# Coexistence between LTE and DTT - Practical experience following the clearance and relicensing of 800 MHz spectrum in the UK

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**Abstract**

The re-use of 800 MHz spectrum for mobile broadband has led governments and regulators to instigate major programmes of interference mitigation. The resulting work programmes have led to a greater understanding of coexistence of TV and mobile services in the same band. This paper summarises the new and important advances in technical understanding of coexistence from the mitigation programme in the UK. The new licences for the 800 MHz spectrum in the UK required licensees to set up a company to mitigate interference. It is required to operate an interference prediction model, to communicate with the public, to provide practical assistance to mitigate interference and to report on its performance to an independent Oversight Board. In practice, television interference has been reported by only a small number of those households predicted to be at risk. A combination of operational experience, practical observations and research have led to improved modelling, more targeted communications and a revised approach to viewer support.

## Introduction - study results have fed back to improve models and specifications

An interference mitigation programme is underway in the UK and this has led to an improved understanding of real-world TV reception and interference prediction and mitigation. This paper reports the key results to date, including a number of improvements to predictive modelling of which homes are more likely to be affected by TV interference from LTE base stations. The results are important because they provide background information for future spectrum reuse programmes and provide insights into how to improve products and system designs for better coexistence. Amongst the results is the finding that predictive modelling can be improved significantly by adopting household antenna gains from measurement campaigns, rather than assuming a standard antenna response. Adoption of this and other findings summarised in this paper can lead to a worthwhile improvement in the accuracy of predictive modelling.

**Background to the LTE/TV Interference mitigation programme**

The current interference mitigation programme is associated with the reuse, for mobile broadband (LTE), of UHF 800 MHz spectrum. This was formerly used mainly for terrestrial television. It was recognised early in planning for Digital Terrestrial TV (DTT) in the 1990s that the increase in spectrum efficiency DTT brings would mean that a switch to all digital operation would free up some spectrum for other uses. Agreements between Western European countries later led to the repurposing of the 800 MHz band for mobile broadband use. The technical issues relating to this mobile allocation were first studied by a European working group, CEPT WG-SE42 [1]. During the lead up to the auction of this spectrum in the UK in March 2013, Ofcom (The UK's independent regulator for communications industries and spectrum) led a comprehensive programme of work with stakeholders in 2010 which included measurements, computer simulations and a field trial. The reports from the Ofcom studies [2,3,4] illustrated an interference risk that could largely be mitigated by the use of DTT receiver filters. This and subsequent Government policy decisions about the extent and nature of mitigation [5] led to a mitigation programme. The LTE licensees were required to set up and jointly fund a company to implement the mitigation policy. The resulting company is Digital Mobile Spectrum Limited (DMSL, referred to in some policy documents as "mitco"), which operates under the brand at800. The mitigation process includes using a computer model to predict which homes might be affected by interference in the near future, based on DTT coverage data from the UK Planning Model [6], and data on prospective LTE base station deployments provided by the 800 MHz licensees. The data is used for communication with people living in areas at risk of interference. This consists of the targeted mailings of postcards to properties identified as at risk, as well as broader public relations, advertising, stakeholder relations and social media marketing.

The work of DMSL is monitored from a regulatory point of view by the 4G/TV Coexistence Oversight Board, made up of representatives of the 800 MHz licensees, terrestrial TV broadcasters and three independent members including a chairman. The board also includes observers from Ofcom, Government and DMSL. This Oversight Board asked technical representatives from DMSL, Ofcom, and the broadcasters to undertake support work to monitor technical aspects of the mitigation programme with a view to improving interference prediction and mitigation; and it is that work that forms the basis of this paper. Two important reasons for creating a joint Oversight Board are to build a collaborative environment where mobile network operators, DTT broadcasters, the regulator and the Government can work together to ensure an effective and efficient mitigation process; and to allow flexibility to agree changes to the mitigation programme as it progresses to allow it to adapt in line with experience, maintaining and improving its effectiveness.

From the outset of the planning for reuse of the 800 MHz spectrum, it was envisaged that computer predictions of interference would be used as the basis for the interference mitigation programme. The UK has a well-established model for planning and predicting DTT coverage (the UK Planning Model [6]) and outputs from this model are used for calculating interference. Two aspects of interference prediction are of interest: prediction of the specific areas that might be affected; and the overall numbers of homes that could be affected, for example to plan the mitigation programme. The following paragraphs give a brief outline of the UK Planning Model and the interference prediction modelling.

