Measured DVB-T Protection Ratios in the presence of Interference from White space Devices

Mark Waddell and Tim Harrold

BRITISH BROADCASTING CORPORATION
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Abstract

This document presents the results of DTT receiver protection ratio measurements which are required to ensure adequate DVB-T reception in the presence of interference from white space devices. A number of candidate technologies have been assessed and the resulting DTT receiver performance is presented.

The protection ratio values have been obtained from laboratory testing of 14 commercially available DVB-T receivers in the presence of a wanted DTT signal from a test generator. The receivers chosen are current designs being marketed in the UK and include IDTVs, STBs and PVRs. The interfering white space signal in each case has been implemented using a vector signal generator to replay a waveform previously recorded from a candidate white space technology radio.

The results show a considerable spread in performance. One or two high-end receivers appear fairly resilient to interference from WSD, but the remainder show vulnerabilities to particular candidate technologies. The WSD technology causing the greatest interference impact varies from receiver to receiver. Broadcast-like signals (e.g. LTE BS 100%) are handled without difficulty, but bursty signals (e.g. low traffic CPE signals) result in up to a 30dB degradation in protection ratios. Further investigation of these issues will be required if the value of the TVWS is to be fully exploited.

We conclude that WSD deployments will initially require the use of very conservative protection ratio values in order to protect the installed base of DTT receivers. A geolocation database based approach to TVWS is feasible, but only if the database is able to take account of the WSD technology class and predicted field strength.

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Authorisation of the Chief Scientist or General Manager is required for publication.
Summary:
The results show a considerable spread in performance. One or two high-end receivers appear fairly resilient to interference from WSD, but the remainder show vulnerabilities to particular candidate technologies. The WSD technology causing the greatest interference impact varies from receiver to receiver. Broadcast-like signals (e.g. LTE BS 100%) are handled without difficulty, but bursty signals (e.g. low traffic CPE signals) result in up to a 30dB degradation in protection ratios. Further investigation of these issues will be required if the value of the TVWS is to be fully exploited. We conclude that WSD deployments will initially require the use of very conservative protection ratio values in order to protect the installed base of DTT receivers. A geolocation database based approach to TVWS is feasible, but only if the database is able to take account of the WSD technology class and predicted field strength.

Proposal:
For consideration by SE43 and inclusion in the draft ECC Report on Geolocation Database techniques from SE43.

SE43 has been tasked by WGSE to define technical and operational requirements for the operation of cognitive radio systems in the white spaces of the UHF broadcasting band (470-790 MHz) to ensure the protection of incumbent radio services/systems and investigate the consequential amount of spectrum potentially available as “white space”.

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SE43 has been tasked by WGSE to define technical and operational requirements for the operation of cognitive radio systems in the white spaces of the UHF broadcasting band (470-790 MHz) to ensure the protection of incumbent radio services/systems and investigate the consequential amount of spectrum potentially available as “white space”.

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1 Introduction

The introduction of unlicensed devices into spectrum bands traditionally used exclusively by TV transmissions and Services Ancillary to Broadcasting (SAB) has the potential to cause harmful interference to the receivers of the incumbent systems. Knowledge of the protection requirements for these receivers in the presence of interference from new White space Devices (WSD) is necessary in order to manage the deployments and prevent such interference.

The work described in this report concerns the measurement of a number of commercially available DVB-T receivers representative of those currently being marketed in the UK. A library of interfering waveforms has been captured from a range of prototype WSDs deployed in UK trials. This library has been used to measure the level of protection required to the DVB-T receivers over a range of signal powers and frequency offsets between the wanted and interfering signals.

The aim of these measurements is to make proposals for protection ratio values that can be used when planning the future deployment of WSDs and explore how the interference characteristics vary with technology and operating point.

2 Background

2.1 Protection Ratios

The protection ratio (PR or C/I) value is defined as the minimum ratio of the wanted signal (C) to the maximum interfering signal (I) applied to the input of a DVB-T receiver that can be tolerated whilst maintaining an acceptable picture quality. The protection ratio is required in planning the deployment of future white space devices (WSDs), and will be used to determine the maximum permissible power that can be transmitted without causing interference to an incumbent receiver.

