

# The co-existence of LTE and DTT services at UHF: a field trial

**Ofcom**

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## EXECUTIVE SUMMARY

This document reports on a series of field trials recently undertaken to clarify issues concerning possible interference from future mobile network base stations in the 800 MHz band to digital terrestrial TV (DTT) services operating below 790 MHz.

The objectives of the field trial were as follows:

- Validation of the UKPM<sup>1</sup>/*Punch*<sup>2</sup> approach for calculating the location probability of DTT reception in the presence of interference.
- Validation of the Ofcom model (used in both UKPM and *Punch*) for the failure of a DTT receiver.
- Validation of the Ofcom model (used in *Punch* simulations) of propagation loss from mobile base station to DTT receiver.
- Validation of the Ofcom models for the impact of receiver filtering, polarisation discrimination and DTT 'on-channel repeaters'.

The trials made use of transportable equipment, configured to represent a 4G mobile base station using the LTE<sup>3</sup> standard. As it was unacceptable to cause interference to existing services, a temporary DTT transmitter was commissioned, to allow the impact of the LTE transmissions to be assessed. The trials were undertaken in Tamworth (some 20km north-east of Birmingham).

### 0.1 Validation of the approach for modelling DTT location availability

- Predictions of interference made by 'Punch' have been compared with the interference statistics observed during the field trial;
- When modelling a comparable receiver, 'Punch' tends to be pessimistic in that it overestimates the number of households affected;
- We note the field trials have limited statistical basis and have been undertaken in one, suburban, environment;
- Although the trials were necessarily limited, the 'Punch' algorithms appear appropriate, particularly when used to determine the statistics of interference from multiple LTE sites.

### 0.2 Validation of receiver failure model

- DTT Receivers whose sensitivity to interference had previously been tested in the laboratory were assessed in the field in realistic conditions;

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<sup>1</sup> UK Planning Model - the software used for DTT service planning

<sup>2</sup> A software tool developed for Ofcom, to predict interference to DTT receivers from mobile services in the 800 MHz band

<sup>3</sup> 'Long Term Evolution'.

- It was found that, generally, the laboratory performance figures provided a good model for the failure point of the receivers;
- One receiver was found to show anomalously good performance in the field, when compared with previous measurements. No firm explanation for this behaviour has been determined.

### **0.3 Validation of propagation model**

- Ofcom presently use the Okumura-Hata propagation model to predict interference power at DTT receiver locations;
- There was found to be a good correspondence between the predictions made of median path loss by this model and measurements made in the field trial;
- This correspondence would not be expected in environments different from that of Tamworth (low-density suburban). In urban areas losses may be higher, implying that the Ofcom model might over-predict interference levels and therefore the households affected;
- The field trial also examined the location variability of interfering-path loss. On longer paths (>500m) This was found to be somewhat lower than currently assumed by Ofcom; as the majority of interference will occur on shorter paths, the difference is unlikely to be significant, [but would tend again to make the punch modelling results pessimistic in that they will overestimate number of households affected.

## **0.4 Mitigation methods**

### **0.4.1 Filtering**

- It was found to be straightforward to cure interference to any DTT services from LTE transmissions on Blocks B and C using simple low-pass filters;
- For interference from Block A into DTT channels 59 or 60 it was not always possible to overcome interference with the nominally appropriate filters;
- Where DTT signal strength was sufficient, DTT services could, however, be restored using filters that introduced significant loss on the wanted channel.

### **0.4.2 Polarisation**

- Measurements were made to assess the degree to which the use of opposite (orthogonal) polarisation by the DTT and LTE transmitters might mitigate interference;
- It was found that, where the LTE and DTT signals arrives at the DTT receiver from a similar direction, a discrimination of around 16dB is available, in line with present Ofcom modelling;
- For angular separations beyond around 10 degrees, this discrimination may not be available. This is not reflected in the present Ofcom and ITU-R models which assume discrimination over a greater arc;

- As the most severe interference will be experienced for small angular separations, polarisation discrimination may be a useful mitigation method;
- The use of vertical or horizontal (rather than slant) polarisation by LTE services will incur significant additional cost and complexity (associated with the provision of transmit diversity or MIMO).

#### **0.4.3 On channel repeaters**

- An on-channel repeater (OCR) was tested in the course of the trials;
- this is a method for repairing interference by transmitting a low-power DTT service from the LTE site;
- The trial found that this method worked as predicted in previous laboratory trials;
- The use of OCRs requires that sufficient DTT signal is present at the LTE site and that good isolation can be achieved between receive and transmit antennas. These requirements will not always be met.

## 1 INTRODUCTION

Spectrum currently used for television broadcasting is being released throughout Europe, as the transition to digital transmission, using the DVB-T<sup>4</sup> standard, allows more efficient use of available bandwidth.

One likely use for part of this spectrum, that from 790 MHz to 862 MHz, is for the provision of broadband cellular radio services using the new LTE<sup>5</sup> standards. If this were to be the case, a situation would arise in some areas of the country in which high-power LTE base stations located in, or near, residential areas might cause interference to television services using channels just below 790 MHz.

To quantify the risk of such interference, Ofcom and other interested parties have undertaken theoretical studies and laboratory testing, which indicate that a small, but significant proportion of DVB-T receivers could be affected. To verify these findings, and to assess a variety of potential mitigation measures, Ofcom have undertaken a series of field trials in Tamworth, Staffordshire.

In these trials, a temporary DVB-T transmitter operating on TV channel 59 or 60 (778 MHz or 786 MHz) was established at the existing Arqiva Lichfield Transmitting Station, some 6 km to the west of Tamworth. These transmissions used both the DVB-T and DVB-T2 standards.

Transportable equipment was used to simulate an LTE base station operating in the three 10 MHz-wide channels immediately above 790 MHz. This equipment was set up at four different sites within Tamworth, and the interference to the temporary DTT services assessed.

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<sup>4</sup> 'Digital Video Broadcasting—Terrestrial'.

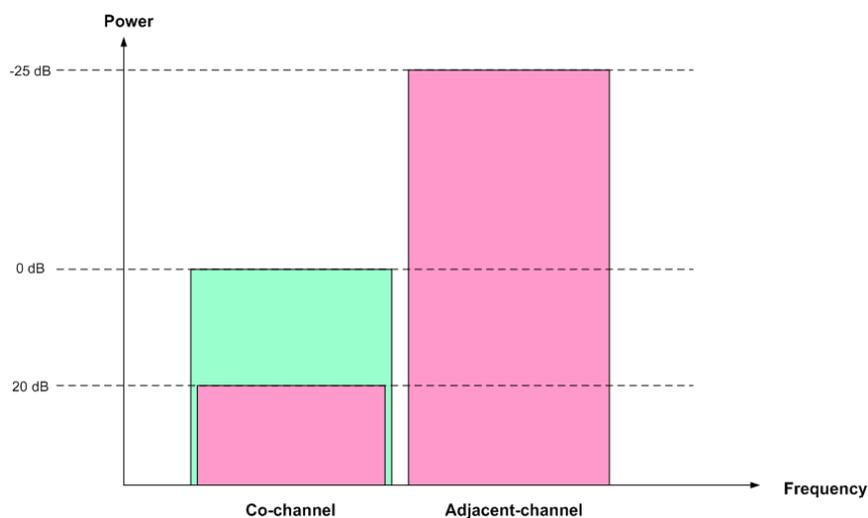
<sup>5</sup> 'Long Term Evolution'.

## 2 THE VULNERABILITY OF DVB-T RECEIVERS TO LTE TRANSMISSIONS

### 2.1 Protection ratios

In broadcasting, and many other radio services, it is normal to discuss interference in terms of the 'protection ratio' required. This is the ratio by which the received power of the wanted signal must exceed that of the unwanted signal (for a given type of interference at a specified frequency offset). The powers involved refer to the total power of each signal in its own system bandwidth, rather than a power density, or normalised power.

Thus, for example, where DVB-T is interfered-with by another DVB-T service, a protection ratio of 19.8 dB is required by the UK planning process [JPP, 2003] when the services share the same channel. If the interferer is in an adjacent channel, the protection ratio is relaxed to -25dB; note the change of sign; the interference power at the receiver is now permitted to *exceed* the wanted signal by 25dB (see Figure 2.1, wanted signal shown in green, maximum unwanted levels in red).



**Figure 2.1: Illustrating protection ratios**

The example above illustrates one of the advantages of the move to digital broadcasting: the co-channel ratio required between analogue (PAL) broadcasts is +30dB or more and +1 dB in the adjacent channel.

### 2.2 Previous protection ratio measurements

Between 2006 and 2008, ERA technology undertook a series of laboratory measurements to quantify the impact of interference into DVB-T receivers.

In the first study [ERA,2006], interference from 5 MHz UMTS and 10 MHz WiMAX signals was evaluated with guard bands of 0.4 MHz, 1 MHz and 2 MHz. In addition, the protection ratio for interferers at the DVB-T image channel ( $n+9$ ) was evaluated.

Six DTT receivers were tested, and the results are summarised in Table 2.1.

**Table 2.1: Protection ratio required**

|              | <b>0.4 MHz G/B</b> | <b>1 MHz G/B</b> | <b>2 MHz G/B</b> | <b>N+9<sup>6</sup></b> |
|--------------|--------------------|------------------|------------------|------------------------|
| <b>UMTS</b>  | -28                | -35              | -38              | -47                    |
| <b>WiMAX</b> | -27                | -31              | -32              | -40                    |

The following year, measurements [ERA, 2007a] were made of DVB-T interference to DVB-T receivers, for a large range of frequency offsets and for 15 receivers. The average adjacent channel protection ratios (lower and upper) were found to be -36 dB and -33dB, considerably better than the -25dB assumed for planning. The protection ratio required was found to be dependent on the absolute signal levels - for a wanted signal greater than around -50dBm, the protection ratio was degraded; at -30dBm, a protection ratio of around -23dB was required.

In the same year, more comprehensive measurements were made [ERA, 2007b] which also investigated the impact of fading channels on DTT protection ratio requirements.

Summarising the lower-adjacent results only, DTT interference required a -37dB ratio, in line with previous measurements. For interference from a static UMTS, a ratio of only -47dB was required, but this degraded rapidly for simulated Rayleigh fading<sup>7</sup> channels to around -24dB. The impact of mobile WiMAX was comparable to that of DVB-T, with the uplink being somewhat worse than the downlink.

The final set of measurements [ERA, 2008] added to the above tests by investigating the DVB-T protection ratios required at different wanted signal power levels, for DVB-T, UMTS user terminal and WiMax subscriber equipment.

For a DVB-T interferer the P/R of -34 dB (at -70dBm and -50dBm wanted power) degraded to -15dB at -20dBm wanted power. When a domestic distribution amplifier was used, the performance was degraded by some 12dB with -50dBm wanted input signal. For the UMTS case (with a Rayleigh fading channel and transmit power control), the protection ratio was -28dB at -70dBm, -23dB at -50dBm and degraded to only -10dB at -20dBm wanted signal.

### 2.3 Recent protection ratio measurements

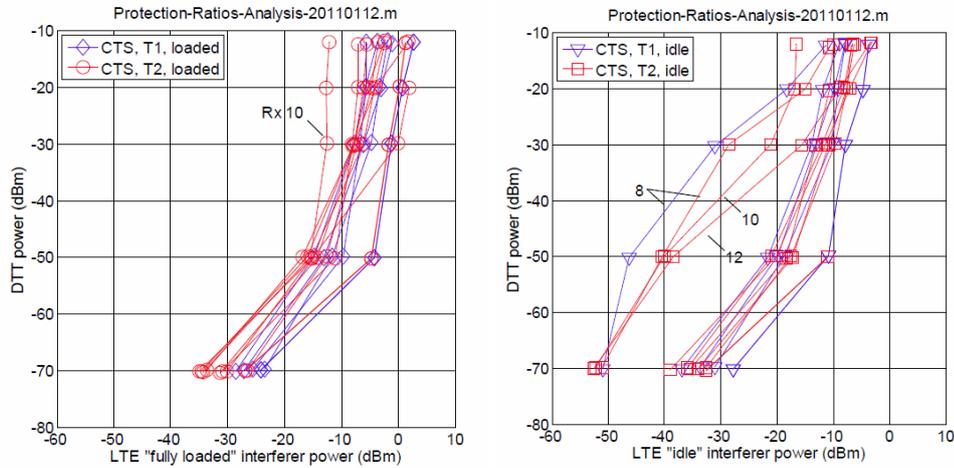
Within the last year or so, measurements have revealed that the protection ratio requirements of some DTT receivers are particularly degraded when in the presence of interference from an LTE base station in 'Idle Mode'. A base station in this condition emits impulsive bursts of power that appear to interfere with the operation of the AGC or channel estimation mechanisms of the DTT receiver.

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<sup>6</sup> The performance of one receiver was very much worse than average.

<sup>7</sup> The fading relates to the UMTS user -base channel. The fading on this triggers transmit power control on the user terminal, leading to a very bursty pattern of radiated power.

A substantial body of measurements has been carried out on behalf of Ofcom by ERA, characterising the performance of a range of DTT receivers in the presence of LTE signals, both fully-loaded and in idle mode. These are described in a separate report [ERA, 2011].

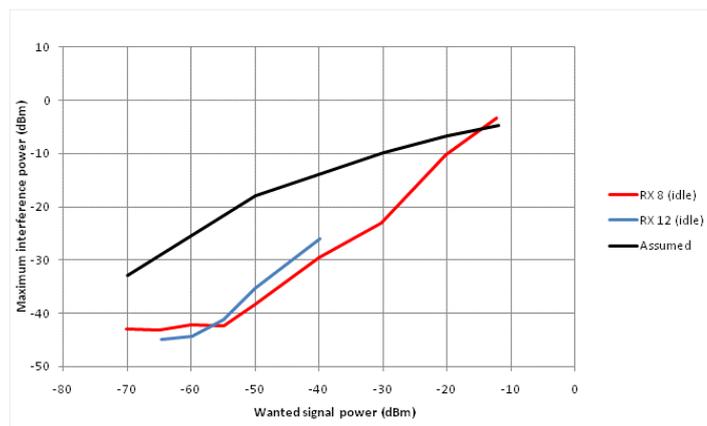


**Figure 2.2: DTT protection ratios for ‘100% loaded’ (left) and ‘Idle mode’ (right) LTE signals [source ERA Technology]**

From Figure 2.2, it can be seen that a minority of DTT receivers are anomalously sensitive to the bursty nature of LTE signals from an idling base station. This appears to be related to the behaviour of automatic gain control circuits/channel estimation algorithms in the receivers.

**2.3.1 Characteristics assumed by Ofcom**

The receiver C/I characteristics currently assumed for some modelling by Ofcom are compared in Figure 2.3 below<sup>8</sup>, with the measured characteristics of the two worst-performing DTT receivers tested.



**Figure 2.3: Characteristics of two poorly-performing receivers in the presence of LTE interference**

<sup>8</sup> Note that, in this figure the axes have been reversed, as the LTE power was the dependant variable in the measurements.

It can be seen that, at levels typical of DTT reception in average areas (~-50dBm), the performance of the two receivers is some 20dB worse than that assumed. This should not be taken to imply that the assumed performance curve is inappropriate, as the two receivers represent a very small proportion of the overall test population, most of which exhibited a significantly better performance (as in Figure 2.2).

### 3 TAMWORTH FIELD TRIALS

#### 3.1 Introduction

A series of field trials have been undertaken by Ofcom to clarify technical issues concerning the compatibility of 4G mobile services, if they are operated in the newly-released 800 MHz spectrum, with existing digital television services.

The field trials took place in Tamworth, the location being largely determined by the need to avoid interference to, or from, existing services. The area of the trials is indicated in Figure 3.1.



**Figure 3.1: Field trial area**

The trials commenced on the 19<sup>th</sup> January 2011, and fieldwork continued until 12<sup>th</sup> May 2011. The work involved staff from Ofcom, Arqiva, ERA and Aegis Systems.

#### 3.2 DTT transmissions

As it would be unacceptable to cause deliberate interference to an existing DTT service, Arqiva were contracted by Ofcom to provide a DTT test transmission for the field trial. This was configured to be switchable between channels 59 and 60, as these are expected to be the channels likely to suffer the most interference from future LTE services.

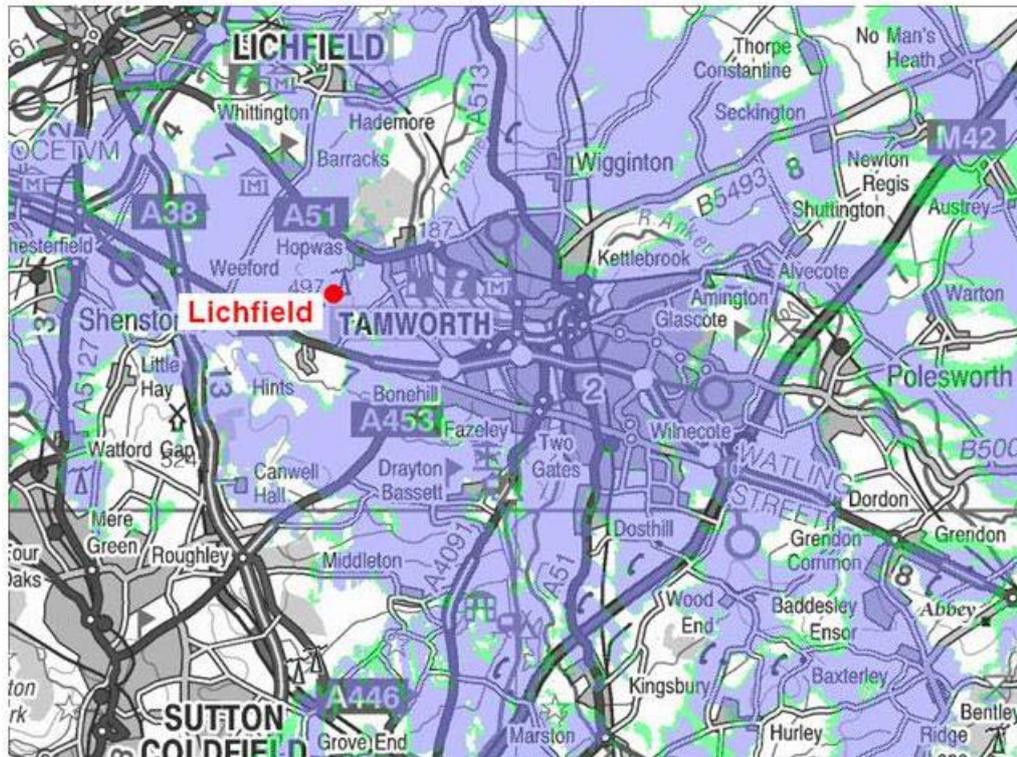
The DTT transmissions were provided from the Arqiva Lichfield transmitter site, some 6 km to the west of Tamworth. Some initial transmissions were made from a temporary mast, but for the majority of the trials a pair of phased log-periodic antennas on the main mast structure was used to radiate the test transmissions.

The technical characteristics of the DTT service are given in Table 3.1.

**Table 3.1: DTT test transmission parameters**

|                |  |                                |
|----------------|--|--------------------------------|
| Site location: | SK 16406 04350   | NGR                            |
| Site height:   | 152  | metres AOD                     |
| Aerial height: | 35   | metres AGL                     |
| Aerial:        | 2 phased log-periodics   |                                |
| Aerial azimuth | 110  | Degrees ETN                    |
| Aerial gain:   | 8  | dBd                            |
| Polarisation   | Horizontal   |                                |
| ERP:           | 23.1   | dBW                            |
| RF Channel     | 59, 60   | (remotely switchable)          |
| Modulation:    | DVB-T, 8k FFT, 64-QAM, CR=2/3<br>DVB-T2, 32k FFT 256-QAM, CR=2/3 | (remotely switchable)          |
| Video:         | MPEG2 and MPEG4 streams  | (BBC 'Cornwall' test material) |

The predicted coverage of the DTT service is indicated in Figure 3.2.

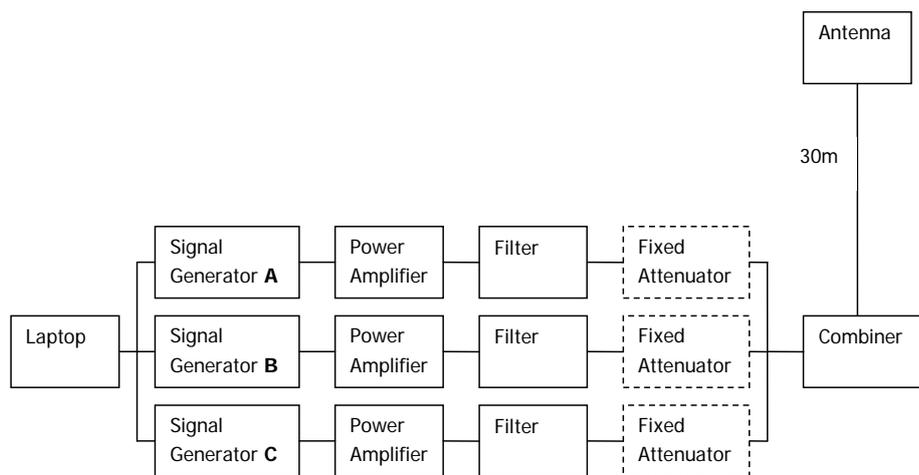


**Figure 3.2: Predicted service area of DTT test transmitter [source: Aegis]**

### 3.3 LTE transmissions

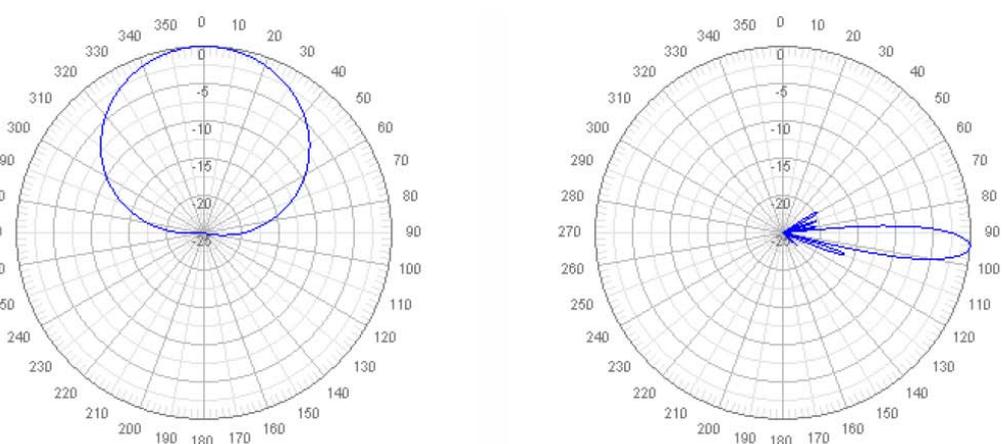
The LTE test transmissions were provided by ERA Technology limited, using vector signal generators (Agilent E8267D) feeding power amplifiers, with custom filters used to establish the an output spectral mask corresponding to the emission limits specified in EC Decision 2010/267/EU (6<sup>th</sup> May 2010).

Three separate transmitters were configured to allow the radiation of LTE signals in blocks A, B and C simultaneously. The overall arrangement is indicated in Figure 3.3 below. The fixed attenuators were manually swapped to adjust the individual block transmission levels while retaining the required spectrum mask setting.



**Figure 3.3: LTE transmission arrangement [source: ERA]**

It was required by Ofcom that the LTE transmissions should be representative of the most powerful base stations that would be licensed. It was, consequently, necessary to provide for a maximum EIRP in each block of 59dBm (800W). The three transmitters were combined into a slant polarised transmit antenna with a nominal 17dBi gain (Figure 3.4). This antenna has a fixed electrical downtilt of 4°.



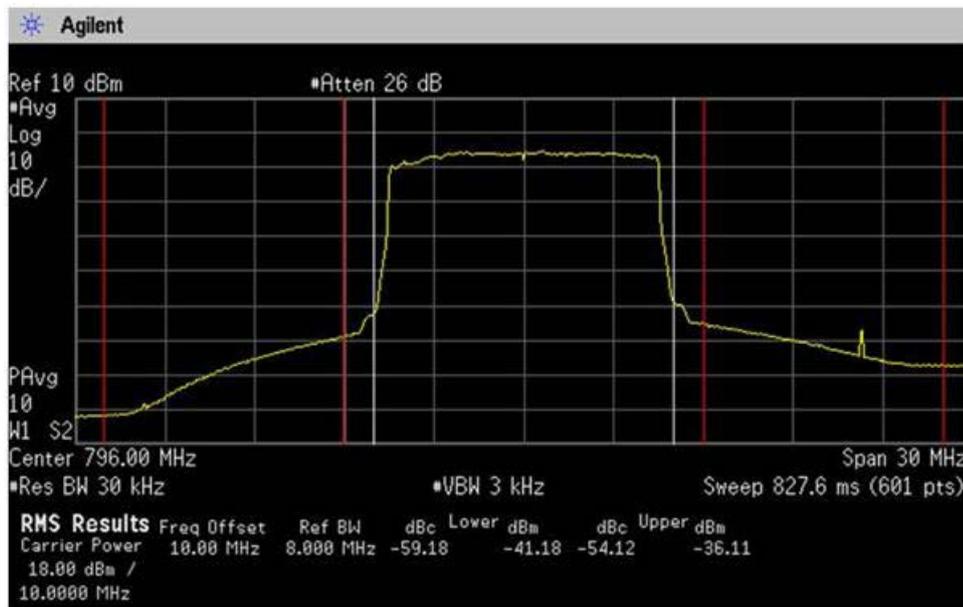
**Figure 3.4: LTE transmit antenna HRP (left) and VRP (right) [source: Andrews]**

For the initial trials, this antenna was mounted on a short tripod on the roof of the Tamworth Council offices (see below), but, for the majority of the trial a trailer mast was used as the antenna support, extended to 17 or 20m height.



**Figure 3.5: LTE transmission equipment at Council Office site**

The vector signal generators were used to replay arbitrary waveform files (arb) that had been recorded earlier on the premises of an LTE equipment manufacturer. Test files were available representing ‘fully loaded’ and ‘idle’ LTE base station emissions.



**Figure 3.6: LTE spectrum, showing asymmetrical filtering**

As noted above, particular attention was paid to ensuring that the emissions of the trial LTE transmitters met the ECC mask, which specifies that LTE power into any DTT channel below 790 MHz shall be at -59dBc. Filters were specially commissioned to provide the appropriate suppression of the adjacent channel leakage power from the generator/amplifier combination, and the result of this

filtering is shown in Figure 3.6, taken from a coupler on the feeder to the transmit antenna.

### 3.4 Measurement vehicles

The bulk of the measurements were undertaken by the Ofcom in-house field monitoring team, based at Baldock. Some supplementary measurements were also carried out by Aegis Systems. Communication between the three vehicles and the LTE base station was by VHF R/T.

#### 3.4.1 Ofcom (Baldock)

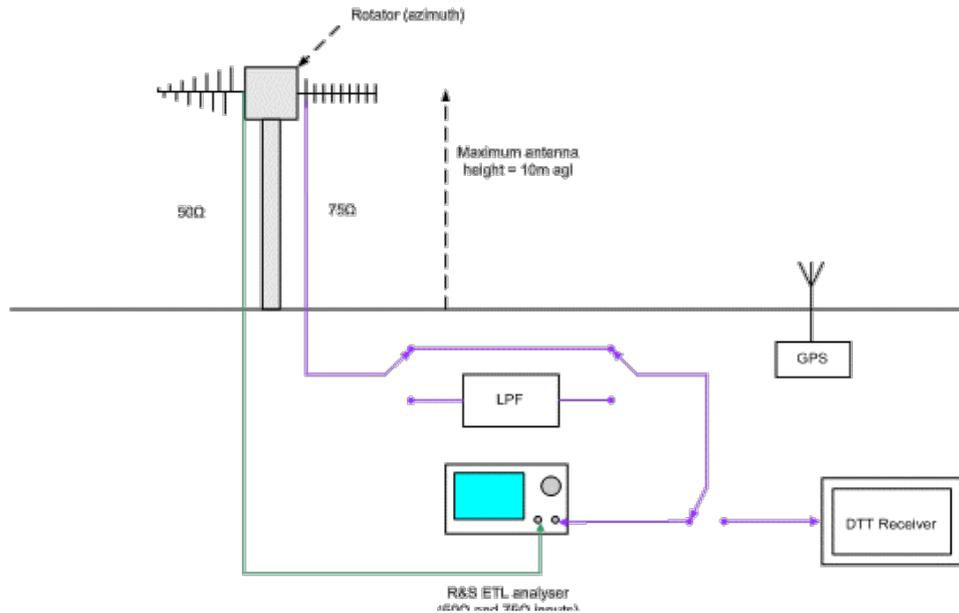
Two Ofcom general purpose vehicles were provided for the duration of the trial. Each of these vehicles is fitted with a 10m pneumatic mast, and is large enough to accommodate several staff members simultaneously.

One vehicle, referred to as the 'mitigation van' was equipped with a variety of domestic DTT receivers and filters, as well as a Rohde and Schwarz ETL test receiver/spectrum analyser. Two receiving aerial systems were installed - a standard (BBC design) 8dBd log-periodic [Riley, 1973] with a 50Ω feeder and a representative domestic Yagi aerial connected to a 75Ω downlead.



**Figure 3.7: Ofcom measurement vehicle**

A sketch of the measurement system is given in Figure 3.8, below, indicating the way in which the receiver low-pass filters ('LPF') under test could be switched in or out of circuit. The ETL analyser has both 50Ω and 75Ω inputs, allowing it to be used to examine filter performance, or signals from the 'domestic' aerial without external matching pads.



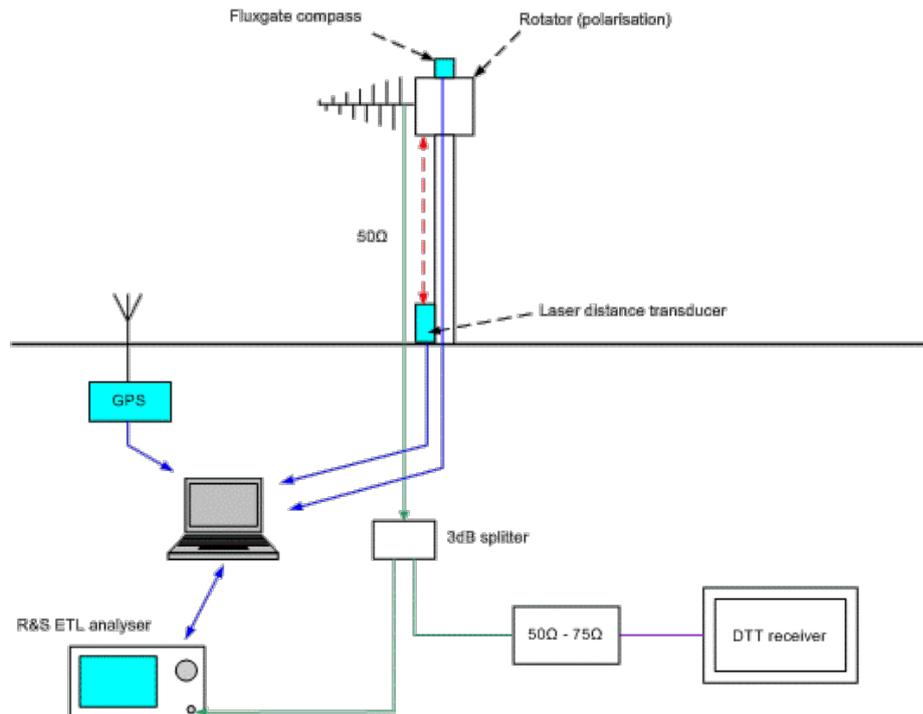
**Figure 3.8: Ofcom 'mitigation van' setup**

The other vehicle, the 'propagation van' was equipped with only the 50Ω antenna system, and was used primarily for field strength measurement using a spectrum analyser.

Data gathering was by manual means with screenshots saved from the ETL receiver.

### 3.4.2 Aegis

The Aegis Systems Land Rover was also used to perform some measurements during the field trial. This vehicle is equipped with an internally-mounted 10m pneumatic mast. A standard (BBC-design) log-periodic aerial was used, and the system fed a domestic DTT receiver and a Rohde & Schwarz 'ETL' test receiver/spectrum analyser through a splitter arrangement, as shown in Figure 3.9.