## DTT Planning in the UK

National UK DTT services are provided on six multiplexes, three mainly for public service broadcasts and three for commercial services. The public service multiplexes have coverage obligations and are broadcast from 1156 transmitter sites, with the additional three commercial multiplexes being carried by 80 of those sites serving larger populations. The UK Planning Model for DTT coverage has its basis in propagation modelling using well-tested algorithms and has been refined and updated to include changes required for both DVB-T and DVB-T2. Terrain height and clutter data is used when determining path profiles; diffraction loss over the surface as well as duct /scatter losses over a tropospheric path are considered in order to determine interference limited coverage in the presence of both UK and external interferers. The network carrying the three public service broadcast multiplexes has been planned to provide acceptable coverage to 98.5% of UK households for 99% of the time. The predictions are given in terms of the percentage of locations covered within a given area; a 100 m x 100 m square area of land (or pixel). This is determined by comparison of the wanted signal level and the nuisance signal; the latter comprising a component due to noise in addition to the contributions from the relevant interferers weighted according to their protection ratios. The spatial variation in signal level across the pixel is assumed to follow a log-normal distribution.

## Initial Trials and Pilot deployments

Before the licences were auctioned, Ofcom organised a technical trial of LTE transmissions in the Tamworth area in central England. Two important findings led to refinements in the modelling and technical work. Firstly, some receivers were found to be more sensitive than expected to "idle" signals from LTE base stations. These signals occur when a base station is unloaded and has time varying output power. In the trial, these were seen to disrupt the automatic gain functions in some TV receivers. Secondly, it was found that amplified TV reception systems were more susceptible to interference than simple unamplified ones. This trial, which did not involve viewers, also resulted in minor changes to the propagation model used for the interfering path.

Later, during the preliminary stages of the licensed service roll-out in early 2013, a number of pilot projects were organised by DMSL to test its processes (such as the mailing of postcard advice) and gave a chance for further technical measurements. Typically these pilot projects involved activating a few base stations in a small area. The early technical observations included:

- Viewers sometimes watch transmitters that wouldn't be expected; in particular a preference was noted for 6-multiplex sites transmitting both public service and commercial multiplexes, even when a better quality signal was available from a 3-multiplex public service only site;
- In London numbers of reported interference cases were lower than expected and this led to an investigation of the impact of DTT antennas having lower gains than assumed in areas of high television signal field strengths.

In the early days of rollout, it quickly became clear that of those homes considered to be at some risk of interference, the number that actually complain of interference is relatively small. Whereas before the programme it was envisaged that 900,000 homes that solely rely on DTT for television services might be affected, current forecasts based on experience so far put the final figure at below 90,000 across the UK. The reasons for these differences are explored in the following paragraphs. There is still some uncertainly associated with the figure of fewer than 90,000 anticipated cases and this is discussed later in this paper.

**Summary of main variables involved in interference occuring, being observed and reported**

There are many sources of real world uncertainty that will affect the number of instances of reception failure linked to LTE.

