is designed to protect channels 57 and below. This is because the roll-off between pass-band and stop-band can be made less steep and traded off against better stop-band attenuation.

Table 45. DTT receiver protection ratios:
EC BEM with roll-off.

Block A r_A (dB)		C (dBm)					
		-70	-50	-30	-20	-12	
DTT channel	60	-37	-32	-20	-13	-7	
	59	-46	-43	-28	-18	-11	
	58	-47	-37	-31	-20	-12	
	57	-48	-40	-30	-21	-13	
	56	-49	-45	-32	-21	-13	
	55	-49	-46	-31	-21	-13	
	54	-50	-48	-30	-20	-12	
	53	-52	-48	-30	-19	-11	
	52	-43	-44	-28	-18	-11	
	≤ 51	-52	-47	-28	-18	-12	

Block B r_B (dB)		C (dBm)					
		-70	-50	-30	-20	-12	
DTT channel	60	-40	-39	-28	-18	-11	
	59	-46	-40	-31	-20	-12	
	58	-48	-40	-30	-21	-13	
	57	-49	-45	-31	-21	-14	
	56	-49	-47	-31	-21	-13	
	55	-50	-48	-30	-20	-12	
	54	-47	-45	-29	-19	-11	
	53	-46	-47	-28	-18	-11	
	52	-52	-47	-28	-18	-12	
	≤ 51	-52	-47	-28	-18	-12	

Block C r_C (dB)		C (dBm)					
		-70	-50	-30	-20	-12	
DTT channel	60	-40	-39	-31	-20	-12	
	59	-47	-41	-30	-21	-13	
	58	-49	-46	-31	-21	-14	
	57	-50	-47	-30	-21	-13	
	56	-51	-48	-30	-20	-12	
	55	-42	-41	-28	-18	-11	
	54	-52	-48	-28	-18	-11	
	53	-52	-47	-28	-18	-12	
	52	-52	-47	-28	-18	-12	
	≤ 51	-52	-47	-28	-18	-12	

Table 46. DTT receiver protection ratios:
EC BEM with roll-off and Rx filtering.

Block A r_A (dB)		C (dBm)					
		-70	-50	-30	-20	-12	
DTT channel	60	-38	-33	-21	-14	-8	
	59	-49	-47	-32	-23	-16	
	58	-60	-55	-49	-39	-31	
	57	-66	-59	-49	-40	-32	
	56	-68	-64	-51	-40	-33	
	55	-68	-65	-50	-41	-33	
	54	-69	-67	-49	-40	-32	
	53	-71	-67	-49	-39	-30	
	52	-62	-63	-47	-37	-30	
	≤ 51	-71	-67	-48	-37	-31	

Block B r_B (dB)		C (dBm)					
		-70	-50	-30	-20	-12	
DTT channel	60	-40	-41	-34	-25	-18	
	59	-50	-51	-48	-39	-31	
	58	-60	-58	-49	-40	-32	
	57	-67	-64	-51	-41	-33	
	56	-69	-66	-50	-41	-33	
	55	-70	-68	-50	-40	-32	
	54	-66	-65	-49	-39	-31	
	53	-66	-67	-48	-38	-31	
	52	-72	-67	-48	-38	-31	
	≤ 51	-72	-67	-48	-38	-31	

Block C r_C (dB)		C (dBm)					
		-70	-50	-30	-20	-12	
DTT channel	60	-40	-41	-41	-37	-31	
	59	-50	-51	-48	-40	-32	
	58	-60	-60	-51	-41	-33	
	57	-68	-66	-51	-42	-34	
	56	-71	-68	-50	-40	-32	
	55	-62	-61	-49	-39	-31	
	54	-73	-68	-49	-39	-32	
	53	-72	-68	-49	-39	-32	
	52	-72	-68	-49	-39	-32	
	≤ 51	-72	-68	-49	-39	-32	

Table 47. DTT receiver protection ratios:
Measured LTE base station SEM and Rx filtering.

Block A r_A (dB)		*C* (dBm)					
		-70	-50	-30	-20	-12	
DTT channel	60	-40	-33	-21	-14	-8	
	59	-52	-48	-33	-23	-16	
	58	-66	-56	-50	-39	-31	
	57	-67	-59	-49	-40	-32	
	56	-68	-64	-51	-40	-33	
	55	-68	-65	-50	-41	-33	
	54	-69	-67	-49	-40	-32	
	53	-71	-67	-49	-39	-30	
	52	-62	-63	-47	-37	-30	
	≤ 51	-71	-67	-48	-37	-31	

Block B r_B (dB)		*C* (dBm)					
		-70	-50	-30	-20	-12	
DTT channel	60	-51	-50	-35	-25	-18	
	59	-66	-59	-50	-39	-31	
	58	-67	-60	-49	-40	-32	
	57	-68	-65	-51	-41	-33	
	56	-69	-66	-50	-41	-33	
	55	-70	-68	-50	-40	-32	
	54	-66	-65	-49	-39	-31	
	53	-66	-67	-48	-38	-31	
	52	-72	-67	-48	-38	-31	
	≤ 51	-72	-67	-48	-38	-31	

Block C r_C (dB)		*C* (dBm)					
		-70	-50	-30	-20	-12	
DTT channel	60	-66	-61	-50	-40	-31	
	59	-68	-61	-50	-41	-32	
	58	-69	-66	-51	-41	-33	
	57	-70	-68	-51	-42	-34	
	56	-71	-68	-50	-40	-32	
	55	-62	-61	-49	-39	-31	
	54	-73	-68	-49	-39	-32	
	53	-72	-68	-49	-39	-32	
	52	-72	-68	-49	-39	-32	
	≤ 51	-72	-68	-49	-39	-32	

Conclusions

A3.19 We have summarised the results of measurements commissioned by Ofcom in relation to the MFCN-to-DTT protection ratios of five DTT receivers. We have shown how these raw measurements are post-processed in order to derive protection ratios that account for the spectral masks of actual LTE base station equipment.

A3.20 For purposes of modelling, we have adopted the *largest* protection ratio (worst performance) among the five tested devices at each frequency separation and DTT wanted signal power. In this respect, our modelling over-estimates the impact of interference.

Annex 4

Measurements of protection ratios: Communal aerial systems

A4.1 Ofcom recently commissioned ERA Technology to perform measurements of MFCN-to-DTT protection ratios for a communal aerial TV amplifier feeding a DTT receiver (Silicon tuner). We have used the results of these measurements for our modelling of the impact of interference from MFCN base stations in the 800 MHz to broadcasting services below 790 MHz.

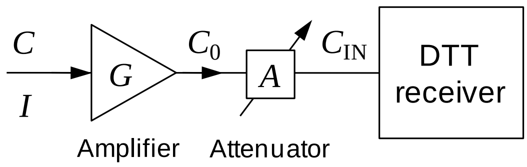
A4.2 There are a wide variety of communal aerial system (CAS) amplifier models and installations in the UK, and as such, examination of all possible architectures is a challenging task. However, we believe that the presented measurements go a long way towards capturing the scale of the susceptibility of CAS systems with respect to interference from MFCN base stations in the 800 MHz band.

A4.3 In this annex we first describe the logic behind the test methodology. We then present the raw measurement results provided by ERA, as well as the post-processed protection ratios used in our modelling.

Set-up and assumptions

A4.4 Figure 56 shows the measurement set-up we have used for modelling a CAS system. The variable C is the (wanted) DTT carrier power, while I is the (unwanted) MFCN carrier power. The attenuator represents the total post-amplifier distribution losses in a building. The objective is to model a range of potential installations. This implies exploring a range of plausible amplifier gains, G, and distribution gains, A.

Figure 56. CAS amplifier test set-up.



A4.5 The typical approach used for the installation of CAS systems (performed prior to the introduction of MFCN base stations in the 800 MHz band) is described next.

A4.6 Depending on the values of C and A, the installer will deploy an amplifier of gain G such that a) the output of the amplifier C_0 is appropriately *backed-off* from the maximum rated output value, and b) the input to the DTT receiver, C_{IN}, is at an *appropriate* level.

A4.7 We have used C_{IN} = -50 dBm to represent an appropriate level of power into the DTT receiver. The gain of the specific tested amplifier can be adjusted to anywhere between 25 and 40 dB. The amplifier has a maximum output rating of 117 dBμv into 75Ω (equivalent to 8 dBm).

A4.8 It is common practice for the gain of the amplifier to be reduced such that the power at the amplifier output is maintained below the maximum output rating by a margin of 10 log(n–1) dB where n is the number of analogue channels received. We also include an addition margin of 7 dB to account for the lower power of a DTT carrier in comparison with that of an analogue carrier[82]. For the purposes of these measurements we have assumed that n = 5, in which case the back-off value is 13 dB. This implies that the amplifier's gain is always adjusted such that the output power does not exceed 8 - 13 = -5 dBm.

A4.9 Based on the above arguments, the constraints on the various parameter values may be written as follows:

$$-70 \le C_{(dBm)} \le -20$$
$$+25 \le G_{(dB)} \le +45$$
$$C_{0\,(dBm)} \le -5$$
$$C_{IN\,(dBm)} = -50$$
$$A_{(dB)} \le 0 \text{ (by definition)}$$

A4.10 Note that the proposed range of C is typical of DTT coverage (according to the UKPM, albeit for an aerial at a height of 10 m and a 9.15 dBi gain which includes a feeder loss of 5 dB).

Test points

A4.11 Based on the above constraints, Table 48 describes a number of appropriate test points, specified in terms of (G, A) combinations. Note that $G_{(dB)} + A_{(dB)}$ is set to provide a fixed value of C_{IN} = -50 dBm at the DTT receiver, with gain G adjusted to the maximum permitted value subject to compliance with the back-off constraint.

Table 48. CAS amplifier maximum-gain test points.

$C_{(dBm)}$	$C_{IN\,(dBm)}$	$G_{(dB)} + A_{(dB)}$	$G_{MAX\,(dB)}$	$C_{0\,(dB)}$	$A_{MIN\,(dB)}$
–70	–50	+20	45	-25	-25
–60	–50	+10	45	-15	-35
–50	–50	0	45*	-5	-45
–40	–50	–10	35*	-5	-45
–30	–50	–20	25*	-5	-45
–20	–50	–30	25#	+5	-55

* Maximum gain is upper-bounded by back-off rule.
# Back-off cannot be achieved. Pre-amp attenuator is required.

A4.12 Note that compliance with the back-off constraint is not possible for C values greater than -30 dBm. Compliance would require the insertion of an attenuator at the input to the amplifier such that the amplifier would experience a C value of -30 dBm. To account for this, we use the protection ratio measured at C = -30 dBm as a proxy for protection ratios at C > -30 dBm.

A4.13 In order to explore a range of installations, one can also consider the alternative set of test points described in Table 49. Here $G_{(dB)} + A_{(dB)}$ is again set to provide a fixed value of C_{IN} = -50 dBm at the DTT receiver, but with gain G adjusted to the minimum permitted value. As compared to Table 48, the test points in Table 49 correspond to lower system gains (higher system losses).

[82] The majority of amplifiers would be tuned before the digital switchover and in the presence of the analogue network.

Table 49. CAS amplifier minimum-gain test points.

$C_{(dBm)}$	$C_{IN\ (dBm)}$	$G_{(dB)} + A_{(dB)}$	$G_{MIN(dB)}$	$C_{0(dB)}$	$A_{MAX(dB)}$
–70	–50	+20	25	-45	-5
–60	–50	+10	25	-35	-15
–50	–50	0	25	-25	-25
–40	–50	–10	25	-15	-35
–30	–50	–20	25	-5	-45
–20	–50	–30	25#	+5	-55

Back-off cannot be achieved. Pre-amp attenuator is required.

A4.14 For each test point, a LTE signal[83] is applied at the input to the amplifier as a proxy for an MFCN base station adjacent channel interferer in block A. The interferer carrier power, I, is then recorded at the point of failure (onset of pixelation). The MFCN-to-DTT protection ratio is then given by the ratio of C to I.

A4.15 Measurements indicate that the system's protection ratio is primarily dictated by the extent to which the power at the output of the amplifier is lower than the amplifier's maximum output rating; i.e., the extent to which the amplifier is overloaded. As such, the test points in Table 48 represent worst-case scenarios in the context of the impact of interference on the broadcasting service.

Raw measurements

A4.16 Table 50 shows the raw values of MFCN-to-DTT protection ratios measured by ERA based on the test points for maximum amplifier gain (see Table 48). The test LTE interferer has a 10 MHz bandwidth centred at 796 MHz (block A), and has an ACLR of 59 dB over channel 60, and 69 dB over the lower DTT channels.

Table 50. CAS amplifier measured protection ratios (maximum gain).
Values are quoted to two decimal place for transparency of further calculations.
Measurement uncertainty is of the order of 1 dB.

Block A r_A (dB)	C (dBm)				
	-70	-60	-50	-40	≥ -30
co-channel	+15.3	+15.42	+15.44	+14.92	+15.12
60	-36.95	-29.82	-22.09	-22.42	-22.45
59	-41.57	-35.01	-26.38	-26.22	-25.56
58	-44.11	-36.08	-27.33	-26.67	-26.47
57	-45.95	-37.13	-28.48	-27.21	-26.32
51	-46.86	-37.19	-28.11	-28.07	-26.85

[83] This was based on recordings from an actual LTE base station fully loaded with traffic. The LTE signal was heavily filtered and the required ACLR was then achieved by the introduction of AWGN.

Post-processed protection ratios

A4.17 In this sub-section we present the protection ratios derived via post-processing of the raw measurements of Table 50. The post-processing involves the following:

a) Interpolation in frequency to account for the multitude of interferer-victim frequency separations.

b) Mathematical manipulation (see Annex 3) to account for the ACLR of actual LTE base station equipment.

c) Accounting for the impact of pre-amp filtering through an increase (equal to the filter's stop-band attenuation) in the frequency selectivity of the receiver system.

A4.18 Protection ratios for channel 51 are used as proxies for channels 50 and below.

ECC BEM with roll-off

A4.19 Table 51 shows post-processed protection ratios based on the scenario where the base station emissions from blocks A, B, and C each achieve an ACLR of (59+10*n*) dB over DTT channel (60–*n*).

ECC BEM with roll-off and Rx filtering

A4.20 Table 52 shows post-processed protection ratios based on the scenario where the base station emissions from blocks A, B, and C each achieve an ACLR of (59+10*n*) dB over DTT channel (60–*n*). Receiver filtering is modelled via a stop-band attenuation of 45 dB for the protection of channel 60, and 60 dB for the protection of channels 59 and below[84]. Insertion loss is 1 dB or lower.

Measured LTE base station SEM and Rx filtering

A4.21 Table 53 shows post-processed protection ratios based on the scenario where the base station emissions from block A achieve an ACLR of (76+10*n*) dB over DTT channel (60–*n*). Base station emissions from blocks B and C follow a similar mask but shifted in frequency by +10 MHz and +20 MHz, respectively. Receiver filtering is modelled via a stop-band attenuation of 45 dB for the protection of channel 60, and 60 dB for the protection of channels 59 and below.

[84] Based on information from Isotek Electronic Limited.

Table 51. CAS amplifier protection ratios:
EC BEM with roll-off.

Block A r_A (dB)		C (dBm)				
		-70	-60	-50	-40	≥ -30
DTT channel	60	-37	-30	-22	-22	-22
	59	-42	-35	-26	-26	-26
	58	-45	-36	-27	-27	-26
	57	-47	-37	-28	-27	-26
	56	-47	-37	-28	-27	-26
	55	-48	-37	-28	-28	-26
	54	-48	-37	-28	-28	-26
	53	-48	-37	-28	-28	-26
	52	-48	-37	-28	-28	-27
	≤ 51	-48	-37	-28	-28	-27

Block B r_B (dB)		C (dBm)				
		-70	-60	-50	-40	≥ -30
DTT channel	60	-40	-35	-27	-26	-26
	59	-45	-36	-28	-27	-26
	58	-47	-37	-28	-27	-26
	57	-47	-37	-28	-28	-26
	56	-48	-37	-28	-28	-26
	55	-48	-37	-28	-28	-26
	54	-48	-37	-28	-28	-27
	53	-48	-37	-28	-28	-27
	52	-48	-37	-28	-28	-27
	≤ 51	-48	-37	-28	-28	-27

Block C r_C (dB)		C (dBm)				
		-70	-60	-50	-40	≥ -30
DTT channel	60	-41	-36	-28	-27	-26
	59	-46	-37	-28	-27	-26
	58	-47	-37	-28	-28	-26
	57	-48	-37	-28	-28	-26
	56	-48	-37	-28	-28	-26
	55	-48	-37	-28	-28	-27
	54	-48	-37	-28	-28	-27
	53	-48	-37	-28	-28	-27
	52	-48	-37	-28	-28	-27
	≤ 51	-48	-37	-27	-28	-28

Table 52. CAS amplifier protection ratios:
EC BEM with roll-off and Rx filtering.

Block A r_A (dB)		*C* (dBm)				
		-70	-60	-50	-40	≥ -30
DTT channel	60	-43	-43	-43	-43	-43
	59	-53	-53	-53	-53	-53
	58	-63	-63	-63	-63	-63
	57	-73	-73	-73	-73	-73
	56	-83	-83	-82	-82	-81
	55	-93	-92	-87	-87	-86
	54	-102	-96	-88	-88	-86
	53	-107	-97	-88	-88	-86
	52	-108	-97	-88	-88	-87
	≤ 51	-108	-97	-88	-88	-87

Block B r_B (dB)		*C* (dBm)				
		-70	-60	-50	-40	≥ -30
DTT channel	60	-43	-43	-43	-43	-43
	59	-53	-53	-53	-53	-53
	58	-63	-63	-63	-63	-63
	57	-73	-73	-73	-73	-73
	56	-83	-83	-82	-82	-81
	55	-93	-92	-87	-87	-86
	54	-102	-96	-88	-88	-86
	53	-107	-97	-88	-88	-87
	52	-108	-97	-88	-88	-87
	≤ 51	-108	-97	-88	-88	-87

Block C r_C (dB)		*C* (dBm)				
		-70	-60	-50	-40	≥ -30
DTT channel	60	-43	-43	-43	-43	-43
	59	-53	-53	-53	-53	-53
	58	-63	-63	-63	-63	-63
	57	-73	-73	-73	-73	-73
	56	-83	-83	-82	-82	-81
	55	-93	-92	-87	-87	-86
	54	-102	-96	-88	-88	-87
	53	-107	-97	-88	-88	-87
	52	-108	-97	-88	-88	-87
	≤ 51	-108	-97	-87	-88	-88

Table 53. CAS amplifier protection ratios:
Measured LTE BS SEM and Rx filtering.