**Figure 3.9: Aegis vehicle setup**



**Figure 3.10: Internal arrangement of Aegis measuring vehicle**

Measurements were made using software that logged vehicle position, mast height, azimuth, DTT parameters and channel powers. A mast-mounted remote camera recorded the environment in the direction of the transmitter.

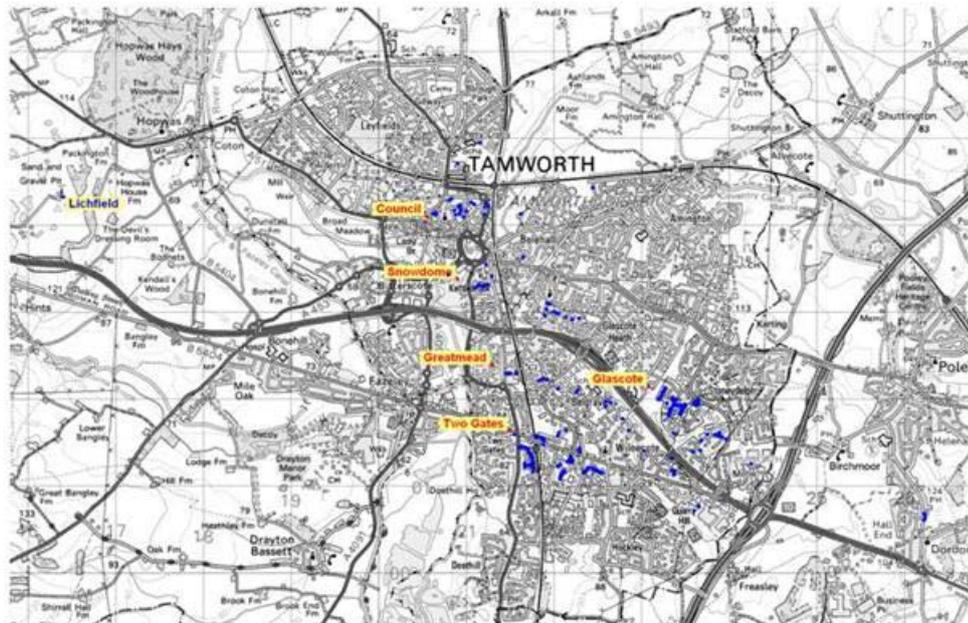
### 3.5 Test sites

A total of five sites were used for the LTE transmissions, and these are described below.

**Table 3.2: LTE transmitter locations**

| Site                  | Location           | NGR            | ASL  | AGL  |
|-----------------------|--------------------|----------------|------|------|
| <b>Council office</b> | Rooftop            | SK 20546 04105 | 62 m | 31 m |
| <b>Greatmead</b>      | Public car park    | SK 21298 02394 | 73 m | 20 m |
| <b>Two Gates</b>      | Club car park      | SK 21494 01632 | 79 m | 17 m |
| <b>Glascote</b>       | Scout hut car park | SK 23081 02148 | 81 m | 17 m |
| <b>Snowdome</b>       | Car park           | SK 20900 03378 | 59 m | 15 m |

The five locations, the DTT transmitter and some of the measurement points are indicated on the map below.



**Figure 3.11: Measurement locations**

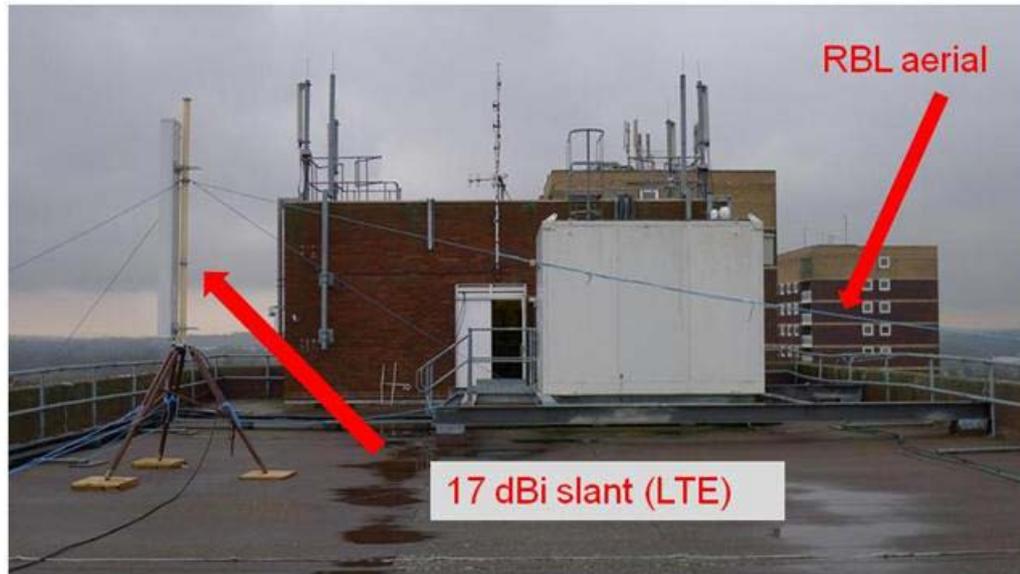
In general, Tamworth is characterised by low-density suburban housing, and is on low-lying, fairly flat terrain.

#### 3.5.1 Tamworth Council office roof

For the initial testing and configuration of equipment the LTE transmitters were installed at the Tamworth Council offices<sup>9</sup>, in the centre of the town. The equipment

<sup>9</sup> The project team are particularly grateful to Tamworth Council for providing these facilities, and for their help during this work.

was accommodated in the lift motor room, allowing convenient access and providing ample working space for the initial configuration and testing of the trial arrangement.



**Figure 3.12: Antenna locations on Council rooftop**

The 17dBi slant-polarised antenna was rigged on a tripod on the roof of the office building, as shown in Figure 3.12, with an azimuth of 110° ETN. The RBL (re-broadcast link) aerial for the OCR was located on the other side of the roof, screened from the transmit antenna by an existing cellular radio base station cubicle. The RBL aerial had a clear line of sight to the DTT transmitter mast at the Lichfield site.



**Figure 3.13: View from Council rooftop**

The roads in the area surrounding the council offices are narrow and busy, or pedestrianised; it was consequently necessary to make the majority of measurements in public car parks.



**Figure 3.14 Area surrounding 'Council' transmit site**  
[source: Google Earth Pro]

The area around the council offices was also not ideal for propagation measurements, as it is somewhat to the north of the main beam of the DTT transmitter, requiring a correction for the roll-off of the radiation pattern.

### **3.5.2 Greatmead car park**

In the fifth week of the trials, the transmitter site was moved to a suburban car park, some 2km south of the town centre. For this location, and for the remainder of the trials, the transmit and RBL antennas were mounted on a transportable trailer mast, as shown in Figure 3.15.



**Figure 3.15: Trailer mast at 'Greatmead' site**



**Figure 3.16: Area surrounding 'Greatmead' transmit site  
[source: Google Earth Pro]**

The roads in this area were largely unrestricted and residential, allowing measurement locations to be chosen freely.

### **3.5.3 Two Gates Club**

This site was in the car park of the 'Two gates' working men's club. The LTE transmit antenna beamwidth, on an azimuth of 110° ETN, covered an area of light industrial units.



**Figure 3.17: Area surrounding 'Two Gates' transmit site**  
 [source: Google Earth Pro]

**3.5.4 Glasgote Scout Hut**

The fourth site was in the car park of a scout hut, in the largely residential Glasgote / Stonydelph area.



**Figure 3.18: Area surrounding 'Glasgote' transmit site**  
 [source: Google Earth Pro]

### 3.5.5 Snowdome

Following an 'Open Day' held to present intermediate results to an industry group, a limited number of measurements were made using an LTE transmitter site in the large car park surrounding the Tamworth 'Snowdome' leisure complex.

This area is the lowest-lying part of the town, and a relatively low transmit antenna height of 15m was used, due to high winds and guying restrictions.



**Figure 3.19: Area surrounding 'Snowdome' transmit site**  
[source: Google Earth Pro]

## 4 IMPACT OF LTE ON DTT

### 4.1 Interference statistics

Perhaps one of the more immediately interesting results from the field trials is simply to understand the pattern and extent of interference to DTT reception.

At two of the trial locations (Two Gates and Glascoate), areas around the LTE site were sampled densely, noting the points at which interference was experienced to reception using the more susceptible DTT receivers.

For these tests the LTE transmitter was configured to radiate in block A at full power (i.e. a nominal fully-loaded eirp of 59dBm), but in idle mode. The median DTT field strength predicted by the UKPM is around 75-80 dBµV/m in both areas, and the UKPM predicts 100% location coverage in all 100 metre pixels.

Measurements were made by both Ofcom vehicles, using set top boxes (referred to as RX 8 and RX 12) the C/I performance of which had previously been tested in the laboratory at ERA. The results are shown in the figures below.

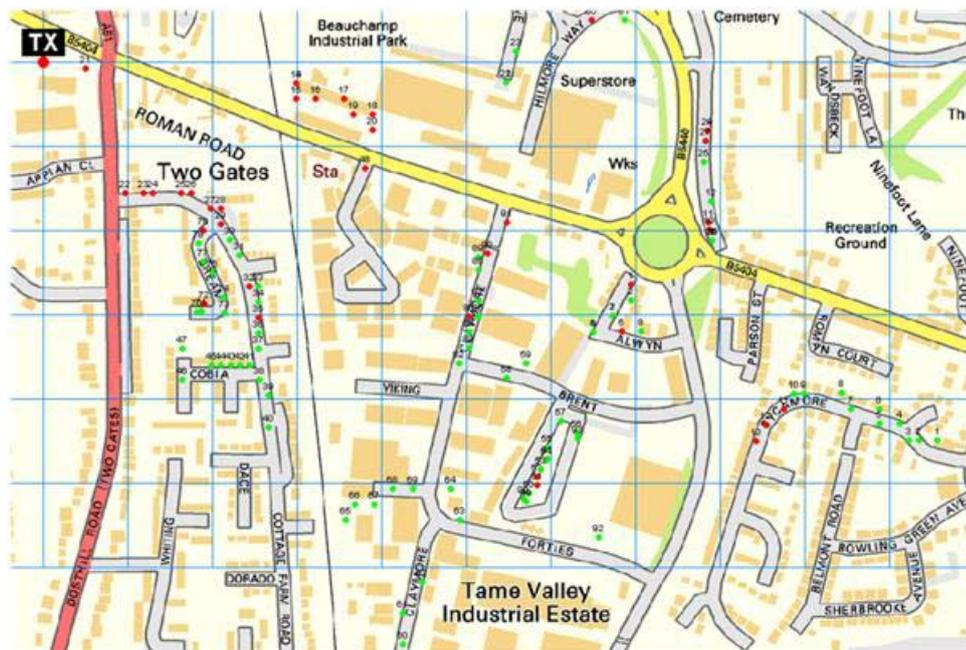
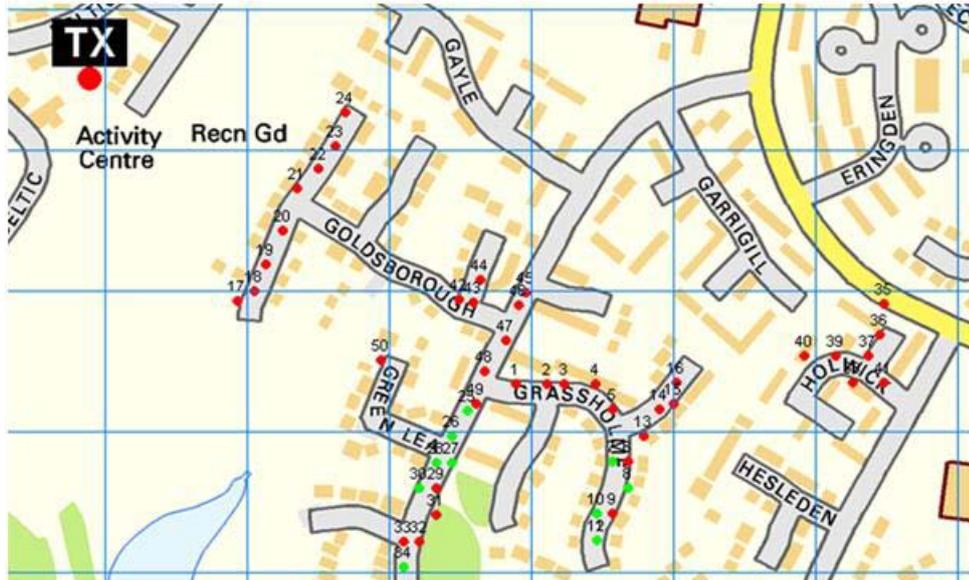


Figure 4.1: DTT failure points (Two Gates site)



**Figure 4.2: DTT failure points (Glascote site)**

In the Two Gates area, interference was experienced at up to 1km from the LTE site; In Glascote, the farthest points measured, at around 600m from the LTE site, all suffered interference.

In both cases, the LTE antenna boresight was at 110° ETN and the effect of the horizontal radiation pattern can be seen clearly.

It should be stressed that these results were obtained using the two DTT receivers most susceptible to LTE interference; the majority of DTT receivers would function correctly at the C/I ratios (typically -20 to -30dB) found at the failure points shown in the figures.

## 4.2 Comparison with ‘Punch’ predictions

### 4.2.1 Prediction algorithms

Ofcom have contracted Arqiva to develop a software tool, ‘Punch’ to allow predictions of ‘hole punching’ by LTE transmitters to be made. An attempt has been made to compare the interference observed in the field trial with the predictions made by ‘Punch’.

This program makes the following assumptions:

- The median DTT field strength in a given pixel is that predicted by the UKPM.
- DTT self-interference is predicted as in the UKPM, aggregated using the Schwartz-Yeh approximation.
- The median LTE field strength in the pixel is calculated using the Okumura Hata model (suburban or urban as appropriate), and taking into account the horizontal and vertical radiation patterns of the base station antenna.
- The susceptibility of DTT receivers to interference is characterised by a table specifying the protection ratio (dB) versus frequency offset (MHz) for a

number of different wanted signal levels (dBm). Typically, levels of -70,-50, -30,-20 and -10 dBm might be used.

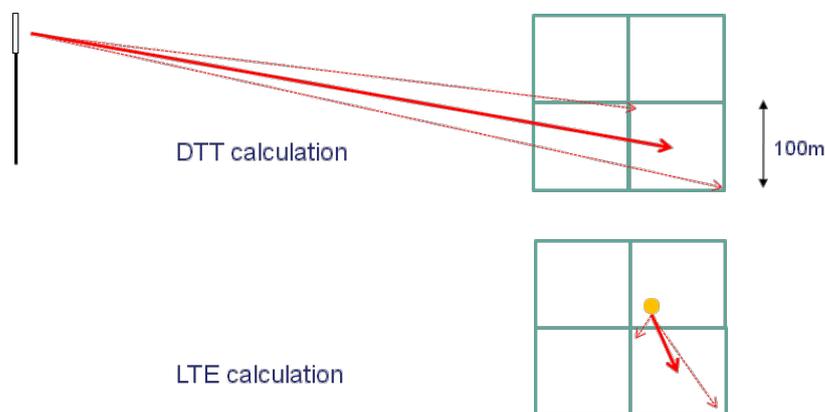
The output is given as a matrix of statistics. Each pixel is characterised by a variety of interference metrics, including:

- the percentage-location DTT coverage with and without the interference
- the population lost, based on a given %-location threshold (i.e. if the percentage-location coverage falls below a given value, the pixel is deemed unserved)
- the proportional population lost (i.e. the reduction in %-location coverage, multiplied by the population of the pixel)
- increase in interference (dB).

As the field trial measurements are made at arbitrary locations, and the population of a given pixel has no particular significance, the most relevant comparison is probably with the percentage-location DTT coverage from ‘Punch’.

A set of ‘Punch’ prediction runs<sup>10</sup> were undertaken by Ofcom, using the LTE parameters and locations of the field trial. The C/I requirement was assumed to be that of the receiver (‘rx 8’) used in the comparative measurements, as indicated in Figure 2.3 above.

The nature of the ‘Punch’ tool is such that a close correspondence with measured interference statistics should not be expected in any particular area, although statistics taken over a wide area should be accurate.



**Figure 4.3: Path-loss calculations in ‘Punch’**

In ‘Punch’, the calculation area is subdivided into elemental areas, each 100m square, with DTT and LTE powers being assessed and compared at the centre of each area. This granularity does not pose a significant constraint for the calculation of DTT powers, as transmitter sites will generally be sufficiently distant that path loss

<sup>10</sup> The ‘Punch’ predictions made for this report use parameters different from those used in modelling previously-published by Ofcom

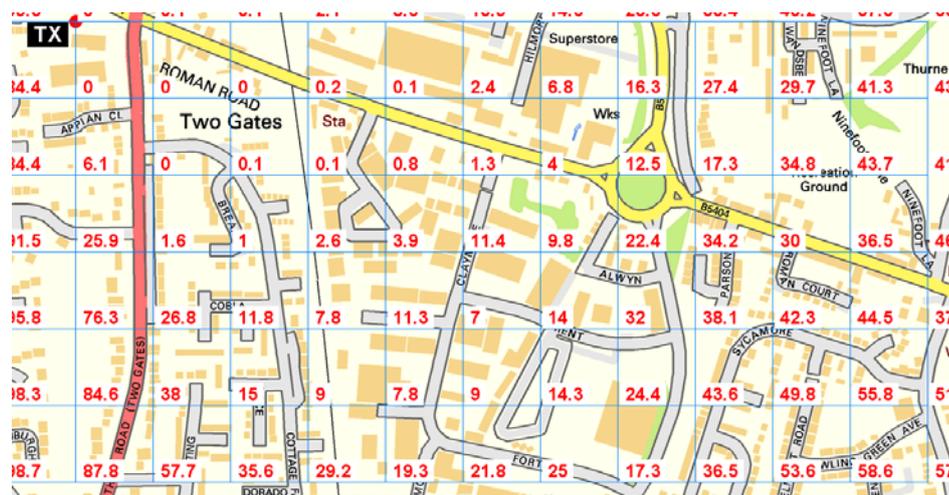
does not change significantly across a 100m square (see the upper diagram in Figure 4.3).

For the LTE case, however, this does not hold, as the likely interference radius around a base station is comparable to the dimensions of the elemental areas. If a particular site is located near the centre of a pixel, the path loss will be tens of dB less than if the site is located at the edge of a square. The implication of this is that the predictions made by ‘Punch’ are only valid on a statistical basis when the interference from many base stations is modelled; the algorithm is not intended to produce a site-specific prediction on a pixel-by-pixel basis.

This sort of mismatch is unavoidable in a practical tool, and is not intended as a criticism, but rather to provide a background for the comparison with measurement that follows.

**4.2.2 Comparison with measurement**

‘Punch’ prediction were made with LTE sites corresponding to two of the base station locations used in the trials, Two Gates and Glascote, as shown in figures 4.4a and 4.5a below. These are compared, in Figures 4.4b and 4.5b, with the measured statistics of interference occurring in a number of elemental 100m areas.



**Figure 4.4a: ‘Punch’ %-location coverage (Two Gates)**



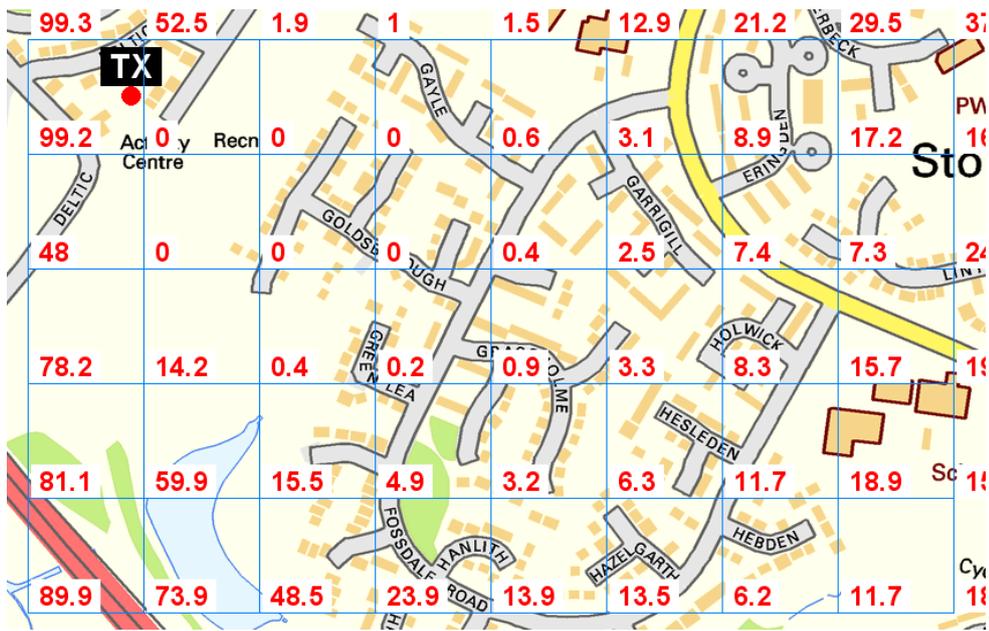


Figure 4.5a: 'Punch' %-location coverage (Glascote)—



Figure 4.5b: Measured %-location coverage (Glascote)

It can be seen that the general pattern of interference statistics is broadly similar. There is, however, a pronounced tendency for 'Punch' to overestimate the extent of interference.

The two sets of statistics are compared in tabular form below.

**Table 4.1: Two Gates comparison**

| Eastings | Northing | Punch | Measured | delta |
|----------|----------|-------|----------|-------|
| 421600   | 301200   | 26.8  | 100      | 73.2  |
| 421600   | 301300   | 1.6   | 66       | 64.4  |
| 421600   | 301400   | 0     | 0        | 0     |
| 421700   | 301200   | 11.8  | 89       | 77.2  |
| 421700   | 301300   | 1     | 88       | 87    |
| 421800   | 301000   | 29.2  | 100      | 70.8  |
| 421800   | 301500   | 0.2   | 0        | -0.2  |
| 421900   | 301000   | 19.3  | 100      | 80.7  |
| 422000   | 301000   | 21.8  | 75       | 53.2  |
| 422000   | 301100   | 9     | 80       | 71    |
| 422000   | 301200   | 7     | 83       | 76    |
| 422000   | 301300   | 11.4  | 75       | 63.6  |
| 422100   | 301100   | 14.3  | 100      | 85.7  |
| 422100   | 301200   | 14    | 40       | 26    |
| 422100   | 301300   | 9.8   | 50       | 40.2  |
| 422200   | 301400   | 12.5  | 50       | 37.5  |
| 422200   | 301500   | 16.3  | 0        | -16.3 |
| 422300   | 301100   | 43.6  | 0        | -43.6 |
| 422300   | 301200   | 38.1  | 100      | 61.9  |
| 422400   | 301100   | 49.8  | 100      | 50.2  |
| 422500   | 301100   | 55.8  | 100      | 44.2  |

**Table 4.2: Glasgote comparison**

| Eastings | Northing | Punch | Measured | delta |
|----------|----------|-------|----------|-------|
| 423200   | 302000   | 0     | 0        | 0     |
| 423300   | 301800   | 4.9   | 56       | 51.1  |
| 423300   | 301900   | 0.2   | 11       | 10.8  |
| 423400   | 301800   | 3.2   | 57       | 53.8  |
| 423400   | 301900   | 0.9   | 0        | -0.9  |
| 423600   | 301900   | 8.3   | 0        | -8.3  |

From the comparisons above it can be seen that 'Punch' has significantly overestimated the level of interference actually experienced during the field trial measurements.

As discussed, such a direct comparison with interference in a specific area is not entirely valid as the 'Punch' algorithms are intended to be used on a larger scale (e.g. over the whole of a main station coverage area) basis to assess interference from many LTE sites.

Further runs of 'Punch' were made, using the 'average' receiver characteristics indicated in Figure 2.3, instead of those of the poorly-performing 'rx 8'; with this change it was found that the model, as would be expected, underestimated the levels of interference by a similarly significant amount.

These results suggest that ‘Punch’ gives somewhat pessimistic results for the specific cases examined in Tamworth and highlights the sensitivity of the model to changes in input parameters.

Finally, it must be stressed that the measured failure statistics are very sparse with an average of only 3-10 points per 100m square.

### 4.3 Receiver failure points

As noted above, a variety of DTT receivers have been investigated in the laboratory and their performance in the presence of LTE interference evaluated. These measurements have all been made in closely controlled conditions, with a Gaussian channel for both wanted and interfering signals, and with no noise contributions other than the thermal noise of the measuring system and device under test. It was, therefore, felt worthwhile to investigate the DTT receiver failure characteristics under realistic field conditions.

Figures 4.6–4.9 compare the observed performance of two set-top box receivers in the field with the measurements made of the same receivers in the laboratory at ERA [ERA, 2011].

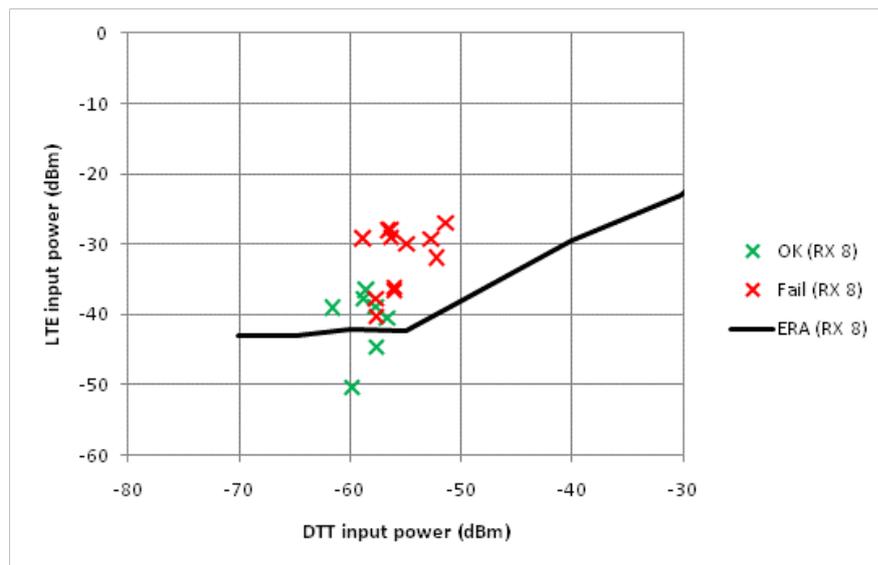
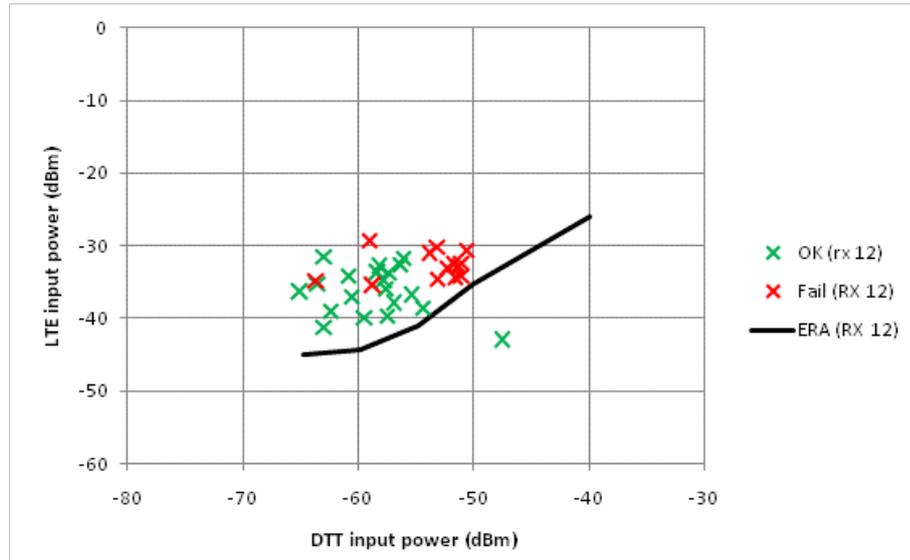
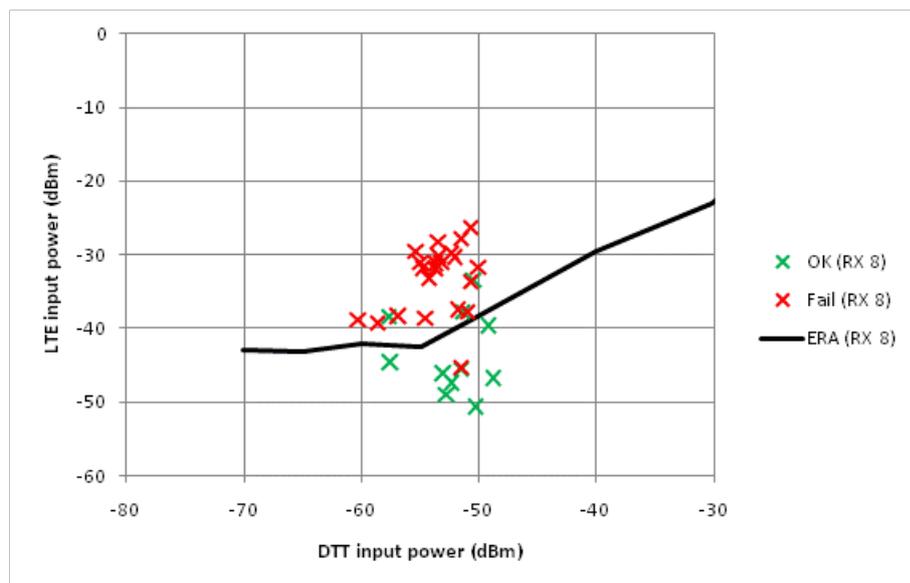


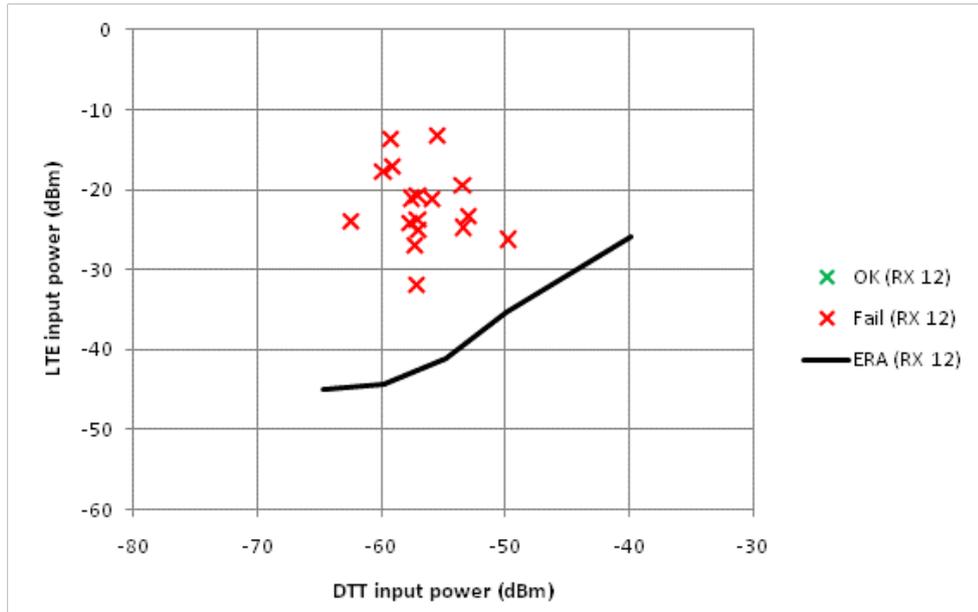
Figure 4.6: Receiver 8 measured failure points (Two Gates, 15-23 March)



**Figure 4.7: Receiver 12 failure points (Two Gates, 15-23 March)**



**Figure 4.8: Measured receiver failure points (Glasgote area)**



**Figure 4.9: Measured receiver failure points (Glascote area)**

It can be seen from Figures 4.6 and 4.8 that receiver 8 performs broadly in line with expectations, allowing for experimental error.

The results obtained with receiver 12 are surprising; the measurements in the Glascote area (Figure 4.9) were all made at points where the high LTE signal strength was expected to cause interference, which it duly did. The results in the Two Gates area (Figure 4.7) show the receiver continuing to work with protection ratios that would be expected to cause the receiver to fail. In many cases, increasing the received DTT power, for the same LTE power, appears to cause the box to stop working.