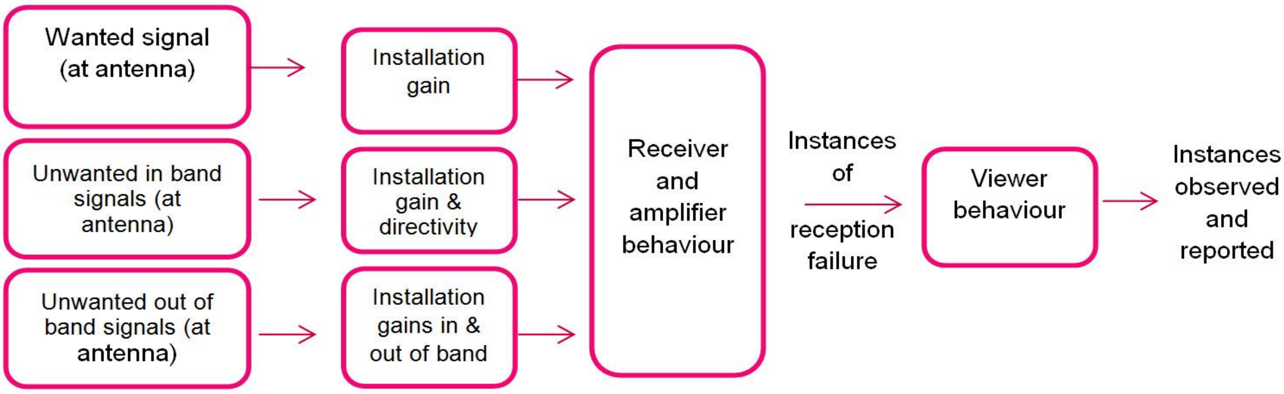


**Figure 1 – Simplified view of sources of uncertainty**

Not all instances of reception failure will be observed and reported. There is additional uncertainty about viewer behaviour when they notice a problem. Consumer research from DMSL prior to the roll out of LTE800 in the UK indicated that where viewers had noticed a problem with DTT reception in the past, only 25% had taken action to resolve it. Figure 1 breaks down, at high level, the types of sources of uncertainty. Each of the headings in the boxes has an associated variability. Variability in antenna system and receiver performance leads to very large differences between the susceptibility of individual homes to TV interference, even in adjacent houses. So there are wide ranges of difference in: prediction accuracy for wanted and interfering signal levels in homes; the way the TV receiver handles those signals; and whether or not users notice and report any problem. This means that many more homes are necessarily categorised as 'at risk' of interference than are actually affected by it, notice it, or report it.

As the LTE rollout and corresponding mitigation programme has progressed we have been able to learn from experience and so adapt the interference prediction modelling and other aspects of the mitigation programme to take account of the wide range of susceptibility to interference

The key observations made during the early stages of the programme have been:

| **Key observations from the interference mitigation programme** |
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| There have been fewer reports of interference in strong DTT signal areas compared with predictions. The prediction modelling originally assumed the ITU standard DTT reception antenna response. In practice most antennas in these areas are lower gain than assumed. This means the interfering and wanted signals are |

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|---|
| both lower, and receivers are better protected against near channel interference at lower signal levels. Predictive modelling is being adjusted to take account of this. |
| London has generally strong DTT signals from the Crystal Palace transmitter and there have been very few instances of interference in London. In addition to the lower antenna gain issue mentioned above, for London the DTT frequencies are at the bottom end of the band, far away from the LTE signals. Both wide band antennas and antennas that are optimised for the lower part of the band are in use in London, and the latter give additional protection from LTE signals. Around half of UK homes use wideband antennas.[7] |
| In practice, many reports of interference are associated with poor quality antenna reception systems and systems with amplifiers. Twice as many interference cases have been found in homes where DTT signal powers at the receiving equipment are over the recommended range for acceptable reception (>65dBµV) than below this range (<45dBµV). |
| Call centres dealing with telephone and email enquiries make a contribution to diagnosis of problems; often home visits by technicians are needed to correctly diagnose problems. In practice, even with a home visit it is often difficult to determine if a problem is caused by LTE or some other reason. |
| Relatively small changes in base station radiated power levels can significantly affect predictions of interference. |
| In some areas with weak DTT levels, higher numbers of incidences of interference are observed. |
| In a small number of cases, interference has been caused by LTE signal ingress to system cabling, unshielded TV antenna outlet sockets and poor quality fly leads (that connect the TV receiver to the wall socket outlet). |
| Homes experiencing interference that have received explanatory postcards are much more likely to call the help line and get interference resolved than equivalent homes with no postcard. |
| The earlier observation that viewers often receive services from a transmitter different to the one that might be expected has an impact on the susceptibility to interference. |

A selection of these observations and related work and developments are explored in the following paragraphs:

**TV antenna system gain has a significant impact on susceptibility to LTE interference:-**

Modelling the effects of LTE interference on DTT reception relies on predictions of the LTE and DTT signal levels received by domestic DTT antenna installations. The effect of these signal levels depends in turn on the levels delivered to antenna and distribution amplifiers and to TV receivers. There are three different mechanisms by which the LTE signals can potentially interfere with DTT reception, as shown in Table 1. The effect of these different mechanisms is determined by different received combinations of DTT and LTE signal levels, falling in and outside the TV band.