The protection ratio is a function of the offset frequency between wanted and interfering signals and typically decreases (improves) as the offset increases. Additionally, the PR value will change according to the total signal strength received by the receiver as a consequence of receiver saturation (as described in Section 2.2). As a consequence, PR values must be specified for a range of frequency offsets and signal powers.

The specification of a PR for a particular frequency offset and DTT signal power allows a limit to be placed on the transmit power output of the WSD. This approach has been discussed in the UK's proposal for geolocation databases for WSD operation [1].

The protection ratio value is a combination of the selectivity of the victim receiver and the assumed adjacent channel leakage of the interfering WSD. The approach made in these measurements (described further in Section 3.4.3) is to measure the protection ratio using an interfering source with a known adjacent channel leakage ratio (ACLR) and then to use this value to derive protection ratio values based on predicted actual ACLRs for the interfering device. WSDs with inferior ACLR performance will require higher protection ratios.

2.2 Overload Thresholds

As the combined value of the wanted and interfering signal powers increases, DTT receivers start to exhibit non-linear behaviour and eventually become overloaded or blocked. At the blocking point, the receiver will be unable to decode a TV picture, regardless of the wanted signal level.

Receiver non-linearity manifests itself as a gradual increase in protection ratios with signal level. This behaviour results in the receiver being unable to discriminate between the wanted and interfering signals, and occurs for all frequency offsets.

The significance of this is that it cannot be assumed that the protection ratio values will remain constant irrespective of the wanted and interfering signal levels. The measurements presented in this report therefore are made for a range of input signal powers.

3 Measurements

3.1 Introduction

The approach taken in the measurements is to combine a wanted DVB-T signal with an interfering signal and to present this to the input of the DTT receiver under test. The wanted and interfering
waveforms may be on different frequencies, and their relative signal strengths are adjusted until satisfactory reception is obtained. This procedure is described further in the following sections.

### 3.2 Equipment Tested

A set of 14 DVB-T receivers were tested, 8 of these were set-top boxes (STBs), and the remaining 6 were standalone TV sets with integrated DVB-T receivers (IDTVs).

For the purposes of the tests presented in this report, each receiver has been allocated a reference code. A list of the codes is given in Table 1, together with the receiver type, and whether the unit uses a “can” tuner or a silicon device. The information about the tuner type is derived from the protection ratio performance at the image frequency (72MHz above the wanted signal); a degraded performance is taken as an indication that the receiver uses a can tuner.

The receivers tested were all being marketed in the UK at the time of testing and displayed the “Freeview” logo. This means that they would have passed product testing by the Digital TV Group (DTG) whose procedures include tests of RF performance.

<table>
<thead>
<tr>
<th>Receiver</th>
<th>Type</th>
<th>Tuner Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>STB</td>
<td>Silicon</td>
</tr>
<tr>
<td>D2</td>
<td>IDTV</td>
<td>Can</td>
</tr>
<tr>
<td>D3</td>
<td>STB</td>
<td>Silicon</td>
</tr>
<tr>
<td>D4</td>
<td>STB/PVR</td>
<td>Silicon</td>
</tr>
<tr>
<td>D5</td>
<td>IDTV</td>
<td>Can</td>
</tr>
<tr>
<td>D6</td>
<td>STB</td>
<td>Silicon</td>
</tr>
<tr>
<td>D7</td>
<td>STB</td>
<td>Silicon</td>
</tr>
<tr>
<td>D8</td>
<td>STB</td>
<td>Can</td>
</tr>
<tr>
<td>D9</td>
<td>STB/PVR</td>
<td>Can</td>
</tr>
<tr>
<td>D10</td>
<td>IDTV</td>
<td>Silicon</td>
</tr>
<tr>
<td>D11</td>
<td>IDTV</td>
<td>Can</td>
</tr>
<tr>
<td>D12</td>
<td>IDTV</td>
<td>Silicon</td>
</tr>
<tr>
<td>D13</td>
<td>IDTV</td>
<td>Can</td>
</tr>
<tr>
<td>D14</td>
<td>STB</td>
<td>Can</td>
</tr>
</tbody>
</table>

Table 1 - Summary of Equipment Tested

### 3.3 Test Equipment Configuration

[Diagram of test arrangement]

Figure 1 - Test arrangement
The test equipment arrangement is shown in Figure 1. The interfering (WSD waveform) and wanted (DVB-T) transmissions are combined using a 20dB coupler. The signal generator's waveform selection and frequency are under GPIB control from a control PC, its output power is selected by means of a GPIB controlled variable attenuator. Similarly, the level of wanted signal generated by the DVB-T generator is controlled by the PC. Further details of the signal sources are given in Section 3.4.