No explanation has been found for these effects; although it was noted that the receiver would intermittently ‘lock up’ and require a reset, this does not explain the ‘anomalously good’ performance<sup>11</sup>.

#### 4.4 An unexpected mitigation technique

In the course of the trials, communication between the units was by means of VHF radio transceivers, working at 149 MHz, with a power of around 1W.

When interference conditions were observed, the VHF radio would often be used to ask the LTE base station to switch mode or activate the on-channel repeater. It was soon noticed that when these radios were transmitting, the DTT picture would generally be restored.

This effect has not been examined in any detail, but it might be speculated that the AGC circuitry in the receiver is sensitive to RF input signals across a wide band, and

<sup>11</sup> The receivers showed signs of hysteresis during bench testing, i.e. they tend to stay locked for longer than expected if already receiving, but tend to need a better input before relocking.

that the local VHF transmission serves to anchor the AGG signal at a constant level, effectively switching in an RF attenuator, rather than attempting to follow the bursty LTE signal.

## 5 PROPAGATION MEASUREMENTS

### 5.1 Path loss

Ofcom have made the tentative assumption that it is reasonable to model the propagation loss on the interference path (LTE base station to rooftop DTT aerial) using the Okumura-Hata model.

This well-known empirical model is based on data gathered in the Tokyo area in the 1960s, using effective transmitter heights between 40-800m and mobile receiving antennas at 3m above ground. Measurements were made at distances of between 1-100km from the transmitters. The model is widely used to predict mobile radio coverage, though it is often 'tuned' for use in specific circumstances.

The version of the Okumura-Hata model adopted for interference prediction by Ofcom is the same as that used in version 2.1 of the 'SEAMCAT software tool developed by the European Radiocommunications Office<sup>12</sup> and described in Annex 7.1 of [ERO, 2004].

For urban areas, and distances between 0.1 and 20km, UHF path loss is given by:

$$L_{urban} = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, Hb\}) + [44.9 - 6.55 \log(\max\{30, Hb\})] (\log(d) - a(Hm) - b(Hb)) \quad (\text{eq 5.1})$$

A further correction is applied in suburban areas:

$$L_{suburban} = L_{urban} - 2 \{ \log(f/28) \}^2 - 5.4 \quad (\text{eq 5.2})$$

The model assumes that free-space path loss applies for distances <100m from the base station.

$Hm$  and  $Hb$  are the mobile and base station antenna heights respectively, and  $a(Hm)$ ,  $b(Hm)$  are corrections for these terminal heights. The base station height correction is additional to that embodied in the original Hata formulation of Eq.5.1, and allows base station heights below 30m to be modelled, with a logarithmic increase<sup>13</sup> in path loss.

#### 5.1.1 Measured path loss

As the Okumura-Hata model is normally applied to the case of a low-height mobile terminal, and the data that underlies the model was gathered at ranges beyond 1km, it is not necessarily the case that it can be expected to represent the path loss to fixed DTT aerials at roof-height and at ranges of a few hundred metres.

In the course of the compatibility testing, calibrated measurements were therefore made of the path loss between the transmitter sites and the measuring vehicles. The main intention of these measurements was to confirm the suitability of the Okumura-Hata model for prediction of interfering path loss.

<sup>12</sup> Now the 'European Communications Office'.

<sup>13</sup> In dB.

Figures 5.1 to 5.4 show measured path loss data from the Tamworth trials compared, in each case, with curves for free-space path loss, the (suburban) Okumura-Hata model used by Ofcom and path loss assuming a two-ray propagation involving a single ground reflection.

The two-ray curve was included because some of the measurements indicated the presence of significant ground reflections giving rise to strong nulls and field strengths occasionally in excess of the free-space value. This is particularly evident in the measurements made from the Council offices. Owing to the very site-specific geometries involved, such a model is not a candidate for use in an interference prediction algorithm, but is a useful reminder of the mechanisms involved.

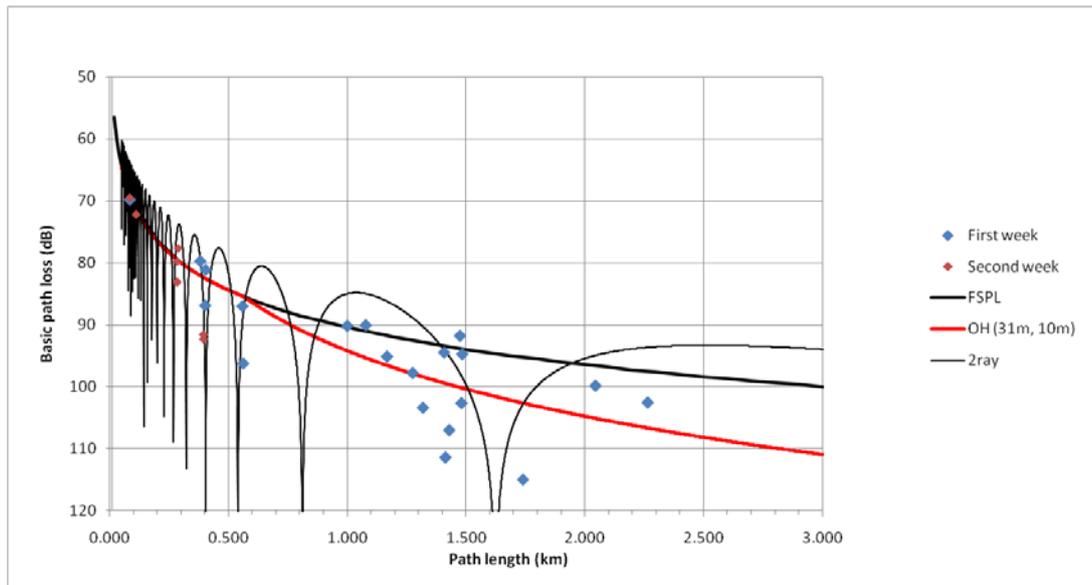


Figure 5.1: LTE path loss measurements ('Council' area, Aegis 19-27 Jan)

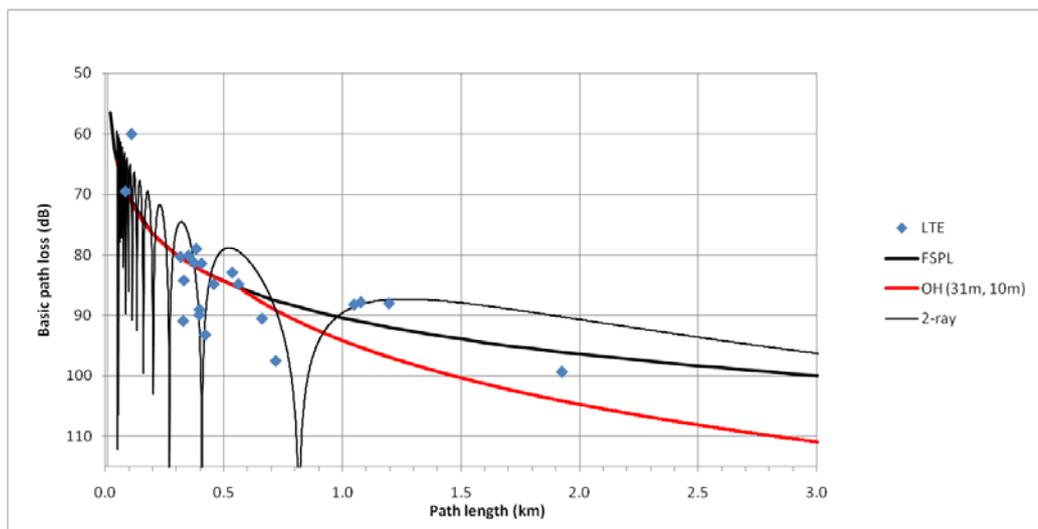
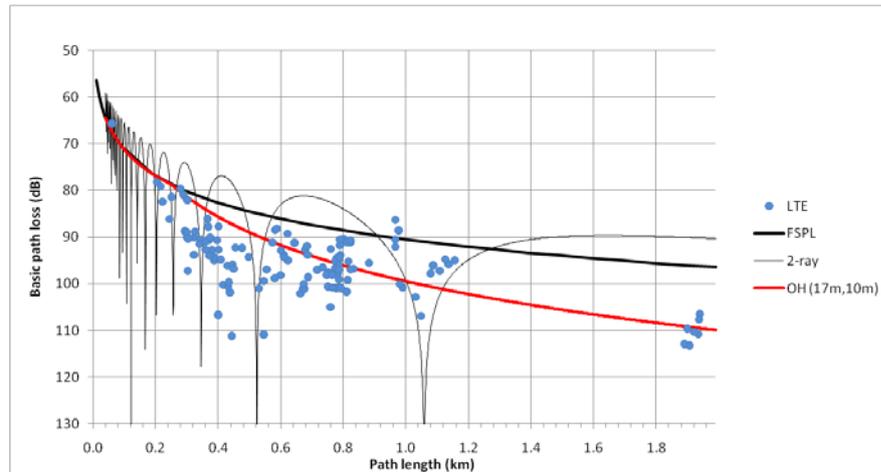
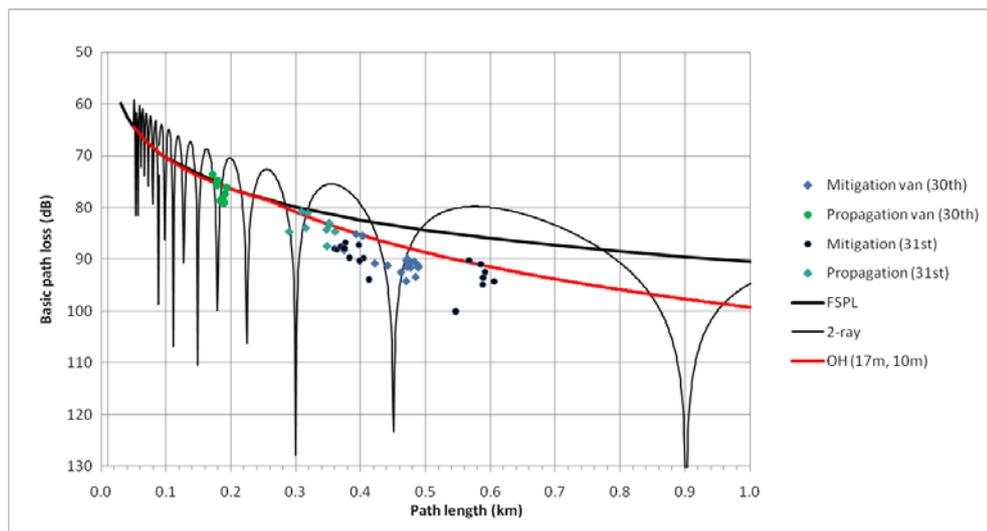


Figure 5.2: LTE path loss measurements ('Council' area, Ofcom 19-21 Jan)



**Figure 5.3: LTE path loss measurements (Two Gates, 15-23 March)**

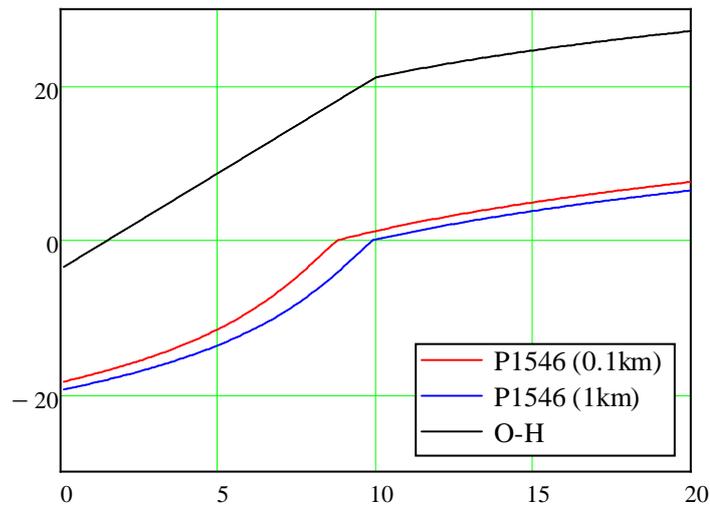


**Figure 5.4: LTE path loss measurements (Stoneydelph, 30-31 March)**

The measurements made suggest that, for the relatively low-density environment of Tamworth, the Okumura-Hata suburban model gives a reasonable fit to the median path loss between the LTE base station and domestic DTT antennas. The associated location variability of the path loss is discussed below.

## 5.2 Height gain

The Okumura-Hata predicts path loss to a mobile terminal at 1.5m above ground. For other heights, a correction is applied, rising from zero at 1.5m, to some 21dB at 10 m above ground. The original Hata model limits mobile height to a maximum of 10m, but the variant used in SEAMCAT allows greater heights, with path loss falling logarithmically (in dB).



**Figure 5.5: Receiver terminal height gain (R=10m, Hb=17m)**

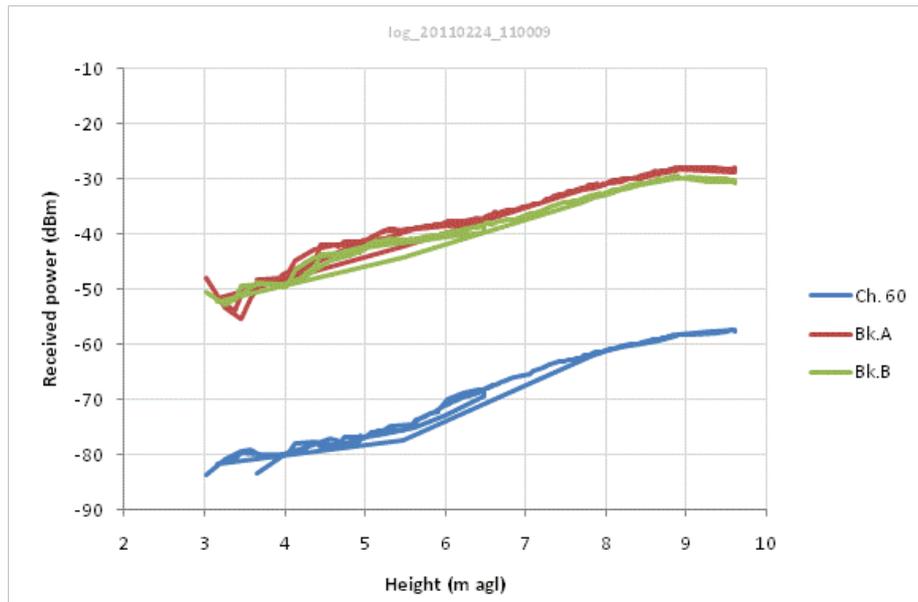
The original Okumura-Hata model uses no path-specific information, but the ‘Punch’ software allows the user to enter a ‘representative clutter height’. If the receive antenna is above the local clutter, the SEAMCAT Okumura-Hata model is used directly; if the receive antenna is below the clutter, the Okumura-Hata model is used to predict the field strength at the clutter height, and the height gain model of ITU-R Recommendation P.1546 is used to correct for the lower height, taking the ‘representative clutter height into account. The difference between the two height gain functions is slight (see Figure 5.5).

In practice, it is understood that Ofcom intend always to set the clutter to a height below the receiver aerial height (10m); the original Okumura-Hata height gain correction (1.5m to 10m) of 21 dB is, therefore, always applied.

### 5.2.1 Measured values of height gain

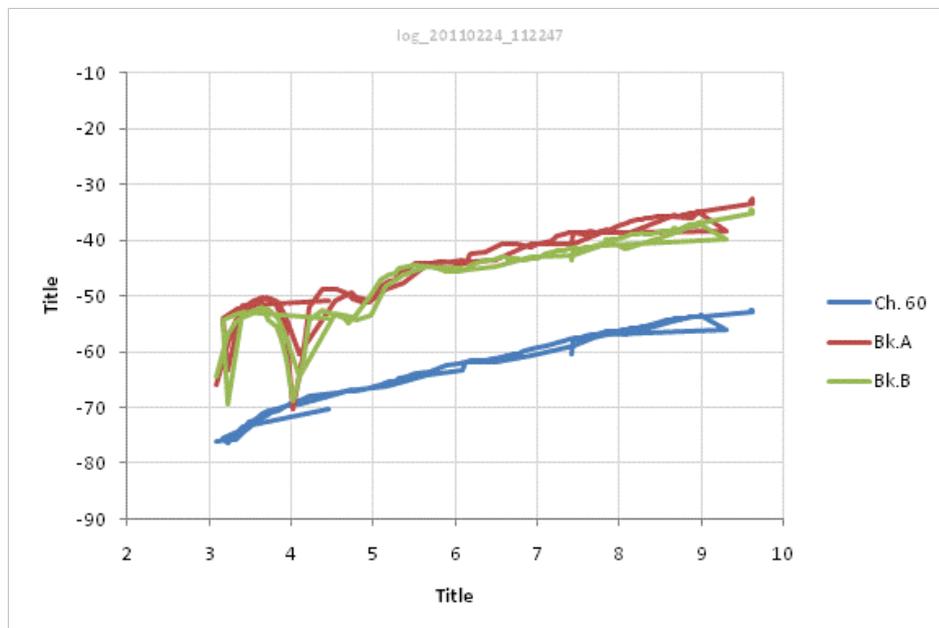
The Aegis measuring vehicle is equipped to measure height gain, and such measurements were made throughout the Tamworth survey. This data is potentially useful both to validate the assumptions in the propagation model and also as an indicator of the degree of correlation between wanted DTT and interfering LTE field strengths. If such correlation is high it may be possible to reduce the required protection margin between median signal levels.

Sample traces from the raw measurements are shown in Figures 5.6–5.8 below. In the first case, both signals show a smooth increase in field strength from 3m to 10m above ground. The protection ratio remains almost invariant at around -30dB.



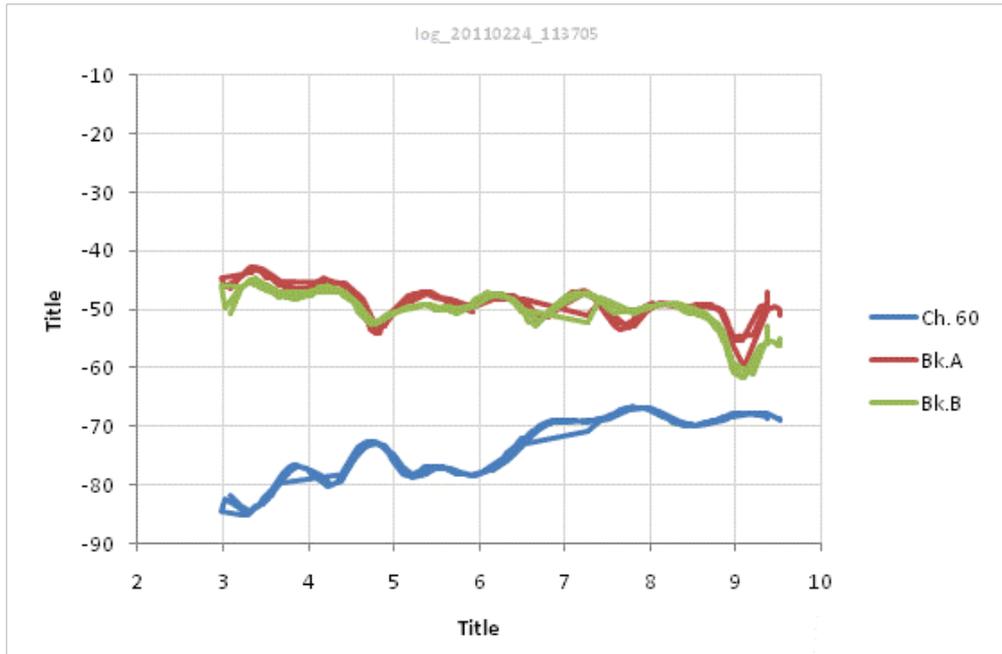
**Figure 5.6: Highly correlated LTE and DTT height gains**

In the second example (Figure 5.7) the effect of a ground reflection can be seen on the LTE signal, giving rise to nulls at around 3m and 4m. No such coherent interference can be seen on the DTT signal. As a consequence, good DTT reception was obtained at this point with the antenna lowered, but reception was lost as the mast was raised. For most realistic DTT receive aerial heights, the two signals are well correlated, with a protection ratio of around -20dB.



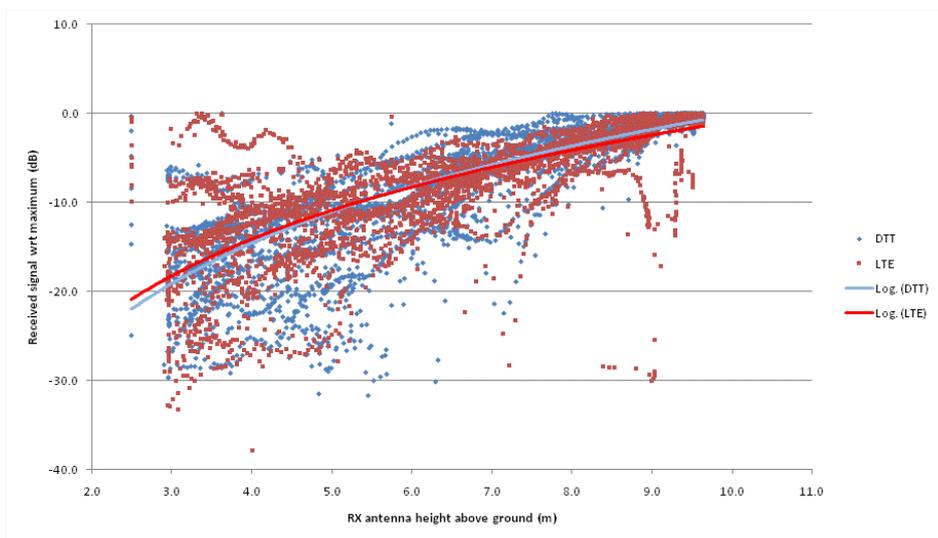
**Figure 5.7: Height gains with LTE multipath**

In the final example (Figure 5.8) the height gains are almost anti-correlated, with the LTE field strength tending to decrease with height. In this case the protection ratio improves from -30dB to -15dB as the mast is raised.

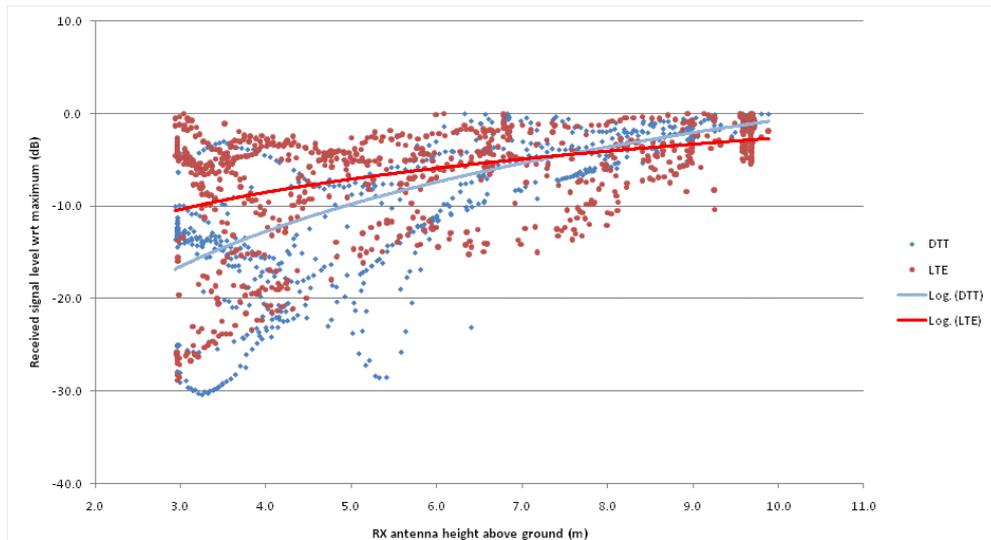


**Figure 5.8: Height gains showing different characteristics for DTT and LTE**

The height gain statistics measured in two areas are gathered in Figures 5.9 and 5.10 below. Each individual data set is normalised to the maximum signal value, which may not occur at the maximum height.



**Figure 5.9: Height gain measurements (Greatmead, 24 Feb)**



**Figure 5.10: Height gain measurements (Snowdome, 10<sup>th</sup> May)**

In the measurements made at Greatmead, the DTT and LTE signals show very similar trends, with a median gain of around 20dB from 2.5m to 10m. This compares reasonably well with the 21dB predicted by the Okumura-Hata correction over a slightly greater range (1.5m to 10m). It is interesting to note that the shape of the logarithmic fit is inverted with respect to the curve assumed in the P.1546 height gain model.

The more sparse set of data from the Snowdome site shows smaller height gains, of around 7dB for the LTE signal and 15dB for the DTT. This site used a lower LTE antenna height (15m instead of 20m) at a more cluttered location (Trees close to the LTE antenna obstructed the direct line of sight towards the receiver) and path lengths were shorter (<500m, compared with paths up to 3km).

### 5.3 Location variability

In broadcast planning, a location variability of 5.5dB is assumed for the wanted DTT signal.

The initial Ofcom assumption was that the location variability on the interference path is 3.5dB for paths of less than 50m, and 5.5dB for paths of greater than 100m, with linear interpolation between these values.

In the course of the field trial, location variability of both wanted and interfering signals was assessed (at 10m above ground).



**Figure 5.11: Sample location variability measurements**

There is a reasonable uniformity between the values measured for the DTT transmissions (range ~7km) and the LTE signals (range ~2km). The average value of around 2.2dB is significantly different from the 5.5 dB value often assumed in broadcast planning, though it does agree with previous measurements made by the author [ITU, 2004].

**Table 5.1: Measured values of location variability**

| Area | points  | DTT | LTE A | LTE B | LTE C |
|------|---------|-----|-------|-------|-------|
| a    | 6       | 1.9 | 1.1   | 1.9   | 1.2   |
| b    | 8       | 3.5 | 3.9   | 4.6   | 3.6   |
| c    | 11      | 2.2 | 2.2   | 2.0   | 2.3   |
| d    | 5       | 2.5 | 1.0   | 1.1   | 0.6   |
| e    | 6       | 0.9 | 1.1   | 1.5   | 1.4   |
| f    | 3       | 1.8 | 3.4   | 3.8   | 3.8   |
| g    | 4       | 0.6 | 2.0   | 2.2   | 1.8   |
|      | average | 1.9 | 2.1   | 2.5   | 2.1   |

The number of measurements made is, however, too small to allow any firm statistical conclusions to be drawn; to do so would require a separate, substantial, measuring campaign.

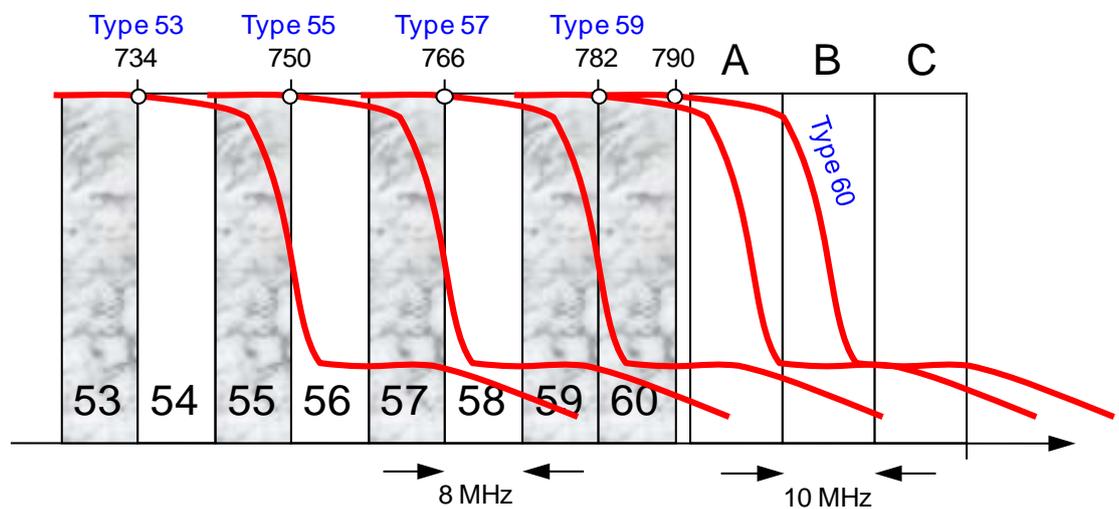
In the light of the field trial measurements the original Ofcom assumptions for location variability were revised to 1dB for ranges <100m and 5.5dB for ranges >1km, with interpolation between these values.

## 6 MITIGATION—FILTERING

### 6.1 Prototype filters

Ofcom procured samples of filters, potentially suitable for use in curing interference to domestic DTT reception, from two companies. The intention is that these filters could be widely distributed at low cost, and fitted by householders at the aerial sockets of DVB-T receivers.

One filter type was designed and implemented by Technetix in response to an Ofcom brief that required an essentially flat response to the top of channel 60 (790 MHz), followed by a roll-off that was as steep as possible at low cost. The same prototype was also used as the basis for a set of filters offering the same response but with different cut-off frequencies, referred to as 'Type n' where n is the highest DTT channel that is below the filter roll-off point.



**Figure 6.1: Notional filter characteristics [source: Ofcom]**

For DTT services operating at channel 59 and below, it should be possible to repair interference using filters with a less stringent roll-off characteristic, which would also allow for a greater ultimate attenuation in the stop band. A suitable design by Braun was identified.