| ***Interference mechanism*** | ***Conditions necessary for interference to occur*** | ***Locations where it is most likely to occur*** |
|---|---|---|
| 1) DTT receivers and amplifiers overloaded by high level LTE signals falling outside the wanted TV channels | **A sufficient level of LTE signal level** is received to overload the DTT receiver and/or associated amplifier | In rural areas where higher gain DTT antenna installations are used to receive weaker DTT signals and locations within 1 km of an LTE base station. |
| 2) In channel leakage from LTE transmitters (Adjacent Channel Leakage) | Highest DTT channels in use **and** high LTE leakage level ***and*** low DTT level ***at rooftop antenna*** | The subset of rural areas where weaker DTT signals are available, higher DTT channel frequencies are in use and homes are within 1 km of an LTE base station. |

| | | |
|---|---|---|
| 3) Temporal power variations in LTE base station signal cause instability in some DTT receivers | LTE signal level around 10dB greater than DTT signal level ***at TV antenna, and***<br>LTE transmitter has high temporal power variations ***and*** a susceptible DTT receiver is in use | In areas where LTE base stations are in use with high temporal power variations and locations within 1 km of an LTE base station. |

**Table 1 - principal interference mechanisms**

The predictions of DTT coverage are based on an assumption that domestic antenna systems have a nominal gain of 7 dBd, with the antenna 10 m above ground. In practice households only need a receiver antenna system of this gain and height in areas of low DTT signal strength. Households in higher signal strength areas generally have much lower gain antenna systems and may in fact require this lower gain to avoid DTT signals alone overloading the television reception equipment.

The interference mechanism that has been to found in practice to have the greatest effect is mechanism 1 in Table 1, and is dependent on the strength of the LTE signal level arriving at the TV receiver or amplifier. This level is dependent on four main factors: i) the power of the LTE base station, ii) the distance of the DTT household from the LTE base station, iii) the alignment of the DTT household's rooftop antenna to the LTE base station and iv) the height and gain of the home antenna system (including the presence or otherwise of an amplifier) at both the DTT frequencies and the LTE frequencies. To better understand the effect of this assumption, Ofcom conducted a study in early 2015, measuring the real-world gain of 300 domestic DTT antenna installations in different DTT signal strength areas.

The study found that the gain of domestic TV antenna systems varied significantly between households and had a typical standard deviation of 11.3 dB. It also found that on average much lower gain antenna systems were in use closer to transmitters and higher gain antenna systems in lower signal strength areas. As can be seen in Chart 1, the mean antenna system gains varied from around 23 dBd in low signal strength areas to -20 dBd in high signal strength areas compared with the 7 dBd antenna system gain assumed for coverage predictions.

The higher gain of some antenna systems can result from a combination of using higher gain antennas, height gain due to higher antenna position and amplification. Lower system gains can result from a combination of using lower gain antennas, lower mounting positions, use of passive signal splitters, damaged antennas and/or cables, water-filled termination boxes or cables, corrosion, lack of power to masthead amplifiers. Many of these factors can result from natural ageing of system components.

The effect of the variation in antenna system gain is to reduce the susceptibility to interference of homes in medium to high signal strength areas whilst increasing it in lower field strength areas, particularly in homes where an amplifier has been fitted, as is shown in Figure 2.