Block A r_A (dB)		C (dBm)				
		-70	-60	-50	-40	≥ -30
DTT channel	60	-60	-60	-59	-60	-59
	59	-70	-70	-70	-70	-70
	58	-80	-80	-79	-79	-79
	57	-90	-89	-86	-85	-85
	56	-99	-95	-88	-87	-86
	55	-106	-97	-88	-88	-86
	54	-108	-97	-88	-88	-86
	53	-108	-97	-88	-88	-86
	52	-108	-97	-88	-88	-87
	≤ 51	-108	-97	-88	-88	-87

Block B r_B (dB)		C (dBm)				
		-70	-60	-50	-40	≥ -30
DTT channel	60	-71	-70	-68	-68	-68
	59	-81	-81	-80	-80	-80
	58	-91	-90	-87	-86	-85
	57	-100	-96	-88	-87	-86
	56	-106	-97	-88	-88	-86
	55	-108	-97	-88	-88	-86
	54	-108	-97	-88	-88	-87
	53	-108	-97	-88	-88	-87
	52	-108	-97	-88	-88	-87
	≤ 51	-108	-97	-88	-88	-87

Block C r_C (dB)		C (dBm)				
		-70	-60	-50	-40	≥ -30
DTT channel	60	-82	-79	-73	-72	-71
	59	-92	-91	-87	-86	-85
	58	-101	-96	-88	-87	-86
	57	-106	-97	-88	-88	-86
	56	-108	-97	-88	-88	-86
	55	-108	-97	-88	-88	-87
	54	-108	-97	-88	-88	-87
	53	-108	-97	-88	-88	-87
	52	-108	-97	-88	-88	-87
	≤ 51	-108	-97	-87	-88	-88

Annex 5

Measurements of protection ratios: Domestic installations with amplifiers

A5.1 Ofcom recently commissioned ERA Technology to perform measurements of MFCN-to-DTT protection ratios for a domestic TV amplifier feeding a DTT receiver (Silicon tuner). We have used the results of these measurements for our modelling of the impact of interference from MFCN base stations in the 800 MHz to broadcasting services below 790 MHz.

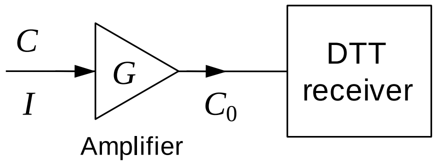
A5.2 There are a wide variety of domestic amplifier models and installations in the UK. Such amplifiers might be used to boost the DTT signal in areas of poor coverage, or for distributing the DTT signal to multiple TVs within the home. The amplifiers may be installed on the TV aerials (mast-head amplifier, MHA), may be installed in the loft, or inside the home near the receiver. For this reason, examination of all possible deployment arrangements is a challenging task. Nevertheless, the presented measurements go some way towards capturing the scale of the susceptibility of domestic installations with amplifiers with respect to interference from MFCN base stations in the 800 MHz band.

A5.3 In this annex we first describe the logic behind the test methodology. We then present the raw measurement results provided by ERA, as well as the post-processed protection ratios use in our modelling.

Set-up and assumptions

A5.4 Figure 57 shows the measurement set-up we have used for modelling a domestic amplifier installation. The variable C is the (wanted) DTT carrier power, while I is the (unwanted) MFCN carrier power. No attenuator is used in this set up. This is because any feeder loss (from amplifier to TV) can be neglected in the context of the wide range of DTT signal powers.

Figure 57. Domestic amplifier test set-up.



A5.5 The typical approach used for the installation of domestic amplifiers (performed prior to the introduction of MFCN base stations in the 800 MHz band) is described next.

A5.6 Where the amplifier has adjustable gain, consumers will initially set the gain as high as possible and then back off until picture quality is restored. Where the amplifier does not have adjustable gain, back-off is not possible (unless through the use of a pre-amp attenuator).

A5.7 The specific amplifier we have tested is a 4-way splitter with a fixed gain of 10 dB. The amplifier was selected for its mid-range input rating. It has a maximum output rating of 92 dBuv (equivalent to -16 dBm). Note that given the fixed gain of the amplifier, the value of $C_{IN} = C_0$ varies directly with C.

A5.8 Based on the above arguments, the constraints on the various parameter values may be written as follows:

$$-70 \le C_{(dBm)} \le -20$$
$$G_{(dB)} = +10$$
$$C_{IN\ (dBm)} = C_{0\ (dBm)}$$

A5.9 Note that the proposed range of C is typical of DTT coverage (according to the UKPM, for an aerial at a height of 10 m and a 9.15 dBi gain which includes a feeder loss of 5 dB).

Test points

A5.10 Based on the above constraints, Table 54 describes a number of appropriate test points, specified in terms of C values.

Table 54. Domestic amplifier test points.

$C_{(dBm)}$	$G_{(dB)}$	$C_{0\ (dB)}$
–70	+10	–60
–60	+10	–50
–50	+10	–40
–40	+10	–30
–30	+10	–20
–20	+10	–10

A5.11 Note that for C values greater than -26 dBm the output rating (-16 dBm) of the amplifier is exceeded. In order to avoid this, the consumer would need to insert an attenuator at the input to the amplifier so that the amplifier would experience a C value of less than -26 dBm. Having said that, it is unlikely that domestic amplifiers would be used in areas where the C values are so high (i.e., in areas of good DTT coverage).

A5.12 For each test point, a LTE signal[85] is applied at the input to the amplifier as a proxy for an MFCN base station adjacent channel interferer in block A. The interferer carrier power, I, is then recorded at the point of failure (onset of pixelation). The MFCN-to-DTT protection ratio is then given by the ratio of C to I.

Raw measurements

A5.13 Table 55 shows the raw values of MFCN-to-DTT protection ratios measured by ERA based on the test points of Table 54. The test LTE interferer has a 10 MHz bandwidth centred at 796 MHz (block A), and has an ACLR of 59 dB over channel 60, and 69 dB over the lower DTT channels.

A5.14 Note the high protection ratios for C = -20 dBm. This is because at such high wanted signal powers the amplifier is driven into overload in the presence of MFCN interferers. As indicated earlier, it is unlikely that domestic amplifiers would be used

[85] This was based on recordings from an actual LTE base station fully loaded with traffic. The LTE signal was heavily filtered and the required ACLR was then achieved by the introduction of AWGN.

in areas where the C values are so high. In this sense, our modelling over-estimates the impact of interference.

Table 55. Domestic amplifier measured protection ratios.
Values are quoted to one decimal place for transparency of further calculations.
Measurement uncertainty is of the order of 1 dB.

Block A *r* (dB)	*C* (dBm)					
	-70	-60	-50	-40	-30	-20
co-channel	+14.5	+14.9	+15.0	+15.1	+15.0	+14.9
60	-42.3	-40.2	-33.1	-25.0	-18.1	-9.9
59	-50.3	-46.2	-39.2	-30.9	-21.0	-11.7
58	-50.3	-48.1	-40.7	-30.9	-21.8	-11.6
57	-51.5	-49.1	-41.4	-31.0	-20.8	-11.7
51	-53.0[86]	-50.1	-41.2	-31.2	-20.9	-11.6

Post-processed protection ratios

A5.15 In this sub-section we present the protection ratios derived via post-processing of the raw measurements of Table 55. The post-processing involves the following:

a) Interpolation in frequency to account for the multitude of interferer-victim frequency separations.

b) Mathematical manipulation (see Annex 3) to account for the ACLR of actual LTE base station equipment.

c) Accounting for the impact of pre-amp filtering through an increase (equal to the filter's stop-band attenuation) in the frequency selectivity of the receiver system.

A5.16 Protection ratios for channel 51 are used as proxies for channels 50 and below.

ECC BEM with roll-off

A5.17 Table 57 shows post-processed protection ratios based on the scenario where the base station emissions from blocks A, B, and C each achieve an ACLR of (59+10*n*) dB over DTT channel (60–*n*).

ECC BEM with roll-off and Rx filtering

A5.18 Table 58 shows post-processed protection ratios based on the scenario where the base station emissions from blocks A, B, and C each achieve an ACLR of (59+10*n*) dB over DTT channel (60–*n*).

A5.19 Receiver filtering is modelled via the stop-band attenuations (or more precisely, filter discrimination gains) presented in the table below[87]. Note that large stop-band attenuations can be achieved when the filter is designed to protect channels 57 and

[86] At this test point, measurements were made with a test interferer ACLR of 79 dB, giving a measured protection ratio of -59.2 dB. This was then post-processed, resulting in a protection ratio of -53 dB corresponding to a test interferer ACLR of 69 dB.
[87] Based on information from Technetix and Braun Telecom GmbH.

below. This is due to the less steep roll-off between pass-band and stop-band. Insertion loss is 1 dB or lower.

Table 56. Filter discrimination gains.

Protected channel	Filter cut-off (MHz)	Rx filter discrimination gain G_D (dB)		
		Block A f_0 = 796 MHz	Block B f_0 = 806 MHz	Block C f_0 = 816 MHz
60	790	-1	-7	-19
59	782	-5	-19	-19
58	774	-19	-19	-20
57	766	-21	-42	-58
56	758	-38	-55	-67
55	750	-52	-65	-68
54	742	-63	-68	-68
≤53	734	-68	-68	-68

Measured LTE base station SEM and Rx filtering

A5.20 Table 59 shows post-processed protection ratios based on the scenario where the base station emissions from block A achieve an ACLR of (76+10*n*) dB over DTT channel (60–*n*). Base station emissions from blocks B and C follow a similar mask but shifted in frequency by +10 MHz and +20 MHz, respectively.

A5.21 Receiver filtering is modelled via the stop-band attenuations shown in Table 56.

Table 57. Domestic amplifier protection ratios:
EC BEM with roll-off.

Block A	r_A (dB)	C (dBm)					
		-70	-60	-50	-40	-30	-20
DTT channel	60	-42	-40	-33	-25	-18	-10
	59	-50	-46	-39	-31	-21	-12
	58	-53	-49	-41	-31	-22	-12
	57	-55	-51	-42	-31	-21	-12
	56	-57	-52	-42	-31	-21	-12
	55	-58	-52	-42	-31	-21	-12
	54	-59	-52	-42	-31	-21	-12
	53	-60	-53	-42	-31	-21	-12
	52	-61	-53	-42	-31	-21	-12
	≤ 51	-61	-53	-42	-31	-21	-12

Block B	r_B (dB)	C (dBm)					
		-70	-60	-50	-40	-30	-20
DTT channel	60	-43	-42	-38	-31	-21	-12
	59	-50	-48	-41	-31	-22	-12
	58	-55	-51	-42	-31	-21	-12
	57	-57	-52	-42	-31	-21	-12
	56	-58	-52	-42	-31	-21	-12
	55	-59	-52	-42	-31	-21	-12
	54	-60	-53	-42	-31	-21	-12
	53	-61	-53	-42	-31	-21	-12
	52	-61	-53	-41	-31	-21	-12
	≤ 51	-61	-53	-41	-31	-21	-12

Block C	r_C (dB)	C (dBm)					
		-70	-60	-50	-40	-30	-20
DTT channel	60	-43	-43	-39	-31	-21	-12
	59	-52	-49	-41	-31	-21	-12
	58	-56	-52	-42	-31	-21	-12
	57	-58	-52	-42	-31	-21	-12
	56	-60	-52	-42	-31	-21	-12
	55	-60	-53	-42	-31	-21	-12
	54	-61	-53	-42	-31	-21	-12
	53	-61	-53	-41	-31	-21	-12
	52	-60	-53	-41	-31	-21	-12
	≤ 51	-59	-53	-41	-31	-21	-11

Table 58. Domestic amplifier protection ratios:
EC BEM with roll-off and Rx filtering.

Block A r_A (dB)		C (dBm)					
		-70	-60	-50	-40	-30	-20
DTT channel	60	-43	-41	-34	-26	-19	-11
	59	-52	-50	-44	-36	-26	-17
	58	-63	-62	-58	-50	-41	-31
	57	-72	-70	-62	-52	-42	-33
	56	-83	-82	-78	-69	-59	-50
	55	-94	-93	-90	-83	-73	-64
	54	-104	-103	-101	-94	-84	-75
	53	-114	-113	-108	-99	-89	-80
	52	-123	-119	-109	-99	-89	-80
	≤ 51	-128	-121	-109	-99	-89	-80

Block B r_B (dB)		C (dBm)					
		-70	-60	-50	-40	-30	-20
DTT channel	60	-44	-43	-42	-37	-28	-19
	59	-54	-53	-52	-48	-40	-31
	58	-63	-63	-59	-50	-40	-31
	57	-74	-73	-73	-70	-62	-54
	56	-84	-83	-83	-81	-75	-67
	55	-94	-93	-93	-91	-85	-77
	54	-104	-103	-102	-98	-89	-80
	53	-114	-113	-108	-99	-89	-80
	52	-123	-119	-109	-99	-89	-80
	≤ 51	-127	-120	-109	-99	-89	-80

Block C r_C (dB)		C (dBm)					
		-70	-60	-50	-40	-30	-20
DTT channel	60	-44	-43	-43	-42	-39	-30
	59	-54	-53	-53	-48	-40	-31
	58	-64	-63	-59	-51	-41	-32
	57	-74	-73	-73	-73	-72	-68
	56	-84	-83	-83	-83	-82	-77
	55	-94	-93	-93	-92	-88	-79
	54	-104	-103	-102	-98	-89	-80
	53	-114	-113	-108	-99	-89	-80
	52	-122	-119	-109	-99	-89	-80
	≤ 51	-127	-120	-109	-99	-89	-79

Table 59. Domestic amplifier protection ratios:
Measured LTE BS SEM and Rx filtering.

Block A	r_A (dB)	*C* (dBm)					
		-70	-60	-50	-40	-30	-20
DTT channel	60	-49	-44	-35	-26	-19	-11
	59	-58	-52	-44	-36	-26	-17
	58	-71	-68	-60	-50	-41	-31
	57	-76	-72	-63	-52	-42	-33
	56	-94	-89	-80	-69	-59	-50
	55	-107	-103	-94	-83	-73	-64
	54	-118	-114	-105	-94	-84	-75
	53	-126	-120	-110	-99	-89	-80
	52	-128	-121	-110	-99	-89	-80
	≤ 51	-129	-121	-110	-99	-89	-80

Block B	r_B (dB)	*C* (dBm)					
		-70	-60	-50	-40	-30	-20
DTT channel	60	-60	-55	-47	-38	-28	-19
	59	-72	-69	-60	-50	-41	-31
	58	-75	-70	-61	-50	-40	-31
	57	-97	-93	-84	-73	-63	-54
	56	-109	-106	-97	-86	-76	-67
	55	-120	-116	-107	-96	-86	-77
	54	-127	-120	-110	-99	-89	-80
	53	-129	-121	-110	-99	-89	-80
	52	-129	-121	-109	-99	-89	-80
	≤ 51	-129	-121	-109	-99	-89	-80

Block C	r_C (dB)	*C* (dBm)					
		-70	-60	-50	-40	-30	-20
DTT channel	60	-73	-69	-60	-50	-40	-31
	59	-75	-70	-61	-50	-40	-31
	58	-77	-72	-62	-51	-41	-32
	57	-112	-108	-99	-89	-79	-70
	56	-122	-118	-108	-98	-88	-79
	55	-127	-120	-110	-99	-89	-80
	54	-129	-121	-110	-99	-89	-80
	53	-129	-121	-109	-99	-89	-80
	52	-128	-121	-109	-99	-89	-80
	≤ 51	-127	-121	-109	-99	-89	-79

Annex 6

Measurements of protection ratios: Discontinuous LTE signals

A6.1 As a result of discussions with stakeholders in 2010, concerns were raised with regards to the susceptibility of certain DTT receivers to adjacent channel interference from time-discontinuous or *bursty* LTE base station emissions. Consequently, we commissioned ERA to perform additional measurements of 10 DTT receivers (DVB-T and T2) subjected to both time-continuous and bursty LTE emissions.

A6.2 In this section we summarise the results of these measurements[88] and compare them with the measurements of DVB-T receivers we had commissioned in 2009 with time-continuous LTE signals, as well as more recent measurements performed by the DTG with bursty LTE signals.

Measurements: Fully loaded base station

A6.3 Figure 58 shows the results of measurements performed by ERA (in 2011) of five DVB-T, and ten DVB-T2 receivers in channel 60 subjected to test signals from a fully loaded LTE base station operating in block A.

A6.4 The LTE test signals were recorded in the lab and generated by a commercial base station prototype. Specifically, the base station transmits user traffic on all available resource blocks and is therefore substantially time-continuous in nature. The LTE test signal has an adjacent-channel leakage ratio (ACLR) of 59 dB over DTT channel 60 (consistent with the requirements of the EC Decision).

A6.5 As seen in previous measurements, the tested devices exhibit a broad range of behaviours. However, the upper envelope of the protection ratios (worst performance) is dominated by the DVB-T2 mode and is in good agreement with the measurements performed by ERA in 2009 (see later) and hence the values we have used in our modelling to characterise DTT receivers (in standard domestic installations).

[88] Full details of these measurements and the results will be published in a final report by ERA in due course. The results have already been shared with stakeholders via the DTT coexistence Technical Working Group.

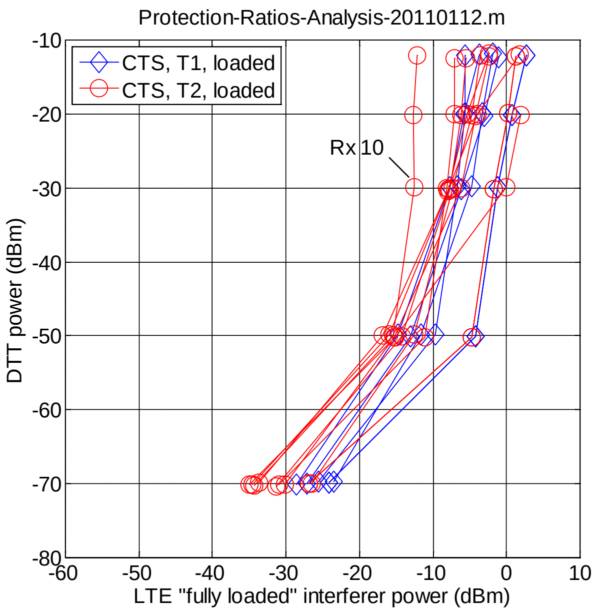


Figure 58. ERA raw protection ratio measurements (channel 60).
Fully loaded (time-continuous) LTE in block A with ACLR of 59 dB.

Measurements: Idle base station

A6.6 Figure 59 shows the results of measurements with the DTT receivers in channel 60 subjected to test signals from an “idle” LTE base station operating in block A.

A6.7 The LTE signals were again recorded in the lab and generated by a commercial base station prototype. Specifically, the base station transmits little (or no) user traffic; i.e., only transmits broadcast and control data. As a result, the signal appears bursty in time. The LTE test signal’s ACLR is again equal to 59 dB over channel 60.

A6.8 Note that three of the tested receivers (interestingly, all Silicon tuners) perform very poorly in the presence of bursty LTE signals. The reason underlying this poor performance is not absolutely clear, but is likely due to the inability of the receivers’ adaptive gain control mechanisms to deal with the rapid fluctuations of the LTE interferer whose carrier power is orders of magnitude greater than that of the wanted DTT signal.

A6.9 The remaining well-behaved tested receivers still exhibit a wide range of performances.

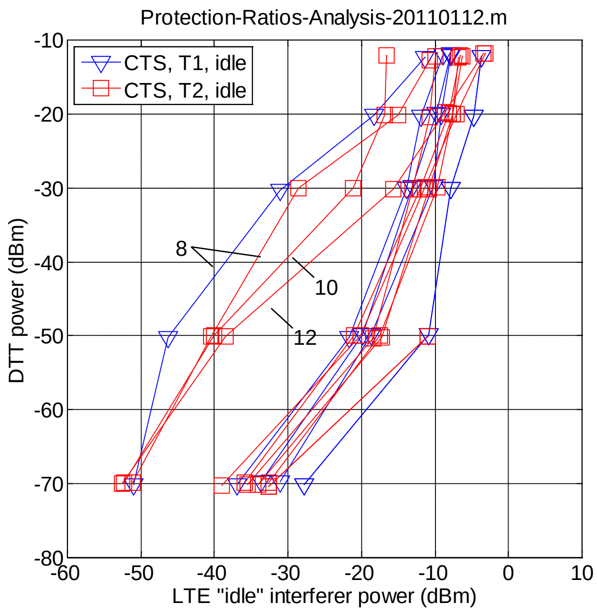


Figure 59. ERA raw protection ratio measurements (channel 60). Idle (bursty) LTE in block A with ACLR of 59 dB.