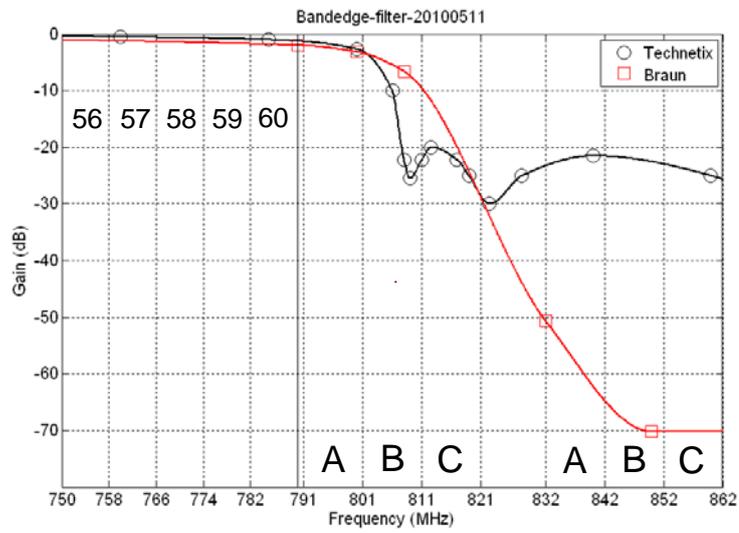


Figure 6.2: 'Type 60' filters compared

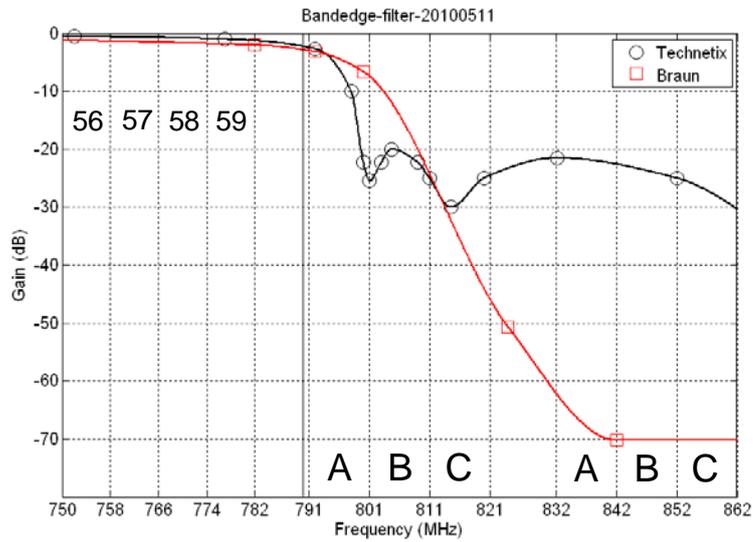


Figure 6.3: 'Type 59' filters compared

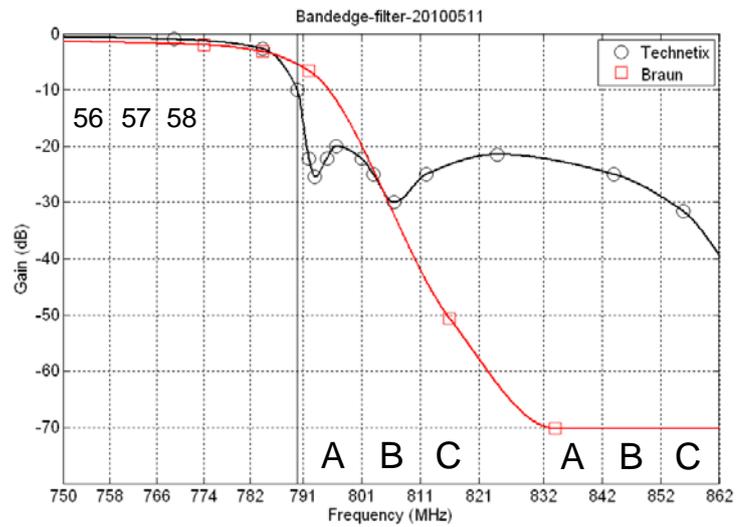


Figure 6.4: 'Type 58' filters compared

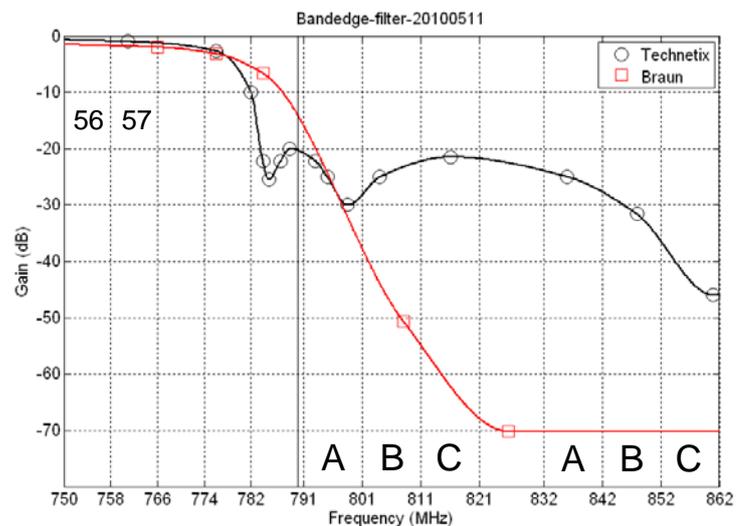


Figure 6.5: 'Type 57' filters compared

In all cases, the Braun filter offers worse<sup>14</sup> rejection of power from the Block A downlink, but better rejection of the uplink channels and, for the lower-frequency units, better rejection of Blocks B and C. It should be noted that the mitigation provided against interference from downlink Block A is limited for both the 'channel 60' and 'channel 59' units.

The filters are referred to in this report as, e.g. 'B\_60' or 'T\_59', to indicate the manufacturer, and the nominal upper channel within the passband. 'B\_58' therefore corresponds to the unit marked 'LPF774' from Braun.

<sup>14</sup> Or similar, in the 'channel 57' case.

## 6.2 Field trial evaluation

The Ofcom measurement team made a series of measurements intended to evaluate the performance of the receiver filters in realistic conditions. For these tests the measurement vehicle was located relatively close (200-400m) to the LTE base station, at a location where interference was known to be experienced to DTT reception. For all the tests, the ‘domestic’ DTT receive aerial was used, and interference evaluated on a set top box (‘RX 8’), known to be particularly susceptible to LTE interference. The signal levels were measured by plugging the aerial connector from the STB into the 75Ω input of the ETL analyser, with or without the filter in circuit as appropriate.

### 6.2.1 Results

A summary illustration of the effectiveness of the different filters during the trials is given in the figure below. For each filter, the first column indicates whether the wanted DTT signal was on channel 59 or 60, while the first row indicates which LTE blocks were in use. In all cases, no reception was possible without the filter. ‘Y’ indicates that reception was restored, ‘N’ that it wasn’t and ‘B’ represents a borderline case. Cells that are ‘greyed-out’ indicate combinations that were not tested.

**Table 6.1: Filter testing summary—see caveat in text below**

|                     |       |     |     |       |     |   |   |
|---------------------|-------|-----|-----|-------|-----|---|---|
| <b>Braun 60</b>     | A,B,C | A,B | A,C | A     | B,C | B | C |
| 59                  | N     |     | N   | N     | Y   | Y | Y |
| 60                  |       |     |     |       | Y   |   |   |
| <b>Technetix 60</b> | A,B,C | A,B | A,C | A     | B,C | B | C |
| 59                  | N     | N   | N   | N     | Y   | Y | Y |
| 60                  |       |     | N   |       | Y   | Y |   |
| <b>Braun 59</b>     | A,B,C | A,B | A,C | A     | B,C | B | C |
| 59                  | B     | B   | N   | B     | Y   |   |   |
| 60                  |       | N   | N   |       |     |   |   |
| <b>Technetix 59</b> | A,B,C | A,B | A,C | A     | B,C | B | C |
| 59                  | N     | N   | N   | Y     | Y   |   |   |
| 60                  | N     | N   | N   | Y / N | Y   |   |   |
| <b>Braun 58</b>     | A,B,C | A,B | A,C | A     | B,C | B | C |
| 59                  | Y     | Y   | Y   |       |     |   |   |
| 60                  |       | Y   | Y   | Y     |     |   |   |

It can be seen from the above that, in broad terms, it is simple to correct interference due to LTE emissions in blocks B and C, but that interference from Block A presents a more severe challenge, as would be expected. In the trials, interference from Block A into channel 60 was only reliably addressed using the ‘B\_58’ filter, which has an insertion loss of around 10dB on the wanted channel, which implies that a significant ‘headroom’ had to be available from the wanted DTT signal for this to be viable. *It is important to note that the table above gives only*

*anecdotal information*, as the levels of wanted and interfering signal are arbitrary. To understand the utility of the different filters in a quantitative way further analysis was necessary, as described below.

**6.2.2 Insertion loss**

The following insertion loss figures were measured in the course of the field trial measurements:

**Table 6.2: Receiver filter insertion losses**

| (dB)         | T_60    | B_60    | T_59    | B_59    | B_58     |
|--------------|---------|---------|---------|---------|----------|
| <b>Ch.59</b> | 0.4–1.3 | 2.8–3.1 | 1.3–1.8 | 3.5–3.9 | 4.5–4.7  |
| <b>Ch.60</b> | 2.8–3.4 | 4.4     | 3.7–3.8 | ??      | 6.4–10.9 |

These losses are broadly in line with expectation, based on the measured filter responses shown in Figures 6.2–6.5 above, although some of the variation found in the measurements is surprising<sup>15</sup> (e.g. B\_58 at channel 60). In general, sufficient margin was available to allow successful DTT decoding with any of the filters in circuit.

**6.2.3 Additional margin afforded by filters**

The most helpful way in which to characterise the filters is probably in terms of the ‘additional margin’ afforded against interference *from* a particular LTE block *into* a particular DTT channel.

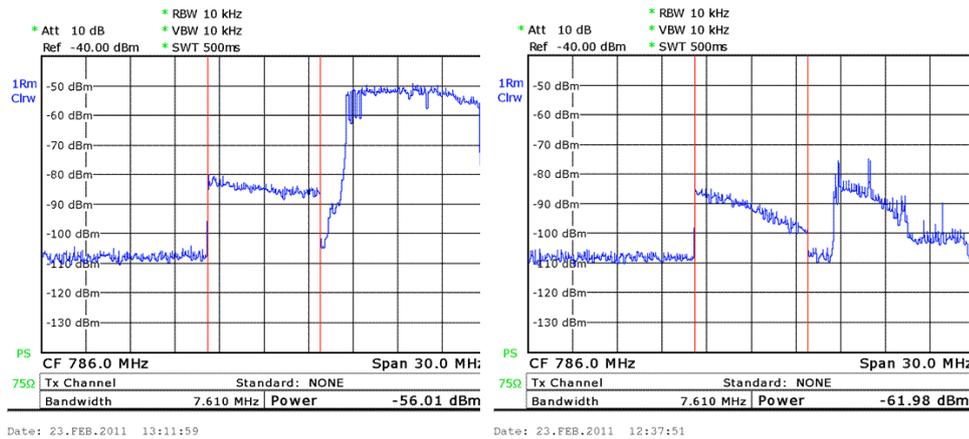
Thus, although a particular filter may attenuate the wanted DTT signal by, say, 6dB, if it also attenuates the unwanted LTE signal by 15dB, the margin will have been improved by 9dB. If the C/I deficiency at the receiver is known, it is then, apparently, simple to determine whether the interference would be corrected by a particular filter. In practice, however, it is also necessary to take account of further factors:

- If the insertion loss is too great, the DTT signal may fall below the noise-limited sensitivity of the receiver, regardless of any interference.
- The filter may introduce sufficient distortion in frequency or phase across the DTT channel to render demodulation impossible, although the absolute power in the DTT channel may appear sufficient.

In practice, neither of these mechanisms was apparent in the trials undertaken; for example, Figure 6.6 shows a case in which a reliable DTT service was restored despite the filter introducing a 10dB slope across the channel. A further set of sample spectral plots is given in Appendix E.

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<sup>15</sup> The variations may be due to fading on the received signal due to changing multipath or clutter (moving cars, trees, etc.).



**Figure 6.6: Use of filter with nominal pass-band below channel 59 to restore service on channel 60.**

In all cases examined, the ‘additional margin’ provided by the filter was found to be a good guide to the utility of any particular filter. The performance of the individual filters, as measured in the trial, is summarised in Table 6.3 below.

**Table 6.3: Additional margin afforded by receiver filters**

|                 | Block | T_60 | B_60 | T_59 | B_59 | B_58 |
|-----------------|-------|------|------|------|------|------|
| C/I improvement | A     | 0.7  |      | 13.3 | 10.3 | 20.6 |
| <b>Ch.60</b>    | B     | 16.7 | 18.3 | 21.4 |      |      |
|                 | C     | 19.5 |      |      |      |      |
|                 | Block | T_60 | B_60 | T_59 | B_59 | B_58 |
| C/I improvement | A     | 2.3  | 1.8  | 14.4 | 6.9  | 24.7 |
| <b>Ch.59</b>    | B     | 12.4 | 13.4 |      |      |      |
|                 | C     | 22.9 | 33.2 |      |      |      |

It can be seen from this table that it is probably unlikely that either of the ‘channel 60’ filters will ever provide sufficient additional rejection of interference to be of practical use where interference from Block A to channels 59 or 60 is concerned. The ‘T\_59’ filter may be useful in some cases, but the response of the ‘B\_59’ type is insufficiently sharp. Where interference is severe, and the DTT signal is strong enough to allow the high insertion loss to be tolerated, the ‘B\_58’ filter may be an option.

## **7 MITIGATION—ON CHANNEL REPEATER**

### **7.1 Introduction**

Where an LTE transmitter is ‘punching a hole’ in DTT coverage, a conceptually simple, but potentially complex and costly, option for mitigation would be to re-broadcast the affected DTT services from the offending LTE site, at a level sufficient to restore the necessary protection ratio.

One obvious problem with such an approach might be the need to find clear DTT spectrum for a potentially large number of such re-broadcast transmissions. Digital technology has, however, made it possible, given the right conditions, to rebroadcast DTT services without changing the frequency using an ‘On Channel Repeater’ (OCR).

The technology used in OCRs is briefly described in Annex C, which also gives the results of some preparatory bench-testing of one such unit. The key requirements for the successful use of an OCR can, however, be summarised:

- sufficient incoming DTT signal level and quality must be available at the OCR site
- the OCR must transmit at a sufficient power to restore the required DTT protection ratio
- sufficient isolation must exist between the input and output antennas of the OCR.

These three parameters are inter-related; if the incoming DTT signal is low, a higher gain will be needed in the OCR to deliver a given output power. This will necessitate a greater antenna isolation. In practice, it will be necessary to make a judgment on the practicability of an OCR on a site-by-site basis.

### **7.2 Field trial evaluation**

During the field trials, the opportunity was taken to test the operation of an OCR in realistic circumstances. For the majority of tests, the output of the OCR was combined with that of the LTE transmitters, and radiated through the same panel antenna.

The bench testing reported in Annex C indicates that isolation levels of between 80-90 dB are required for typical operating conditions.

At the Council office location, as shown in Figure 3.12, the RBL antenna was located on the opposite side of the roof, behind and to one side of the LTE panel transmit antenna, and was additionally screened by the presence of a metallic cubicle housing cellular base station equipment. The isolation measured with this arrangement (a separation of around 14m) was 103 dB. The isolation was also measured with the RBL antenna moved to a position 5m directly behind the LTE panel antenna, with no additional screening. In this configuration, the isolation fell to 89dB.

When used on the trailer mast, the RBL antenna was mounted at the same height as the transmit antenna (see Figure 7.1), but pointing on a reciprocal bearing. In this configuration an isolation of around 86dB was typically (and rather surprisingly) measured. A further discussion of the antenna isolation achieved in practical installations is given in Annex C.



**Figure 7.1: Showing relative location of LTE transmit and DTT receive antennas on trailer mast**

When used on the trailer mast it was found necessary to provide additional filtering to mitigate the impact of adjacent channel interference from the LTE signals; the modest rejection provided by the tuneable filter described in Annex C was found to be sufficient to remove this interference.

The OCR was normally operated at power levels of around 10W. Taking into account the combiner and feeder losses (9dB), and the antenna gain (17dBi), this resulted in a transmitted eirp of 48 dBm (63W). This gave a fixed protection ratio with respect to the 59dBm eirp LTE signal of 11dB, which, on the basis of the receiver performance measurements [ERA, 2011] should be sufficient to repair coverage to all DTT receivers.

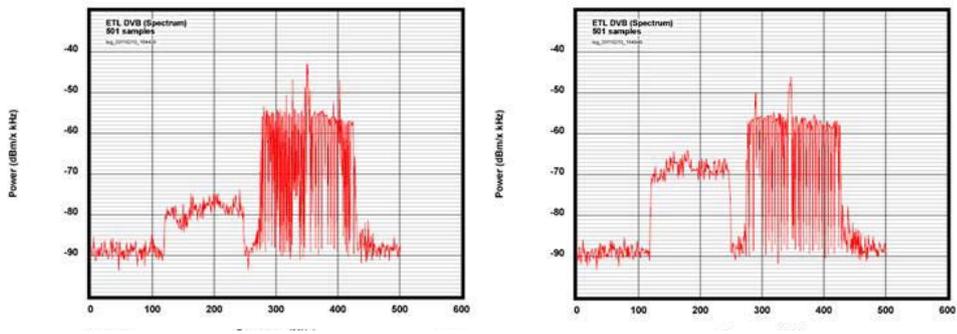


Figure 7.2: Spectrum at DTT test set with OCR off and on

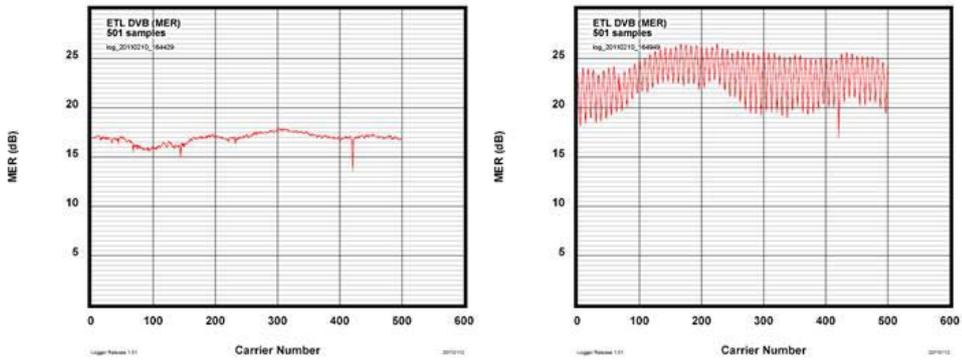


Figure 7.3: MER measured on DTT test set with OCR off and on

This was found to be the case in practice, and typical results are illustrated in Figures 7.2 and 7.3 below, which relate to a location where DTT reception was initially impossible, but was successfully restored with the OCR.

## 8 MITIGATION—POLARISATION DISCRIMINATION

### 8.1 Background

It is expected that LTE base station transmitters will employ dual slant polarisation, to support MIMO operation while minimising the mast aperture required. In this scheme the necessary channel diversity is engineered by using antennas containing orthogonally-slanted elements in place of pairs of vertically-polarised antennas, separated by a number of wavelengths, with a significant saving of space required on the mast structure.

DTT transmissions, on the other hand, always use either horizontal polarisation (all main stations, and a few relays) or vertical polarisation (the majority of relay transmitters). The combination of slant-polarised LTE and horizontally- or vertically-polarised DTT implies that the maximum discrimination afforded by DTT receive antennas against the LTE signals will be 3dB.

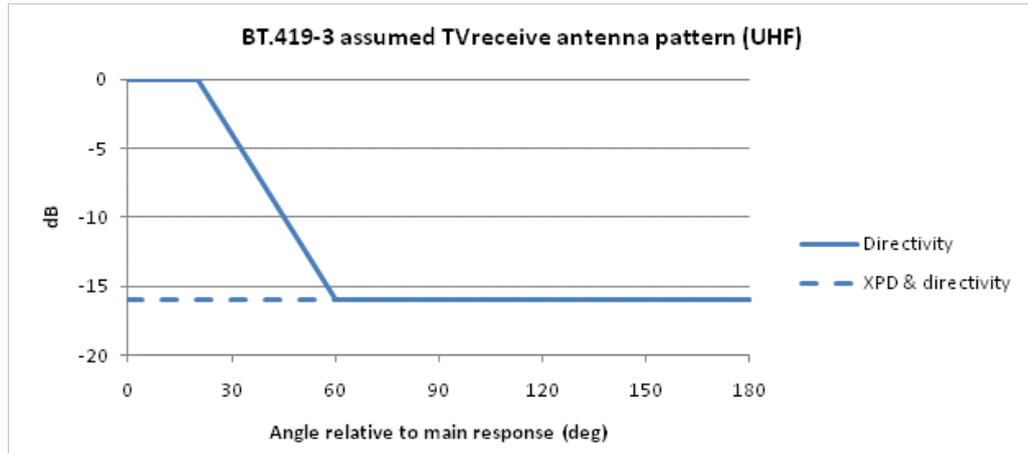
In cases where hole-punching interference is predicted, one mitigation strategy might be to arrange for the polarisation of the LTE transmissions to be orthogonal to the local DTT services. In main station areas, this would imply that VP should be used at the LTE site, which would have little impact on the link budget, but would necessitate the use of spaced antennas if MIMO were to be implemented.

Where the local DTT services are vertically-polarised, it would be necessary to use horizontal polarisation at the LTE site; As handsets can now be assumed to be 'polarisation agnostic', owing to the small antenna size, uncontrolled orientation and user proximity effects, this should also have no impact on the link budget.

### 8.2 Current planning assumptions

A Recommendation of the ITU-R describes the characteristics of domestic TV receiver aerials that should be assumed for the purposes of network planning. This Recommendation, BS.419-3, describes the angular discrimination that is to be expected from typical installations, with a maximum rejection of 16dB for signals arriving at 60° or more off-axis. The Recommendation also notes that the rejection of orthogonally-polarised signals is 'expected' to be exceeded at more than 50% of locations. It is noted that investigations carried out in the UK showed that "*there is also some small variation of discrimination with angle relative to the direction of main response*".

The Recommendation notes that polarisation and directivity are not simply additive, but that a combined maximum discrimination of 16dB should be assumed for all azimuths—see Figure 8.1. The value historically assumed for UK planning is different, at 15dB.

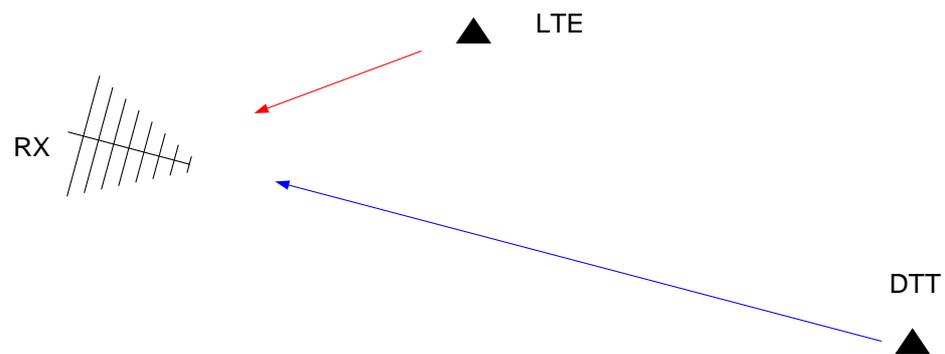


**Figure 8.1: ITU-R assumed antenna performance**

The value of cross-polar discrimination achieved in any given case will be a function of the performance of both the transmit and receive antennas, and of the environment between them. The discrimination (in azimuth and polarisation) of domestic aerials is often compromised by the absence of a balun<sup>16</sup>, while the environment may contain objects that scatter energy, some of which will generally be re-radiated with a polarisation different to that of the incident wave, degrading the overall cross-polar discrimination.

### 8.3 Measurements

To assess the degree of protection that might be afforded in practice by the cross-polar discrimination of DTT receive antennas in a real environment, a brief series of measurements were made during the field trial.



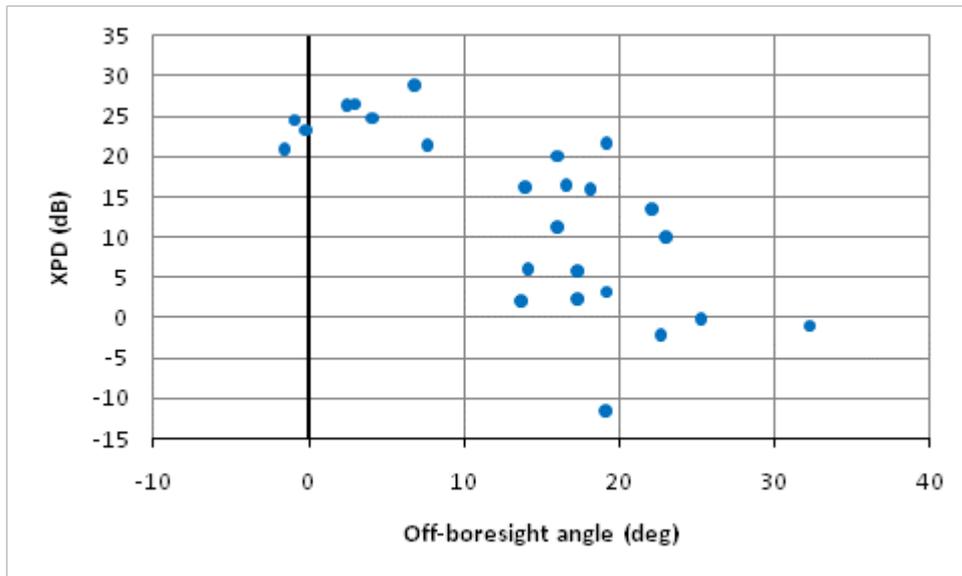
**Figure 8.2: Geometry for XPD measurements**

In these measurements, the receive antenna, which was either the ‘domestic’ Yagi or the professional log-periodic was directed at the DTT site, as would be the case for an actual domestic installation. The off-axis angle to the LTE site varied

<sup>16</sup> BALanced to UNbalanced transformer, used to allow a naturally-symmetrical system such as a dipole antenna to be connected to an asymmetrical coaxial cable.

depending on the individual measurement location. The measurements were made using the 'Two Gates' and 'Snowdome' LTE test sites.

The results, for the domestic Yagi, are plotted in Figures 8.3 and 8.4 below.

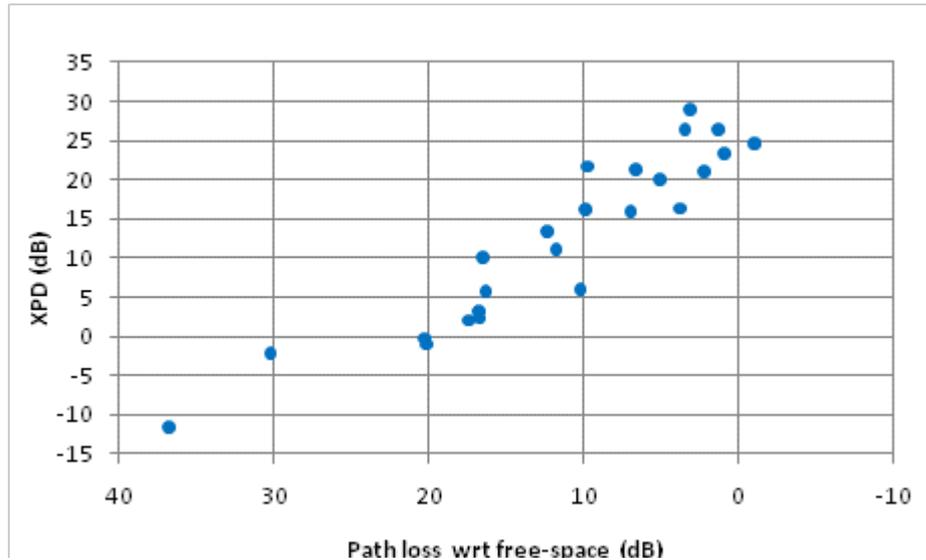


**Figure 8.3: Cross-polar discrimination versus off-axis angle (domestic Yagi)**

In the first figure, the degradation of cross-polar discrimination for signals appearing off-axis can clearly be seen; with the (rather good) discrimination of more than 20dB falling to zero, or negative values, for LTE signals arriving at more than 20° separation from the DTT signal.

The cross-polar discrimination was also plotted with respect to the excess loss on the path from the LTE transmitter. This is the difference between the measured<sup>17</sup> loss and the theoretical free-space loss on this path; in other words this is the additional attenuation due to diffraction and absorption by local clutter, or due to destructive interference between direct and reflected rays.

<sup>17</sup> Measured with the receive antenna aligned to the LTE, and using the same polarisation.



**Figure 8.4: Cross-polar discrimination versus excess path loss (domestic Yagi)**

Figure 8.4 shows that there is a very strong correlation between excess path loss and cross-polar discrimination; this suggests that the main mechanism for the degradation of cross-polar discrimination is that of environmental scattering; if the direct path is attenuated, a greater proportion of the total energy arriving at the receive antenna will have undergone reflection or scattering.

It is fortunate that the cases where the least protection is available from cross-polar discrimination are those where LTE interference is relatively low due to angular separation or losses on the interference path.

The data plotted in Figures 8.3 and 8.4 would tend to support the use of the ITU-R 'combined' 16dB figure for antenna discrimination, or the UK 15dB XPD figure, although this may degrade more rapidly away from boresight than currently assumed. A more substantial set of data would be required to support any revised assumptions.

## 9 PRE-AMPLIFIER OVERLOAD

On a number of occasions during the field trial, the measurement team were approached by members of the public reporting issues of interference to domestic TV reception, both analogue and digital.

One such report concerned a sheltered housing scheme, at a distance of some 300m from the temporary LTE base station on the Council office roof. TV services at this location were from Sutton Coldfield, some 10km to the South West, and separated by only 10° in azimuth from the LTE signal. The interference appeared to be due to overload in one of the distribution amplifiers of the Master Antenna TV system (this system was configured as several separate groups of flats each with its own antenna hidden in the roof space).

Sutton Coldfield services are radiated on channels 40 -55 (analogue and pre-switchover DTT), so the minimum frequency separation from the local LTE signals was 41 MHz. This large frequency separation made it straightforward to correct the problem by installing any of the low-pass filters described above between each source antenna and the associated distribution system amplifiers.

Other reported problems, relating to individual domestic installations, also appeared to be due to overload effects in masthead or distribution amplifiers. Given the high levels of signal strength available from Sutton Coldfield in the area, it is possible that these installations were operating with excessive gain, as this is not always readily adjusted on domestic installations.

In response to concerns relating to receive amplifier overload (as distinct from adjacent channel interference), Ofcom commissioned ManderCom Ltd to undertake further research on this topic [ManderCoM, 2011a], [ManderCoM, 2011b].

Laboratory measurements of amplifier overload performance have also been undertaken by ERA Technology, and will be reported separately.

## 10 CONCLUSIONS

The field trials undertaken at Lichfield have demonstrated or confirmed the following issues:

- There is a risk of harmful interference from high-power (59dBm eirp) LTE signals to domestic DTT reception in adjacent channels at distances up to around 1km.
- For some DTT receivers, the impact of LTE signals in idle mode is much more severe than for a fully loaded transmission, despite a mean interference power level that is some 8dB lower.
- Receiver performance in the field is broadly in line with bench tests allowing for environmental effects.
- It was noted that interfered-with DTT receivers would often recover the signal when VHF transmitters were operated nearby; this may provide an insight into the failure mechanism.
- The propagation model used in the 'Punch' prediction tool is appropriate for suburban environments such as that of Tamworth, and there is some indication that actual values of location variability are lower than those assumed.
- The 'Punch' prediction tool broadly identifies the areas likely to suffer interference, but direct comparison with measurements gathered from individual trials is not possible owing to the statistical nature of the tool output, and the limited sampling density possible in the field trial measurements.
- The use of low-pass filters, similar to the devices provided by Ofcom, provides a simple remedy for interference where there is sufficient frequency difference between the LTE and DTT signals. In general, simple, cost-constrained filtering will not remedy cases of interference between Block A and Channels 59 or 60, unless the DTT signal level is sufficient to allow a high insertion loss to be tolerated.
- The use of a polarisation for the LTE signals that is orthogonal to that for DTT will provide up to around 15dB of additional isolation, which should be sufficient to repair the majority of interference problems. The discrimination that can be achieved, however, is dependent on the quality of the receive antenna, the environment and the relative bearing of the wanted and interfering signals. In some cases the discrimination can fall to zero, or become negative.
- An on-channel repeater can repair DTT coverage successfully if the radiated power is such as to restore the required protection ratio. Not all LTE sites will have sufficient incoming DTT signal level and quality to allow successful rebroadcast at the required powers, and careful attention is required to achieve the necessary isolation between antennas, which may not be achievable at some locations.

- The trials highlighted the danger that masthead and distribution amplifiers may be overloaded by nearby base station emissions, even when the local DTT service is provided on channels well-removed in frequency from LTE services. Further work is required to fully understand the interference effects on amplifiers.

**A GLOSSARY**

|        |  |
|--------|--|
| AGC    | Automatic Gain Control   |
| AGL    | Above Ground Level   |
| AOD    | Above Ordnance Datum (i.e. above sea level)  |
| COFDM  | Coded Orthogonal Frequency Division Multiplexing: a modulation scheme making use of multiple radio-frequency carriers to give robust transmission. |
| DSO    | Digital Switch Over: the transition from analogue (PAL) television services to DVB-T.  |
| DTT    | Digital Terrestrial Television   |
| DVB-T  | Digital Video Broadcasting—Terrestrial: the terrestrial component of the DVB standards, using COFDM for robust transmission.                       |
| DVB-T2 | An evolved version of the DVB-T standard, offering higher data rates and improved resilience to interference. Used in the UK for HD services.      |
| EIRP   | Effective Isotropic Radiated Power   |
| ERP    | Effective Radiated Power   |
| ETN    | East of True North   |
| HD     | High definition (television)   |
| ITU-R  | International Telecommunications Union—Radiocommunications sector  |
| LPF    | Low Pass Filter  |
| LTE    | Long Term Evolution: a new set of standards for cellular mobile services.  |
| PAL    | The analogue TV standard used in the UK ('Phase Alternation, Line' describes the colour coding method).  |
| RBL    | Re-broadcast Link  |
| R/T    | Radio telephone  |
| STB    | Set-top box  |
| UHF    | Ultra High Frequency (300MHz–3GHz)   |
| VHF    | Very High Frequency (30MHz–300MHz)   |

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## **C ON-CHANNEL REPEATER ISSUES**

### **C.1 Introduction**

This document describes work undertaken, as part of the 'Protection Clause Field Trial', to investigate the practicality of using 'on-channel repeaters' to repair DTT coverage 'holes' caused by LTE interference.