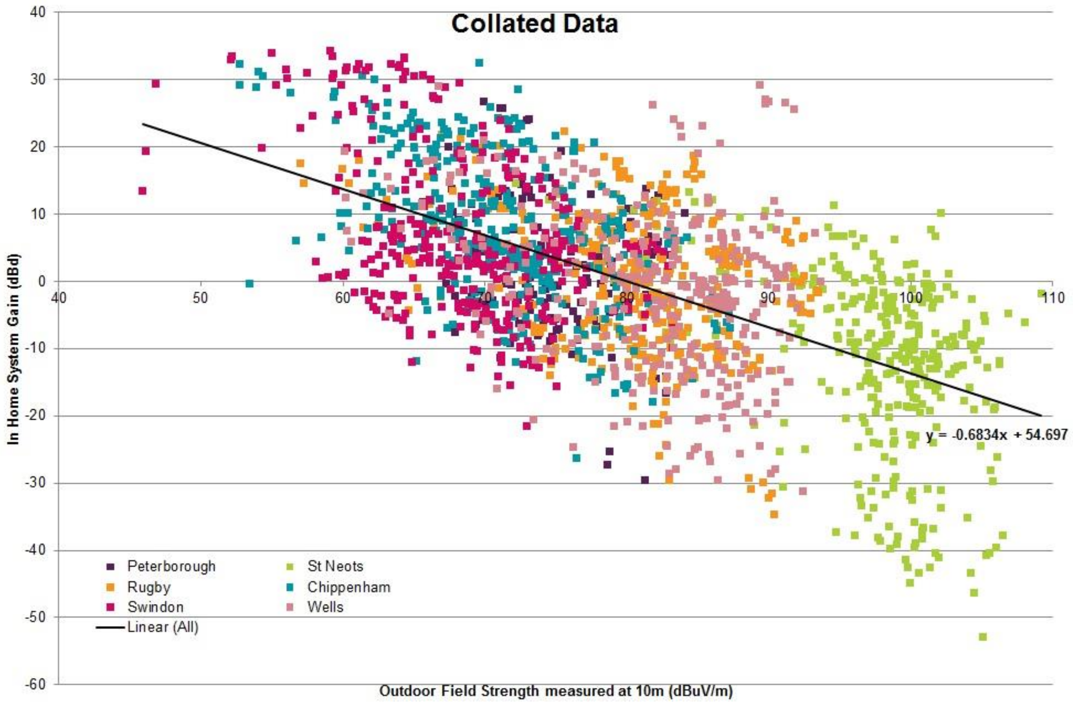



**Chart 1 - Measured system gain against measured outdoor DTT field strength**

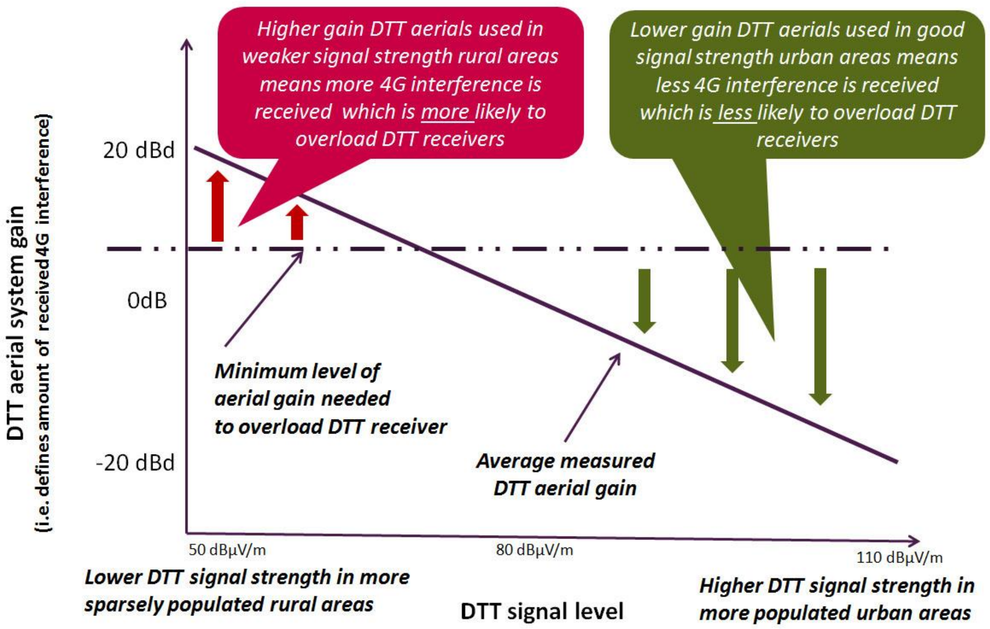



**Figure 2 Antenna System Gain versus DTT signal level**

At the time of writing, the results are being fed back into the model so that the modelling takes account of the variation of antenna gain with DTT field strength. Early indications are that this improves the accuracy of predictive modelling.