Comparison of fully loaded and idle measurements

A6.10 Here we compare and contrast the measurements of protection ratio for emissions from fully loaded and idle LTE base stations.

A6.11 It is important to note that for a consistent comparison, the "idle" curves of Figure 59 need to be shifted to the right by 8.3 dB. This is because the EIRP of an "idle" base station is 8.3 dB lower than the EIRP of a "fully loaded" base station[89], whereas in our modelling (e.g., via Punch) we assume the base stations always radiate at their fully loaded power (e.g., at 59 dBm/(10 MHz)). This is explained next.

A6.12 Let P_{loaded} and P_{idle} be the received LTE powers (in dBm) from loaded and idle base stations, respectively. Also let the corresponding protection ratios be r_{loaded} and r_{idle} (in dB). Following our modelling approach (see Section 4) we quantify the impact of interference to DTT reception in the fully loaded case as $P_{\text{loaded}} + r_{\text{loaded}}$. Similarly, we model the impact of interference in the idle case as

$$P_{\text{idle}} + r_{\text{idle}} = P_{\text{loaded}} + (r_{\text{idle}} + P_{\text{idle}} - P_{\text{loaded}}) \quad (32)$$

$$= P_{\text{loaded}} + (r_{\text{idle}} - 8.3).$$

A6.13 As can be seen, the impact of interference from an idle base station can be modelled as if the base station radiates at the fully loaded power, but with the idle protection ratios reduced by 8.3 dB.

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[89] This value was reported by the BBC and was subsequently confirmed by ERA.

A6.14 Figure 60 brings together the protection ratios for the fully loaded and idle LTE signals subject to the 8.3 dB shift of the latter. Note that the x-axis represents the interferer power received from a fully loaded base station.

A6.15 The results indicate that, notwithstanding the poor performance by the three receivers #8, #10, and #12, the upper envelope of the protection ratios (i.e., worst case performance) is actually dominated by the measurements with signals from the fully loaded base station.

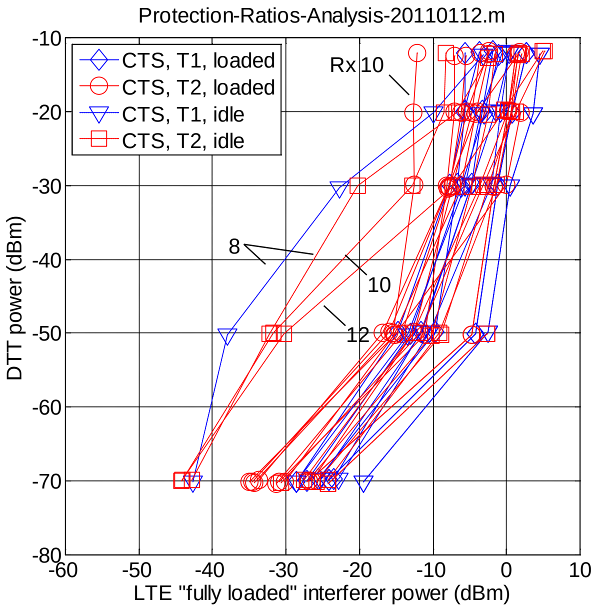

Figure 60. ERA raw protection ratio measurements (channel 60).
Fully loaded and idle (bursty) LTE in block A with ACLR of 59 dB.

A6.16 The protection ratios are summarised in the table below. For purposes of brevity, these are presented here for a wanted DTT signal power of -70 dBm only.

		Protection ratio (dB) DTT power = -70 dBm			
		Fully loaded		Idle* (bursty)	
	Description	DVB-T	DVB-T2	DVB-T	DVB-T2
1	iDTV (Silicon)	-45.79	-43.18	-42.37	-37.85
4	iDTV (can)	-41.54	-39.06	-33.27	-34.63
6	PVR (Silicon)	-42.98	-39.99	-38.68	-36.13
7	iDTV (can)	–	-43.47	–	-37.31
8	STB (Silicon)	-44.14	-39.28	-19.13	-18.85
9	iDTV (can)	–	-36.19	–	-31.38
10	PVR (Silicon)	–	-35.97	–	-17.56
11	iDTV (can)	–	-35.47	–	-34.06
12	STB (Silicon)	–	-35.14	–	-17.45
13	STB (Can)	-46.25	–	-36.12	–

* Note that for a consistent comparison, the above *idle* protection ratios must be reduced by 8.3 dB to account for the reduced EIRP of idle base stations as compared to fully loaded base stations.

Comparison of new ERA measurements and the protection ratios used in our modelling

A6.17 For purposes of modelling in this report, we have used protection ratios which were derived from measurements undertaken by ERA in 2009. Those measurements were performed with time-continuous LTE signals created by a signal generator, and characterised DVB-T receivers.

A6.18 Here we compare the 2009 measurements with the more recent ERA measurements. Once again we need to account for discrepancies in the test LTE ACLRs used in the different measurement campaigns.

A6.19 The 2009 measurements were performed with a LTE ACLR of 61 dB in channel 60. The protection ratios have been post processed[90] to correspond to LTE ACLR of 59 dB for direct comparison with the more recent ERA measurements. A margin of 1.1 dB has been added to both sets of measurements to account for Rician fading (as explained in Annex 3).

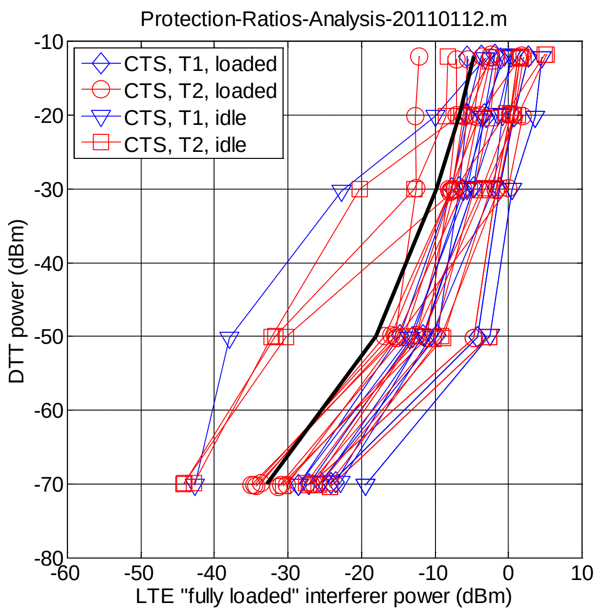

Figure 61. ERA post processed measurements, old and new.
The old measurements are shown as a thick black curve and represents the worst performance measured over three super-heterodyne and 3 Silicon tuners.
These have been used in our modelling.
LTE in block A with ACLR of 61 dB.

A6.20 As can be seen, with the exception of the poorly performing receivers #8, #10, and #12, the protection ratios we have used in our modelling capture the upper envelope (worst performance) of the recent ERA measurements. This is not very surprising, since the former values were themselves based on the upper envelope

[90] If r_1 is the protection ratio corresponding to an interferer with $ACLR_1$, then the protection ratio r_2 corresponding to the same interferer but with $ACLR_2$ can be computed as:
$ACIR_1 = r(0)/r_1$, $ACIR_1 = (1/ACLR_1 + 1/ACS)^{-1}$, $ACIR_2 = (1/ACLR_2 + 1/ACS)^{-1}$
then $r_2 = r(0)/ACIR_2$ where $r(0)$ is the co-channel protection ratio, ACIR is the adjacent-channel interference ratio, and ACS is adjacent channel selectivity.

of protection ratios measured by ERA in 2009, and as such, are conservative estimates of the adjacent channel immunity of DTT receivers.

Comparison with measurements by the DTG

A6.21 In parallel with the measurements commissioned by Ofcom, the DTG also performed tests on a large number of receivers in the DTG Zoo.

A6.22 The DTG measurements were made with LTE signals from an idle base station. These signals were identical to those used by ERA, with two exceptions:

- In the DTG tests the interferer power was set to a fixed level of -23.3 dBm (equivalent to -15 dBm for a fully loaded base station).
- In the DTG tests the ACLR of the LTE signal was set to 68 dB over channel 60.

A6.23 Recall that the ERA measurements were made with a range of interferer powers, and for a LTE signal ACLR of 59 dB over channel 60.

A6.24 The above discrepancy in the ACLR values between the two measurements can be resolved by *post-processing* the ERA protection ratio measurements[91] so that they too correspond to a LTE signal ACLR of 68 dB. See also Annex 1 for a detailed description of the post-processing.

A6.25 Figure 62 shows the ERA and DTG protection ratio measurements. Here fully loaded and idle results are shown together. As elaborated earlier, for a consistent comparison, the idle curves are shifted to the right by 8.3 dB.

[91] If r_1 is the protection ratio corresponding to an interferer with $ACLR_1$, then the protection ratio r_2 corresponding to the same interferer but with $ACLR_2$ can be computed as:
$ACIR_1 = r(0)/r_1$, $ACIR_1 = (1/ACLR_1 + 1/ACS)^{-1}$, $ACIR_2 = (1/ACLR_2 + 1/ACS)^{-1}$
then $r_2 = r(0)/ACIR_2$ where $r(0)$ is the co-channel protection ratio, ACIR is the adjacent-channel interference ratio, and ACS is adjacent channel selectivity. We were unable to post-process the DTG measurements as they did not include measurements of co-channel protection ratio. So we post-processed the ERA measurements to align with the DTG measurements.

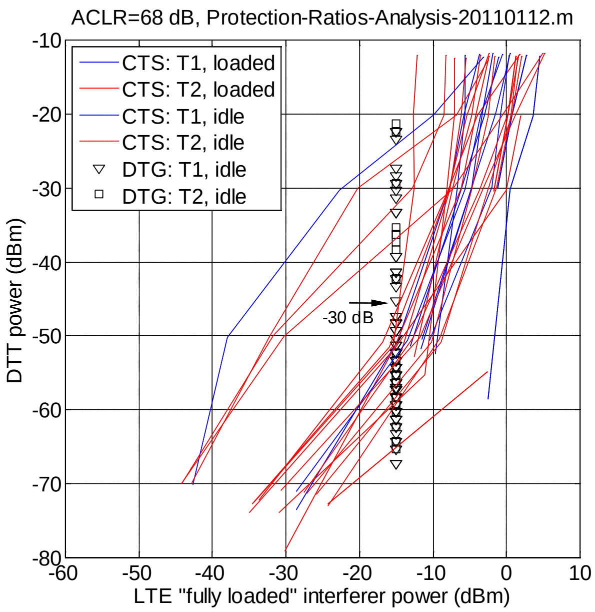

Figure 62. DTG and ERA post processed measurements (channel 60) LTE in block A with ACLR of 68 dB.

A6.26 The DTG results indicate a broad range of performances. Notice that the protection ratio of -30 dB represents the highest protection ratio (over T & T2 modes) of the "well-behaved" receivers tested by ERA (at -15 dBm interferer level). In this sense, the protection ratio of -30 dB is an interesting point of reference.

A6.27 Figure 63 below shows the cumulative distribution of the DTG protection ratio measurements.

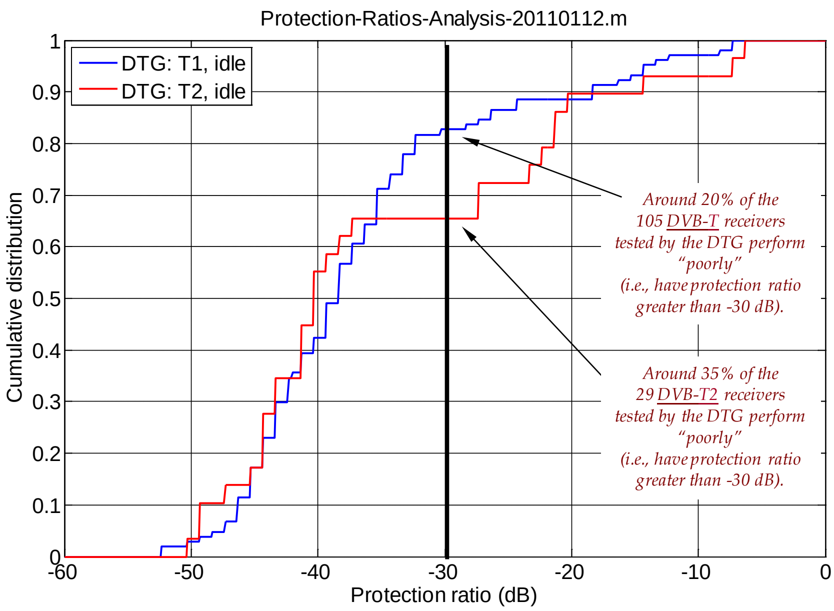

Figure 63. Cumulative distribution of DTG protection ratio measurements (channel 60). Bursty LTE in block A with ACLR of 68 dB.
The above does not account for market share of the tested receivers.

A6.28 The distributions indicate that

- around 20% of the 105 DVB-T receivers tested by the DTG perform “poorly” (i.e., have protection ratio greater than -30 dB @ -23.3 dBm wanted power);
- around 35% of the 29 DVB-T2 receivers tested by the DTG perform “poorly” (i.e., have protection ratio greater than -30 dB @ -23.3 dBm wanted power).

A6.29 However, the above statistics do not account for the UK market shares of the tested devices in the UK. Subsequently, the DTG compiled the corresponding statistics based on the numbers of the respective receivers in the UK market. The resulting distributions appear to indicate that

- around 1% of the DVB-T receivers in the UK market perform “poorly” (i.e., have protection ratio greater than -30 dB @ -23.3 dBm wanted power);
- around 3% of the 29 DVB-T2 receivers the UK market perform “poorly” (i.e., have protection ratio greater than -30 dB @ -23.3 dBm wanted power).

Conclusions

A6.30 We have presented the results of recent measurements of protection ratios by ERA. These measurements quantified the adjacent channel immunity of DVB-T and DVB-T2 receivers when subjected to time-continuous and bursty LTE interferers.

A6.31 The results of these measurements indicate the following

- Different receivers exhibit a wide range of immunity to adjacent-channel interferers; e.g., differences in protection ratio of over 10 dB for the same value of wanted signal power.
- The DVB-T and DVB-T2 modes of DTT are broadly (to within 2 to 3 dB) equally susceptible to interference from MFCN base stations.
- Only three (all Silicon tuners) of the thirteen devices tested performed poorly when subjected to bursty LTE signals.

A6.32 With the exception of three poorly performing DTT receivers, the measured protection ratios typically indicated better adjacent channel immunity than implied by the protection ratios we have used in our modelling.

A6.33 Furthermore, independent measurements and analysis by the DTG appear to indicate that 99% of DVB-T receivers, and 97% of DVB-T2 receivers currently in the UK market have better adjacent-channel immunity than implied by the protection ratios we have used in our modelling.

A6.34 The above has justified our decision to continue using our original protection ratio measurements of 2009 in our modelling.

Annex 7

Partitioning of UK households across DTT channels

A7.1 The Punch modelling tool implicitly assumes that all households within each pixel in the coverage area of the examined DTT transmitter are associated with the same category of DTT receiver installation. We refer to these households as *generic* households.

A7.2 However, in practice, each pixel contains different proportions of households associated with specific installation categories. For example, there may be a higher proportion of communal aerial systems in urban pixels than in rural pixels. It is therefore important to determine the number of households associated with each installation category that are served and affected at a pixel level.

A7.3 This means that post-processing of the raw results from Punch is required to convert the number of generic households served and affected in each pixel to the number of installation-specific households that are served and affected in each pixel.

A7.4 We present details of the required post-processing in this annex.

A7.5 We first present the distributions of generic households across DTT channels. These can be derived from the DSO/Clearance plan.

A7.6 We then describe how the numbers of households associated with specific installation categories that are served and affected can be derived from the pixel-level estimates of Punch.

A7.7 We finally describe how the numbers of households associated with specific installation categories that are served throughtout the UK in a specific DTT channel can be calculated.

A7.8 The following notation is used in this annex:

k = index of DTT transmitter.
i = index of DTT channel.
p = index of pixel.
q = index of census output area.

$\overline{m}$ = number of households (in generic) served at pixel level.
m' = number of households (in communal aerial systems) served at pixel level.
m'' = number of households (standard domestic installation) served at pixel level.
m''' = number of households (with domestically installed amplifiers) served at pixel level.

$\overline{n}$ = number of households (generic) affected at pixel level.

n' = number of households (in communal aerial systems) affected at pixel level.

n'' = number of households (standard domestic installation) affected at pixel level.

n''' = number of households (with domestically installed amplifiers) affected at pixel level.

$\overline{M}$ = number of households (generic) served at UK level.

M' = number of households (in communal aerial systems) served at UK level.

M'' = number of households (standard domestic installation) served at UK level.

M''' = number of households (with domestically installed amplifiers) served at UK level.

Distribution of generic households across DTT channels

A7.9 As described in Section 8, in order to analyse the impact of interference to DTT, and to avoid double counting of households, it is necessary to examine first those households that are served by DTT channels which are more susceptible to interference; i.e., according to the *susceptibility rank* of the channels.

A7.10 By definition, a channel with a lower susceptibility rank is more susceptible to interference from MFCN base stations.

A7.11 The order of the *susceptibility ranks* of DTT channels is a function of the protection ratios, which themselves depend on the installation category (i.e., whether the N+9 image exists or is drowned by amplifier overload) and the filtering applied.

A7.12 In this sub-section we present the numbers of generic households served (based on the 70% cut-off rule) within each DTT channel as extracted from the DSO/Clearance plan, and calculated based on the susceptibility ranks of the respective channels for different installation categories and filtering scenarios.

A7.13 Three filtering scenarios are considered: a) no filtering, b) DTT receiver filtering, and c) filtering at both the DTT receivers and the base station transmitters.

Distribution of generic households across DTT channels based on the channel susceptibility order for standard installations

A7.14 For standard domestic installations, the protection ratios do not decrease monotonically with a reduction in channel number. This is due to N+9 affect, and results in different orders of susceptibility rank among the DTT channels based on the filtering scenario considered.

A7.15 The resulting generic household distributions are presented in the following tables.

Table 60. Distribution of generic households served (based on standard installation protection ratios), in the absence of filtering.

DTT channel i	Rank	Protection ratio (dB)	Number of generic HHs served, $\overline{M}_i$		Number of DTT transmitters	
			Main	Relay	Main	Relay
60	1	-34	2,025,196	754,672	13	111
59	3	-41.5	0	11,336	11	118
58	5	-43.1	785,101	265,849	3	85
57	6	-43.9	0	6,132	0	1
56	9	-44.7	0	852	2	37
55	2	-40.4	4,274,593	439,978	0	3
54	7	-44.3	207,199	5,443	1	2
53	8	-44.3	0	19,093	0	1
52	4	-42	3,649,341	345,277	6	14
51	10	-47.2	0	6,814	0	2
≤50	11	-47.2	11,951,714	2,420,557	41	666
Total			22,893,144	4,276,003	77	1040

Table 61. Distribution of generic households served (based on standard installation protection ratios), with DTT receiver filtering

DTT channel i	Rank	Protection ratio (dB)	Number of generic HHs served, $\overline{M}_i$		Number of DTT transmitters	
			Main	Relay	Main	Relay
60	1	-34.5	2,025,196	754,672	13	111
59	2	-44.9	4,274,593	446,278	11	118
58	3	-55.5	1,508,426	294,333	3	85
57	6	-61.9	0	6,132	0	1
56	9	-63.8	0	852	0	1
55	4	-60	0	3,512	0	3
54	7	-63.5	207,199	5,443	1	2
53	8	-63.6	0	19,093	0	3
52	5	-61	2,926,016	318,317	8	48
51	10	-66.5	0	6,814	0	2
≤50	11	-66.5	11,951,714	2,420,557	41	666
Total			22,893,144	4,276,003	77	1,040

Table 62. Distribution of generic households served
(based on standard installation protection ratios),
with filtering at both BS transmitter and DTT receiver.