Measurements have been made of the performance of a Rohde & Schwarz XLx8000 unit, in laboratory configurations representing operation in a 'coverage repair' role with adjacent-channel LTE interference.

Measurements have also been made of the isolation available between aerials mounted on a variety of structures.

It is tentatively concluded that on-channel repeaters will provide a realistic approach to coverage repair in many circumstances.

A brief description of OCR operating principles is given in an appendix (Section C4).

### **C.2 Requirements for coverage repair**

#### **C.2.1 DTT signal available at input**

The greatest requirement for coverage repair will, of course, be where towards the edge of DTT service areas, where the wanted signal is lowest and, therefore, most vulnerable to interference.

In the UK, the DTT limit of service is defined as the field strength providing a C/N ratio of 22.8 dB (the value required for reliable decoding of 64-QAM, 2/3 DVB-T signals) at 70% of locations. At channel 60, this corresponds<sup>18</sup> to a field strength of **54.6 dBµV/m**.

Assuming a standard BBC-design log-periodic receive antenna with a nominal gain of 7.8 dBd and a 3dB feeder loss, this field strength will give an input signal of **-73.5 dBm**.

The specification for the Rohde & Schwarz XLV8000 unit states that the MER<sup>19</sup> possible for an input of -60dBm is  $\geq 30$  dB, falling to  $\geq 24$  dB at -70dBm. The latter figure will be taken as the absolute sensitivity limit of the device, though this would be a very marginal service.

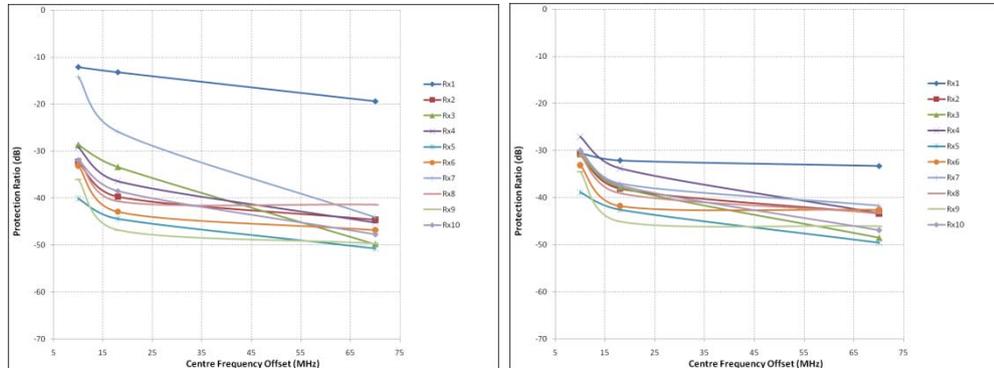
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<sup>18</sup> Assuming a 10dBd receive aerial gain and 3dB feeder loss and 8dB noise figure.

<sup>19</sup> Modulation Error Rate.

**C.2.2 Output power requirement**

The reliable demodulation of DTT in channel 60 requires that the total power of an LTE signal in Block A, at the receiver, be no more than around 30 dB above the DTT signal (i.e. a protection ratio of -30).



**Figure C2.1: BBC protection ratio measurements: LTE BS idle (left) and 100% (right)**

This implies that, to repair a coverage hole due to adjacent channel LTE interference, it would be necessary to radiate a DTT signal at a power around 24 dB lower than the LTE signal itself (giving some 6dB of margin).

If it is assumed that the highest radiated EIRP from an LTE site is 59dBm, this implies that OCRs would need to operate with an EIRP of 35 dBm.

There are at least two options for OCR configuration, in which the DTT signals may be radiated from a separate omni-directional aerial, or combined with an LTE sector panel. In the former case, a gain of around 5dBi may be available, in the latter case the gain may be around 17dBi. Assuming a feeder system loss of 3dB, the output power requirement from the OCR is, therefore between 21dBm and 33dBm (126 mW–2 W).

**C.2.3 Expected performance (DTT only)**

The table below shows the expected system performance for different options. Note that for stable operation with minimal degradation to the DVB-T signal, a W/U ratio of around 10-15dB is required. It can be seen that operation without some form of echo cancelling is impossible.

**Table C2.1: OCR performance (no interference)**

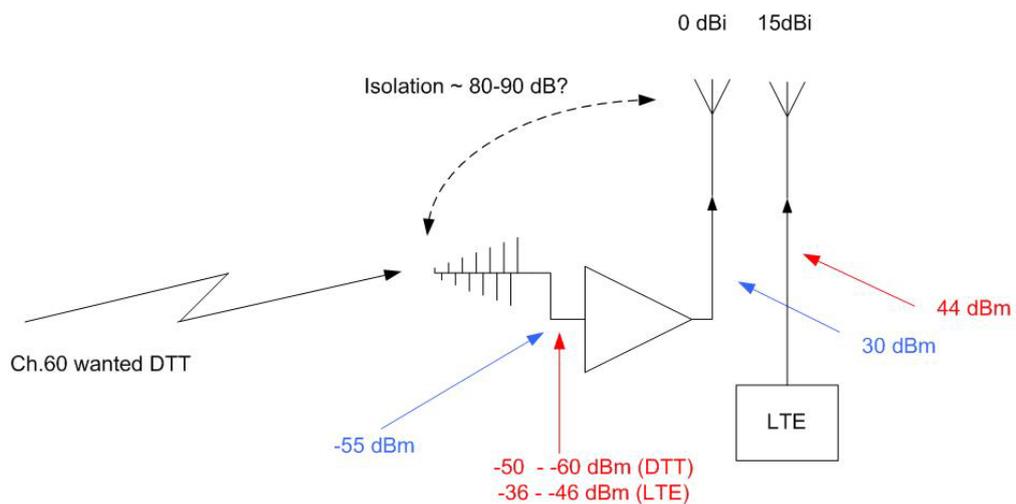
| Output power | 200 mW  |       |         |       | 2 W     |       |         |       |
|--------------|---------|-------|---------|-------|---------|-------|---------|-------|
|              | -60 dBm |       | -50 dBm |       | -60 dBm |       | -50 dBm |       |
| Input signal |         |       |         |       |         |       |         |       |
| Isolation    | 70 dB   | 80 dB |
| Gain         | 83 dB   | 83 dB | 73 dB   | 73 dB | 93 dB   | 93dB  | 83 dB   | 83 dB |
| U            | -47     | -57   | -47     | -57   | -37     | -47   | -37     | -47   |
| W/U (-)      | -13     | -3    | -3      | 7     | -23     | -13   | -13     | -3    |
| W/U (EC)     | -       | 32    | 32      | 42    | -       | -     | -       | 32    |
| WU (EEC)     | 22      | 32    | 32      | 42    | -       | 22    | 22      | 32    |

The standard echo canceller ('EC') permits echoes of up to 5dB above the direct signal, while the 'Enhanced' option (EEC) increases this to 15dB. Table C2.1 shows that, with the EEC the OCR will only fail for the high-power, low-input scenario.

The initial bench tests will verify this performance.

**C.2.4 Expected performance (with LTE interference)**

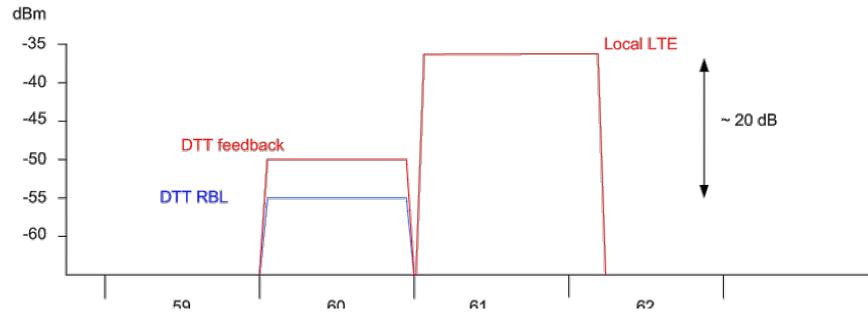
If used in a coverage-repair role, the OCR will need to operate in the presence of very strong adjacent channel signals from an LTE base station.



**Figure C2.2: Signal levels for 'hole-filling' OCR**

Assuming that the LTE site is running at the maximum permitted EIRP of 59 dBm, with a 15dBi gain antenna, a transmitter power of 44dBm is implied. If an isolation of 80dB is assumed between antenna ports, this would imply an LTE signal level of -36dBm at the transposer input.

The frequencies, and some indicative levels, are sketched below.



**Figure C2.3: Signals at repeater input**

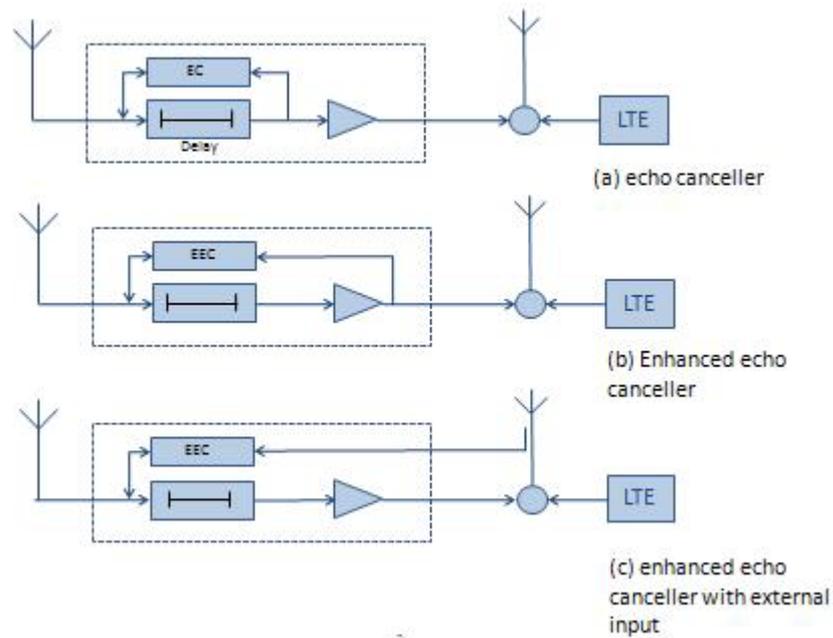
The OCR is equipped with a digital filter that offers 50dB or 70dB rejection of the adjacent channel. This filter adds to the overall delay through the system, but is adequate to ensure that the retransmitted signal does not contain significant adjacent channel energy.

The strong adjacent channel signal will, however, cause two main problems. Firstly, the power involved may cause overloading in the A-D converters in the input paths (main and reference) of the OCR. Secondly, the adjacent channel leakage from the LTE signal (i.e. the intermodulation products falling in channel 60) will corrupt the DTT signal itself.

No specification is given for the behaviour of the OCR in the presence of ACI, and this has therefore been investigated in the bench tests.

**C.2.5 Echo canceller reference input**

The basic echo canceller provided in the XLx8000 is self-contained, and works entirely in the digital domain, as sketched in Figure C2.4a. This is cost effective, but does not allow degradations due to non-linearity in the power amplifier stage to be compensated for.



**Figure C2.4: Echo canceller configurations**

If the additional expense of a second A-D converter can be tolerated, there are advantages in using a reference signal taken at the output of the OCR power amplifier as shown in Figure C2.4b (middle).

The additional A-D converter also allows the possibility of allowing for a reference feed taken from a point external to the OCR, If, as shown in Figure C2.4c, this is coupled from a point after the DTT and LTE signals have been combined into a joint aerial feed, then LTE products falling within the DTT channel can also benefit from cancellation.

As delivered, the XLx8000 was configured as in Figure C2.4b, but it proved possible to bring an external reference into the unit, as shown in Figure C2.4c. (the relevant internal connection is shown in Figure C2.5).

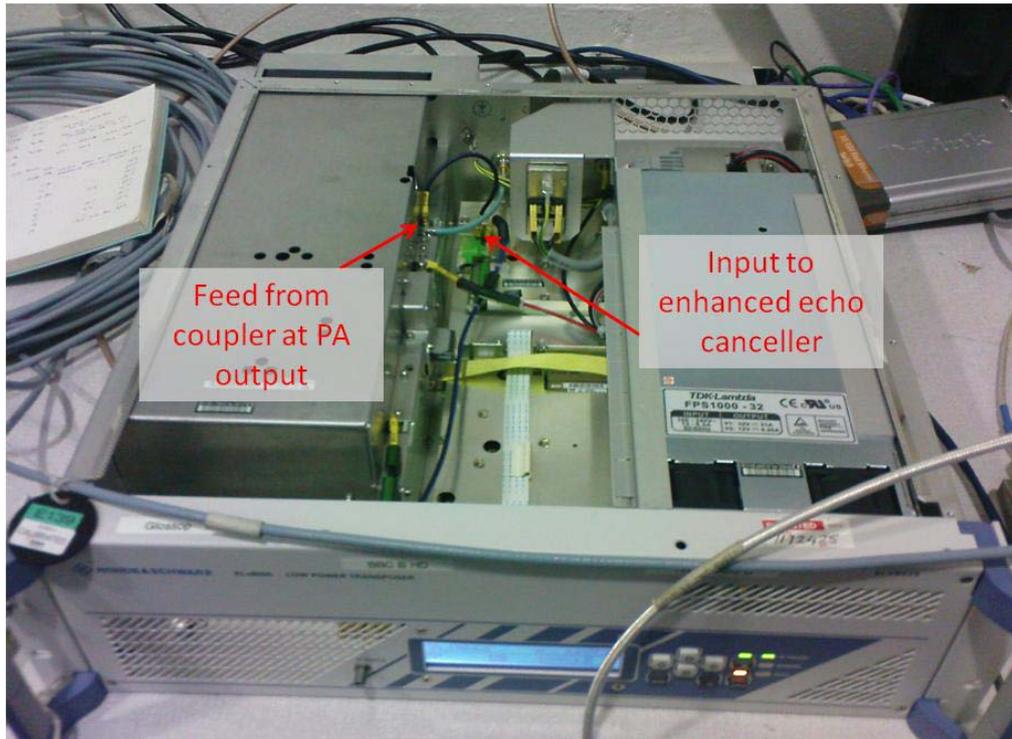
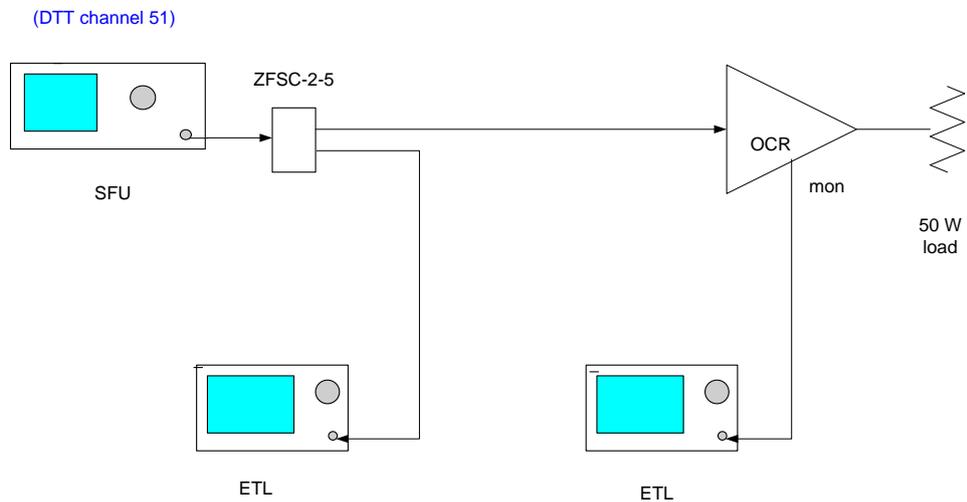


Figure C2.5: Enhanced echo canceller feed point

### C.3 Bench testing

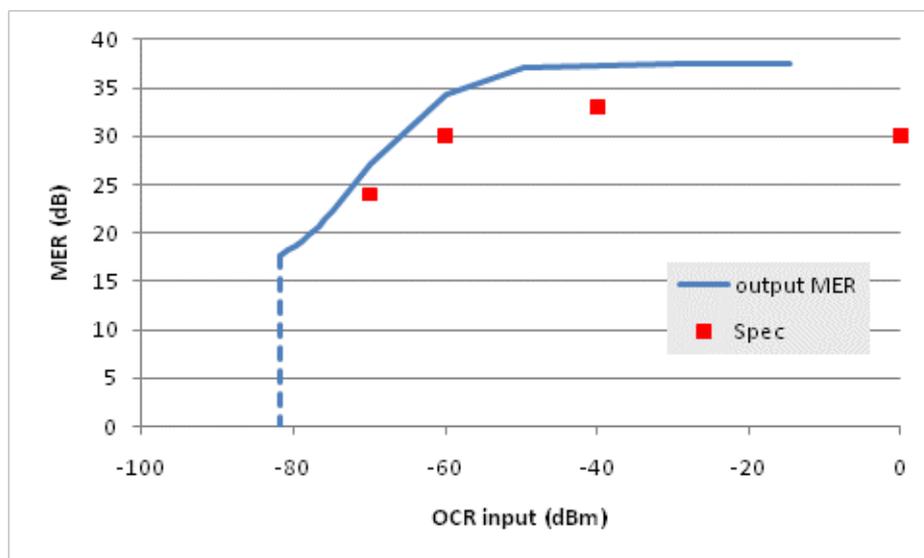
#### C.3.1 Sensitivity

The output MER of the device was monitored for a number of input power levels and an input MER of 34dB.



**Figure C3.1: Test setup for sensitivity measurements**

The measured performance of the Xl8000 is compared with the specification in Figure C3.2 below. It can be seen that the specification is comfortably exceeded.

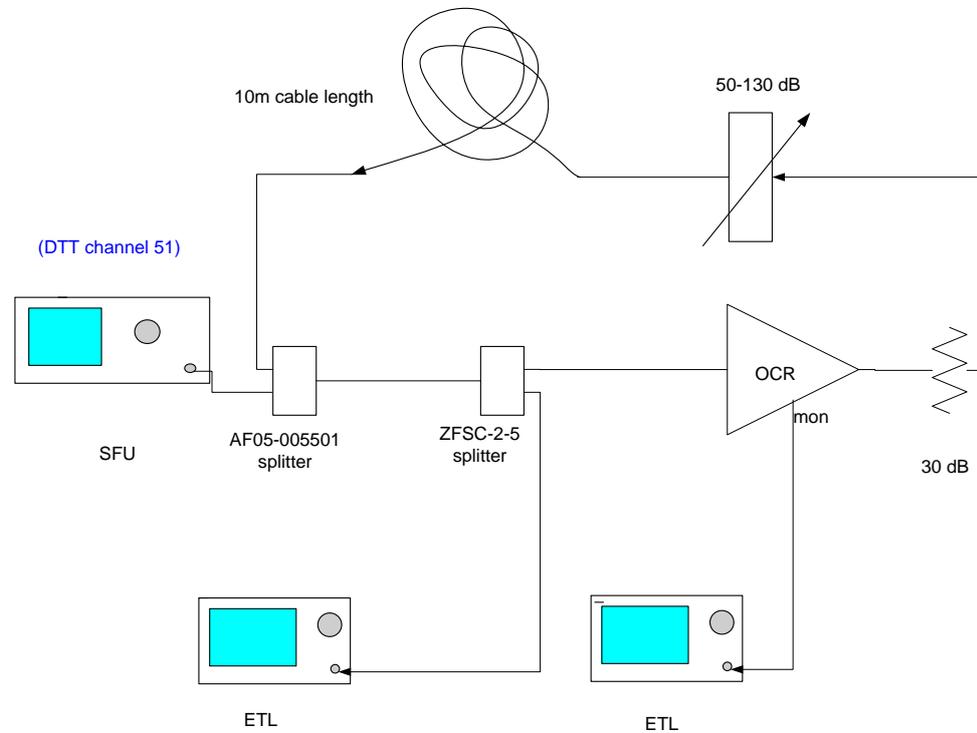


**Figure C3.2: XLV8000 MER versus input level**

A value of -60dBm would seem to be a pragmatic target minimum for the wanted DTT signal; level. This corresponds to a field strength of 68.1 dBµV/m, some 15dB above the service area limit of 54.6 dBµV/m. While the OCR would operate at the limit of service, the MER would be around 23dB.

**C.3.2 Feedback cancellation**

The performance of the OCR in a realistic scenario was investigated using the configuration of equipment shown in Figure C3.3.



**Figure C3.3: Test configuration with feedback**

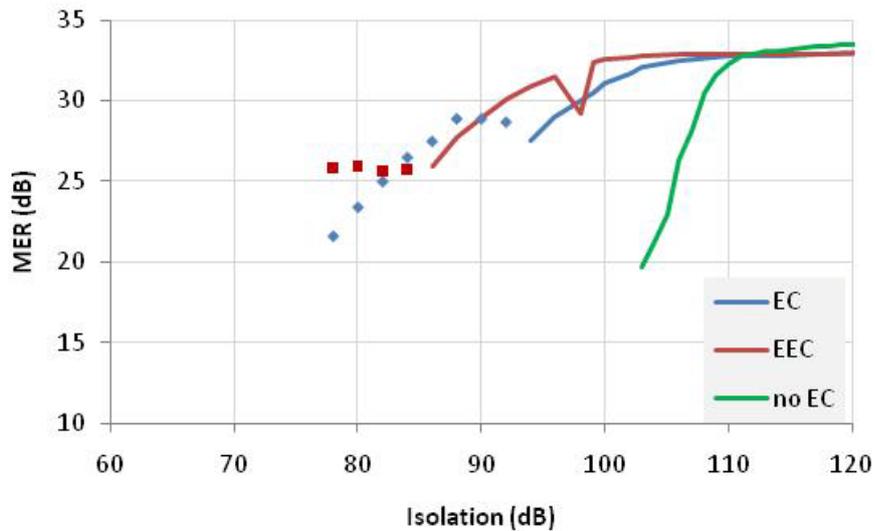
This scenario is intended to represent the situation in which the OCR is re-radiating a DTT signal, and an unwanted feedback path therefore exists between the transmit and RBL<sup>20</sup> (receive) aerials. This feedback path is represented by the loss and delay through the 30dB power attenuator on the output of the OCR, the 0-130dB attenuator and the 10m cable length which has a loss of 7.2dB.

**C.3.2.1 OCR at 25W output**

For the initial tests the SFU was configured to provide an input of -60dBm at the OCR. The results for the maximum rated OCR output of 25W are shown in Figure C3.4<sup>21</sup>. The dotted results for the echo canceller cases indicate that the OCR was reducing the OCR output power to maintain the maximum permitted echo amplitude (10dB for the EC and 18dB for the EEC).

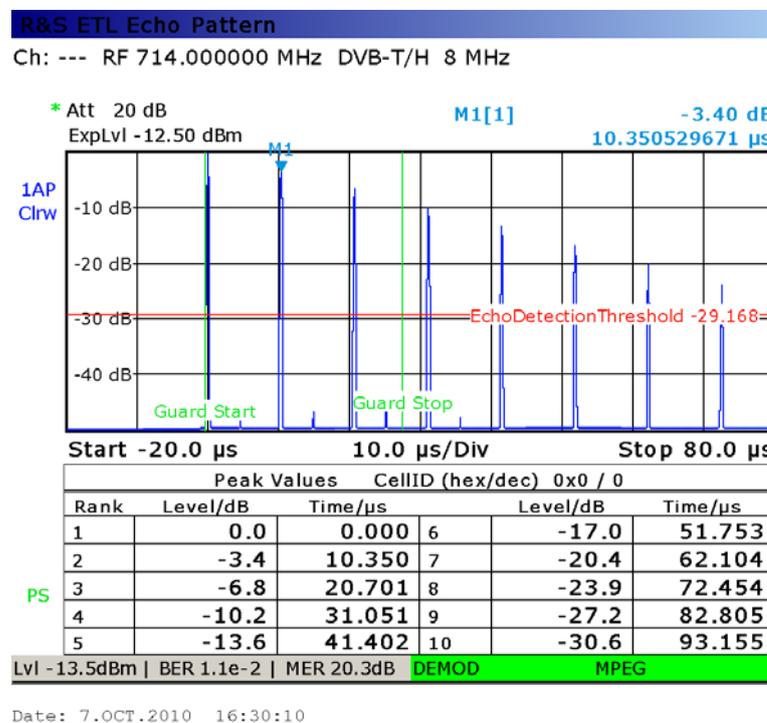
<sup>20</sup> Re-Broadcast Link.

<sup>21</sup> The cause of the anomalous point at 98dB isolation for the EEC case is not known.



**Figure C3.4: OCR with feedback path (25W OCR output)**

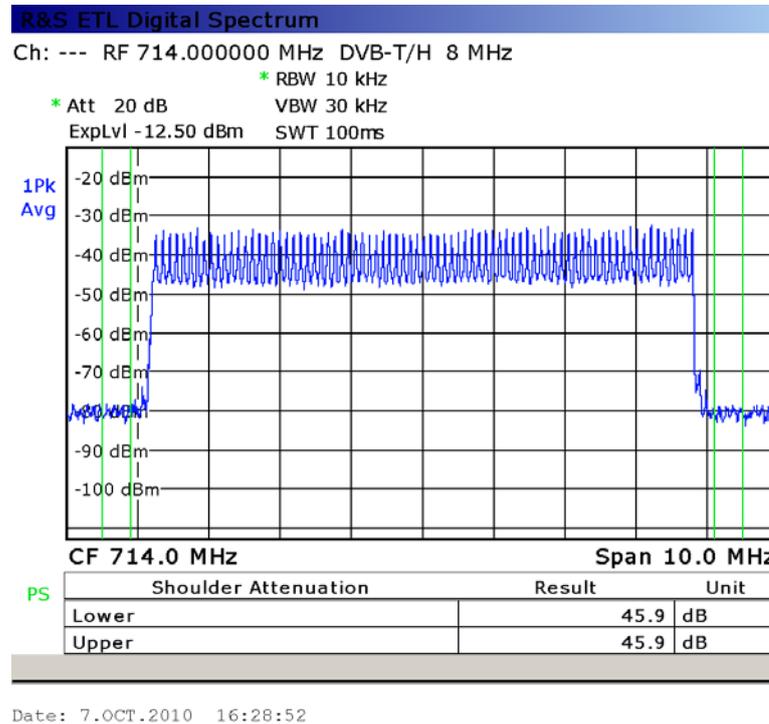
With no echo cancellation, it was found that the OCR output MER fell to 20.4dB for 104 dB isolation. At this point, the wanted DTT signal is only 0.5dB higher than the echo at the input of the OCR. It must be borne in mind that the initial echo, which is retarded by the processing delay of the OCR (8-10us) plus the feedback loop (~3 ns), is well within the guard interval of the DTT signal. The channel impulse response at the OCR output under these conditions is shown in Figure C3.5.



**Figure C3.5: Impulse response of DTT channel for 104dB isolation**

It can be seen from Figure C3.5 that the initial echo at 10.35µs is itself retransmitted, leading to further echoes at the increments of 10.35µs with diminishing amplitude. A significant amount of this delayed energy falls outside the DTT guard interval.

Figure C3.6 shows the same conditions in the frequency domain, illustrating the high level of ripple present on the signal.



**Figure C3.6: Frequency response of DTT channel for 104dB isolation**

Despite the fact that the DTT is hopelessly corrupt, the isolation could still be reduced by a further 15dB before the OCR output was muted. The gain of the OCR with an input of -60dBm and an output of 25W is 104dB.

With no echo cancellation, the minimum permitted coupling between the input and output antenna ports will need to be around 108dB. This is a figure that would be unrealisable in practice, as typical isolation<sup>22</sup> figures are 70-90dB.

**C.3.2.2 Echo canceller performance**

The R&S echo-canceller is specified to reduce the echo amplitude by 35dB. Although this might seem to imply that the required isolation could be reduced to around 79dB (for the case of a 25W OCR operating with a -60dBm input), the situation is actually dominated by the ability of the echo canceller to handle strong echo signals. With the basic option, the echo amplitude cannot exceed 5dB above the wanted signal, while the enhanced (EEC) option extends this to 15dB.

<sup>22</sup> This has been investigated in a separate series of measurement described elsewhere in this report.

The echo canceller on the XLx8000 was switched on (offset = 0µs, window=2 µs, 'slow'), and it was found that, at 104dB isolation the output MER increased from 20.2dB to 32.5dB.

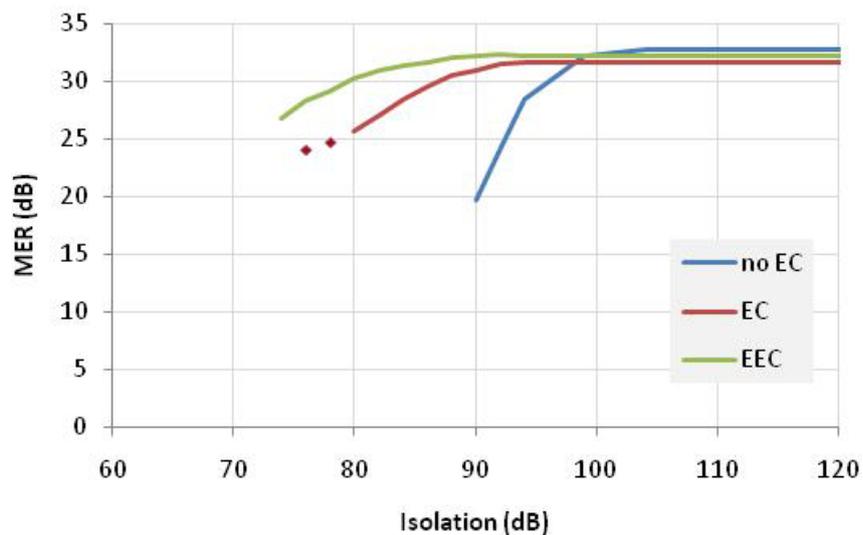
The isolation was then decreased to 94dB (MER=28dB) and then to 84dB at which point the output power dropped to 2.5W, with an MER of 27.2dB.

The EEC was also switched in, and this allowed operation of the OCR at 16W (echo 17dB above DTT) though with an MER of only 24.4dB.

The enhanced echo canceller therefore reduces the isolation requirement by around 20dB to a figure that is challenging but potentially realisable.

**C.3.2.3 OCR at 1W output**

However, as noted above, the power output required from the OCR will generally be at least 10dB lower than the 25W used in the tests, reducing the isolation requirement to a more realistic, if still challenging, value. The output of the OCR was therefore set to 1W, and the results shown in Figure C3.7 obtained.



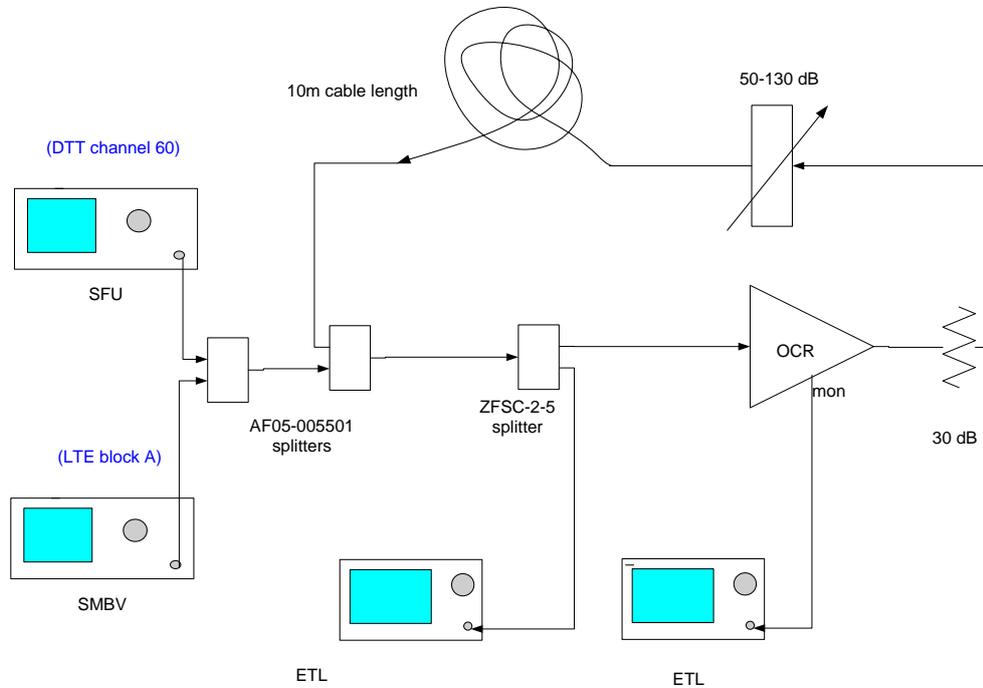
**Figure C3.7: OCR with feedback path (1W OCR output)**

As would be expected, the results of Figure C3.4 are essentially shifted in the x-axis by an amount corresponding to the output power reduction, i.e. by 14dB.