**The cause of TV reception problems are usually difficult to diagnose by phone, meaning home visits are necessary:-**

Even with home visits, attribution of reception problems to a particular cause can be difficult. This means that the interference mitigation programme has needed to adapt as we have learnt more about diagnosis, and to provide a greater proportion of home visits than was originally envisaged. Following its first six months supporting viewers in the second half of 2013, the Oversight Board agreed operational changes to DMSL's approach. This change meant resources could be shifted from the proactive mailing of 800 MHz signal filters to households that could be at risk of interference to providing more focused support to households that reported interference once an LTE800 mast had been activated. The overall number of reported cases remains lower than the maximum range allowed for within this revised approach, so the additional home visits have been accommodated within the original financial budget.

In the early stages of the mitigation programme, it was thought that in some cases interference was being incorrectly attributed to LTE. This led DMSL to improve the consistency of mitigation and diagnosis. The improvement process had four main parts:

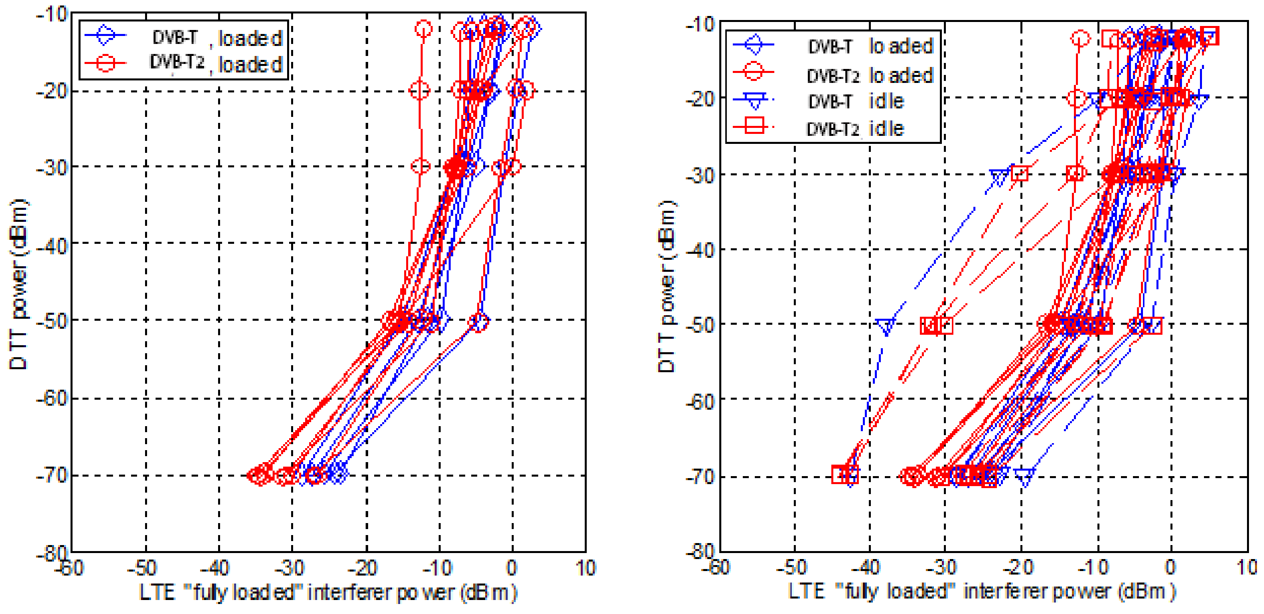
- More specialised workforce
- Technician training programme
- Clearer and more easily testable criteria for diagnosing LTE interference (and erring on the side of diagnosing LTE interference in borderline cases)
- Expert technicians auditing in-home mitigation work in a proportion of cases

The original technician workforce was drawn from a relatively wide pool of antenna installers and, though qualified, they were only occasionally working on mitigation cases. It was decided that mitigation work could be better done by a smaller and more dedicated work-force that were spending a greater proportion of time on mitigation work, were better trained, and properly equipped with measurement instruments. To ensure consistency of diagnoses, relatively simple rules based partly on theory and partly on experience have been developed. These are designed to err on the side of attributing cases to LTE interference rather than not. Even with these improvements, diagnosis can still be difficult, with interference apparently being present in practice when the measured signal levels indicate that TV signal should be adequate. This will be an area for further investigation over the coming months.

Receiver protection ratios are level dependent and frequency dependent. As DTT levels increase, the protection ratios increase (receivers are less immune) as a consequence of overload and saturation. Protection ratios decrease with interferer frequency offset as the tuner IF filters become more effective at rejecting interference.