DTT channel i	Rank	Protection ratio (dB)	Number of generic HHs served, $\overline{M}_i$		Number of DTT transmitters	
			Main	Relay	Main	Relay
60	1	-39.4	2,025,196	754,672	13	111
59	2	-51.3	4,274,593	446,278	11	118
58	5	-62.4	785,101	265,849	2	83
57	6	-63.2	0	6,132	0	1
56	9	-63.9	0	852	0	1
55	3	-60	0	5,036	0	4
54	7	-63.5	207,199	5,443	1	2
53	8	-63.6	0	19,093	0	3
52	4	-61	3,649,341	345,277	9	49
51	10	-66.5	0	6,814	0	2
≤50	11	-66.5	11,951,714	2,420,557	41	666
Total			22,893,144	4,276,003	77	1,040

Distribution of generic households across DTT channels based on the channel susceptibility order for non-standard installations

A7.16 For non-standard installations (i.e., communal aerial systems and domestic installations with amplifiers), the protection ratios decrease monotonically with a reduction in channel number. This is due to amplifier overload, and results in the same order of susceptibility ranks among the DTT channels. Filtering does not change the order.

A7.17 The resulting generic household distribution is presented below.

Table 63. Distribution of generic households served
(based on protection ratios for communal aerial systems
or domestic installations with amplifiers) for all filtering scenarios.

DTT channel i	Channel order	Number of generic HHs served, $\overline{M}_i$		Number of DTT transmitters	
		Main	Relay	Main	Relay
60	1	2,025,196	754,672	13	111
59	2	4,274,593	446,278	11	118
58	3	1,508,426	294,333	3	85
57	4	0	6,132	0	1
56	5	261	87,791	2	37
55	6	0	3,512	0	3
54	7	207,199	7,915	1	2
53	8	0	11,857	0	1
52	9	2,925,755	236,142	6	14
51	10	0	6,814	0	2
≤50	11	11,951,714	2,420,557	41	666
Total		22,893,144	4,276,003	77	1,040

Post processing of Punch results to derive installation-specific figures

A7.18 Punch output corresponds to generic households (albeit based on installation-specific protection ratios).

A7.19 Consequently further post-processing of the raw results from Punch is required to convert the number of generic households served and affected in each pixel to the number of installation-specific households that are served and affected in each pixel.

A7.20 As noted in Section 7, 2001 Census data on communal dwellings (i.e. flats/apartments) can be used as a reasonable proxy for determining the locations of communal aerial systems.

A7.21 It has not been possible to use the Census data for the entire UK in the modelling, so data for England and Wales only has been used. For this reason, we have not considered DTT transmitters in Scotland and Northern Ireland in our modelling. Nevertheless, we have examined a variety of DTT transmitter coverage areas in terms of size and environment.

A7.22 The lowest level of granularity in the Census data is the *output area* level. An output area is a boundary designed to contain an average of around 300 residents or 125 households. Output areas therefore vary in size according to population density.

A7.23 For each output area in England and Wales, the total number of "houses" and the total number of "flats"[92] is known. For consistency with the total APSA population figures introduced we use the relative proportion between these two classes of residence, rather than the absolute numbers.

A7.24 Punch calculates the served and affected numbers of generic households within each 100m x 100m pixel. There will typically be several such pixels within a single Census output area. The generic households served and affected are aggregated for all pixels within an output area, and multiplied by the relative proportion of flats or houses, depending on the category of interest. This is described in the following three sub-sections.

Communal antenna systems

A7.25 The number of households, m'_k , in communal aerial systems served within the coverage area of DTT transmitter k is calculated as

$$m'_k = \sum_{q=1}^{Q_k} X_{q,k} \sum_{p=1}^{P_{q,k}} \overline{m}_{p,k} \qquad (33)$$

where

$P_{q,k}$ = total number of pixels in the q^{th} output area served by transmitter *k*,
Q_k = total number of output areas served by transmitter *k*,
$\overline{m}_{p,k}$ = number of generic households served by in pixel p by transmitter *k*,

[92] 'Flats' includes total households from Census Table UV56 under the categories 'Flat, maisonette or apartment', and 'In a shared dwelling'. 'Houses' includes all households under 'House or Bunglaow'.

$X_{q,k}$ = proportion of generic households which are flats in the q^{th} output area of transmitter *k*.

A7.26 Similarly, the number of households, n'_k , in communal aerial systems within the coverage area of DTT transmitter *k* , who are affected as a result of interference is calculated as

$$n'_k = \sum_{q=1}^{Q_k} X_{q,k} \sum_{p=1}^{P_{q,k}} \overline{n}_{p,k} \tag{34}$$

where $\overline{n}_{p,k}$ is the computer modelled estimate of the number of generic households (using protection ratios specific to communal aerial systems) within pixel p that are affected as a result of interference.

Domestic installations

A7.27 The parameter $X_{q,k}$ in the above equations represents the proportion of flats in each output area. Consequently, the corresponding numbers of "non-flat" households can be calculated by replacing $X_{q,k}$ in Equations (33) and (34) with $(1-X_{q,k})$. However, these non-flat households need to be analysed differently according to whether they correspond to standard domestic installations or domestic installations with amplifiers.

A7.28 It has not been possible to accurately determine the relative local geographic distributions of these two categories. Absent any reliable guidelines, we have assumed that the ratio of the number of households with standard domestic installations to the number of households with domestic amplifiers is the same in every pixel. We define this ratio as

$$Y = \frac{M''}{M'' + M'''} \tag{35}$$

where M'' and M''' are the UK-wide numbers of standard domestic installations and domestic installations with amplifiers, respectively.

A7.29 The values of M'' and M''' can be inferred from the numbers of domestic amplifiers in the UK. Based on the estimates presented in Section 7 of this report, Y = 16.3/(16.3+5.6) ≡ 74.24%.

A7.30 The corresponding numbers of served and affected households with standard domestic installations in the coverage area of DTT transmitter k can then be written as

$$m''_k = Y \sum_{q=1}^{Q_k} (1 - X_{q,k}) \sum_{p=1}^{P_{q,k}} \overline{m}_{p,k} \tag{36}$$

$$n''_k = Y \sum_{q=1}^{Q_k} (1 - X_{q,k}) \sum_{p=1}^{P_{q,k}} \overline{n}_{p,k} \tag{37}$$

respectively, where $\overline{n}_{p,k}$ is the computer modelled estimate of the number of affected generic households (based on protection ratios specific to standard domestic installations) within pixel p.

A7.31 Following the same logic, the numbers of served and affected households with domestic amplifier installations in the coverage area of DTT transmitter k can be written as

$$m_k''' = (1-Y)\sum_{q=1}^{Q_k}(1-X_{q,k})\sum_{p=1}^{P_{q,k}}\overline{m}_{p,k} \tag{38}$$

$$n_k''' = (1-Y)\sum_{q=1}^{Q_k}(1-X_{q,k})\sum_{p=1}^{P_{q,k}}\overline{n}_{p,k} \tag{39}$$

respectively, where $\overline{n}_{p,k}$ is the computer modelled estimate of the number of affected generic households (based on protection ratios specific to domestic amplifier installations) within pixel p.

Calculation of numbers of UK households per installation category served in each DTT channel

A7.32 In order to calculate the number of households per installation category served throughout the UK in a specific DTT channel i, we extrapolate from the numbers of households per category served in the coverage areas of the limited number of DTT transmitters examined by Punch.

A7.33 We illustrate the above via an example for communal aerial systems.

A7.34 Consider the case where we have examined via Punch a total of K_i DTT transmitters in relation to channel i. Also assume that the analysis of the previous section has identified $m'_{k,i}$ households with communal aerial systems, and $\overline{m}_{k,i}$ generic households served in the coverage area of transmitter *k*. Then, by a process of extrapolation, the UK-wide number of households with communal aerial systems in channel *i* can be written as

$$M'_i = U'_i\overline{M}_i = \frac{\sum_{k=1}^{K_i} m'_{k,i}}{\sum_{k=1}^{K_i}\overline{m}_{k,i}}\overline{M}_i \tag{40}$$

where $\overline{M}_i$ is the UK-wide number of generic households in channel *i* (available from the DSO/Clearance plan and presented earlier in tabular form in this annex).

A7.35 Note that U_i'' and U_i''' can be similarly calculated for standard domestic installations and domestic installations with amplifiers respectively.

Discrepancy

A7.36 There will inevitably be a discrepancy between the extrapolated value M_i' calculated above and the national estimate, M', based on the UK-wide proportion of communal aerial systems. From the results presented in Section 7, the UK-wide proportion of communal aerial systems is given by

$$V' = 5{,}213{,}819 / (16{,}299{,}699 + 5{,}213{,}819 + 5{,}655{,}629).$$

A7.37 In short, the discrepancy means that

$$M' = V'\overline{M} \neq \sum_i M_i' \, . \quad (41)$$

A7.38 We therefore apply a correction factor to the channel-specific figures so that the total coverage values become consistent. The total error, e', aggregated over all channels is given by:

$$e' = \sum_i M_i' - M' \quad (42)$$

A7.39 To reconcile this, the total error is distributed among the DTT channels according to the relative proportion of generic households in each channel. The resulting error, e_i, in channel i is then subtracted from the estimated number of communal aerial households households in channel i. This correction can be described as follows:

$$M_i' \leftarrow M_i' - e_i' \quad (43)$$

A7.40 The same correction procedure applies to M_i'' and M_i''' for standard domestic installations and domestic installations with amplifiers, respectively.

A7.41 It should be noted that this error distribution process introduces some anomalies into the numbers of households served. For example, the number of standard domestic installations in channel 60 varies slightly between the different filtering scenarios. This is counter-intuitive as channel 60 is always the most susceptible channel, and therefore the number of households analysed in channel 60 should not be related to the protection ratios. However, the discrepancies are relatively minor and do not significantly impact the results.

A7.42 The resulting distributions of served households per installation category among the DTT channels are presented in Sections 8, 9, and 10 of this report.

Annex 8

Detailed results of computer modelling

A8.1 In this section we present detailed results of our computer modelling for the individual main and relay transmitters examined. These are included for completeness, and complement the results we have presented in Section 8, 9, and 10 of this report.

A8.2 Note that some of the tables are related to “generic” households. These tables contain the raw outputs of Punch, where every household in each pixel is considered to be associated with the same category of receiver installation; i.e., either a standard domestic installation, or a community aerial system, or a domestically installed amplifier.

A8.3 The results in these tables are generated based on the appropriate protection ratios specific to the installation category of interest.

A8.4 The raw results in the “generic” households tables are subsequently post-processed (as described in Annex 7) to account for different proportions of receiver installations in each pixel. The results are then presented in the installation-specific tables.

Standard domestic installations

No mitigation

Table 64. Estimated numbers of "generic" households affected due to interference for specific DTT transmitters and channels, and in the absence of mitigation.

DTT transmitter k	Channel i	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to interference — MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	11,770	4,542	2,501	2,641	8,949
Oxford	60	Main	388,430	8,612	3,884	2,315	2,393	6,638
Sudbury	60	Main	333,162	8,697	3,990	2,397	2,470	6,751
Whitehawk Hill	60	Relay	115,538	4,710	1,316	659	784	3,785
Brierley Hill	60	Relay	77,683	1,063	241	101	120	795
Reigate	60	Relay	65,756	1,179	444	259	283	941
Winter Hill	55	Main	2,562,268	17,167	13,966	11,168	2,927	3,440
Pontop Pike	55	Main	669,709	3,767	3,100	2,530	610	735
Tacolneston	55	Main	314,748	927	758	611	143	175
Hemel Hemp.	55	Relay	70,607	758	631	530	144	174
Luton	55	Relay	27,080	89	66	56	13	14
Beecroft Hill	55	Relay	19,859	44	32	21	5	4
Emley Moor	52	Main	1,473,633	6,743	3,216	1,509	1,507	3,733
Sandy Heath	52	Main	863,300	3,924	1,704	844	840	2,393
Mendip	52	Main	681,878	3,335	1,567	823	820	2,064
Nottingham	52	Relay	67,091	215	112	51	51	109
Tunbridge Wells	52	Relay	50,027	180	84	32	32	91
Guildford	52	Relay	43,347	187	86	37	37	90
Waltham	58	Main	726,193	7,832	3,629	1,058	2,678	4,850
Plympton	58	Main	32,404	152	76	23	50	81
Kidderminster	58	Relay	31,247	97	35	7	20	39
Hertford	58	Relay	21,228	61	26	4	17	28
Workington	58	Relay	8,892	137	70	31	57	84
Bluebell Hill	54	Main	194,997	508	378	160	230	143
Crystal Palace	30	Main	4,245,632	64,866	42,649	18,893	18,830	18,761
Sutton Coldfield	46	Main	1,786,890	5,925	3,958	1,864	1,856	1,851
Rowridge	28	Main	467,784	2,630	1,827	932	926	922
Fenton	28	Relay	116,268	478	315	142	142	141
Kilvey Hill	29	Relay	112,919	652	413	165	164	163
Sheffield	45	Relay	107,064	469	306	133	133	131

Table 65. Estimated numbers of SDI households affected due to interference for specific DTT transmitters and channels, and in the absence of mitigation.

DTT transmitter k	Channel i	Type	Number of SDI HHs served*, m_k	Number of SDI HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	450,398	7,293	2,742	1,494	1,580	5,549
Oxford	60	Main	256,752	5,077	2,241	1,320	1,364	3,872
Sudbury	60	Main	220,644	5,191	2,366	1,421	1,463	4,054
Whitehawk Hill	60	Relay	53,729	1,572	463	249	283	1,261
Brierley Hill	60	Relay	50,957	725	169	71	84	549
Reigate	60	Relay	40,041	676	260	156	169	543
Winter Hill	55	Main	1,648,209	8,671	6,962	5,466	1,472	1,689
Pontop Pike	55	Main	419,981	1,768	1,445	1,156	275	328
Tacolneston	55	Main	213,364	500	408	327	77	96
Hemel Hemp.	55	Relay	41,793	390	320	267	64	79
Luton	55	Relay	15,409	38	27	24	4	5
Beecroft_Hill	55	Relay	12,622	30	22	15	4	3
Emley Moor	52	Main	976,095	3,904	1,856	869	868	2,157
Sandy Heath	52	Main	568,203	2,401	1,059	529	526	1,457
Mendip	52	Main	442,215	1,941	929	491	489	1,212
Nottingham	52	Relay	43,079	102	54	24	24	51
Tunbridge Wells	52	Relay	30,412	88	39	14	14	36
Guildford	52	Relay	25,828	79	37	17	17	38
Waltham	58	Main	482,021	4,374	2,045	608	1,520	2,715
Plympton	58	Main	19,452	60	25	5	15	25
Kidderminster	58	Relay	20,706	58	22	5	13	24
Hertford	58	Relay	12,410	36	16	2	11	17
Workington	58	Relay	5,778	96	51	23	42	62
Bluebell Hill	54	Main	128,498	301	225	94	134	84
Crystal Palace	30	Main	1,951,265	17,792	11,830	5,433	5,421	5,402
Sutton Coldfield	46	Main	1,143,589	3,313	2,222	1,053	1,049	1,045
Rowridge	28	Main	275,310	1,252	867	432	428	425
Fenton	28	Relay	77,932	325	215	96	96	95
Kilvey Hill	29	Relay	73,777	402	255	102	101	100
Sheffield	45	Relay	61,792	281	186	85	85	83

Table 66. Estimated numbers of "generic" households affected due to overload only for specific DTT transmitters and channels, and in the absence of mitigation.

DTT transmitter k	Channel i	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to overload				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	400	40	4	8	77
Oxford	60	Main	388,430	357	74	4	21	82
Sudbury	60	Main	333,162	209	42	21	21	60
Whitehawk Hill	60	Relay	115,538	275	38	25	25	84
Brierley Hill	60	Relay	77,683	62	13	2	2	14
Reigate	60	Relay	65,756	120	9	7	9	9
Winter Hill	55	Main	2,562,268	1,209	699	186	102	47
Pontop Pike	55	Main	669,709	335	233	38	9	1
Tacolneston	55	Main	314,748	85	31	0	0	0
Hemel Hemp.	55	Relay	70,607	0	0	0	0	0
Luton	55	Relay	27,080	2	1	0	0	0
Beecroft Hill	55	Relay	19,859	0	0	0	0	0
Emley Moor	52	Main	1,473,633	562	274	78	80	131
Sandy Heath	52	Main	863,300	220	85	8	8	31
Mendip	52	Main	681,878	353	228	152	152	164
Nottingham	52	Relay	67,091	24	20	0	1	4
Tunbridge Wells	52	Relay	50,027	0	0	0	0	0
Guildford	52	Relay	43,347	0	0	0	0	0
Waltham	58	Main	726,193	104	13	0	0	1
Plympton	58	Main	32,404	0	0	0	0	0
Kidderminster	58	Relay	31,247	0	0	0	0	0
Hertford	58	Relay	21,228	14	14	14	14	14
Workington	58	Relay	8,892	35	11	0	0	1
Bluebell Hill	54	Main	194,997	111	64	17	17	13
Crystal Palace	30	Main	4,245,632	2,205	1,352	370	399	431
Sutton Coldfield	46	Main	1,786,890	461	299	99	103	106
Rowridge	28	Main	467,784	194	125	12	16	18
Fenton	28	Relay	116,268	11	1	0	0	0
Kilvey Hill	29	Relay	112,919	0	0	0	0	0
Sheffield	45	Relay	107,064	31	27	22	22	23

Table 67. Estimated numbers of SDI households affected due to overload only for specific DTT transmitters and channels, and in the absence of mitigation.

DTT transmitter k	Channel i	Type	Number of SDI HHs served*, m_k	Number of SDI HHs, n_k, affected due to overload				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	450,398	229	26	2	5	46
Oxford	60	Main	256,752	203	46	3	15	50
Sudbury	60	Main	220,644	128	19	5	5	32
Whitehawk Hill	60	Relay	53,729	102	14	10	10	27
Brierley Hill	60	Relay	50,957	42	9	1	1	10
Reigate	60	Relay	40,041	61	5	4	5	5
Winter Hill	55	Main	1,648,209	691	408	103	56	27
Pontop Pike	55	Main	419,981	155	104	16	4	1
Tacolneston	55	Main	213,364	48	20	0	0	0
Hemel Hemp.	55	Relay	41,793	0	0	0	0	0
Luton	55	Relay	15,409	1	1	0	0	0
Beecroft_Hill	55	Relay	12,622	0	0	0	0	0
Emley Moor	52	Main	976,095	318	131	41	42	61
Sandy Heath	52	Main	568,203	145	52	5	5	19
Mendip	52	Main	442,215	201	119	67	67	75
Nottingham	52	Relay	43,079	15	12	0	1	2
Tunbridge Wells	52	Relay	30,412	0	0	0	0	0
Guildford	52	Relay	25,828	0	0	0	0	0
Waltham	58	Main	482,021	70	9	0	0	1
Plympton	58	Main	19,452	0	0	0	0	0
Kidderminster	58	Relay	20,706	0	0	0	0	0
Hertford	58	Relay	12,410	10	10	10	10	10
Workington	58	Relay	5,778	25	8	0	0	1
Bluebell Hill	54	Main	128,498	67	41	10	10	7
Crystal Palace	30	Main	1,951,265	927	564	162	174	186
Sutton Coldfield	46	Main	1,143,589	284	177	48	50	50
Rowridge	28	Main	275,310	68	42	5	6	7
Fenton	28	Relay	77,932	8	1	0	0	0
Kilvey Hill	29	Relay	73,777	0	0	0	0	0
Sheffield	45	Relay	61,792	22	19	16	16	16

Table 68. Weighted percentages of SDI households affected due to interference (main DTT transmitters) in the absence of mitigation.