For a situation in which a DTT input signal of -60dBm is available, and an OCR transmitter power of 1W is required, it would be necessary to engineer an aerial isolation of around 80dB.

**C.3.3 Adjacent channel performance**

If the OCR is to be used for coverage repair, a strong LTE signal will unavoidably be present at the DTT RBL antenna. To assess the impact of such a strong adjacent channel interferer, an SMBV signal generator was configured to replay .ARB files representing the output of an LTE base station at different traffic levels.

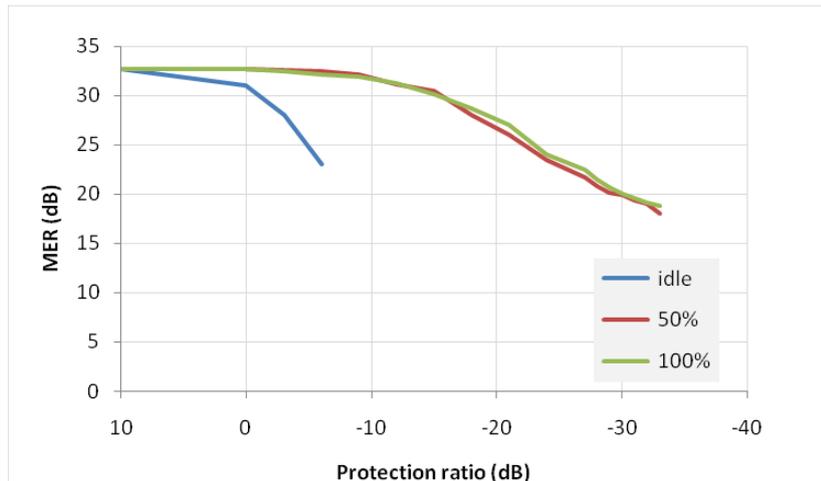


**Figure C3.8: Test configuration with LTE interference**

In the initial arrangement, the SFU was set up to provide a -60dBm DTT signal at the OCR input. With no interferer and no echo<sup>23</sup>, and at an output power of 25W, an MER of 29.5dB was obtained.

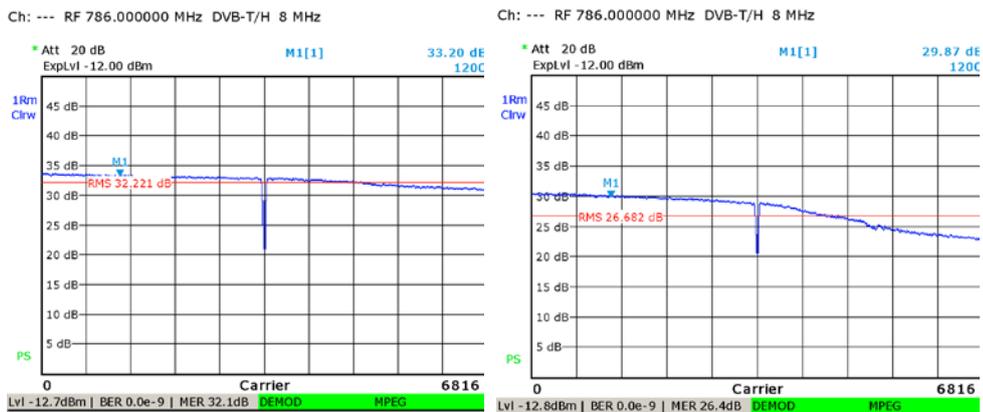
The SMBV was configured to play back an ‘.ARB’ file (provided by the BBC) recorded at the output of an 800 MHz LTE base station for three traffic conditions (‘idle’, 50% and 100%). The results are shown in Figure C3.9.

<sup>23</sup> i.e. with the attenuator set to 130dB, giving a total of 174dB in the feedback path.



**Figure C3.9: MER versus interferer level (50% traffic)**

It can be seen that, for the 50% and 100% cases a usable output is maintained until the adjacent channel LTE signal is some 20dB higher than the wanted signal. The channel filtering in the OCR provides efficient rejection of the energy in block A, and the main interference mechanism is presumably due to spurious products of the LTE signal that fall in channel 60 (the comparatively low levels of both signals rules out degradation due to front-end overload).



**Figure C3.10: Degradation due to ACI for 50% LTE traffic (left: PR=-10dB, right: PR= -20dB)**

Figure C3.10 shows the variation of MER across the DVB-T ensemble, showing clearly the degradation at the HF end of the channel.

The performance with the LTE base station in idle mode is significantly worse, with the failure point degraded by around 15dB, although the average power in the LTE signal is some 10dB lower. This is, perhaps, due to the time-constants embedded in the hardware and algorithms of the OCR.

While the performance in respect of LTE interference at 50% and 100% traffic levels will be sufficient to allow OCR operation with the relative input levels expected, interference from idling base stations would cause system failure.

C.3.3.1 Additional front-end filtering

Given the poor performance in the presence of interference from an idling base station, the impact of external filtering was investigated.

As no purpose-built channel 60 band pass (or block-A reject) filters were available, a general-purpose tuneable filter (Lorch Microwave) with a 5% passband was used.

This filter was tuned to give the optimum performance, balancing degradation to the channel 60 DTT signal with suppression of the power in LTE block A.

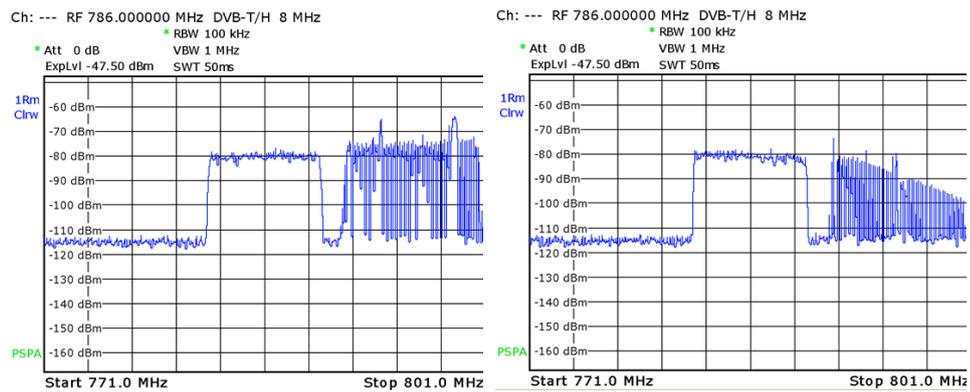


Figure C3.11: ACI at OCR input without (left) and with (right) tuneable filter

It can be seen that the rejection obtained from the filter is modest, reducing the block A power by less than 10dB.

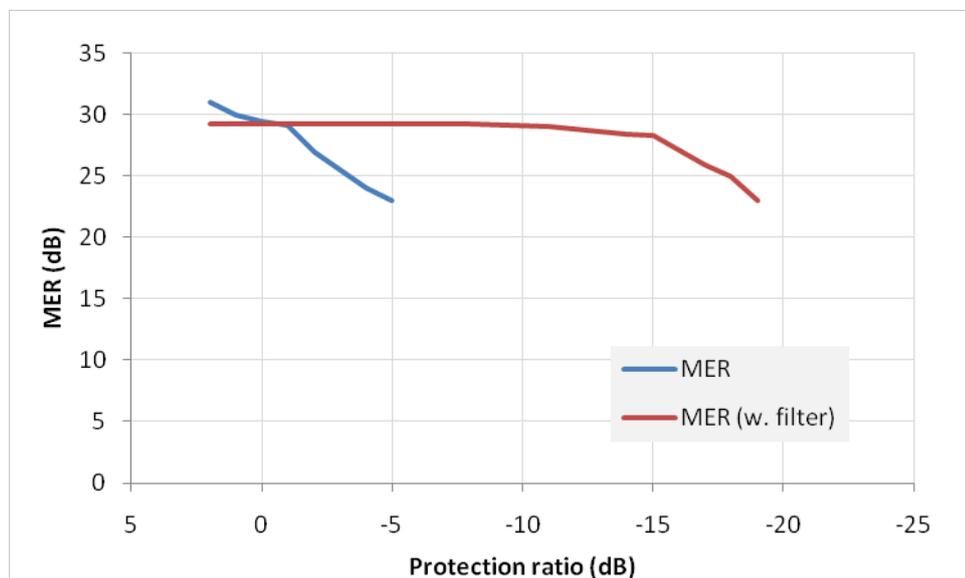


Figure C3.12: Impact of additional front-end filter

Figure C3.12 shows that the additional filter goes a long way towards making the performance in respect of LTE idle-mode interference comparable with that at higher traffic levels (the degradation of MER at low interference levels is due to the slope of the filter across the DTT channel).

This result gives confidence that a channel 60 band pass filter of modest performance would allow OCR operation in the presence of LTE interference at all traffic levels.

**C.3.3.2 OCR filter options**

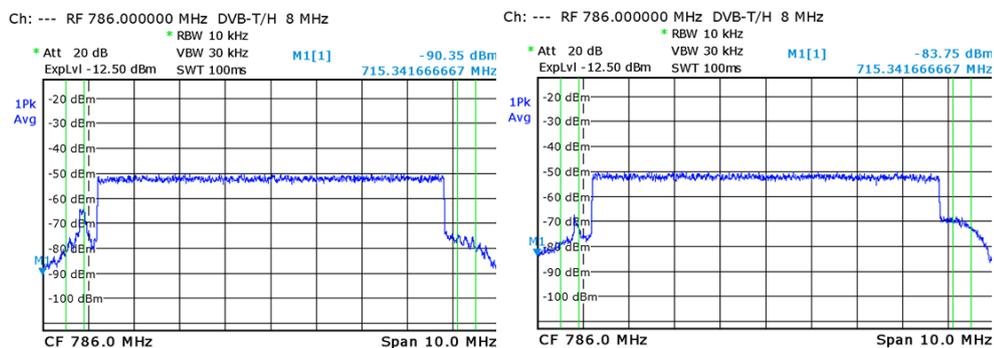
The XLx8000 includes two filters—one an optional SAW filter and the other a channel filter implemented in DSP. The latter can be configured to provide 50dB or 70dB rejection with ‘normal’ or ‘steep’ slopes.

The performance of these filter options was compared for the case of a 100% traffic LTE signal at 21dB above the wanted DTT (i.e. a protection ratio of -21dB). This is close to the failure point, and the MER was consequently fluctuating. The figures obtained are recorded in Table C3.1 below.

**Table C3.1: OCR filter performance**

| MER (dB)            | off       | 50dB      | 50dB steep | 70dB      | 70dB steep |
|---------------------|-----------|-----------|------------|-----------|------------|
| <b>SAW inactive</b> | 25.9-27.0 | 25.8-26.9 | 25.3-26.8  | 25.8-26.8 | 26.2-27.0  |
| <b>SAW active</b>   | 21.9-22.9 | 22.0-22.9 | 21.5-22.7  | 21.4-22.8 | 21.7-22.9  |

It can be seen that the use of the SAW filter actually degrades the overall performance of the unit. In Figure C3.13 below, the increase in adjacent channel LTE energy above the DTT channel can be clearly seen.



**Figure C3.13: OCR output without (left) and with (right) optional SAW filter**

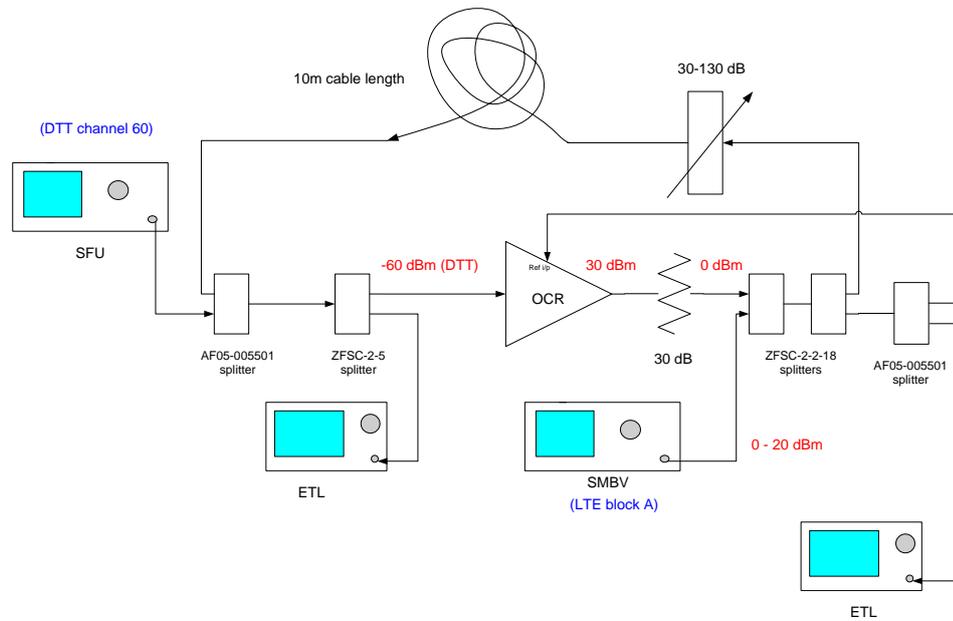
The use of the DSP filter does not measurably enhance the performance of the OCR with respect to interference from LTE signals separated by a 1 MHz guard band.

It should be borne in mind that the purpose of the OCR filter options is to improve performance with regard to adjacent channel DTT signals (with no guard band), and no measurements have been made of the unit’s performance in such a situation.

**C.3.4 External reference input**

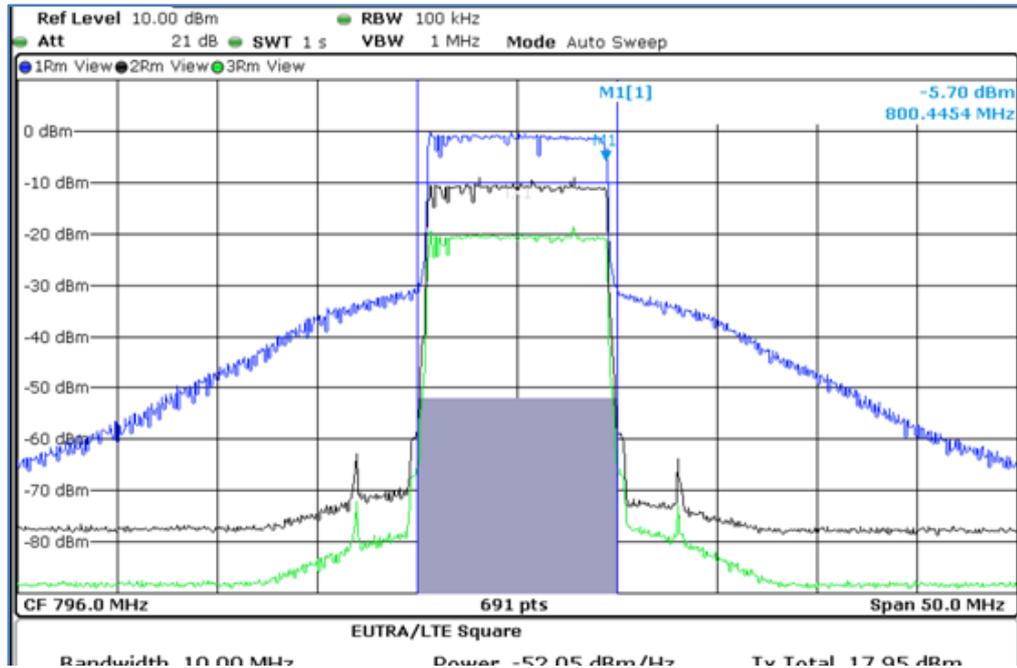
The XLx8000 was modified as described in Section C2.5 above to use an external reference input.

The test arrangement was modified to simulate the case in which the OCR output is combined into the LTE base station antenna. The intention is to represent a situation in which the OCR transmitter output is around 1W ERP, used to repair coverage holes caused by an LTE transmitter of up to around 20dB greater power (e.g. of 60dBm EIRP, if a 10dBi antenna is used).



**Figure C3.14: Test configuration with external EC reference and ACI**

Unlike the arrangement of Figure C3.3, in which the LTE signal is injected at low power, the scenarios that can be investigated are limited by the output power available from the LTE source.



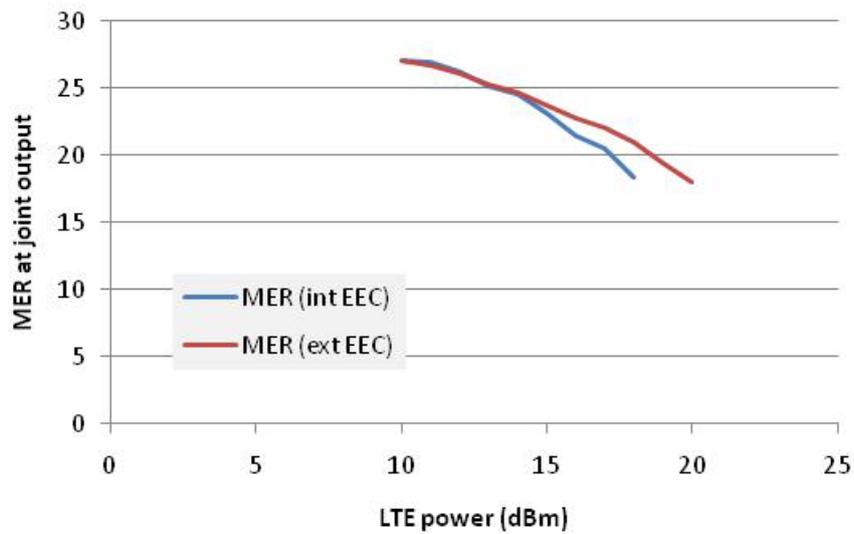
**Figure C3.15: Output from SMBV, replaying 100% traffic .ARB file at 0, 10 and 20dBm nominal powers**

It can be seen from Figure C3.15 that, while the out of band emissions at the 0dBm and 10dBm power levels are broadly in line<sup>24</sup> with the required ACLR of -59dB, the out-of-block emissions increase dramatically at the higher power levels, as intermodulation occurs in the output stage of the generator. The cause of the spuri at +/- 3 MHz from the LTE channel edges is not known—these features do not appear when the .ARB file is replayed on an Agilent generator.

In more comprehensive testing, the emission mask could be controlled at all power levels by the use of an additional power amplifier and attenuators. For the current exercise, the spectral re-growth was allowed to occur, as the intention was to compare the performance of the EEC using internal and external references near the point-of-failure.

The feedback path was set to represent an aerial isolation figure of 80dB, and LTE signals added at realistic levels; +10dBm from the SMBV corresponding to a 10W LTE transmitter output owing to the presence of the 30dB attenuator at the OCR output.

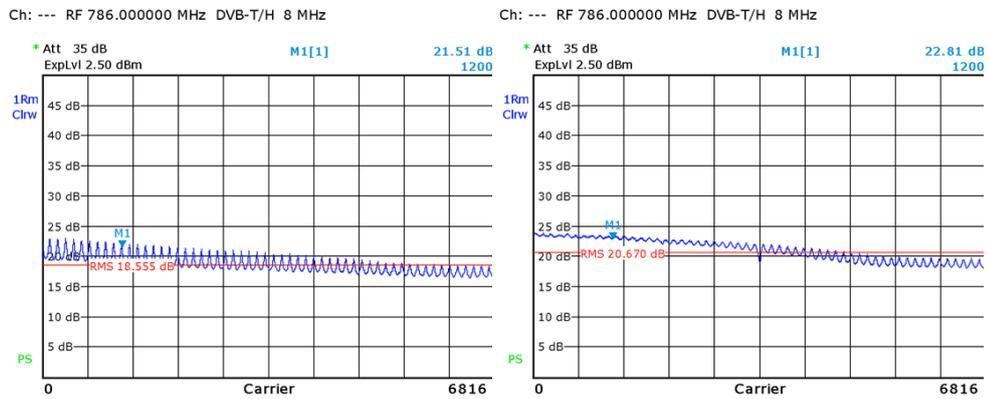
<sup>24</sup> Somewhat surprisingly, the ACLR at 10dBm seems slightly better than that at 0dBm.



**Figure C3.16: Relative performance of internal and external EEC references near point-of-failure**

It can be seen that the benefit of using the external reference is real, but modest, gaining 1-2dB of additional margin. It should be noted that no operation was possible using the basic echo-canceller (EC) in this configuration.

Plots of MER across the DTT channel are given in Figure C3.17 below for both configurations at an LTE power level of 18dBm.



**Figure C3.17: MER vs frequency at combined OCR/LTE output (left = internal reference, right = external reference)**

## C.4 Aerial isolation measurements

### C.4.1 Background

Even with active echo-cancellation, stringent requirements are placed on the isolation between receive and transmit aerials on masts where an OCR is to be used.

#### C.4.1.1 *Measurements from B21C project—Spain*

Broadcast for the 21<sup>st</sup> Century (B21C) was a collaborative project, within EUREKA, aimed particularly at issues surrounding the deployment of DVB-H networks.

One work package within B21C was concerned with the use of gap-fillers as a cost-effective means of network coverage improvement. As part of this work, measurements were made of the isolation between antennas on a small (15m) lattice tower in a mountainous rural area of Spain.

The description of the measurements and the analysis given in the B21C report<sup>25</sup> are not entirely clear (to the author, at any rate). The aerials used were a panel (VP) at the top of the mast and either a single yagi, or phased pair of yagis at a lower level.

A range of antenna separations and relative azimuths were explored; It appears that median isolation values of around 62-73dB were obtained at 2m separation, 69-80dB at 6m and 77-87dB at 10m separation (B21C report, table 8).

Assuming Gaussian statistics, 90% isolation values are given; 55-64dB at 2m separation, 64-74dB at 6m and 69-79dB at 10m separation (B21C report, table 11).

Tests were also made involving a 2m x 0.7m metal grid, positioned to shield the lower aerial. It was found that this gave an additional isolation of around 10dB. The optimum position for the grid was found to be around 2m above the yagi.

#### C.4.1.2 *Measurements from B21C project—Finland*

A 66m mast was rigged with HP and VP panel antennas at the top of the mast, and HP and VP receiving arrays were set up so as to be movable over a range of 30-50m from the top of the mast. The report is ambiguous about the frequency range over which measurements were made—at one point stating 512 MHz to 612 MHz, but elsewhere referring to 374 MHz-414 MHz.

Over the range of separations explored, there was little change in the isolation obtained, which was around 100dB for VP-VP coupling and around 90dB for the HP-HP case.

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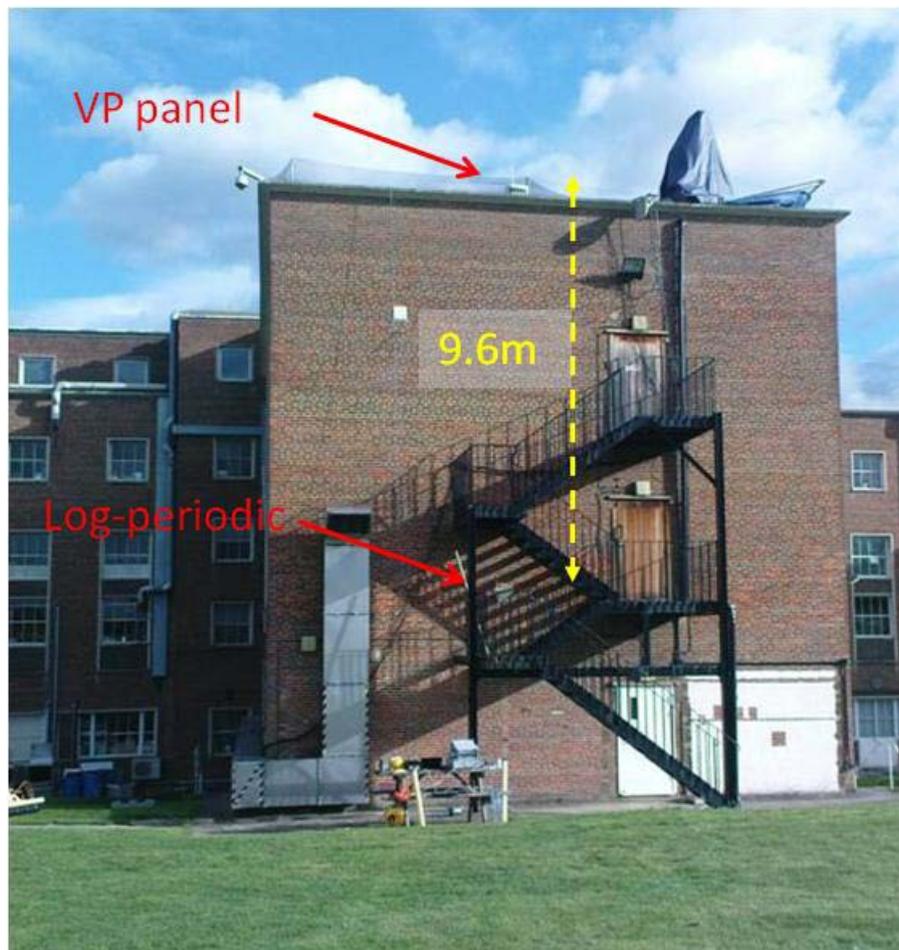
<sup>25</sup> Available at: <http://projects.celtic-initiative.org/b21c/B21C%20-%20D09%20-%20Report%20on%20Gapfiller%20Studies%20-%20final%20version.pdf>

## C.4.2 Measurements at ERA

An initial set of measurements were made at the ERA Technology site in Leatherhead<sup>26</sup>. For this exercise the antennas were mounted on a fire escape and the flat roof of a building at around 12m above the ground. Details of the antennas used in these tests are given in the Appendix at C6, with the exception of the 'sleeve dipole' which was produced in-house by Aegis.

### C.4.2.1 Panel on roof, log-periodic on fire escape

The initial arrangement, in which the Kathrein VP panel antenna (type 769 731) was mounted on the rooftop, and the log-periodic on the fire escape, is illustrated below. The panel antenna was mounted on a tripod 1.8m back from the parapet.



**Figure C4.1: Trial arrangement with panel on roof**

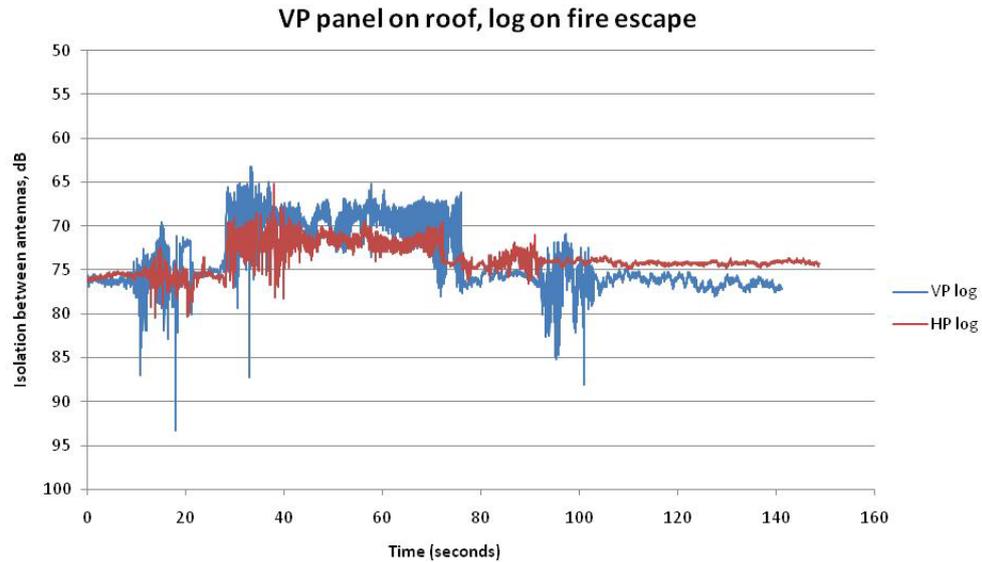
In the first test, the vertically-polarised panel was fed with a 0dBm CW signal at 790 MHz, and the power received on the log-periodic was recorded over a period of a few minutes. In all the plots below, the isolation refers to that available between the panel antenna port, and the connector at the far end (i.e. away from the

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<sup>26</sup> The assistance of ERA staff in these measurements is gratefully acknowledged.

antenna) of the cable connected to the log-periodic; this gives the isolation figure most relevant to OCR performance.

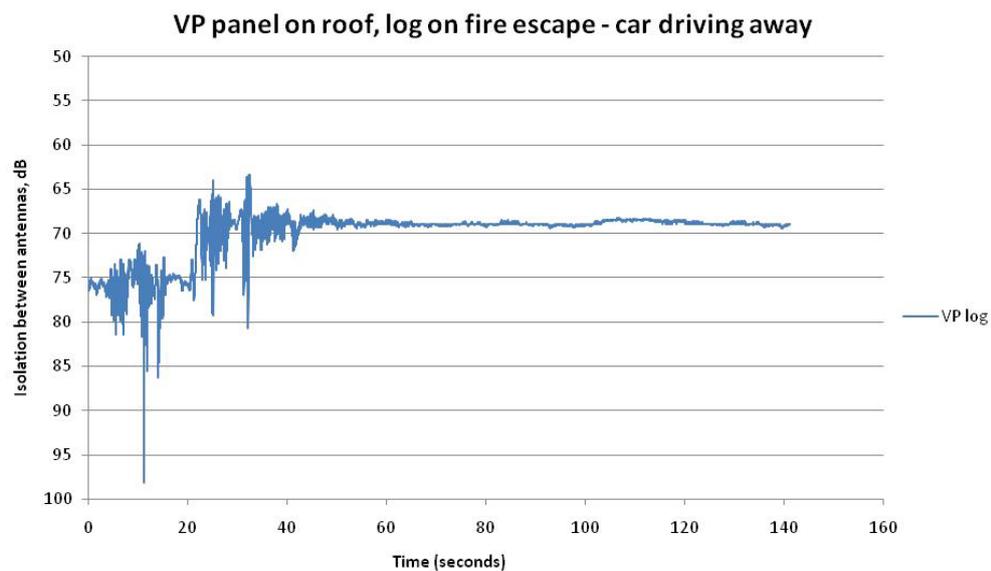
The results for two polarisations of the log-periodic antenna are recorded in Figure C4.2 below.



**Figure C4.2: Coupling between VP panel on roof and log-periodic antenna**

Each test started with the personnel stationary below the antennas. One person then walked to a car parked some 10m in front of the building, and drove the car back and forth before emerging and returning to the original position. The impact of both man and car on the coupled energy between antennas is clearly seen.

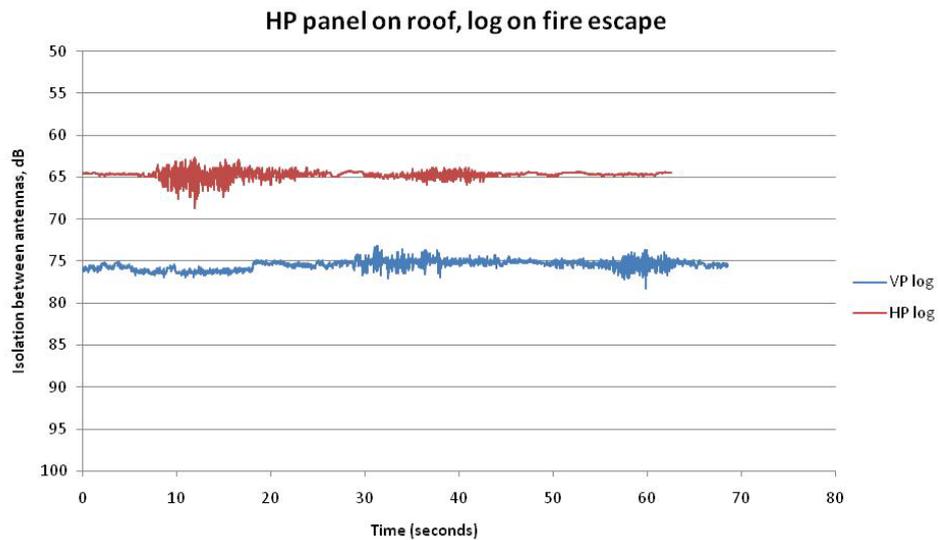
In the next measurement, the car was driven away from the foreground of the antennas, and parked behind buildings some distance away.