During the course of Ofcom's early studies, RF recordings were made on a production LTE base station carrying different traffic loads and subsequent tests showed that some receivers were particularly susceptible to interference from a lightly loaded LTE base station. The lightly loaded base station has a bursty characteristic with a high peak to average ratio and it is understood that this interacts with the automatic gain control circuitry of some receivers increasing the susceptibility to interference. This effect is shown in figure 4, which shows that a few receivers are particularly susceptible to the idle LTE waveform.

## RECEIVER PROTECTION RATIO CONSIDERATIONS




(a) Loaded LTE-Base station

(b) Idle LTE-base

Figure 4: Carrier vs Inteferer characteristics for 5 DVB-T DVB-T2 receivers for LTE at 796MHz, DTT at 786 MHz showing impact of base

The results have been fed into receiver specifications and so newer receivers are better able to reject these signals. To determine the appropriate protection ratios for the computer modelling a number of measurement campaigns were considered. Initial measurements procured by Ofcom on 15 receivers were supplemented by measurements made on 105 receivers at DTG Testing Ltd. A statistical approach, using a Monte Carlo simulation was used to derive a single set of protection ratios that would give comparable simulation results to a full Monte Carlo simulation accounting for the statistical spread in receiver performance.

## IMPACT OF LTE BASE STATION OUT-OF-BLOCK EMISSIONS

Out of block emissions from the LTE base station are equivalent to co-channel DTT interference and cannot be rejected by DTT receiver filtering. Consequently, it is necessary to increase the protection ratios as out of band levels rise. European Commission Decision 2010/267/EU endorsed the recommendations of CEPT Report 30 specifying a maximum out of band radiated power of 0 dBm/8 MHz in TV channels where broadcasting is to be protected.

Practical measurements suggested that base station out of band performance would improve with frequency offset and the computer modelling assumed an adjacent channel leakage ratio of 64dB into DTT channel 60, 74dB into channel 59 and 84dB into channel 58. This assumption has been validated for some vendor implementations. Measurements suggest a third order behaviour, with adjacent channel leakage typically improving by 2dB for every 1dB of base station back-off. At the time of writing, some more work is being planned to establish the range of actual radiated power levels for LTE base stations.

### Choice of DTT transmitter

A number of factors mean that households receive DTT from a transmitter other than the one that gives the strongest signal. A significant reason is that for many years after digital services were switched on, they were only available from 80 of the 1156 transmitting stations. So it was attractive for viewers to orient their antenna to a distant transmitter because it carried more services than the local one. This has made predictive modelling of interference more difficult. Ofcom is currently considering this problem and investigating the practicability of determining which transmitters are actually in use for each 100 m planning pixel. Such a database would be valuable for a range of UHF planning applications, including TV White Space management.

### How many homes will actually be affected by interference?

From the experience of the early roll-out DMSL estimates that the number of confirmed interference cases by the end of LTE rollout will be considerably less than originally thought and likely fewer than 90,000 cases in total. There is still uncertainty around this figure. In addition to the factors mentioned in this paper, DMSL sends out filters when requested by viewers in preference to a technician visit. The number of those filters that cure actual interference is the subject of current research [*note - we expect to be able to include early results prior to publication of this paper at IBC]*. Similarly, DMSL provides filters for communal distribution systems, mostly in large apartment blocks, and so the numbers of interference cases with communal systems are not known. To date, DMSL has provided over 2,000 communal filters to be fitted to aerial systems serving blocks of properties. Finally, LTE rollout in the frequency block closest to DTT at channel 60 is still in its early stages and the impact of this close channel interference has yet to be fully tested.

### Concluding remarks

Against a back-drop of a mitigation programme that has been set up and managed to adapt to viewers needs quickly as it developed, a collaborative technical improvement programme has led to worthwhile improvements in understanding and modelling coexistence, with results fed back into national and international equipment standards. Particular improvements resulted from incorporation of measured values for the real household antenna population.


### Acknowledgement

The authors are grateful to the 4G/TV Co-existence Oversight Board, (the body that monitors and steers the LTE/TV interference mitigation programme in the UK) for encouraging and enabling the technical work plan described in this paper. The Oversight Board has provided a collaborative and constructive forum across the broadcasters and mobile network operators, regulator and Government that has contributed greatly to an effective mitigation programme.

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