MAIN		% of SDI HHs, F_i, affected due to interference				
DTT channel, i	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,386,555	1.89%	0.79%	0.46%	0.47%	1.45%
59	0	0.00%	0.00%	0.00%	0.00%	0.00%
58	531,956	0.88%	0.41%	0.12%	0.31%	0.55%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	0	0.00%	0.00%	0.00%	0.00%	0.00%
55	2,820,362	0.48%	0.39%	0.30%	0.08%	0.09%
54	139,960	0.23%	0.18%	0.07%	0.10%	0.07%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	2,461,687	0.42%	0.19%	0.10%	0.09%	0.24%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	6,393,859	0.66%	0.44%	0.21%	0.20%	0.20%
Total	**13,734,379**					

Table 69. Weighted percentages of SDI households affected due to interference (relay DTT transmitters) in the absence of mitigation.

RELAY		% of SDI HHs, F_i, affected due to interference				
DTT channel, i	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	409,972	2.05%	0.62%	0.33%	0.37%	1.63%
59	6,624	0.21%	0.31%	0.23%	0.15%	0.15%
58	164,345	0.49%	0.23%	0.08%	0.17%	0.27%
57	3,583	0.31%	0.15%	0.31%	0.17%	0.17%
56	498	0.23%	0.32%	0.06%	0.22%	0.17%
55	254,492	0.33%	0.21%	0.24%	0.31%	0.22%
54	3,181	0.31%	0.19%	0.10%	0.32%	0.31%
53	11,157	0.31%	0.23%	0.10%	0.15%	0.10%
52	208,321	0.27%	0.13%	0.06%	0.06%	0.13%
51	3,982	0.32%	0.17%	0.10%	0.10%	0.10%
≤50**	1,499,167	0.47%	0.31%	0.13%	0.13%	0.13%
Total	**2,565,320**					

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 70. Estimated number of SDI households affected due to interference throughout the UK in the absence of mitigation.

DTT channel, i	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i , affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,796,526	34,662	13,512	7,677	8,101	26,802
59	6,624	14	20	15	10	10
58	696,302	5,504	2,576	779	1,904	3,343
57	3,583	11	5	11	6	6
56	498	1	2	0	1	1
55	3,074,854	14,358	11,440	9,206	3,039	3,170
54	143,141	338	251	105	157	101
53	11,157	34	26	11	16	11
52	2,670,008	10,782	5,035	2,455	2,447	6,242
51	3,982	13	7	4	4	4
≤50**	7,893,026	49,494	32,918	15,105	15,063	14,995
Total	**16,299,699**	**115,212**	**65,793**	**35,369**	**30,749**	**54,684**

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 71. Weighted percentages of SDI households affected due to overload only (main DTT transmitters) in the absence of mitigation.

MAIN		% of SDI HHs, F_i , affected due to overload				
DTT channel, *i*	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,386,555	0.06%	0.01%	0.00%	0.00%	0.01%
59	0	0.00%	0.00%	0.00%	0.00%	0.00%
58	531,956	0.01%	0.00%	0.00%	0.00%	0.00%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	0	0.00%	0.00%	0.00%	0.00%	0.00%
55	2,820,362	0.04%	0.02%	0.01%	0.00%	0.00%
54	139,960	0.05%	0.03%	0.01%	0.01%	0.01%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	2,461,687	0.03%	0.02%	0.01%	0.01%	0.01%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	6,393,859	0.04%	0.02%	0.01%	0.01%	0.01%
Total	13,734,379					

Table 72. Weighted percentages of SDI households affected due to overload only (relay DTT transmitters) in the absence of mitigation.

RELAY		% of SDI HHs, F_i , affected due to overload				
DTT channel, *i*	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	409,972	2.05%	0.62%	0.33%	0.37%	1.63%
59	6,624	0.21%	0.31%	0.23%	0.15%	0.15%
58	164,345	0.49%	0.23%	0.08%	0.17%	0.27%
57	3,583	0.31%	0.15%	0.31%	0.17%	0.17%
56	498	0.23%	0.32%	0.06%	0.22%	0.17%
55	254,492	0.33%	0.21%	0.24%	0.31%	0.22%
54	3,181	0.31%	0.19%	0.10%	0.32%	0.31%
53	11,157	0.31%	0.23%	0.10%	0.15%	0.10%
52	208,321	0.27%	0.13%	0.06%	0.06%	0.13%
51	3,982	0.32%	0.17%	0.10%	0.10%	0.10%
≤50**	1,499,167	0.47%	0.31%	0.13%	0.13%	0.13%
Total	2,565,320					

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 73. Estimated number of SDI households affected due to overload only throughout the UK in the absence of mitigation.

DTT channel, i	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i , affected due to overload				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,796,526	1,418	216	58	84	312
59	6,624	0	0	1	0	0
58	696,302	221	85	41	41	45
57	3,583	3	2	1	1	1
56	498	0	0	0	0	0
55	3,074,854	1,132	707	148	83	103
54	143,141	73	45	11	12	9
53	11,157	1	2	1	1	1
52	2,670,008	855	398	140	142	196
51	3,982	2	0	0	0	0
≤50**	7,893,026	2,634	1,627	517	546	577
Total	**16,299,699**	**6,339**	**3,082**	**916**	**909**	**1,243**

* Derived from census data, based on the 70% cut-off counting approach (APSA).

** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

DTT receiver filtering

Table 74. Estimated numbers of "generic" households affected due to interference for specific DTT transmitters and channels, and with DTT receiver filtering.

DTT transmitter k	Channel i	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to interference — MFCN blocks ABC	BC	C	B	A
Belmont	60	Main	667,029	10,100	3,500	1,942	2,113	8,031
Oxford	60	Main	388,430	7,590	3,301	1,985	2,101	6,118
Sudbury	60	Main	333,162	7,488	3,213	1,908	2,030	5,907
Whitehawk Hill	60	Relay	115,538	3,201	584	264	373	2,808
Brierley Hill	60	Relay	77,683	809	148	74	88	676
Reigate	60	Relay	65,756	942	316	201	219	803
Winter Hill	59	Main	2,561,801	4,608	2,110	1,172	1,163	2,824
Pontop Pike	59	Main	669,597	846	385	211	210	488
Tacolneston	59	Main	331,686	228	90	40	38	148
Hemel Hemp.	59	Relay	71,570	239	134	86	84	151
Luton	59	Relay	27,166	32	20	11	11	20
Beecroft Hill	59	Relay	19,858	5	2	1	1	3
Emley Moor	52	Main	1,473,633	52	36	32	32	48
Sandy Heath	52	Main	863,300	34	7	4	4	23
Mendip	52	Main	681,878	36	5	1	2	20
Nottingham	52	Relay	67,091	1	1	1	1	1
Tunbridge Wells	52	Relay	50,027	2	0	0	0	1
Guildford	52	Relay	43,347	0	0	0	0	0
Waltham	58	Main	726,193	136	64	23	34	59
Plympton	58	Main	32,404	3	2	1	1	1
Kidderminster	58	Relay	31,247	1	0	0	0	0
Hertford	58	Relay	21,228	0	0	0	0	0
Workington	58	Relay	8,892	6	3	1	2	3
Bluebell Hill	54	Main	194,997	2	2	1	2	2
Crystal Palace	30	Main	4,245,632	103	65	26	26	26
Sutton Coldfield	46	Main	1,786,890	36	25	13	13	13
Rowridge	28	Main	467,784	11	6	2	2	2
Fenton	28	Relay	116,268	0	0	0	0	0
Kilvey Hill	29	Relay	112,919	0	0	0	0	0
Sheffield	45	Relay	107,064	1	0	0	0	0

Table 75. Estimated numbers of SDI households affected due to interference for specific DTT transmitters and channels, and with DTT receiver filtering.

DTT transmitter *k*	Channel *i*	Type	Number of SDI HHs served*, m_k	Number of SDI HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	450,398	6,241	2,080	1,134	1,240	4,974
Oxford	60	Main	256,752	4,495	1,912	1,128	1,197	3,584
Sudbury	60	Main	220,644	4,468	1,893	1,113	1,190	3,540
Whitehawk Hill	60	Relay	53,729	1,089	237	117	151	953
Brierley Hill	60	Relay	50,957	552	103	52	62	468
Reigate	60	Relay	40,041	538	189	120	130	463
Winter Hill	59	Main	1,647,867	2,111	895	499	496	1,310
Pontop Pike	59	Main	419,897	371	157	88	88	212
Tacolneston	59	Main	224,915	125	49	22	21	82
Hemel Hemp.	59	Relay	42,308	108	57	38	36	62
Luton	59	Relay	15,471	10	5	4	4	6
Beecroft_Hill	59	Relay	12,622	4	1	1	1	2
Emley Moor	52	Main	976,095	33	25	23	23	32
Sandy Heath	52	Main	568,203	20	4	3	3	14
Mendip	52	Main	442,215	23	2	1	1	13
Nottingham	52	Relay	43,079	1	1	1	1	1
Tunbridge Wells	52	Relay	30,412	0	0	0	0	0
Guildford	52	Relay	25,828	0	0	0	0	0
Waltham	58	Main	482,021	81	39	14	20	36
Plympton	58	Main	19,452	0	0	0	0	0
Kidderminster	58	Relay	20,706	1	0	0	0	0
Hertford	58	Relay	12,410	0	0	0	0	0
Workington	58	Relay	5,778	4	2	1	1	2
Bluebell Hill	54	Main	128,498	1	1	1	1	1
Crystal Palace	30	Main	1,951,265	47	29	11	11	11
Sutton Coldfield	46	Main	1,143,589	15	10	4	4	4
Rowridge	28	Main	275,310	4	2	1	1	1
Fenton	28	Relay	77,932	0	0	0	0	0
Kilvey Hill	29	Relay	73,777	0	0	0	0	0
Sheffield	45	Relay	61,792	1	0	0	0	0

Table 76. Estimated numbers of "generic" households affected due to overload only for specific DTT transmitters and channels, and with DTT receiver filtering.

DTT transmitter k	Channel i	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to overload				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	0	0	0	0	0
Oxford	60	Main	388,430	0	0	0	0	0
Sudbury	60	Main	333,162	0	0	0	0	0
Whitehawk Hill	60	Relay	115,538	0	0	0	0	0
Brierley Hill	60	Relay	77,683	0	0	0	0	0
Reigate	60	Relay	65,756	0	0	0	0	0
Winter Hill	59	Main	2,561,801	0	0	0	0	0
Pontop Pike	59	Main	669,597	0	0	0	0	0
Tacolneston	59	Main	331,686	0	0	0	0	0
Hemel Hemp.	59	Relay	71,570	0	0	0	0	0
Luton	59	Relay	27,166	0	0	0	0	0
Beecroft Hill	59	Relay	19,858	0	0	0	0	0
Emley Moor	52	Main	1,473,633	30	30	30	30	30
Sandy Heath	52	Main	863,300	0	0	0	0	0
Mendip	52	Main	681,878	0	0	0	0	0
Nottingham	52	Relay	67,091	0	0	0	0	0
Tunbridge Wells	52	Relay	50,027	0	0	0	0	0
Guildford	52	Relay	43,347	0	0	0	0	0
Waltham	58	Main	726,193	0	0	0	0	0
Plympton	58	Main	32,404	0	0	0	0	0
Kidderminster	58	Relay	31,247	0	0	0	0	0
Hertford	58	Relay	21,228	14	14	14	14	14
Workington	58	Relay	8,892	0	0	0	0	0
Bluebell Hill	54	Main	194,997	0	0	0	0	0
Crystal Palace	30	Main	4,245,632	0	0	0	0	0
Sutton Coldfield	46	Main	1,786,890	0	0	0	0	0
Rowridge	28	Main	467,784	1	1	1	1	1
Fenton	28	Relay	116,268	0	0	0	0	0
Kilvey Hill	29	Relay	112,919	0	0	0	0	0
Sheffield	45	Relay	107,064	15	15	15	15	15

Table 77. Estimated numbers of SDI households affected due to overload only for specific DTT transmitters and channels, and with DTT receiver filtering.

DTT transmitter k	Channel i	Type	Number of SDI HHs served*, m_k	Number of SDI HHs, n_k, affected due to overload				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	450,398	0	0	0	0	0
Oxford	60	Main	256,752	0	0	0	0	0
Sudbury	60	Main	220,644	0	0	0	0	0
Whitehawk Hill	60	Relay	53,729	0	0	0	0	0
Brierley Hill	60	Relay	50,957	0	0	0	0	0
Reigate	60	Relay	40,041	0	0	0	0	0
Winter Hill	59	Main	1,647,867	0	0	0	0	0
Pontop Pike	59	Main	419,897	0	0	0	0	0
Tacolneston	59	Main	224,915	0	0	0	0	0
Hemel Hemp.	59	Relay	42,308	0	0	0	0	0
Luton	59	Relay	15,471	0	0	0	0	0
Beecroft_Hill	59	Relay	12,622	0	0	0	0	0
Emley Moor	52	Main	976,095	22	22	22	22	22
Sandy Heath	52	Main	568,203	0	0	0	0	0
Mendip	52	Main	442,215	0	0	0	0	0
Nottingham	52	Relay	43,079	0	0	0	0	0
Tunbridge Wells	52	Relay	30,412	0	0	0	0	0
Guildford	52	Relay	25,828	0	0	0	0	0
Waltham	58	Main	482,021	0	0	0	0	0
Plympton	58	Main	19,452	0	0	0	0	0
Kidderminster	58	Relay	20,706	0	0	0	0	0
Hertford	58	Relay	12,410	10	10	10	10	10
Workington	58	Relay	5,778	0	0	0	0	0
Bluebell Hill	54	Main	128,498	0	0	0	0	0
Crystal Palace	30	Main	1,951,265	0	0	0	0	0
Sutton Coldfield	46	Main	1,143,589	0	0	0	0	0
Rowridge	28	Main	275,310	1	1	1	1	1
Fenton	28	Relay	77,932	0	0	0	0	0
Kilvey Hill	29	Relay	73,777	0	0	0	0	0
Sheffield	45	Relay	61,792	10	10	10	10	10

Table 78. Weighted percentages of SDI households affected due to interference (main DTT transmitters) with DTT receiver filtering.

MAIN		% of SDI HHs, F_i , affected due to interference				
DTT channel, *i*	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,386,298	1.64%	0.63%	0.36%	0.39%	1.30%
59	2,820,543	0.11%	0.05%	0.03%	0.03%	0.07%
58	1,021,865	0.02%	0.01%	0.00%	0.00%	0.01%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	0	0.00%	0.00%	0.00%	0.00%	0.00%
55	0	0.00%	0.00%	0.00%	0.00%	0.00%
54	139,934	0.00%	0.00%	0.00%	0.00%	0.00%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	1,973,393	0.00%	0.00%	0.00%	0.00%	0.00%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	6,392,346	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**13,734,379**					

Table 79. Weighted percentages of SDI households affected due to interference (relay DTT transmitters) with DTT receiver filtering.

RELAY		% of SDI HHs, F_i , affected due to interference				
DTT channel, *i*	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	409,929	1.51%	0.37%	0.20%	0.24%	1.30%
59	257,936	0.17%	0.09%	0.06%	0.06%	0.10%
58	181,937	0.01%	0.01%	0.00%	0.00%	0.01%
57	3,583	0.00%	0.00%	0.00%	0.00%	0.00%
56	498	0.00%	0.00%	0.00%	0.00%	0.00%
55	2,052	0.00%	0.00%	0.00%	0.00%	0.00%
54	3,180	0.00%	0.00%	0.00%	0.00%	0.00%
53	11,156	0.00%	0.00%	0.00%	0.00%	0.00%
52	192,037	0.00%	0.00%	0.00%	0.00%	0.00%
51	3,981	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	1,499,032	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**2,565,320**					

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 80. Estimated number of SDI households affected due to interference throughout the UK with DTT receiver filtering.

DTT channel, *i*	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i, affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,796,228	28,890	10,293	5,863	6,390	23,413
59	3,078,478	3,654	1,588	905	893	2,231
58	1,203,802	189	89	32	48	83
57	3,583	0	0	0	0	0
56	498	0	0	0	0	0
55	2,052	0	0	0	0	0
54	143,114	2	2	1	2	2
53	11,156	0	0	0	0	0
52	2,165,430	77	33	28	28	60
51	3,981	0	0	0	0	0
≤50**	7,891,378	131	77	31	31	31
Total	**16,299,699**	**32,942**	**12,082**	**6,860**	**7,392**	**25,820**

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 81. Weighted percentages of SDI households affected due to overload only (main DTT transmitters) with DTT receiver filtering.

MAIN		% of SDI HHs, F_i , affected due to overload				
DTT channel, *i*	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,386,298	0.00%	0.00%	0.00%	0.00%	0.00%
59	2,820,543	0.00%	0.00%	0.00%	0.00%	0.00%
58	1,021,865	0.00%	0.00%	0.00%	0.00%	0.00%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	0	0.00%	0.00%	0.00%	0.00%	0.00%
55	0	0.00%	0.00%	0.00%	0.00%	0.00%
54	139,934	0.00%	0.00%	0.00%	0.00%	0.00%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	1,973,393	0.00%	0.00%	0.00%	0.00%	0.00%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	6,392,346	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**13,734,379**					

Table 82. Weighted percentages of SDI households affected due to overload only (relay DTT transmitters) with DTT receiver filtering.

RELAY		% of SDI HHs, F_i , affected due to overload				
DTT channel, *i*	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	409,929	1.51%	0.37%	0.20%	0.24%	1.30%
59	257,936	0.17%	0.09%	0.06%	0.06%	0.10%
58	181,937	0.01%	0.01%	0.00%	0.00%	0.01%
57	3,583	0.00%	0.00%	0.00%	0.00%	0.00%
56	498	0.00%	0.00%	0.00%	0.00%	0.00%
55	2,052	0.00%	0.00%	0.00%	0.00%	0.00%
54	3,180	0.00%	0.00%	0.00%	0.00%	0.00%
53	11,156	0.00%	0.00%	0.00%	0.00%	0.00%
52	192,037	0.00%	0.00%	0.00%	0.00%	0.00%
51	3,981	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	1,499,032	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**2,565,320**					

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 83. Estimated number of SDI households affected due to overload only throughout the UK with DTT receiver filtering.

DTT channel, i	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i , affected due to overload				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,796,228	0	0	0	0	0
59	3,078,478	0	0	0	0	0
58	1,203,802	45	45	45	45	45
57	3,583	1	1	1	1	1
56	498	0	0	0	0	0
55	2,052	0	0	0	0	1
54	143,114	0	0	0	0	1
53	11,156	1	0	0	0	1
52	2,165,430	22	22	22	22	22
51	3,981	0	0	0	0	0
≤50**	7,891,378	74	74	74	74	74
Total	**16,299,699**	**145**	**143**	**143**	**143**	**145**

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Base station transmitter fitering and DTT receiver filtering

Table 84. Estimated numbers of "generic" households affected due to interference for specific DTT transmitters and channels, with base station transmitter filtering and DTT receiver filtering.