**Figure C4.3: Coupling between VP panel and log-periodic antennas**

It can be seen that the settled field is some 6dB above that obtained with the car present, suggesting that significant anti-phase reflections were being generated from the car, or that it was screening the receive antenna from constructive ground reflections.

The measurements were then repeated with the panel antenna rotated to give horizontally-polarised signals; mechanical constraints meant that it was necessary to position the panel on the parapet of the roof, rather than on the tripod behind it.



**Figure C4.4: Coupling between HP panel on roof and log-periodic antenna**

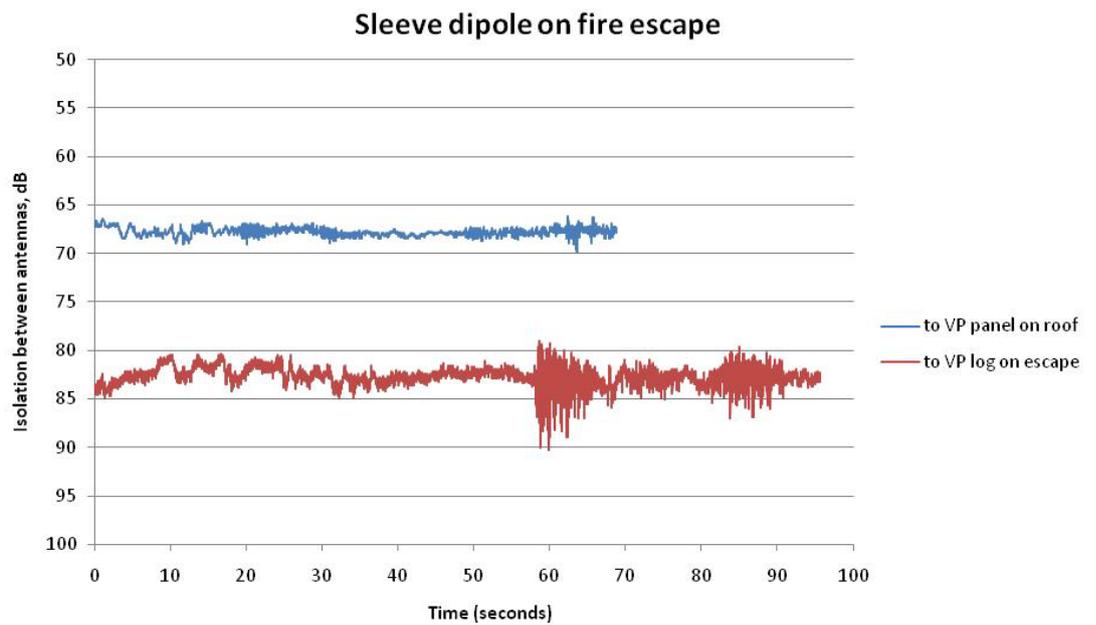
In the HP-HP case, the isolation has been degraded by around 7dB<sup>27</sup>, which might be expected from the geometry of the radiating elements and the position of the panel closer to the edge of the roof. On the other hand, the isolation achieved with the log-periodic vertically-polarised is improved<sup>28</sup> by around 6dB.

*C.4.2.2 With sleeve dipole*

A simple sleeve dipole was constructed and used to replace first the log-periodic and then the panel antennas. When substituted for the panel (red trace), personnel moved in view of both antennas from the mid-point of the measurement run.

<sup>27</sup> Compared with the 'no car' portion of the trace in Figure 4.2 (~72dB median isolation).

<sup>28</sup> Compared with the 'no car' portions of the traces in Figures 4.2 and 4.3 (~69dB median isolation).

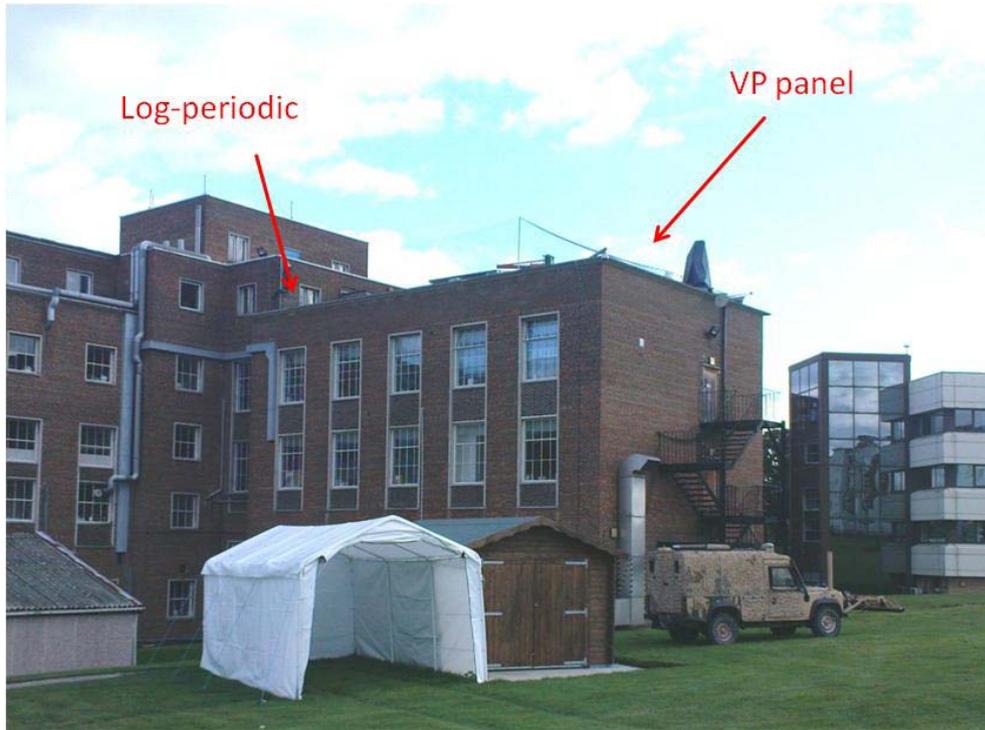


**Figure C4.5: Measurements with sleeve dipole**

When substituted for the log-periodic, the dipole gives very similar results, but in place of the panel the isolation is significantly improved. This may indicate that there is less radiation downwards from the dipole than from the panel, or that the main coupling mechanism is due to reflections from the foreground, and that the higher isolation is due to the ~10dB lower gain of the dipole.

**C.4.2.3 Both antennas on rooftop**

The log-periodic aerial was relocated from the fire escape to the rooftop, pointing roughly in the opposite direction to the panel, and separated by 14.3m.



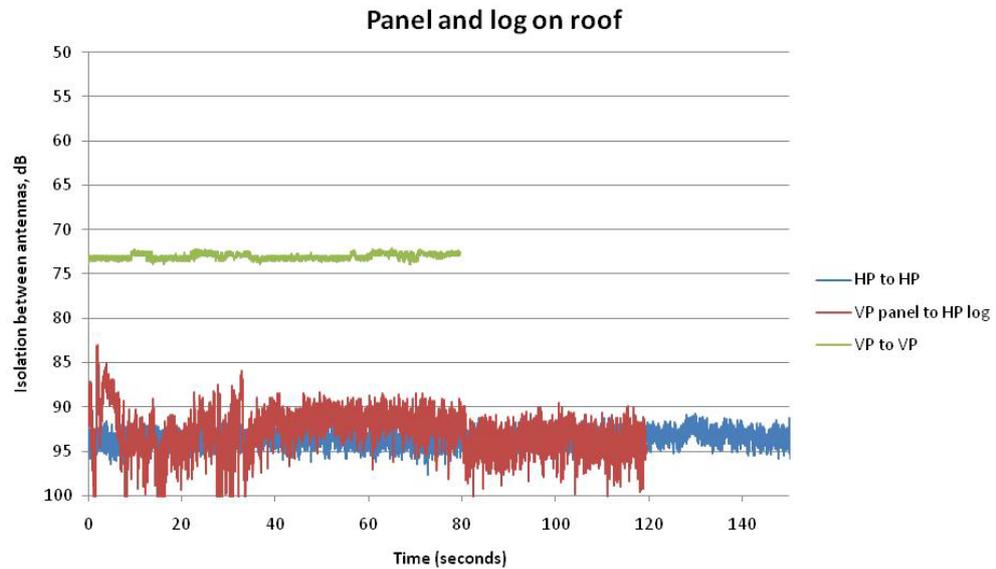
**Figure C4.6: Showing antenna positions on rooftop**

The path between the antennas on the roof was non-line-of-sight, being blocked by a wooden shed, as shown in Figure C4.7.



**Figure C4.7: Showing antenna positions on rooftop**

The results obtained from this configuration are shown in Figure C4.8, and show that the isolation obtained to the HP log-periodic is (perhaps surprisingly) significantly better than for the previous configurations.

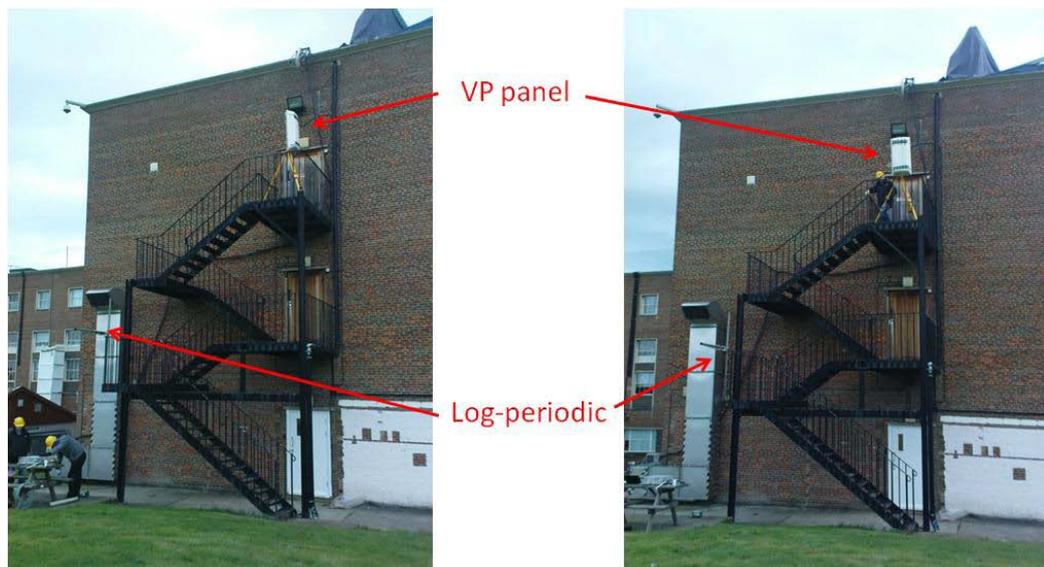


**Figure C4.8: Both antennas on rooftop**

No proper mounting was available to hold the log-periodic in a VP orientation, and the antenna was therefore rested on a convenient felt-covered surface. This may account for the dramatic degradation in the isolation achieved.

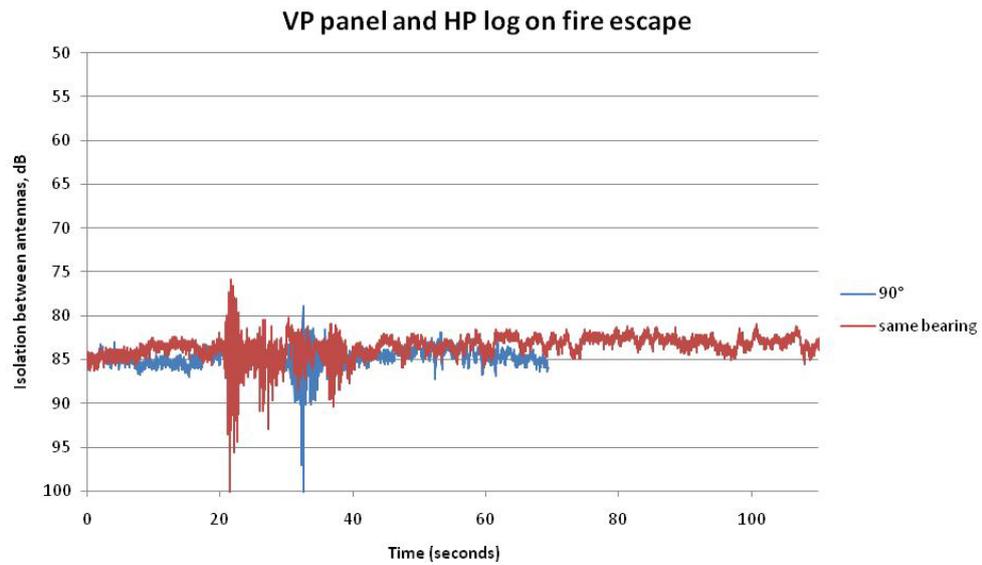
**C.4.2.4 Both antennas on fire escape**

In the final tests, the panel antenna was mounted at the upper level of the fire escape, and the log-periodic returned to its original position.



**Figure C4.9: Both antennas on fire escape**

Figure C4.10 shows the measured results—in both cases, personnel moved in front of the antennas at 20-40 seconds into the run.

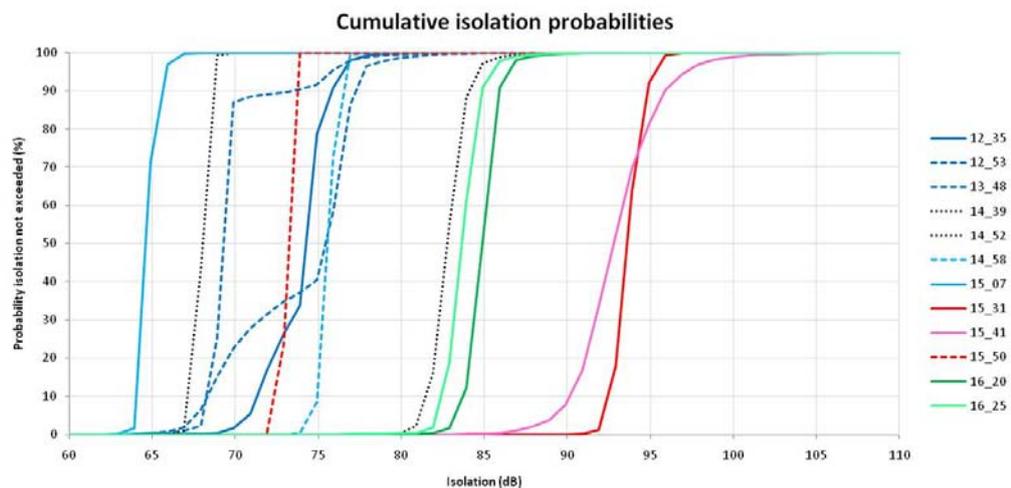


**Figure C4.10: Both antennas on fire escape**

It can be seen that the relative orientation of the aerials has little effect on the isolation achieved, which is significantly better than with the panel antenna mounted on the roof (82-84dB compared with 70-76dB).

*C.4.2.5 Summary*

The Measurements are summarised in the graph below, which shows the distribution of isolation values for each arrangement of antennas.



**Figure C4.11: Isolation statistics for measurements at ERA**

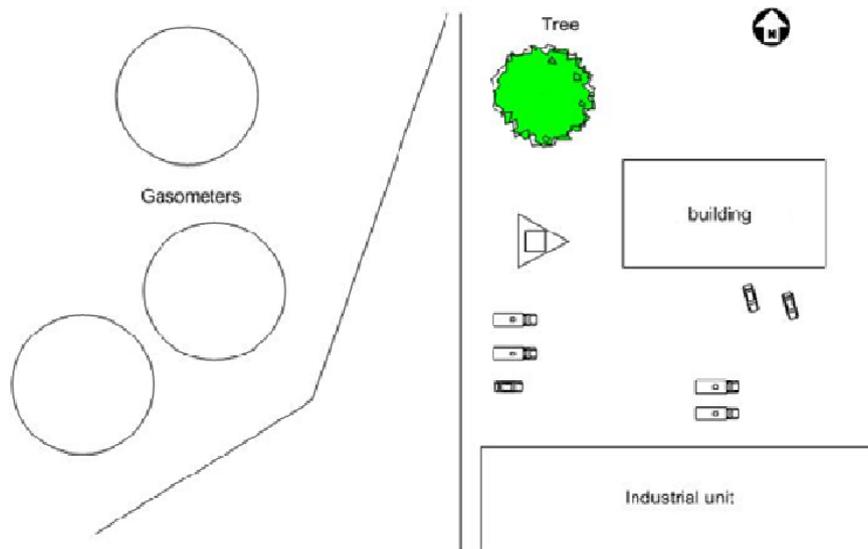
In an attempt to make the information more readily digestible, blue shades have been used for the ‘panel on roof, log-periodic on fire escape’ configurations, red shades for ‘both aerials on rooftop’, green for ‘both aerials on fire escape’ and black for tests with the sleeve dipole. Where the log-periodic is vertically polarised, the trace is dashed.

It can be seen, in the light of the measurements reported in Section 3, that configurations with the panel antenna on the roof and the log-periodic on the fire escape would be unlikely to allow OCR operation. The other configurations, however, seem promising.

On the basis of the limited tests carried out at the ERA site, it seems likely to be possible to engineer the values of aerial isolation required to allow the operation of OCRs in the coverage-repair role.

**C.4.3 Measurements at an industrial site**

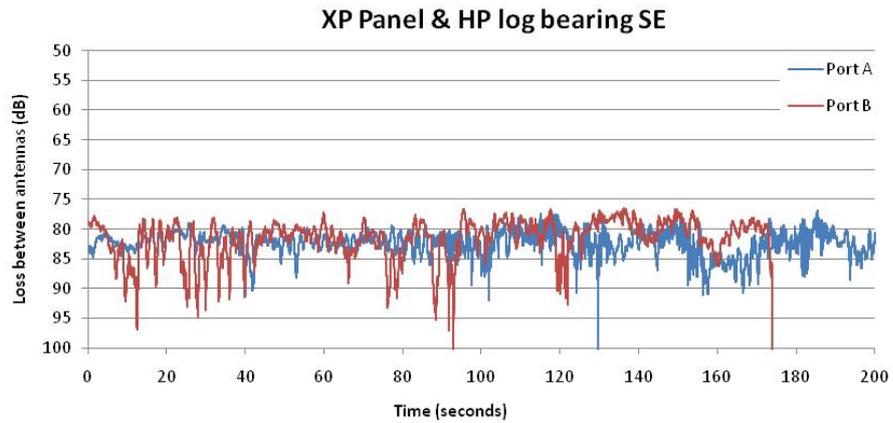
A location was identified, at which a 22m tower has been rigged. This tower was made available for further isolation tests.



**Figure C4.12: Sketch of Industrial site**

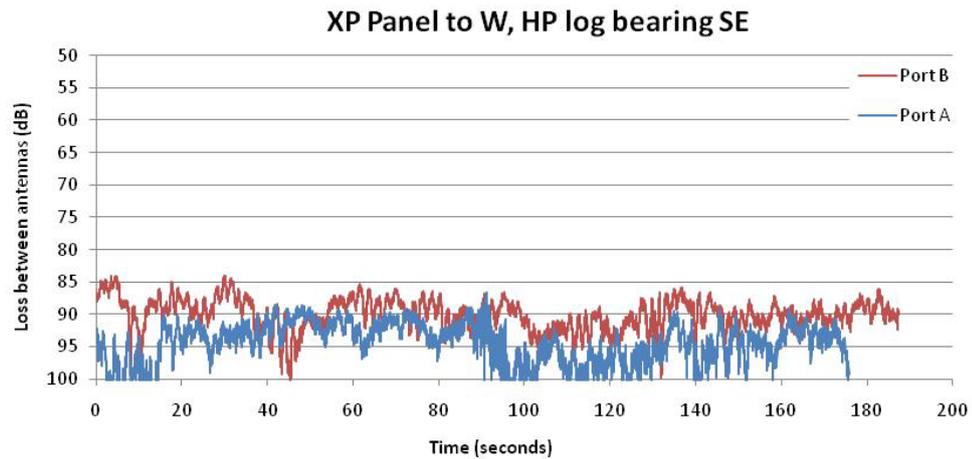
The location is extremely cluttered, facing a number of gasometer tanks, and surrounded by metal-roofed industrial units. As a consequence, it might be expected that the levels of isolation available would be severely restricted due to reflections from this local clutter.

In the initial configuration, the cross-polarised panel (with elements at +45° and -45°, fed from separate ports) and the horizontally-polarised log-periodic were mounted on the same face of the mast, bearing south-east. With the log-periodic at 8m above ground, the vertical separation was 13m. A time-series of the isolation for a three minute period is shown in Figure C4.13 below; it can be seen that results for the two ports of the cross-polarised panel are comparable.



**Figure C4.13: Isolation with antennas on same face of mast**

The panel antenna, still at 21m above ground, was now moved to the western face of the mast, bearing towards the gasometers. The isolation loss, as shown in Figure C4.14, fell by some 10 dB. It can also be seen that there is slightly greater isolation to ‘Port A’ of the X-polarised antenna.



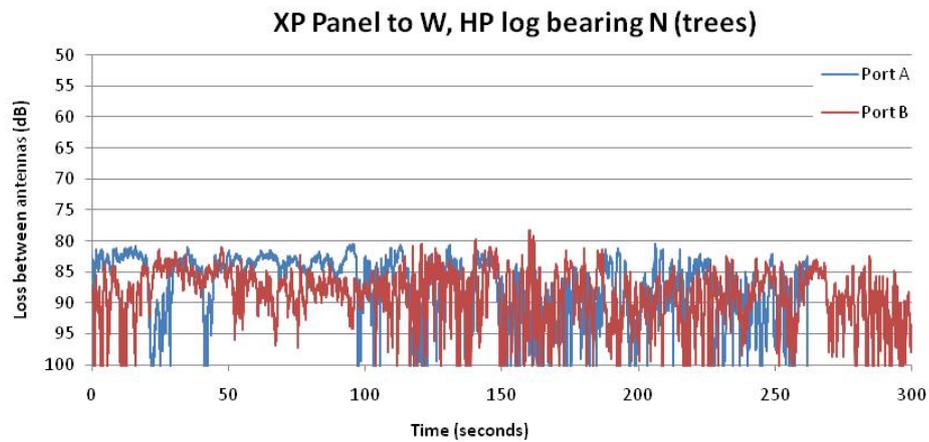
**Figure C4.14: Isolation with antenna azimuths separated by 135°**

With the panel remaining fixed in the west-facing position, the log-periodic was moved to the northern side of the mast, pointing due north. A deciduous tree, still in leaf, was directly in front of the antenna, at a range of ~5m (see Figure C4.15).



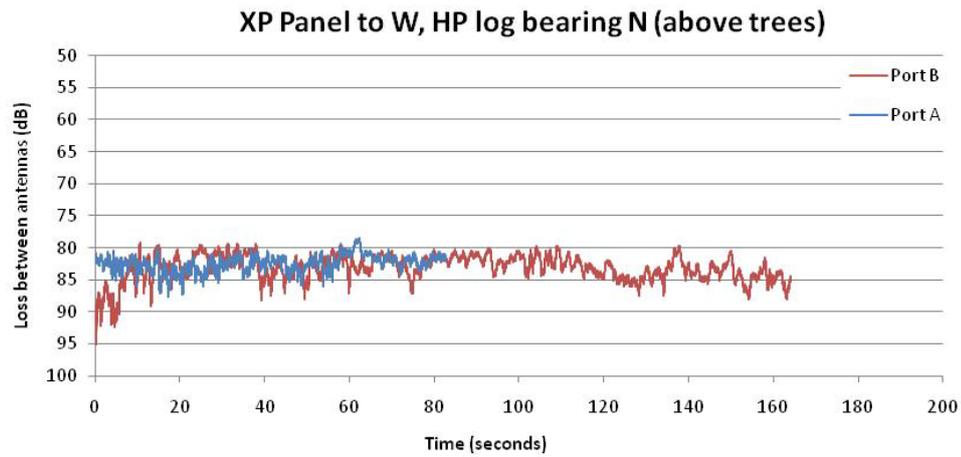
**Figure C4.15: Location, showing north-facing log-periodic**

The isolation was now found to lie between the previous two results, as shown in Figure C4.16. There is evidence of very rapid fading, perhaps due to scattering from the leaves on what was a very windy day.



**Figure C4.16: Isolation with antenna azimuths separated by 90°**

In the final configuration, the azimuths of the antennas were unchanged, but the log-periodic was raised by some 5m, to give a clear line-of-sight above the tree. The results are shown in Figure C4.17.

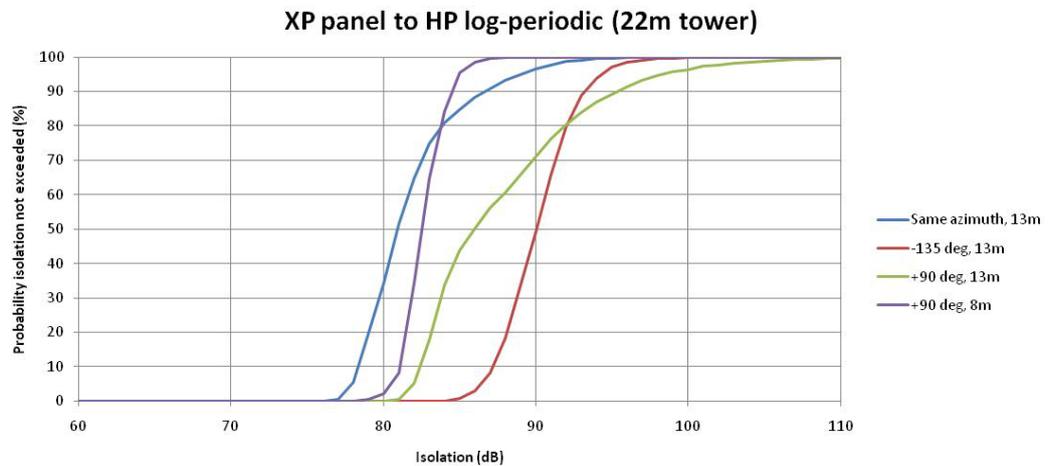


**Figure C4.17: Isolation with antenna azimuths separated by 90°, log at 13m agl**

It can be seen that the fast fading is no longer apparent, but that the median level of coupling has increased, due to the smaller vertical separation distance.

Further measurements had to be abandoned at this point, owing to very heavy rain and high winds.

The final figure (C4.18) shows the cumulative isolation statistics for the four scenarios examined at the industrial site. These results, taken together with the OCR measurements detailed above, suggest that the necessary isolation should be obtainable in most cases, even on small masts in electrically-cluttered surroundings.



**Figure C4.18: Isolation statistics for measurements at industrial site**

## C.5 OCR annex—Conclusions

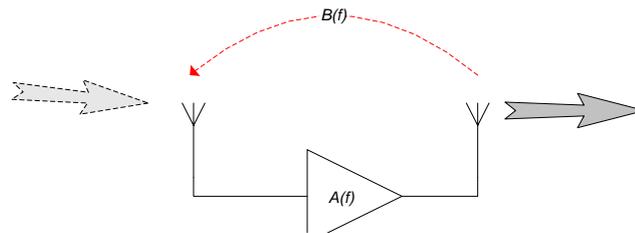
- The OCR is probably usable down to -60dBm input, or 68 dB $\mu$ V/m, which is 15dB greater than the edge of coverage. This could be improved by use of LNA (with penalties in terms of ACI and maximum output power available).
- The OCR will typically be required to work at an output power of around 1W (30dBm). At this level, and assuming 80dB isolation between antennas, stable operation is possible using the echo canceller with an input signal of -60dBm.
- In most realistic situations (i.e. low DTT input signal) the enhanced echo canceller will be required to accommodate echoes of typically, 10dB above the input signal.
- Additional input filtering will be required to protect the OCR from adjacent channel LTE interference for the case of base stations in 'idle' mode. The specification for such filters will be modest, however.
- The adjacent channel leakage power from the LTE transmitter (i.e. the spurious emissions and intermodulation products falling in channel 60) will cause corruption of the re-radiated DTT signal. For a DTT input of 60dBm, this will be tolerable, particularly if an external reference feed to the OCR is provided.
- It appears that providing the required aerial isolation will be possible at many LTE sites, although formal confirmation of the statistics would require a widespread measurement campaign.

## C.6 Appendix to Annex C: echo-cancellation and on-channel repeaters

Note: This material is reproduced from the Aegis report for Ofcom "*The feasibility of DVB T on channel repeaters for coverage repair on Channel 60*" (2009)".

### C.6.1 Introduction

The idea of a relay transmitter which rebroadcasts a signal without changing the frequency has long been attractive, for reasons of spectrum conservation. The simplest form of on-channel repeater simply consist of a receiver aerial directed towards the parent transmitter, feeding a high-gain amplifier, the output of which drives the transmit aerial, directed towards the coverage deficiency. This arrangement is often referred to as an 'active deflector', and is sketched in Figure C6.1, where the forward path has a transfer response  $A(f)$  and the (unwanted) feedback path between the aerials is represented by  $B(f)$ .



**Figure C6.1: Simple ‘active deflector’ (source: Aegis)**

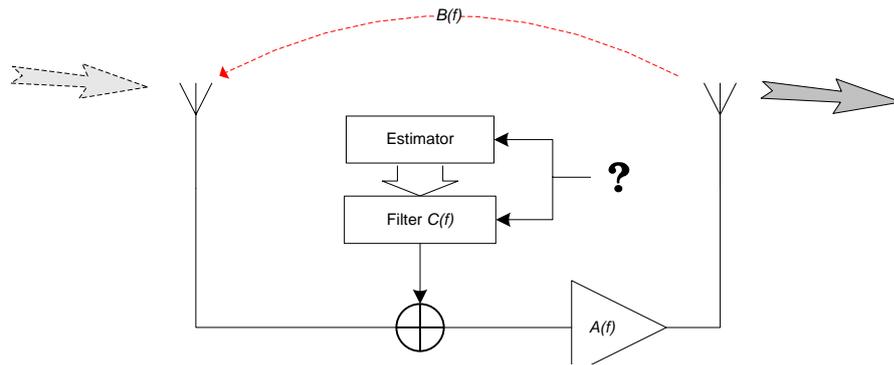
The first such equipment in regular use in the UK was at a UHF television relay at Bethesda, in Snowdonia, operational in 1971. Such methods were not widely adopted during the analogue era for two main reasons; firstly, it is very difficult to ensure sufficient isolation between receive and transmit aerials to avoid instability or oscillation and, secondly, analogue receivers require very high levels of C/I – there are very few cases where the target coverage area is sufficiently well-screened from the parent transmitter to avoid very significant multipath interference (ghosting).

In the case of the Bethesda relay, the target area is on the side of a hill facing away from the main transmitter (Llanddona), giving very large diffraction losses and ensuring that this transmitter would not cause interference. The problem of isolation was solved by locating the transmit and receive aerials on separate masts some 36m apart, and making use of trough antennas with good discrimination for off-axis signals. At Bethesda, the isolation between aerial ports is ~100dB, and the gain through the deflector is ~60dB, giving an output power of 1W (25W ERP).

With the availability of fast digital signal processing (DSP) and the DVB-T standard, both problems can be solved. DSP techniques can be used to implement adaptive echo cancellers, while DVB-T receivers not only have C/I requirements that are smaller than for analogue systems, but are specifically resistant to multipath, so long as the interference falls within the system Guard Interval (GI).