DTT transmitter k	Channel i	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	6,920	278	13	267	6,763
Oxford	60	Main	388,430	5,244	267	9	251	5,144
Sudbury	60	Main	333,162	5,324	312	16	299	5,240
Whitehawk Hill	60	Relay	115,538	3,043	78	4	77	2,979
Brierley Hill	60	Relay	77,683	601	8	0	8	582
Reigate	60	Relay	65,756	749	59	2	58	732
Winter Hill	59	Main	2,561,801	2,225	114	39	68	2,069
Pontop Pike	59	Main	669,597	464	14	6	9	436
Tacolneston	59	Main	331,686	128	1	0	0	116
Hemel Hemp.	59	Relay	71,570	124	11	3	6	113
Luton	59	Relay	27,166	11	0	0	0	11
Beecroft_Hill	59	Relay	19,858	1	0	0	0	1
Emley Moor	52	Main	1,473,633	63	36	32	34	52
Sandy Heath	52	Main	863,300	34	10	4	4	27
Mendip	52	Main	681,878	43	8	2	2	24
Nottingham	52	Relay	67,091	1	1	0	0	1
Tunbridge Wells	52	Relay	50,027	1	0	0	0	1
Guildford	52	Relay	43,347	0	0	0	0	0
Waltham	58	Main	726,193	51	15	3	12	32
Plympton	58	Main	32,404	1	1	1	1	1
Kidderminster	58	Relay	31,247	0	0	0	0	0
Hertford	58	Relay	21,228	0	0	0	0	0
Workington	58	Relay	8,892	5	2	1	1	3
Bluebell Hill	54	Main	194,997	2	2	1	2	2
Crystal Palace	30	Main	4,245,632	103	65	26	26	26
Sutton Coldfield	46	Main	1,786,890	36	25	13	13	13
Rowridge	28	Main	467,784	11	6	2	2	2
Fenton	28	Relay	116,268	0	0	0	0	0
Kilvey Hill	29	Relay	112,919	0	0	0	0	0
Sheffield	45	Relay	107,064	1	0	0	0	0

Table 85. Estimated numbers of SDI households affected due to interference for specific DTT transmitters and channels, and with base station transmitter filtering and DTT receiver filtering.

DTT transmitter k	Channel i	Type	Number of SDI HHs served*, m_k	Number of SDI HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	450,398	4,280	151	7	147	4,178
Oxford	60	Main	256,752	3,034	143	4	137	2,980
Sudbury	60	Main	220,644	3,192	182	9	174	3,147
Whitehawk Hill	60	Relay	53,729	1,030	32	3	32	1,011
Brierley Hill	60	Relay	50,957	414	6	0	6	401
Reigate	60	Relay	40,041	431	33	1	33	420
Winter Hill	59	Main	1,647,867	1,075	57	20	34	1,001
Pontop Pike	59	Main	419,897	201	6	2	3	188
Tacolneston	59	Main	224,915	66	1	0	0	61
Hemel Hemp.	59	Relay	42,308	52	4	1	1	46
Luton	59	Relay	15,471	4	0	0	0	4
Beecroft_Hill	59	Relay	12,622	1	0	0	0	1
Emley Moor	52	Main	976,095	39	25	24	24	33
Sandy Heath	52	Main	568,203	22	7	3	3	17
Mendip	52	Main	442,215	27	4	1	1	16
Nottingham	52	Relay	43,079	1	1	0	0	1
Tunbridge Wells	52	Relay	30,412	0	0	0	0	0
Guildford	52	Relay	25,828	0	0	0	0	0
Waltham	58	Main	482,021	32	11	2	9	20
Plympton	58	Main	19,452	0	0	0	0	0
Kidderminster	58	Relay	20,706	0	0	0	0	0
Hertford	58	Relay	12,410	0	0	0	0	0
Workington	58	Relay	5,778	4	1	1	1	2
Bluebell Hill	54	Main	128,498	1	1	1	1	1
Crystal Palace	30	Main	1,951,265	47	29	11	11	11
Sutton Coldfield	46	Main	1,143,589	15	10	4	4	4
Rowridge	28	Main	275,310	4	2	1	1	1
Fenton	28	Relay	77,932	0	0	0	0	0
Kilvey Hill	29	Relay	73,777	0	0	0	0	0
Sheffield	45	Relay	61,792	1	0	0	0	0

Table 86. Estimated numbers of "generic" households affected due to overload only for specific DTT transmitters and channels, and with base station transmitter filtering and DTT receiver filtering.

DTT transmitter k	Channel i	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to overload				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	74	0	0	0	46
Oxford	60	Main	388,430	82	0	0	0	76
Sudbury	60	Main	333,162	58	0	0	0	45
Whitehawk Hill	60	Relay	115,538	80	1	0	0	47
Brierley Hill	60	Relay	77,683	14	0	0	0	13
Reigate	60	Relay	65,756	9	0	0	0	9
Winter Hill	59	Main	2,561,801	13	0	0	0	13
Pontop Pike	59	Main	669,597	0	0	0	0	0
Tacolneston	59	Main	331,686	0	0	0	0	0
Hemel Hemp.	59	Relay	71,570	0	0	0	0	0
Luton	59	Relay	27,166	0	0	0	0	0
Beecroft_Hill	59	Relay	19,858	0	0	0	0	0
Emley Moor	52	Main	1,473,633	30	30	30	30	30
Sandy Heath	52	Main	863,300	0	0	0	0	0
Mendip	52	Main	681,878	0	0	0	0	0
Nottingham	52	Relay	67,091	0	0	0	0	0
Tunbridge Wells	52	Relay	50,027	0	0	0	0	0
Guildford	52	Relay	43,347	0	0	0	0	0
Waltham	58	Main	726,193	0	0	0	0	0
Plympton	58	Main	32,404	0	0	0	0	0
Kidderminster	58	Relay	31,247	0	0	0	0	0
Hertford	58	Relay	21,228	14	14	14	14	14
Workington	58	Relay	8,892	0	0	0	0	0
Bluebell Hill	54	Main	194,997	0	0	0	0	0
Crystal Palace	30	Main	4,245,632	0	0	0	0	0
Sutton Coldfield	46	Main	1,786,890	0	0	0	0	0
Rowridge	28	Main	467,784	1	1	1	1	1
Fenton	28	Relay	116,268	0	0	0	0	0
Kilvey Hill	29	Relay	112,919	0	0	0	0	0
Sheffield	45	Relay	107,064	15	15	15	15	15

Table 87. Estimated numbers of SDI households affected due to overload only for specific DTT transmitters and channels, and with base station transmitter filtering and DTT receiver filtering.

DTT transmitter k	Channel i	Type	Number of SDI HHs served*, m_k	Number of SDI HHs, n_k, affected due to overload				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	450,398	45	0	0	0	30
Oxford	60	Main	256,752	50	0	0	0	48
Sudbury	60	Main	220,644	30	0	0	0	22
Whitehawk Hill	60	Relay	53,729	25	1	0	0	17
Brierley Hill	60	Relay	50,957	10	0	0	0	9
Reigate	60	Relay	40,041	5	0	0	0	5
Winter Hill	59	Main	1,647,867	8	0	0	0	8
Pontop Pike	59	Main	419,897	0	0	0	0	0
Tacolneston	59	Main	224,915	0	0	0	0	0
Hemel Hemp.	59	Relay	42,308	0	0	0	0	0
Luton	59	Relay	15,471	0	0	0	0	0
Beecroft_Hill	59	Relay	12,622	0	0	0	0	0
Emley Moor	52	Main	976,095	22	22	22	22	22
Sandy Heath	52	Main	568,203	0	0	0	0	0
Mendip	52	Main	442,215	0	0	0	0	0
Nottingham	52	Relay	43,079	0	0	0	0	0
Tunbridge Wells	52	Relay	30,412	0	0	0	0	0
Guildford	52	Relay	25,828	0	0	0	0	0
Waltham	58	Main	482,021	0	0	0	0	0
Plympton	58	Main	19,452	0	0	0	0	0
Kidderminster	58	Relay	20,706	0	0	0	0	0
Hertford	58	Relay	12,410	10	10	10	10	10
Workington	58	Relay	5,778	0	0	0	0	0
Bluebell Hill	54	Main	128,498	0	0	0	0	0
Crystal Palace	30	Main	1,951,265	0	0	0	0	0
Sutton Coldfield	46	Main	1,143,589	0	0	0	0	0
Rowridge	28	Main	275,310	1	1	1	1	1
Fenton	28	Relay	77,932	0	0	0	0	0
Kilvey Hill	29	Relay	73,777	0	0	0	0	0
Sheffield	45	Relay	61,792	10	10	10	10	10

Table 88. Weighted percentages of SDI households affected due to interference (main DTT transmitters) with base station transmitter filtering and DTT receiver filtering.

MAIN		% of SDI HHs, F_i , affected due to interference				
DTT channel, *i*	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,386,491	1.13%	0.05%	0.00%	0.05%	1.11%
59	2,820,949	0.06%	0.00%	0.00%	0.00%	0.05%
58	531,932	0.01%	0.00%	0.00%	0.00%	0.00%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	0	0.00%	0.00%	0.00%	0.00%	0.00%
55	0	0.00%	0.00%	0.00%	0.00%	0.00%
54	139,954	0.00%	0.00%	0.00%	0.00%	0.00%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	2,461,572	0.00%	0.00%	0.00%	0.00%	0.00%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	6,393,482	0.00%	0.00%	0.00%	0.00%	0.00%
Total	13,734,379					

Table 89. Weighted percentages of SDI households affected due to interference (relay DTT transmitters) with base station transmitter filtering and DTT receiver filtering.

RELAY		% of SDI HHs, F_i , affected due to interference				
DTT channel, *i*	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	410,009	1.30%	0.05%	0.00%	0.05%	1.27%
59	257,983	0.08%	0.01%	0.00%	0.00%	0.07%
58	164,358	0.01%	0.00%	0.00%	0.00%	0.01%
57	3,583	0.01%	0.01%	0.00%	0.00%	0.00%
56	498	0.01%	0.00%	0.00%	0.00%	0.00%
55	2,943	0.00%	0.00%	0.00%	0.00%	0.00%
54	3,181	0.01%	0.00%	0.00%	0.00%	0.00%
53	11,158	0.01%	0.00%	0.00%	0.00%	0.00%
52	208,338	0.00%	0.00%	0.00%	0.00%	0.00%
51	3,982	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	1,499,287	0.00%	0.00%	0.00%	0.00%	0.00%
Total	2,565,320					

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 90. Estimated number of SDI households affected due to interference throughout the UK with base station transmitter filtering and DTT receiver filtering.

DTT channel, i	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i , affected due to interference MFCN blocks A/B/C	B/C	C	B	A
60	1,796,500	21,014	913	42	885	20,590
59	3,078,932	1,861	92	30	51	1,725
58	696,290	50	18	5	13	31
57	3,583	0	0	0	0	0
56	498	0	0	0	0	0
55	2,943	0	0	0	0	0
54	143,134	2	2	1	2	2
53	11,158	1	0	0	0	0
52	2,669,910	110	47	35	35	84
51	3,982	0	0	0	0	0
≤50**	7,892,770	131	77	31	31	31
Total	16,299,699	23,167	1,150	144	1,017	22,463

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 91. Weighted percentages of SDI households affected due to overload only (main DTT transmitters) with base station transmitter filtering and DTT receiver filtering.

MAIN		% of SDI HHs, F_i , affected due to overload				
DTT channel, *i*	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,386,491	0.01%	0.00%	0.00%	0.00%	0.01%
59	2,820,949	0.00%	0.00%	0.00%	0.00%	0.00%
58	531,932	0.00%	0.00%	0.00%	0.00%	0.00%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	0	0.00%	0.00%	0.00%	0.00%	0.00%
55	0	0.00%	0.00%	0.00%	0.00%	0.00%
54	139,954	0.00%	0.00%	0.00%	0.00%	0.00%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	2,461,572	0.00%	0.00%	0.00%	0.00%	0.00%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	6,393,482	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**13,734,379**					

Table 92. Weighted percentages of SDI households affected due to overload only (relay DTT transmitters) with base station transmitter filtering and DTT receiver filtering.

RELAY		% of SDI HHs, F_i , affected due to overload				
DTT channel, *i*	Number of SDI HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	410,009	1.30%	0.05%	0.00%	0.05%	1.27%
59	257,983	0.08%	0.01%	0.00%	0.00%	0.07%
58	164,358	0.01%	0.00%	0.00%	0.00%	0.01%
57	3,583	0.01%	0.01%	0.00%	0.00%	0.00%
56	498	0.01%	0.00%	0.00%	0.00%	0.00%
55	2,943	0.00%	0.00%	0.00%	0.00%	0.00%
54	3,181	0.01%	0.00%	0.00%	0.00%	0.00%
53	11,158	0.01%	0.00%	0.00%	0.00%	0.00%
52	208,338	0.00%	0.00%	0.00%	0.00%	0.00%
51	3,982	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	1,499,287	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**2,565,320**					

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 93. Estimated number of SDI households affected due to overload only throughout the UK with base station transmitter filtering and DTT receiver filtering.

DTT channel, *i*	Number of SDI HHs served*, M_i	Number of SDI HHs, N_i , affected due to overload				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	1,796,500	301	2	0	0	236
59	3,078,932	10	0	0	0	10
58	696,290	41	41	41	41	41
57	3,583	1	1	0	1	1
56	498	0	0	0	0	0
55	2,943	0	0	0	0	1
54	143,134	0	0	0	0	1
53	11,158	0	0	0	0	0
52	2,669,910	28	28	28	28	28
51	3,982	0	0	0	0	0
≤50**	7,892,770	74	74	74	74	74
Total	**16,299,699**	**456**	**146**	**143**	**144**	**392**

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Communal antenna systems

No mitigation

Table 94. Estimated numbers of "generic" households affected due to interference for specific DTT transmitters and channels, and in the absence of mitigation.

DTT transmitter k	Channel j	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	38,769	20,711	10,835	13,062	27,234
Oxford	60	Main	388,430	22,802	13,263	7,637	9,043	16,950
Sudbury	60	Main	333,162	24,666	13,893	7,947	9,441	18,190
Whitehawk Hill	60	Relay	115,538	12,595	7,036	3,826	4,529	9,006
Brierley Hill	60	Relay	77,683	3,512	1,665	766	943	2,246
Reigate	60	Relay	65,756	3,696	1,929	1,019	1,220	2,578
Winter Hill	59	Main	2,561,801	109,328	77,776	44,029	48,919	58,420
Pontop Pike	59	Main	669,597	28,901	19,876	10,742	12,165	14,848
Tacolneston	59	Main	331,686	8,633	6,131	3,493	3,920	4,675
Hemel Hemp.	59	Relay	71,570	5,476	3,840	2,158	2,432	2,897
Luton	59	Relay	27,166	1,840	1,197	591	675	812
Beecroft Hill	59	Relay	19,858	707	439	205	234	295
Waltham	58	Main	726,193	41,621	30,120	17,705	17,833	21,134
Mendip	58	Main	680,260	27,642	19,958	11,674	11,785	13,886
Plympton	58	Main	32,404	891	597	303	307	367
Kidderminster	58	Relay	31,247	816	519	248	256	316
Hertford	58	Relay	21,228	381	261	135	143	162
Workington	58	Relay	8,892	876	622	352	355	430
Bluebell Hill	54	Main	194,997	6,017	4,540	2,672	2,633	2,626
Emley Moor	52	Main	1,473,633	50,511	38,340	22,476	21,755	21,364
Sandy Heath	52	Main	863,300	38,638	29,515	17,637	17,038	16,631
Heathfield	52	Main	161,433	5,839	4,638	2,991	2,895	2,843
Nottingham	52	Relay	67,091	2,774	2,082	1,256	1,210	1,196
Tunbridge Wells	52	Relay	50,027	1,515	1,129	637	621	608
Guildford	52	Relay	43,347	2,530	1,980	1,225	1,180	1,153
Crystal Palace	30	Main	4,245,632	370,634	293,687	185,167	184,282	183,450
Sutton Coldfield	46	Main	1,786,890	72,665	55,329	32,918	32,739	32,560
Rowridge	28	Main	467,784	20,000	15,194	9,066	9,022	8,978
Fenton	28	Relay	116,268	6,327	4,869	2,920	2,902	2,879
Kilvey Hill	29	Relay	112,919	4,668	3,506	2,046	2,033	2,024
Sheffield	45	Relay	107,064	4,200	2,981	1,583	1,573	1,557

Table 95. Estimated numbers of CAS households affected due to interference for specific DTT transmitters and channels, and in the absence of mitigation.

DTT Transmitter k	Channel i	Type	Number of CAS HHs served*, m_k	Number of CAS HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	60,473	6,026	3,333	1,770	2,155	4,367
Oxford	60	Main	42,701	4,113	2,564	1,565	1,803	3,163
Sudbury	60	Main	36,016	4,587	2,660	1,516	1,791	3,395
Whitehawk Hill	60	Relay	43,185	6,628	3,761	2,067	2,433	4,767
Brierley Hill	60	Relay	9,062	394	176	69	88	254
Reigate	60	Relay	11,835	756	398	208	244	529
Winter Hill	59	Main	342,720	29,498	22,479	14,109	15,450	18,013
Pontop Pike	59	Main	104,152	9,003	6,508	3,739	4,219	5,046
Tacolneston	59	Main	28,789	1,742	1,315	813	899	1,047
Hemel Hemp.	59	Relay	14,604	1,419	1,014	592	660	788
Luton	59	Relay	6,334	405	274	134	151	183
Beecroft Hill	59	Relay	2,862	157	97	42	51	65
Waltham	58	Main	77,061	9,388	6,954	4,200	4,235	5,012
Mendip	58	Main	86,010	7,088	5,183	3,048	3,079	3,625
Plympton	58	Main	6,206	303	222	123	125	153
Kidderminster	58	Relay	3,366	178	118	53	57	70
Hertford	58	Relay	4,521	90	57	30	33	36
Workington	58	Relay	1,110	119	78	41	42	50
Bluebell Hill	54	Main	21,950	1,201	933	577	568	569
Emley Moor	52	Main	159,194	10,458	8,188	5,116	4,972	4,889
Sandy Heath	52	Main	98,158	6,220	4,757	2,821	2,735	2,669
Heathfield	52	Main	21,974	1,801	1,486	1,018	997	979
Nottingham	52	Relay	9,077	727	588	390	378	373
Tunbridge Wells	52	Relay	9,076	608	463	265	257	247
Guildford	52	Relay	8,563	943	776	517	501	492
Crystal Palace	30	Main	1,618,276	194,979	157,098	101,735	101,338	100,941
Sutton Coldfield	46	Main	246,900	15,950	12,522	7,877	7,846	7,813
Rowridge	28	Main	97,112	6,929	5,363	3,308	3,291	3,280
Fenton	28	Relay	11,321	824	651	413	413	412
Kilvey Hill	29	Relay	13,567	944	702	393	393	393
Sheffield	45	Relay	23,853	823	579	299	299	296

Table 96. Weighted percentages of affected CAS households (main DTT transmitters) in the absence of mitigation.

MAIN		% of CAS HHs, F_i , affected due to interference				
DTT channel, *i*	Number of CAS HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	157,326	10.58%	6.15%	3.49%	4.13%	7.85%
59	474,245	8.46%	6.37%	3.92%	4.32%	5.07%
58	143,444	9.91%	7.30%	4.35%	4.39%	5.19%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	44	0.00%	0.00%	0.00%	0.00%	0.00%
55	0	0.00%	0.00%	0.00%	0.00%	0.00%
54	18,651	5.47%	4.25%	2.63%	2.59%	2.59%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	261,128	6.62%	5.17%	3.21%	3.12%	3.06%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	3,338,406	11.10%	8.92%	5.75%	5.73%	5.71%
Total	**4,393,244**					

Table 97. Weighted percentages of affected CAS households (relay DTT transmitters) in the absence of mitigation.

RELAY		% of CAS HHs, F_i , affected due to interference				
DTT channel, *i*	Number of CAS HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	202,117	12.14%	6.76%	3.66%	4.31%	8.66%
59	98,656	8.32%	5.82%	3.23%	3.62%	4.35%
58	49,150	4.30%	2.81%	1.38%	1.47%	1.73%
57	1,302	5.57%	4.13%	3.69%	3.79%	3.79%
56	18,636	6.92%	4.94%	4.02%	3.69%	3.79%
55	746	6.92%	4.94%	4.02%	4.02%	3.69%
54	1,680	6.92%	4.94%	4.02%	4.02%	3.69%
53	2,517	6.92%	4.94%	4.02%	4.02%	4.02%
52	44,128	8.53%	6.84%	4.39%	4.25%	4.16%
51	1,446	6.92%	4.94%	4.02%	4.02%	4.02%
≤50**	400,197	5.32%	3.96%	2.27%	2.27%	2.26%
Total	**820,574**					

* Derived from census data, based on the 70% cut-off counting approach (APSA).

** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 98. Estimated number of affected CAS households throughout the UK in the absence of mitigation.

DTT channel, i	Number of CAS HHs served*, M_i	Number of CAS HHs, N_i , affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	359,443	41,177	23,345	12,876	15,219	29,853
59	572,901	48,335	35,953	21,789	24,080	28,329
58	192,594	16,333	11,855	6,924	7,025	8,301
57	1,302	72	54	48	49	49
56	18,681	1,290	920	749	687	706
55	746	52	37	30	30	27
54	20,331	1,137	876	558	550	545
53	2,517	174	124	101	101	101
52	305,256	21,038	16,509	10,307	10,013	9,818
51	1,446	100	71	58	58	58
≤50**	3,738,602	391,912	313,558	201,182	200,425	199,641
Total	**5,213,819**	**521,619**	**403,302**	**254,621**	**258,237**	**277,430**

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

DTT receiver filtering

Table 99. Estimated numbers of "generic" households affected due to interference for specific DTT transmitters and channels, and with DTT receiver filtering.

DTT transmitter k	Channel i	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	3,082	2,276	1,304	1,294	1,296
Oxford	60	Main	388,430	2,984	2,266	1,370	1,362	1,357
Sudbury	60	Main	333,162	2,883	2,201	1,303	1,298	1,295
Whitehawk Hill	60	Relay	115,538	448	315	171	171	172
Brierley Hill	60	Relay	77,683	126	92	50	49	49
Reigate	60	Relay	65,756	283	229	154	154	153
Winter Hill	59	Main	2,561,801	1,804	1,295	692	691	690
Pontop Pike	59	Main	669,597	330	235	120	120	120
Tacolneston	59	Main	331,686	77	45	23	23	23
Hemel Hemp.	59	Relay	71,570	120	91	57	57	57
Luton	59	Relay	27,166	17	13	5	5	5
Beecroft Hill	59	Relay	19,858	2	1	0	0	0
Waltham	58	Main	726,193	39	20	8	8	8
Mendip	58	Main	680,260	47	37	19	19	19
Plympton	58	Main	32,404	1	1	1	1	1
Kidderminster	58	Relay	31,247	0	0	0	0	0
Hertford	58	Relay	21,228	0	0	0	0	0
Workington	58	Relay	8,892	2	1	1	1	1
Bluebell Hill	54	Main	194,997	0	0	0	0	0
Emley Moor	52	Main	1,473,633	30	30	30	30	30
Sandy Heath	52	Main	863,300	0	0	0	0	0
Heathfield	52	Main	161,433	0	0	0	0	0
Nottingham	52	Relay	67,091	0	0	0	0	0
Tunbridge Wells	52	Relay	50,027	0	0	0	0	0
Guildford	52	Relay	43,347	0	0	0	0	0
Crystal Palace	30	Main	4,245,632	0	0	0	0	0
Sutton Coldfield	46	Main	1,786,890	0	0	0	0	0
Rowridge	28	Main	467,784	1	1	1	1	1
Fenton	28	Relay	116,268	0	0	0	0	0
Kilvey Hill	29	Relay	112,919	0	0	0	0	0
Sheffield	45	Relay	107,064	0	0	0	0	0

Table 100. Estimated numbers of CAS households affected due to interference for specific DTT transmitters and channels, and with DTT receiver filtering.

DTT Transmitter k	Channel i	Type	Number of CAS HHs served*, m_k	Number of CAS HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	60,473	629	487	287	287	287
Oxford	60	Main	42,701	666	518	338	336	337
Sudbury	60	Main	36,016	598	468	280	278	278
Whitehawk Hill	60	Relay	43,185	184	125	61	61	61
Brierley Hill	60	Relay	9,062	7	5	1	1	1
Reigate	60	Relay	11,835	55	45	28	28	28
Winter Hill	59	Main	342,720	774	556	296	296	296
Pontop Pike	59	Main	104,152	147	105	54	54	54
Tacolneston	59	Main	28,789	22	12	5	5	5
Hemel Hemp.	59	Relay	14,604	52	38	26	26	26
Luton	59	Relay	6,334	11	7	3	3	3
Beecroft Hill	59	Relay	2,862	0	0	0	0	0
Waltham	58	Main	77,061	6	2	0	0	0
Mendip	58	Main	86,010	6	5	3	3	3
Plympton	58	Main	6,206	1	1	1	1	1
Kidderminster	58	Relay	3,366	0	0	0	0	0
Hertford	58	Relay	4,521	0	0	0	0	0
Workington	58	Relay	1,110	0	0	0	0	0
Bluebell Hill	54	Main	21,950	0	0	0	0	0
Emley Moor	52	Main	159,194	0	0	0	0	0
Sandy Heath	52	Main	98,158	0	0	0	0	0
Heathfield	52	Main	21,974	0	0	0	0	0
Nottingham	52	Relay	9,077	0	0	0	0	0
Tunbridge Wells	52	Relay	9,076	0	0	0	0	0
Guildford	52	Relay	8,563	0	0	0	0	0
Crystal Palace	30	Main	1,618,276	0	0	0	0	0
Sutton Coldfield	46	Main	246,900	0	0	0	0	0
Rowridge	28	Main	97,112	0	0	0	0	0
Fenton	28	Relay	11,321	0	0	0	0	0
Kilvey Hill	29	Relay	13,567	0	0	0	0	0
Sheffield	45	Relay	23,853	0	0	0	0	0

Table 101. Weighted percentages of affected CAS households (main DTT transmitters) with DTT receiver filtering.

MAIN		% of CAS HHs, F_i , affected due to interference				
DTT channel, *i*	Number of CAS HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	157,326	1.36%	1.06%	0.65%	0.65%	0.65%
59	474,245	0.20%	0.14%	0.07%	0.07%	0.07%
58	143,444	0.01%	0.00%	0.00%	0.00%	0.00%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	44	0.00%	0.00%	0.00%	0.00%	0.00%
55	0	0.00%	0.00%	0.00%	0.00%	0.00%
54	18,651	0.00%	0.00%	0.00%	0.00%	0.00%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	261,128	0.00%	0.00%	0.00%	0.00%	0.00%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	3,338,406	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**4,393,244**					

Table 102. Weighted percentages of affected CAS households (relay DTT transmitters) with DTT receiver filtering.

RELAY		% of CAS HHs, F_i , affected due to interference				
DTT channel, *i*	Number of CAS HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	202,117	0.38%	0.27%	0.14%	0.14%	0.14%
59	98,656	0.26%	0.19%	0.12%	0.12%	0.12%
58	49,150	0.00%	0.00%	0.00%	0.00%	0.00%
57	1,302	0.00%	0.00%	0.00%	0.00%	0.00%
56	18,636	0.00%	0.00%	0.00%	0.00%	0.00%
55	746	0.00%	0.00%	0.00%	0.00%	0.00%
54	1,680	0.00%	0.00%	0.00%	0.00%	0.00%
53	2,517	0.00%	0.00%	0.00%	0.00%	0.00%
52	44,128	0.00%	0.00%	0.00%	0.00%	0.00%
51	1,446	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	400,197	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**820,574**					

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 103. Estimated number of affected CAS households throughout the UK with DTT receiver filtering.

DTT channel, *i*	Number of CAS HHs served*, M_i	Number of CAS HHs, N_i , affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	359,443	2,916	2,217	1,307	1,302	1,303
59	572,901	1,201	858	474	474	474
58	192,594	11	7	3	3	3
57	1,302	0	0	0	0	0
56	18,681	0	0	0	0	0
55	746	0	0	0	0	0
54	20,331	0	0	0	0	0
53	2,517	0	0	0	0	0
52	305,256	0	0	0	0	0
51	1,446	0	0	0	0	0
≤50**	3,738,602	0	0	0	0	0
Total	**5,213,819**	**4,128**	**3,081**	**1,784**	**1,780**	**1,781**

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Base station transmitter filtering and DTT receiver filtering

Table 104. Estimated numbers of “generic” households affected due to interference
for specific DTT transmitters and channels,
with base station transmitter filtering and DTT receiver filtering.

DTT transmitter k	Channel i	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	33	1	0	1	31
Oxford	60	Main	388,430	35	1	0	1	32
Sudbury	60	Main	333,162	41	2	0	2	38
Whitehawk Hill	60	Relay	115,538	4	2	0	2	4
Brierley Hill	60	Relay	77,683	0	0	0	0	0
Reigate	60	Relay	65,756	10	1	0	1	9
Winter Hill	59	Main	2,561,801	13	0	0	0	13
Pontop Pike	59	Main	669,597	0	0	0	0	0
Tacolneston	59	Main	331,686	0	0	0	0	0
Hemel Hemp.	59	Relay	71,570	0	0	0	0	0
Luton	59	Relay	27,166	0	0	0	0	0
Beecroft Hill	59	Relay	19,858	0	0	0	0	0
Waltham	58	Main	726,193	0	0	0	0	0
Mendip	58	Main	680,260	0	0	0	0	0
Plympton	58	Main	32,404	0	0	0	0	0
Kidderminster	58	Relay	31,247	0	0	0	0	0
Hertford	58	Relay	21,228	0	0	0	0	0
Workington	58	Relay	8,892	0	0	0	0	0
Bluebell Hill	54	Main	194,997	0	0	0	0	0
Emley Moor	52	Main	1,473,633	30	30	30	30	30
Sandy Heath	52	Main	863,300	0	0	0	0	0
Heathfield	52	Main	161,433	0	0	0	0	0
Nottingham	52	Relay	67,091	0	0	0	0	0
Tunbridge Wells	52	Relay	50,027	0	0	0	0	0
Guildford	52	Relay	43,347	0	0	0	0	0
Crystal Palace	30	Main	4,245,632	0	0	0	0	0
Sutton Coldfield	46	Main	1,786,890	0	0	0	0	0
Rowridge	28	Main	467,784	1	1	1	1	1
Fenton	28	Relay	116,268	0	0	0	0	0
Kilvey Hill	29	Relay	112,919	0	0	0	0	0
Sheffield	45	Relay	107,064	0	0	0	0	0

Table 105. Estimated numbers of CAS households affected due to interference for specific DTT transmitters and channels, with base station transmitter filtering and DTT receiver filtering.

DTT Transmitter *k*	Channel *i*	Type	Number of CAS HHs served*, m_k	Number of CAS HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	60,473	9	0	0	0	9
Oxford	60	Main	42,701	11	0	0	0	10
Sudbury	60	Main	36,016	9	1	0	1	7
Whitehawk Hill	60	Relay	43,185	0	0	0	0	0
Brierley Hill	60	Relay	9,062	0	0	0	0	0
Reigate	60	Relay	11,835	2	0	0	0	2
Winter Hill	59	Main	342,720	5	0	0	0	5
Pontop Pike	59	Main	104,152	0	0	0	0	0
Tacolneston	59	Main	28,789	0	0	0	0	0
Hemel Hemp.	59	Relay	14,604	0	0	0	0	0
Luton	59	Relay	6,334	0	0	0	0	0
Beecroft Hill	59	Relay	2,862	0	0	0	0	0
Waltham	58	Main	77,061	0	0	0	0	0
Mendip	58	Main	86,010	0	0	0	0	0
Plympton	58	Main	6,206	0	0	0	0	0
Kidderminster	58	Relay	3,366	0	0	0	0	0
Hertford	58	Relay	4,521	0	0	0	0	0
Workington	58	Relay	1,110	0	0	0	0	0
Bluebell Hill	54	Main	21,950	0	0	0	0	0
Emley Moor	52	Main	159,194	0	0	0	0	0
Sandy Heath	52	Main	98,158	0	0	0	0	0
Heathfield	52	Main	21,974	0	0	0	0	0
Nottingham	52	Relay	9,077	0	0	0	0	0
Tunbridge Wells	52	Relay	9,076	0	0	0	0	0
Guildford	52	Relay	8,563	0	0	0	0	0
Crystal Palace	30	Main	1,618,276	0	0	0	0	0
Sutton Coldfield	46	Main	246,900	0	0	0	0	0
Rowridge	28	Main	97,112	0	0	0	0	0
Fenton	28	Relay	11,321	0	0	0	0	0
Kilvey Hill	29	Relay	13,567	0	0	0	0	0
Sheffield	45	Relay	23,853	0	0	0	0	0

Table 106. Weighted percentages of affected CAS households (main DTT transmitters) and with base station transmitter filtering and DTT receiver filtering.

MAIN		% of CAS HHs, F_i, affected due to interference				
DTT channel, *i*	Number of CAS HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	157,326	0.02%	0.00%	0.00%	0.00%	0.02%
59	474,245	0.00%	0.00%	0.00%	0.00%	0.00%
58	143,444	0.00%	0.00%	0.00%	0.00%	0.00%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	44	0.00%	0.00%	0.00%	0.00%	0.00%
55	0	0.00%	0.00%	0.00%	0.00%	0.00%
54	18,651	0.00%	0.00%	0.00%	0.00%	0.00%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	261,128	0.00%	0.00%	0.00%	0.00%	0.00%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	3,338,406	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**4,393,244**					

Table 107. Weighted percentages of affected CAS households (relay DTT transmitters) and with base station transmitter filtering and DTT receiver filtering.

RELAY		% of CAS HHs, F_i, affected due to interference				
DTT channel, *i*	Number of CAS HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	202,117	0.00%	0.00%	0.00%	0.00%	0.00%
59	98,656	0.00%	0.00%	0.00%	0.00%	0.00%
58	49,150	0.00%	0.00%	0.00%	0.00%	0.00%
57	1,302	0.00%	0.00%	0.00%	0.00%	0.00%
56	18,636	0.00%	0.00%	0.00%	0.00%	0.00%
55	746	0.00%	0.00%	0.00%	0.00%	0.00%
54	1,680	0.00%	0.00%	0.00%	0.00%	0.00%
53	2,517	0.00%	0.00%	0.00%	0.00%	0.00%
52	44,128	0.00%	0.00%	0.00%	0.00%	0.00%
51	1,446	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	400,197	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**820,574**					

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 108. Estimated number of affected CAS households throughout the UK and with base station transmitter filtering and DTT receiver filtering..

DTT channel, *i*	Number of CAS HHs Served*, M_i	Number of CAS HHs, N_i , affected due to interference — MFCN blocks				
		A/B/C	B/C	C	B	A
60	359,443	39	1	0	1	36
59	572,901	5	0	0	0	5
58	192,594	0	0	0	0	0
57	1,302	0	0	0	0	0
56	18,681	0	0	0	0	0
55	746	0	0	0	0	0
54	20,331	0	0	0	0	0
53	2,517	0	0	0	0	0
52	305,256	0	0	0	0	0
51	1,446	0	0	0	0	0
≤50**	3,738,602	0	0	0	0	0
Total	5,213,819	44	1	0	1	41

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Domestic installations with amplifiers

No mitigation

Table 109. Estimated numbers of "generic" households affected due to interference for specific DTT transmitters and channels, and in the absence of mitigation.

DTT transmitter k	Channel i	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	11,447	5,439	2,759	3,040	7,324
Oxford	60	Main	388,430	8,161	4,434	2,384	2,587	5,145
Sudbury	60	Main	333,162	6,902	3,709	2,030	2,264	4,610
Whitehawk Hill	60	Relay	115,538	6,010	2,639	1,281	1,367	3,874
Brierley Hill	60	Relay	77,683	1,761	755	326	343	1,001
Reigate	60	Relay	65,756	1,413	716	390	406	898
Winter Hill	59	Main	2,561,801	43,433	28,908	14,628	14,182	16,895
Pontop Pike	59	Main	669,597	7,708	4,988	2,393	2,366	2,956
Tacolneston	59	Main	331,686	2,395	1,553	768	778	953
Hemel Hemp.	59	Relay	71,570	1,428	931	479	495	595
Luton	59	Relay	27,166	371	197	62	72	95
Beecroft Hill	59	Relay	19,858	327	208	86	84	91
Waltham	58	Main	726,193	7,405	4,930	2,380	2,437	2,666
Mendip	58	Main	680,260	6,760	4,614	2,291	2,333	2,420
Plympton	58	Main	32,404	361	241	105	105	100
Kidderminster	58	Relay	31,247	228	135	45	46	47
Hertford	58	Relay	21,228	202	137	67	67	61
Workington	58	Relay	8,892	159	112	63	63	68
Bluebell Hill	54	Main	194,997	2,139	1,483	757	746	744
Emley Moor	52	Main	1,473,633	17,535	12,273	6,163	6,098	6,065
Sandy Heath	52	Main	863,300	7,437	5,187	2,566	2,523	2,503
Heathfield	52	Main	161,433	1,577	1,151	640	629	625
Nottingham	52	Relay	67,091	797	578	313	308	306
Tunbridge Wells	52	Relay	50,027	597	423	207	206	206
Guildford	52	Relay	43,347	593	410	191	186	186
Crystal Palace	30	Main	4,245,632	292,095	211,192	110,714	110,228	109,758
Sutton Coldfield	46	Main	1,786,890	23,299	16,031	7,770	7,746	7,719
Rowridge	28	Main	467,784	12,302	8,929	4,849	4,830	4,803
Fenton	28	Relay	116,268	2,273	1,523	738	733	731
Kilvey Hill	29	Relay	112,919	3,325	2,323	1,157	1,154	1,151
Sheffield	45	Relay	107,064	2,365	1,594	759	753	747

Table 110. Estimated numbers of DIA households affected due to interference for specific DTT transmitters and channels, and in the absence of mitigation.