### C.6.2 Digital OCR technology

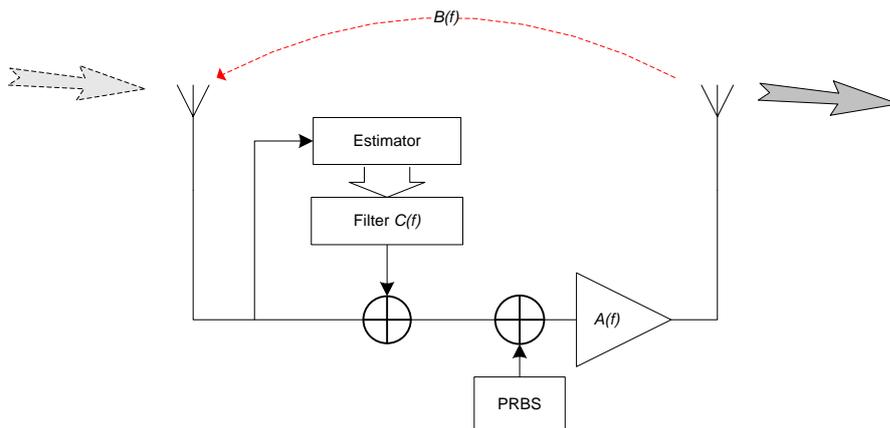
The basic technique in digital OCRs is to convert the received signal to digital form, in which it can be corrected using an echo-cancelling filter, before being converted back to analogue form for re-transmission. The filter characteristics are determined, dynamically, by a channel estimator, the aim of which is to set the response of the filter,  $C(f)$ , to precorrect or neutralise the forward path. A transversal filter is generally used, the number of taps used being one of the many trade-offs between response time, throughput delay and cancellation effectiveness.



**Figure C6.2: Basic digital OCR (source: Aegis)**

Within this basic framework, a number of detailed implementations may be adopted, the main variations relating to the method used for estimating the required filter response.

One conceptually simple approach is to embed a reference training signal within the output of the repeater. This readily identified signal can then be used to determine the necessary filter coefficients in a computationally-efficient manner, as shown in Figure C6.3.



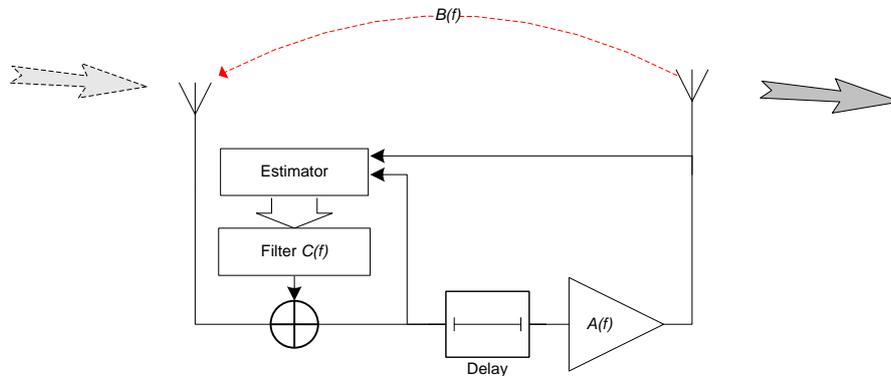
**Figure C6.3: OCR with training sequence (source: Aegis)**

Although this method allows short delay times, and minimises installation complexity, it suffers from a number of disadvantages. The most severe problem is that, because the training sequence must be added to the DVB-T output of the repeater, the C/N ratio is degraded at the point of transmission.

Rather than adding a special training sequence, another option is for the channel estimator to make use of the scattered pilots within the DVB-T COFDM signal. This approach avoids the C/N degradation, but with the penalty of a significantly longer convergence time for the channel estimation. This may well be problematic in practical implementations where there is considerable time-variability in the channel due to reflections from trees, vehicles, etc.

A further variant, patented by the BBC, is non-system specific and removes the need to add any signals to the repeater output. Instead, a deliberate delay is added

in the signal path through the repeater, to ensure that the received and transmitted signals are uncorrelated. Using these methods, with a least mean square (LMS) algorithm for the estimation of filter taps, has been claimed to give some 50dB of echo cancellation.



**Figure C6.4: OCR with decorrelating delay (source: Aegis)**

Three further, patented, developments have been made to the BBC approach. In the first, the reference feed to the estimator is taken after the amplifier (as shown in Figure C6.4). This arrangement, in the words of the BBC patent “enables cancellation of any uncorrelated parasitic signal arriving at the receiving antenna which was present in the transmit antenna feed, not just the recovered version of the wanted signal”. This is particularly valuable where unwanted emissions from an adjacent transmission fall within the DTT bandwidth, but it does involve the expense of a second down-converter and ADC.

The second improvement relates to the reduction of ‘tap noise’. This random error in the channel estimate is caused by the presence of the continually-changing wanted signal at the input to the estimator, but the effect can be estimated and reduced.

Finally, it has been noted that for certain conditions, the estimation algorithm can be slow to converge, and the resulting estimation errors can lead to the generation of spurious signals. This has been addressed in a design that introduces a second correlating side-chain, improving convergence speed and reducing spurious signals.

The BBC approach is particularly attractive in the context of hole-filling, as it is agnostic about the signal being cancelled. If the output of the repeater is combined with that of the interfering cell site, and the reference feed to the estimator is taken from the joint antenna feed, then any energy from the cellular transmitter falling in the DTT channel (e.g. from IPs, or sideband re-growth) will be cancelled as effectively as the output of the repeater.

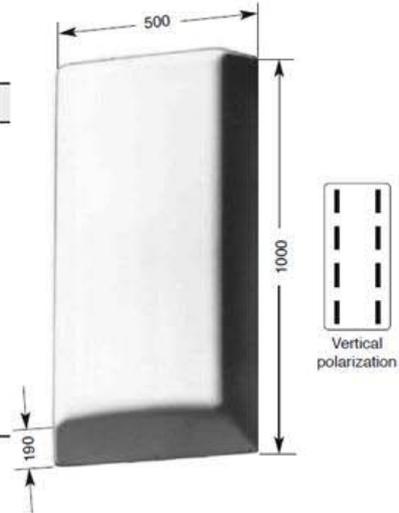
C.7 Appendix to Annex C: antennas used in isolation tests

**K 73 31 4 .**  
**Directional Antenna**  
**470 – 860 MHz**

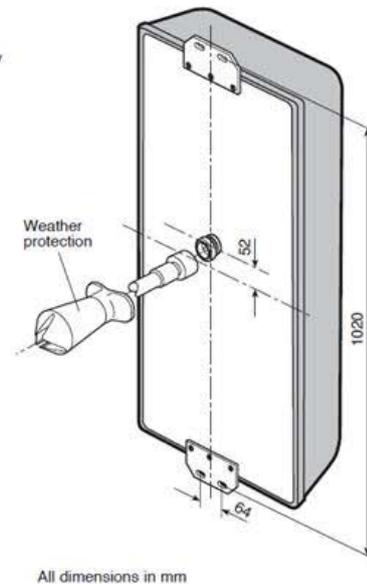
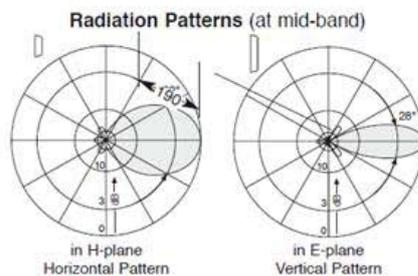
**KATHREIN**  
 Antennen · Electronic

- Vertically polarized broadband directional antenna made of aluminum and protected by a fiberglass cover.
- Similar to type K 73 31 47.

| Type No. / Order No.           | 769 731   |
|--------------------------------|---|
| Input                          | 7-16 female   |
| Frequency range                | 470 – 860 MHz                                       |
| VSWR                           | < 1.12  |
| Gain (ref. $\lambda/2$ dipole) | 11 dB at mid-band                                   |
| Impedance                      | 50 $\Omega$   |
| Polarization                   | Vertical  |
| Max. power                     | 1 kW  |
| Weight                         | 12 kg   |
| Wind load (at 160 km/h)        | Frontal: 565 N<br>Rearside: 815 N<br>Lateral: 250 N |
| Max. wind velocity             | 225 km/h  |
| Packing size                   | 1062 x 562 x 294 mm                                 |
| Height/width/depth             | 1000 x 500 x 190 mm                                 |



- Material:** Reflector screen and dipoles: Weather-resistant aluminum.  
 Protective cover: Fiberglass.  
 Attachment plate: Hot-dip galvanized steel.
- Attachment:** Using M 8 x 35 screws (supplied) to suitable attachment construction.
- Grounding:** Via mounting parts.
- Ice protection:** The dipoles remain fully functioning even in icy conditions as the fiberglass cover protects the whole antenna and also the antenna is of a very robust design.
- Combinations:** The antenna is particularly suitable for use in combinations in order to achieve various radiation patterns.
- Scope of supply:** The 7-16 female connector is supplied with a weather protection unit.



All dimensions in mm

Antennas  
470 – 860 MHz

**LPU/R\***

Log Periodic Antenna

V-Pol or H-Pol | 70° | 7.9 dBd



A Log Periodic antenna designed for UHF Broadcast, TETRA and Cellular communications applications. This antenna is often used in a stacked array to form a rugged, high power, extended range antenna. Produced to the highest quality standards these robust antenna designs will insure reliable operation in harsh environmental conditions.

Type **LPU/R\***

| Electrical Specifications |  |               |                     |         |          |            |                 |
|---------------------------|--|---------------|---------------------|---------|----------|------------|-----------------|
| Frequency:                | 468 MHz to 860 MHz   |               |                     |         |          |            |                 |
| Model Numbers*:           | <table border="0"> <tr> <td><b>Model:</b></td> <td><b>Termination:</b></td> </tr> <tr> <td>LPU/R-N</td> <td>N Female</td> </tr> <tr> <td>LPU/R-7/16</td> <td>7/16-DIN Female</td> </tr> </table> | <b>Model:</b> | <b>Termination:</b> | LPU/R-N | N Female | LPU/R-7/16 | 7/16-DIN Female |
| <b>Model:</b>             | <b>Termination:</b>  |               |                     |         |          |            |                 |
| LPU/R-N                   | N Female   |               |                     |         |          |            |                 |
| LPU/R-7/16                | 7/16-DIN Female  |               |                     |         |          |            |                 |
| Gain:                     | 7.9 dBd  |               |                     |         |          |            |                 |
| VSWR:                     | < 1.3:1  |               |                     |         |          |            |                 |
| Maximum Power:            | 250 W  |               |                     |         |          |            |                 |
| Horizontal Beamwidth:     | 70°  |               |                     |         |          |            |                 |
| Polarisation:             | Vertical or Horizontal   |               |                     |         |          |            |                 |
| Impedance:                | 50 ohms  |               |                     |         |          |            |                 |
| Lightning Protection:     | DC Grounded  |               |                     |         |          |            |                 |

| Mechanical Specifications |  |
|---------------------------|--|
| Materials:                | Aluminium Alloy                                      |
| Dimensions (LxW):         | 1210 x 320 mm  |
| Weight (including mount): | 3.5 kg   |
| Mounting Bracket:         | Mounting Bracket included to fit 38-50 mm dia. pipe. |



**800 10734**  
700 MHz Single Band 4', 65 Degree Antenna  
RET

Kathrein's X-polarized antennas are designed for use in digital polarization diversity systems.

- X-polarized (+45° and -45°).
- UV resistant fiberglass radomes.
- Wideband vector dipole technology.
- DC Grounded metallic parts for impulse suppression.
- RET motor housed inside the radome and field replaceable.

**General specifications:**

|                         |  |
|-------------------------|--|
| Frequency range         | 698–894 MHz                                      |
| VSWR                    | <1.5:1   |
| Impedance               | 50 ohms  |
| Intermodulation (2x20w) | IM3: <-150 dBc                                   |
| Polarization            | +45° and -45°                                    |
| Maximum input power     | 500 watts per input (at 50°C)                    |
| Connector               | 2 x 7-16 DIN female (long neck) (bottom mounted) |
| Isolation               | >30 dB   |
| Electrical downtilt     | 0–16 degrees (continuously adjustable)           |

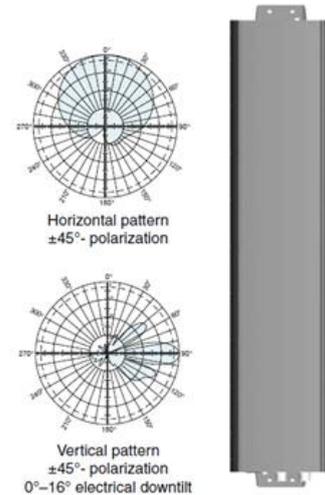
See reverse for order information.

**Specifications:**

|  | 698–806 MHz                               | 824–894 MHz                               |
|--|---|---|
| Gain   | 14.2 dBi                                  | 14.8 dBi                                  |
| Front-to-back ratio  | >30 dB (co-polar)<br>32 dB (average)      | >30 dB (co-polar)<br>33 dB (average)      |
| +45° and -45° polarization horizontal beamwidth                      | 68° (half-power)                          | 65° (half-power)                          |
| +45° and -45° polarization vertical beamwidth                        | 16° (half-power)                          | 14.8° (half-power)                        |
| Min. sidelobe suppression for first sidelobe above main beam average | 0° 8° 16° T<br>16 17 17 dB<br>19 20 20 dB | 0° 8° 16° T<br>18 17 16 dB<br>25 23 23 dB |
| Cross polar ratio  |   |   |
| Main direction 0°  | 24 dB (typical)                           | 23 dB (typical)                           |
| Sector ±60°  | >10 dB, Average: 15 dB                    | >10 dB, Average: 16 dB                    |

**IRT specifications:**

|   |  |
|---|--|
| Logical interface ex factory <sup>1</sup> | AISG 1.1   |
| Protocols                                 | AISG 1.1 and 3GPP/AISG 2.0 compliant   |
| Hardware interface <sup>2</sup>           | 2 x 8 pin connector acc. IEC 60130-9;<br>according to AISG:<br>– IRT in (male): Control / Daisy chain in<br>– IRT in (female): Daisy chain out |
| Power supply                              | 10–30 V  |
| Power consumption                         | <1 watt (standby)<br><8.5 watts (motor activated)  |
| Adjustment time (full range)              | 40 sec.  |
| Adjustment cycles                         | >50,000  |
| Certification                             | FCC 15.107 Class B Computing Devices   |



<sup>1</sup> The protocol of the logical interface can be switched from AISG 1.1 to 3GPP/AISG 2.0 and vice versa with a vendor specific command.

**Please note:** If the Primary of the RETsystem doesn't support the standard of the 'logical interface ex factory', the RCU must be switched to the appropriate standard of the Primary before installation. Please contact Kathrein for further information.

<sup>2</sup> The tightening torque for fixing the connector must be 0.5 – 1.0 Nm ('hand-tightened'). The connector should be tightened by hand only!

**Omnidirectional Antenna**  
**470 ... 860 MHz**  
**768 402**

**KATHREIN**  
 Antennen · Electronic

- 0 dB omnidirectional antenna in fiberglass-radome.

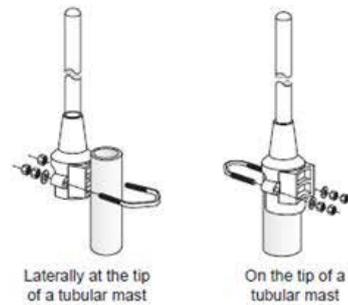
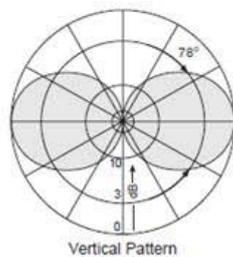
| Type No.           | 768 402                                |
|--------------------|--|
| Input              | N female                               |
| Frequency range    | 470 ... 860 MHz                        |
| VSWR               | < 1.5 at the operating channel*        |
| Gain               | 0 dB                                   |
| Impedance          | 50 Ω                                   |
| Polarization       | Vertical                               |
| Max. power         | 50 Watt (at 50 °C ambient temperature) |
| Weight             | 0.6 kg                                 |
| Wind load          | 19 N (at 160 km/h)                     |
| Max. wind velocity | 200 km/h                               |
| Packing size       | 112 x 97 x 480 mm                      |
| Height             | 260 mm                                 |

\* The antenna is tuned to the operating channel, at factory.

**Material:** Radiator: Brass.  
 Radome: Fiberglass, dia. 21 mm, colour: Grey.  
 Base: Aluminum.  
 Mounting U-bolt and all screws and nuts: Stainless steel.

**Mounting:** The antenna can be attached in two ways with the supplied mounting kit:  
 1. On the tip of any tubular mast of 40 – 54 mm dia. (connecting cable runs inside the mast).  
 2. Laterally at the tip of any tubular mast of 20 – 54 mm dia. (connecting cable runs outside the mast).

**Grounding:** Via mounting parts.

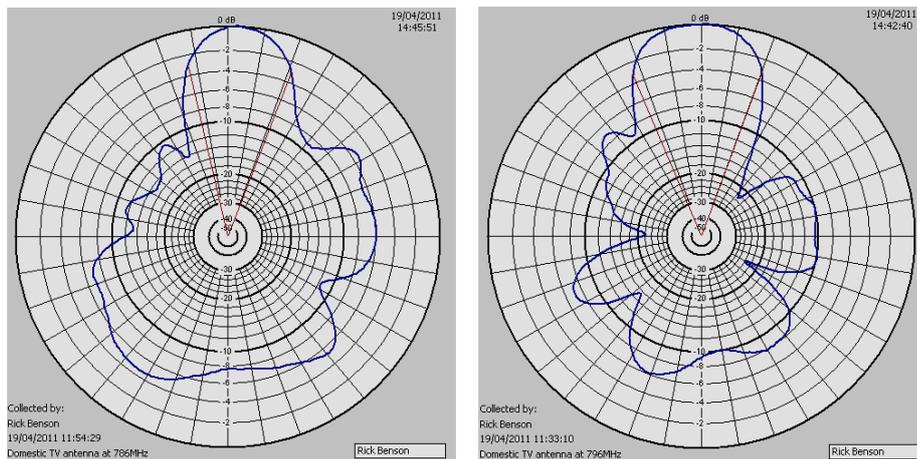


906.765/a Subject to alteration.

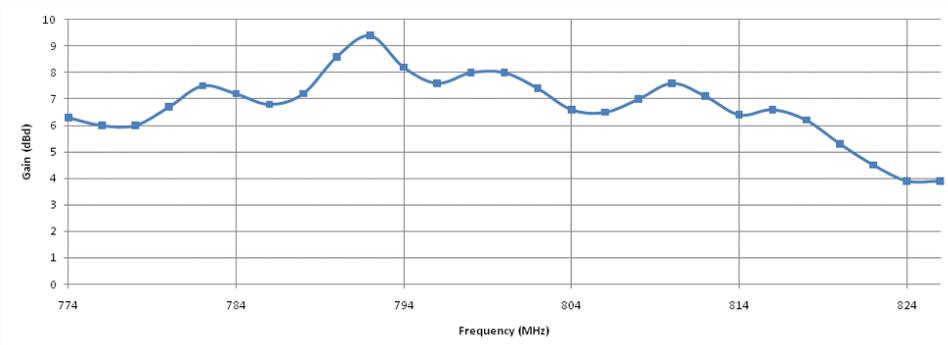
## D RECEIVE ANTENNAS USED IN THE FIELD TRIAL

Following the field trial, measurements were made by Ofcom of the gain and horizontal radiation patterns of the ‘professional’ and ‘domestic’ antennas used on the measurement vehicles.

### D.1 Domestic Yagi



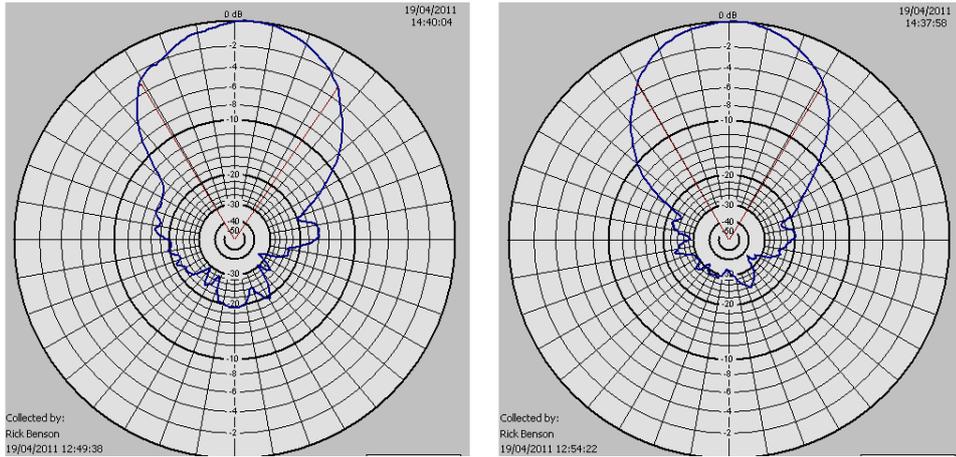
**Figure D.1: Measured E-plane radiation pattern of domestic Yagi at 786 MHz (left) and 796 MHz (right)**



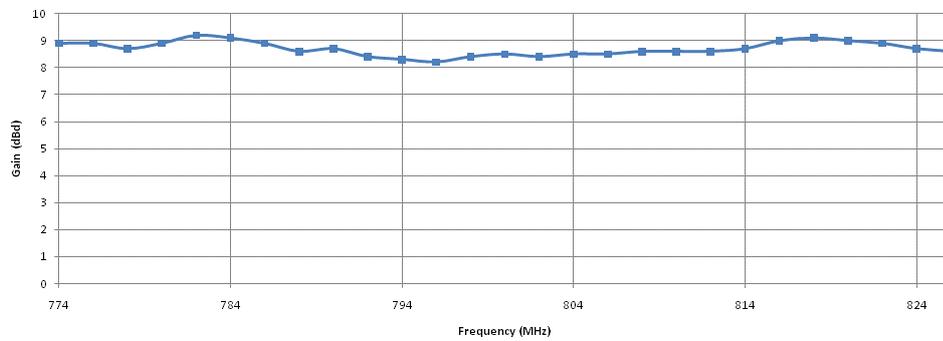
**Figure D.2: Measured gain of domestic Yagi**

### D.2 Professional log-periodic

A number of the BBC design log-periodic aerials were used in the course of the study, on the three measuring vehicles and as an RBL aerial for the OCR. The measured performance of all samples was very similar, and only one set of measurements (for ‘log-periodic A’) is recorded here.



**Figure D.3: Measured E-plane radiation pattern of professional log-periodic at 786 MHz (left) and 796 MHz (right)**



**Figure D.4: Measured gain of professional log-periodic**

## E FILTER TESTING—ADDITIONAL SPECTRAL PLOTS

This annex presents sample additional spectral plots captured while testing filter performance. These measurements were made on Tuesday 23<sup>rd</sup> February, with the LTE transmitter at Greatmead car park, the measuring van at SK 21469 02296 (St Peter’s Close) and using DTT receiver ‘8’. The LTE transmissions were in idle mode for all tests.

### E.1 DTT on Ch.60, LTE on Block A, B\_58 filter

In this test, the B\_58 filter was used to restore a service on channel 60 in the presence of an idle mode LTE signal on Block A.

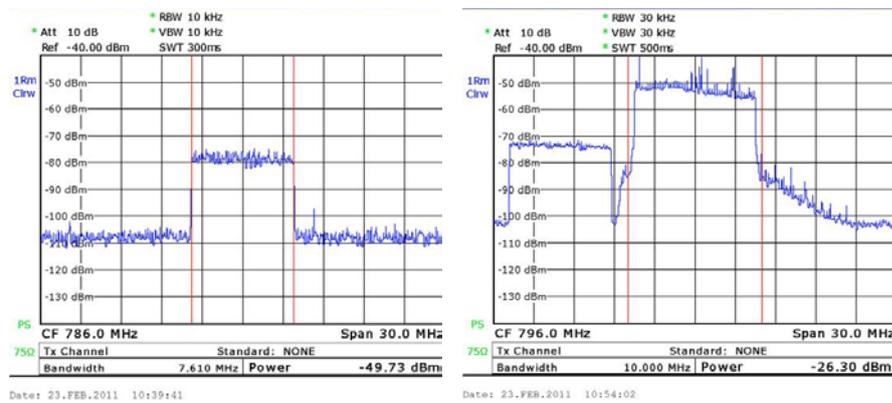


Figure E.1: No filter—DTT power (left) and LTE power (right)

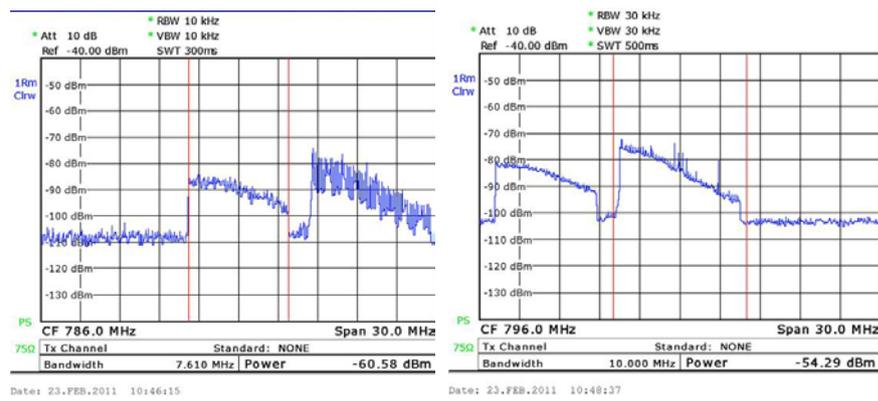


Figure E.2: With B\_58 filter—DTT power (left) and LTE power (right)

### E.2 DTT on Ch.60, LTE on Blocks A, B & C, T\_59 filter

In this test, the T\_59 filter was unable to restore DTT reception on channel 60 in the presence of idle mode LTE signals on Blocks A, B and C. Blocks B and C were switched off, but reception was still not restored. DTT reception was possible with the filter installed and LTE signals on Blocks B and C.

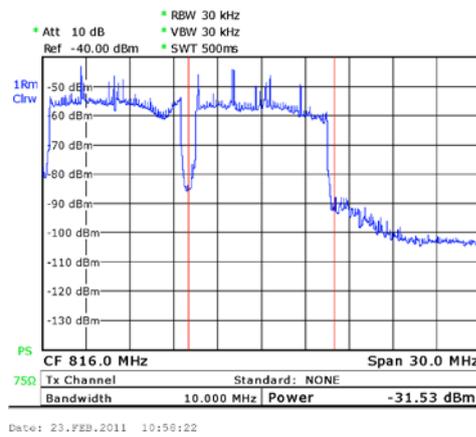


Figure E.3: No filter—Channels A (off-screen), B and C

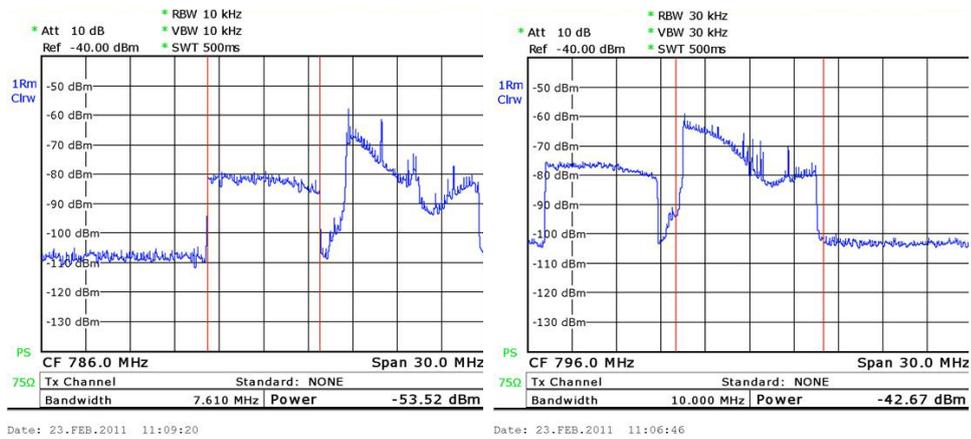


Figure E.4: With T\_59 filter—DTT power (left) LTE 'A' power (right)

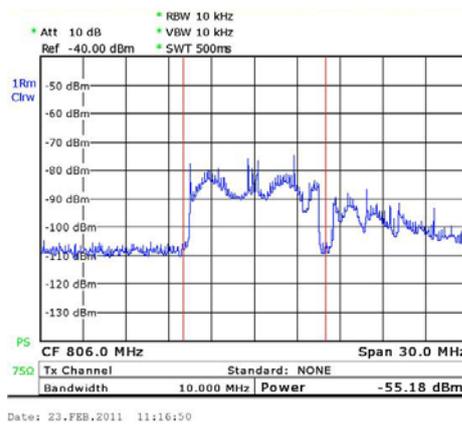


Figure E.5: With T\_59 filter—LTE 'B' power (LTE 'A' switched off)

The ripple seen across the Block A and B LTE signals should be compared with the filter response plotted in Figure 6.3 of the main report.

### E.3 DTT on Ch.60, LTE on Blocks A & B, B\_59 filter

With LTE signals in blocks A and B, the B\_59 filter did not restore DTT services.

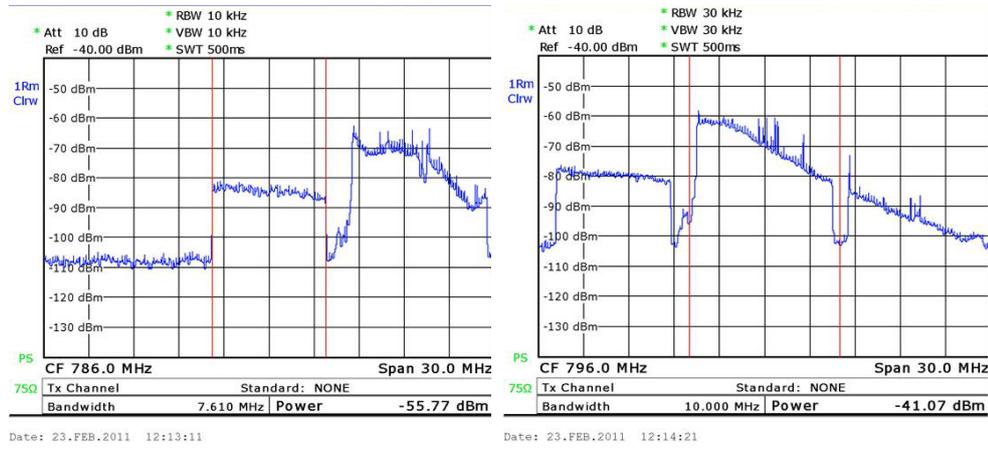


Figure E.6: With B\_59 filter—DTT power (left) and LTE 'A' power (right)

### E.4 DTT on Ch.60, LTE on Blocks A & B, B\_58 filter

With LTE signals on blocks A and B, as above, the B\_58 filter was able to restore DTT service, despite having an insertion loss of X dB in channel 60 and introducing a significant slope across the wanted DTT signal.

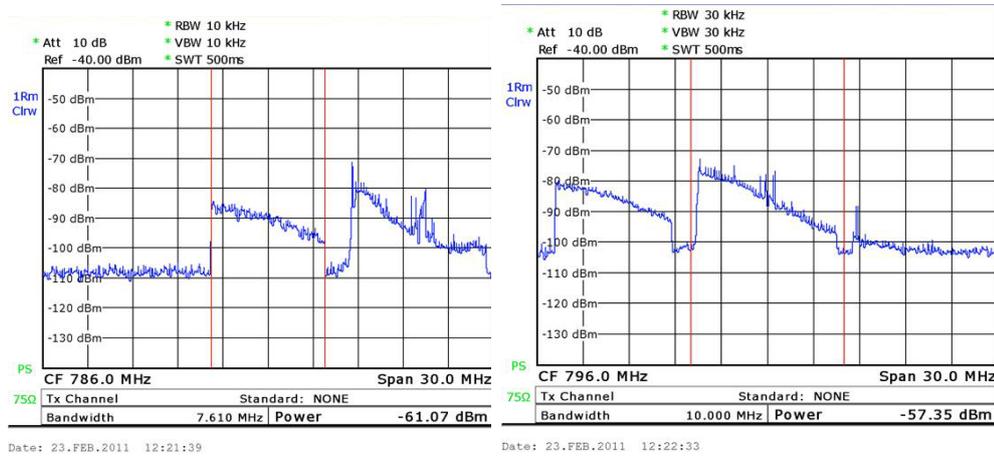


Figure E.7: With B\_58 filter—DTT power (left) and LTE 'A' power (right)