DTT Transmitter k	Channel i	Type	Number of DIA HHs served*, m_k	Number of DIA HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	156,278	2,509	1,176	587	650	1,607
Oxford	60	Main	89,087	1,667	889	468	507	1,034
Sudbury	60	Main	76,558	1,438	770	418	465	963
Whitehawk Hill	60	Relay	18,643	693	307	150	160	446
Brierley Hill	60	Relay	17,681	414	182	80	84	238
Reigate	60	Relay	13,894	273	138	76	79	176
Winter Hill	59	Main	571,773	8,362	5,580	2,834	2,711	3,174
Pontop Pike	59	Main	145,695	1,386	897	434	421	518
Tacolneston	59	Main	78,040	497	323	160	162	196
Hemel Hemp.	59	Relay	14,680	264	169	84	88	107
Luton	59	Relay	5,368	64	34	10	13	16
Beecroft Hill	59	Relay	4,379	75	48	20	20	21
Waltham	58	Main	167,250	1,542	1,040	511	521	564
Mendip	58	Main	153,113	1,319	908	459	467	484
Plympton	58	Main	6,749	78	54	23	23	21
Kidderminster	58	Relay	7,184	43	24	7	7	7
Hertford	58	Relay	4,306	41	28	14	14	13
Workington	58	Relay	2,005	37	26	15	15	16
Bluebell Hill	54	Main	44,586	444	306	157	154	154
Emley Moor	52	Main	338,683	3,608	2,519	1,268	1,256	1,250
Sandy Heath	52	Main	197,153	1,615	1,128	560	550	547
Heathfield	52	Main	35,936	277	199	107	106	105
Nottingham	52	Relay	14,947	153	110	58	57	56
Tunbridge Wells	52	Relay	10,552	115	83	43	43	43
Guildford	52	Relay	8,962	88	61	28	28	28
Crystal Palace	30	Main	677,045	27,922	19,641	9,921	9,880	9,840
Sutton Coldfield	46	Main	396,799	4,485	3,085	1,508	1,502	1,496
Rowridge	28	Main	95,527	2,129	1,537	826	823	818
Fenton	28	Relay	27,041	531	357	176	175	175
Kilvey Hill	29	Relay	25,599	686	484	242	241	240
Sheffield	45	Relay	21,441	427	294	147	147	146

Table 111. Weighted percentages of affected DIA households (main DTT transmitters) in the absence of mitigation.

MAIN		% of DIA HHs, F_i , affected due to interference				
DTT channel, *i*	Number of DIA HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	481,148	1.74%	0.88%	0.46%	0.50%	1.12%
59	978,947	1.29%	0.85%	0.43%	0.41%	0.49%
58	351,604	0.90%	0.61%	0.30%	0.31%	0.33%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	56	0.00%	0.00%	0.00%	0.00%	0.00%
55	0	0.00%	0.00%	0.00%	0.00%	0.00%
54	48,568	1.00%	0.69%	0.35%	0.35%	0.34%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	686,410	0.96%	0.67%	0.34%	0.33%	0.33%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	2,218,788	2.95%	2.07%	1.05%	1.04%	1.04%
Total	**4,765,521**					

Table 112. Weighted percentages of affected DIA households (relay DTT transmitters) in the absence of mitigation.

RELAY		% of DIA HHs, F_i , affected due to interference				
DTT channel, *i*	Number of DIA HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	142,332	2.75%	1.25%	0.61%	0.64%	1.71%
59	89,555	1.65%	1.03%	0.47%	0.49%	0.59%
58	63,165	0.89%	0.58%	0.27%	0.27%	0.27%
57	1,244	0.68%	1.04%	1.04%	0.65%	0.65%
56	17,809	1.04%	1.63%	1.04%	1.10%	0.65%
55	712	1.04%	0.65%	0.66%	1.04%	1.10%
54	1,606	0.65%	1.10%	0.66%	0.72%	1.04%
53	2,405	1.63%	1.10%	0.66%	0.63%	0.72%
52	49,461	1.04%	0.74%	0.37%	0.37%	0.37%
51	1,382	1.18%	1.10%	0.66%	0.66%	0.63%
≤50**	520,437	2.22%	1.53%	0.76%	0.76%	0.76%
Total	**890,108**					

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 113. Estimated number of affected DIA households throughout the UK in the absence of mitigation.

DTT channel, i	Number of DIA HHs served*, M_i	Number of DIA HHs, N_i , affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	623,480	12,303	6,013	3,069	3,342	7,824
59	1,068,501	14,085	9,290	4,638	4,494	5,312
58	414,769	3,723	2,520	1,239	1,259	1,321
57	1,244	8	13	13	8	8
56	17,865	184	290	184	196	116
55	712	7	5	5	7	8
54	50,173	495	350	181	180	184
53	2,405	39	26	16	15	17
52	735,871	7,115	4,981	2,507	2,477	2,464
51	1,382	16	15	9	9	9
≤50**	2,739,226	77,082	54,014	27,223	27,111	26,999
Total	**5,655,629**	**115,058**	**77,517**	**39,084**	**39,099**	**44,263**

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

DTT receiver filtering

Table 114. Estimated numbers of "generic" households affected due to interference for specific DTT transmitters and channels, and with DTT receiver filtering.

DTT transmitter k	Channel i	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to interference — MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	7,873	2,437	1,203	1,499	6,161
Oxford	60	Main	388,430	5,781	2,314	1,251	1,500	4,431
Sudbury	60	Main	333,162	5,283	2,210	1,206	1,414	3,990
Whitehawk Hill	60	Relay	115,538	3,552	522	178	382	3,145
Brierley Hill	60	Relay	77,683	932	117	45	76	792
Reigate	60	Relay	65,756	912	260	147	188	755
Winter Hill	59	Main	2,561,801	6,558	1,312	672	671	5,201
Pontop Pike	59	Main	669,597	1,113	228	115	116	865
Tacolneston	59	Main	331,686	363	49	24	24	289
Hemel Hemp.	59	Relay	71,570	270	89	54	54	212
Luton	59	Relay	27,166	36	12	6	6	28
Beecroft Hill	59	Relay	19,858	17	1	0	0	11
Waltham	58	Main	726,193	63	37	11	14	14
Mendip	58	Main	680,260	116	79	34	41	37
Plympton	58	Main	32,404	1	1	1	1	1
Kidderminster	58	Relay	31,247	0	0	0	0	0
Hertford	58	Relay	21,228	0	0	0	0	0
Workington	58	Relay	8,892	5	3	1	2	2
Bluebell Hill	54	Main	194,997	0	0	0	0	0
Emley Moor	52	Main	1,473,633	30	30	30	30	30
Sandy Heath	52	Main	863,300	0	0	0	0	0
Heathfield	52	Main	161,433	0	0	0	0	0
Nottingham	52	Relay	67,091	0	0	0	0	0
Tunbridge Wells	52	Relay	50,027	0	0	0	0	0
Guildford	52	Relay	43,347	0	0	0	0	0
Crystal Palace	30	Main	4,245,632	0	0	0	0	0
Sutton Coldfield	46	Main	1,786,890	0	0	0	0	0
Rowridge	28	Main	467,784	1	1	1	1	1
Fenton	28	Relay	116,268	0	0	0	0	0
Kilvey Hill	29	Relay	112,919	0	0	0	0	0
Sheffield	45	Relay	107,064	0	0	0	0	0

Table 115. Estimated numbers of DIA households affected due to interference for specific DTT transmitters and channels, and with DTT receiver filtering.

DTT Transmitter k	Channel i	Type	Number of DIA HHs served*, m_k	Number of DIA HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	156,278	1,708	501	242	307	1,348
Oxford	60	Main	89,087	1,167	456	243	291	888
Sudbury	60	Main	76,558	1,098	451	244	288	835
Whitehawk Hill	60	Relay	18,643	413	71	28	52	363
Brierley Hill	60	Relay	17,681	223	28	11	19	190
Reigate	60	Relay	13,894	180	53	31	39	148
Winter Hill	59	Main	571,773	1,168	200	101	101	958
Pontop Pike	59	Main	145,695	184	33	16	16	147
Tacolneston	59	Main	78,040	72	9	5	5	58
Hemel Hemp.	59	Relay	14,680	44	13	8	8	35
Luton	59	Relay	5,368	6	2	1	1	5
Beecroft Hill	59	Relay	4,379	4	0	0	0	3
Waltham	58	Main	167,250	14	8	3	4	4
Mendip	58	Main	153,113	22	15	6	8	7
Plympton	58	Main	6,749	0	0	0	0	0
Kidderminster	58	Relay	7,184	0	0	0	0	0
Hertford	58	Relay	4,306	0	0	0	0	0
Workington	58	Relay	2,005	1	1	0	1	1
Bluebell Hill	54	Main	44,586	0	0	0	0	0
Emley Moor	52	Main	338,683	8	8	8	8	8
Sandy Heath	52	Main	197,153	0	0	0	0	0
Heathfield	52	Main	35,936	0	0	0	0	0
Nottingham	52	Relay	14,947	0	0	0	0	0
Tunbridge Wells	52	Relay	10,552	0	0	0	0	0
Guildford	52	Relay	8,962	0	0	0	0	0
Crystal Palace	30	Main	677,045	0	0	0	0	0
Sutton Coldfield	46	Main	396,799	0	0	0	0	0
Rowridge	28	Main	95,527	0	0	0	0	0
Fenton	28	Relay	27,041	0	0	0	0	0
Kilvey Hill	29	Relay	25,599	0	0	0	0	0
Sheffield	45	Relay	21,441	0	0	0	0	0

Table 116. Weighted percentages of affected DIA households (main DTT transmitters) with DTT receiver filtering.

MAIN		% of DIA HHs, F_i , affected due to interference				
DTT channel, *i*	Number of DIA HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	481,148	1.23%	0.44%	0.23%	0.28%	0.95%
59	978,947	0.18%	0.03%	0.02%	0.02%	0.15%
58	351,604	0.01%	0.01%	0.00%	0.00%	0.00%
57	0	0.00%	0.00%	0.00%	0.00%	0.00%
56	56	0.00%	0.00%	0.00%	0.00%	0.00%
55	0	0.00%	0.00%	0.00%	0.00%	0.00%
54	48,568	0.00%	0.00%	0.00%	0.00%	0.00%
53	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	686,410	0.00%	0.00%	0.00%	0.00%	0.00%
51	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	2,218,788	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**4,765,521**					

Table 117. Weighted percentages of affected DIA households (relay DTT transmitters) with DTT receiver filtering.

RELAY		% of DIA HHs, F_i , affected due to interference				
DTT channel, *i*	Number of DIA HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	142,332	1.63%	0.30%	0.14%	0.22%	1.39%
59	89,555	0.22%	0.06%	0.03%	0.03%	0.17%
58	63,165	0.01%	0.01%	0.00%	0.00%	0.00%
57	1,244	0.01%	0.01%	0.01%	0.01%	0.01%
56	17,809	0.01%	0.01%	0.01%	0.01%	0.01%
55	712	0.00%	0.00%	0.00%	0.00%	0.00%
54	1,606	0.00%	0.00%	0.00%	0.00%	0.00%
53	2,405	0.00%	0.00%	0.00%	0.00%	0.00%
52	49,461	0.00%	0.00%	0.00%	0.00%	0.00%
51	1,382	0.00%	0.00%	0.00%	0.00%	0.00%
≤50**	520,437	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**890,108**					

* Derived from census data, based on the 70% cut-off counting approach (APSA).

** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 118. Estimated number of affected DIA households throughout the UK with DTT receiver filtering.

DTT channel, i	Number of DIA HHs served*, M_i	Number of DIA HHs, N_i , affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	623,480	8,251	2,536	1,289	1,633	6,575
59	1,068,501	1,952	353	182	182	1,585
58	414,769	45	29	11	15	14
57	1,244	0	0	0	0	0
56	17,865	2	2	2	2	2
55	712	0	0	0	0	0
54	50,173	0	0	0	0	0
53	2,405	0	0	0	0	0
52	735,871	9	9	9	9	9
51	1,382	0	0	0	0	0
≤50**	2,739,226	0	0	0	0	0
Total	**5,655,629**	**10,260**	**2,929**	**1,493**	**1,841**	**8,186**

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Base station filtering and DTT receiver filtering

Table 119. Estimated numbers of “generic” households affected due to interference for specific DTT transmitters and channels, with base station transmitter filtering and DTT receiver filtering.

DTT transmitter *k*	Channel *i*	Type	Number of generic HHs served*, m_k	Number of generic HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	667,029	5,394	291	3	279	5,101
Oxford	60	Main	388,430	3,753	272	5	259	3,543
Sudbury	60	Main	333,162	3,209	256	5	248	3,042
Whitehawk Hill	60	Relay	115,538	3,189	194	13	185	3,001
Brierley Hill	60	Relay	77,683	813	26	0	23	749
Reigate	60	Relay	65,756	711	52	1	47	663
Winter Hill	59	Main	2,561,801	4,766	86	28	35	4,460
Pontop Pike	59	Main	669,597	772	7	2	2	733
Tacolneston	59	Main	331,686	269	1	0	0	251
Hemel Hemp.	59	Relay	71,570	182	3	0	0	173
Luton	59	Relay	27,166	25	0	0	0	21
Beecroft Hill	59	Relay	19,858	13	0	0	0	10
Waltham	58	Main	726,193	16	9	2	3	5
Mendip	58	Main	680,260	65	43	13	22	22
Plympton	58	Main	32,404	1	0	0	0	0
Kidderminster	58	Relay	31,247	0	0	0	0	0
Hertford	58	Relay	21,228	0	0	0	0	0
Workington	58	Relay	8,892	3	2	0	2	2
Bluebell Hill	54	Main	194,997	0	0	0	0	0
Emley Moor	52	Main	1,473,633	30	30	30	30	30
Sandy Heath	52	Main	863,300	0	0	0	0	0
Heathfield	52	Main	161,433	0	0	0	0	0
Nottingham	52	Relay	67,091	0	0	0	0	0
Tunbridge Wells	52	Relay	50,027	0	0	0	0	0
Guildford	52	Relay	43,347	0	0	0	0	0
Crystal Palace	30	Main	4,245,632	0	0	0	0	0
Sutton Coldfield	46	Main	1,786,890	0	0	0	0	0
Rowridge	28	Main	467,784	1	1	1	1	1
Fenton	28	Relay	116,268	0	0	0	0	0
Kilvey Hill	29	Relay	112,919	0	0	0	0	0
Sheffield	45	Relay	107,064	0	0	0	0	0

Table 120. Estimated numbers of DIA households affected due to interference
for specific DTT transmitters and channels,
with base station transmitter filtering and DTT receiver filtering.

DTT Transmitter k	Channel i	Type	Number of DIA HHs served*, m_k	Number of DIA HHs, n_k, affected due to interference				
				MFCN blocks				
				ABC	BC	C	B	A
Belmont	60	Main	156,278	1,190	61	1	58	1,127
Oxford	60	Main	89,087	749	51	1	49	708
Sudbury	60	Main	76,558	674	54	1	52	640
Whitehawk Hill	60	Relay	18,643	367	24	2	24	345
Brierley Hill	60	Relay	17,681	195	6	0	6	180
Reigate	60	Relay	13,894	139	10	0	9	130
Winter Hill	59	Main	571,773	902	18	6	7	844
Pontop Pike	59	Main	145,695	136	1	0	0	129
Tacolneston	59	Main	78,040	55	0	0	0	51
Hemel Hemp.	59	Relay	14,680	30	0	0	0	29
Luton	59	Relay	5,368	5	0	0	0	4
Beecroft Hill	59	Relay	4,379	3	0	0	0	2
Waltham	58	Main	167,250	4	2	1	1	1
Mendip	58	Main	153,113	11	7	2	4	4
Plympton	58	Main	6,749	0	0	0	0	0
Kidderminster	58	Relay	7,184	0	0	0	0	0
Hertford	58	Relay	4,306	0	0	0	0	0
Workington	58	Relay	2,005	1	1	0	1	1
Bluebell Hill	54	Main	44,586	0	0	0	0	0
Emley Moor	52	Main	338,683	8	8	8	8	8
Sandy Heath	52	Main	197,153	0	0	0	0	0
Heathfield	52	Main	35,936	0	0	0	0	0
Nottingham	52	Relay	14,947	0	0	0	0	0
Tunbridge Wells	52	Relay	10,552	0	0	0	0	0
Guildford	52	Relay	8,962	0	0	0	0	0
Crystal Palace	30	Main	677,045	0	0	0	0	0
Sutton Coldfield	46	Main	396,799	0	0	0	0	0
Rowridge	28	Main	95,527	0	0	0	0	0
Fenton	28	Relay	27,041	0	0	0	0	0
Kilvey Hill	29	Relay	25,599	0	0	0	0	0
Sheffield	45	Relay	21,441	0	0	0	0	0

Table 121. Weighted percentages of affected DIA households (main DTT transmitters) and with base station transmitter filtering and DTT receiver filtering.

MAIN		% of DIA HHs, F_i , affected due to interference				
DTT channel, *i*	Number of DIA HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	481,148	0.81%	0.05%	0.00%	0.05%	0.77%
59	978,947	0.14%	0.00%	0.00%	0.00%	0.13%
58	351,604	0.00%	0.00%	0.00%	0.00%	0.00%
57**	0	0.00%	0.00%	0.00%	0.00%	0.00%
56**	56	0.00%	0.00%	0.00%	0.00%	0.00%
55	0	0.00%	0.00%	0.00%	0.00%	0.00%
54**	48,568	0.00%	0.00%	0.00%	0.00%	0.00%
53**	0	0.00%	0.00%	0.00%	0.00%	0.00%
52	686,410	0.00%	0.00%	0.00%	0.00%	0.00%
51**	0	0.00%	0.00%	0.00%	0.00%	0.00%
≤50***	2,218,788	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**4,765,521**					

Table 122. Weighted percentages of affected DIA households (relay DTT transmitters) and with base station transmitter filtering and DTT receiver filtering.

RELAY		% of DIA HHs, F_i , affected due to interference				
DTT channel, *i*	Number of DIA HHs served*, M_i	MFCN blocks				
		A/B/C	B/C	C	B	A
60	142,332	1.40%	0.08%	0.01%	0.08%	1.30%
59	89,555	0.16%	0.00%	0.00%	0.00%	0.14%
58	63,165	0.01%	0.00%	0.00%	0.00%	0.00%
57**	1,244	0.01%	0.00%	0.00%	0.00%	0.01%
56**	17,809	0.01%	0.00%	0.00%	0.00%	0.01%
55	712	0.00%	0.00%	0.00%	0.00%	0.00%
54**	1,606	0.00%	0.00%	0.00%	0.00%	0.00%
53**	2,405	0.00%	0.00%	0.00%	0.00%	0.00%
52	49,461	0.00%	0.00%	0.00%	0.00%	0.00%
51**	1,382	0.00%	0.00%	0.00%	0.00%	0.00%
≤50***	520,437	0.00%	0.00%	0.00%	0.00%	0.00%
Total	**890,108**					

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

Table 123. Estimated number of affected DIA households
throughout the UK and with base station transmitter filtering and DTT receiver filtering..

DTT channel, *i*	Number of DIA HHs Served*, M_i	Number of DIA HHs, N_i, affected due to interference				
		MFCN blocks				
		A/B/C	B/C	C	B	A
60	623,480	5,891	365	11	346	5,553
59	1,068,501	1,484	24	8	9	1,389
58	414,769	19	12	2	7	8
57**	1,244	0	0	0	0	0
56**	17,865	1	0	0	0	1
55	712	0	0	0	0	0
54**	50,173	0	0	0	0	0
53**	2,405	0	0	0	0	0
52	735,871	9	9	9	9	9
51**	1,382	0	0	0	0	0
≤50***	2,739,226	0	0	0	0	0
Total	**5,655,629**	**7,405**	**411**	**31**	**373**	**6,961**

* Derived from census data, based on the 70% cut-off counting approach (APSA).
** Derived from the simulation results for 3 highly populated transmitters serving below channel 50.

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