The impairment of the wanted signal is assessed by a Technical Projects MJS401D Audio Measurement System (AMS), also under GPIB control. The AMS input source is the audio output of the DVB-T receiver. Further details about the impairment measurements are given in Section 3.5.

The protection ratio is measured under automatic control from the control PC. A wanted signal of 706MHz (Ch. 50) has been used. For an interfering signal at a particular frequency, the powers of the interfering and wanted waveforms are automatically adjusted until the measured audio impairment falls below a pre-determined threshold. The test procedure and impairment measurement is achieved under the control of the PC, this being described in more detail in Section 3.6.

### 3.4 Signal Sources

For the DVB-T receivers, the wanted signal was generated by a Rohde & Schwarz SFE Broadcast Tester. The signal parameters for the DVB-T signal are given in Table 2. No channel impairment (e.g. multipath) was added to the DVB-T signal.

<table>
<thead>
<tr>
<th>Standard</th>
<th>DVB-T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>8K OFDM</td>
</tr>
<tr>
<td>Modulation</td>
<td>64QAM</td>
</tr>
<tr>
<td>Code Rate</td>
<td>2/3</td>
</tr>
</tbody>
</table>

Table 2 - Wanted signal parameters

The interfering signal sources were reproduced on an Agilent NX5182A arbitrary signal generator, using waveform sequences previously captured using a system able to record directly the transmitted RF output of the WSD. This approach has the advantage that the captured waveform can be replayed at any output frequency or power. The waveform can also be processed prior to playback (e.g. to ensure that any out-of-band emissions are reduced).

For this study, 5 candidate technologies were considered; one each based on the Wi-Fi, WiMAX and LTE standards as well as 2 proprietary WSD standards. 6 waveforms were used for each candidate technology (i.e. a total of 30 waveforms were used to test each receiver), representing typical outputs from both base station (BS) and user terminal (UE or CPE) at 3 traffic levels. The 6 waveforms for each technology were generated by transferring data representing a particular proportion of the maximum available throughput. This was achieved by connecting a BS and UE pair to form an end-to-end link using an IP traffic tool to load the link. The waveforms captured represent 3 data transfer rates: 100% 50% and an idle mode (where the data exchange was limited to control traffic) for both BS and UE devices.

To ensure that the measurements were not contaminated by any out of band signals captured in the recording process, the test waveforms were band-pass filtered in software prior to playback. The LTE waveforms were filtered to fit into a 10MHz channel, all the other waveforms were filtered into an 8MHz channel. This guarantees that the protection ratio measurements are a function only of the receiver selectivity and the adjacent channel leakage ratio (ALCR) of the arbitrary signal generator.

#### 3.4.1 Characteristics of the WSD Waveforms

The candidate WSD technologies assessed for these tests typically use TDD duplex arrangements where the uplink and downlink segments are multiplexed in time. The signals are characterized by a frame duration and a duty cycle. The uplink segment is typically multiplexed between a number of CPE or UE devices and may not be present for each cycle of the TDD transmission frame. The peak to mean ratio of the uplink waveforms tend to be greater as a result, particularly at low data
traffic rate, and the time domain waveforms are quite “bursty” in nature. The power and time
domain characteristics of the waveform are discussed further in Section 3.7.

3.4.2 WSD Waveform Plots

The frequency-domain and time-domain characteristics of some of the WSD technology
candidates are illustrated in the figures below.

The spectrum of the replayed RF recording for WSD technology 1 is shown in Figure 2.

![WSD1 Output Spectrum](image1)

**Figure 2 – WSD1 Output Spectrum**

The IQ vectors associated with the recording have been processed to ensure an ACLR in excess
of 60dB in the first adjacent channel.

Figure 3 shows the corresponding spectra for a 5MHz wide WiMAX base station signal. The impact
of the 8MHz BPF can be seen by the step in the noise floor at 4MHz offset.

![WiMAX BS Output Spectrum](image2)

**Figure 3 – WiMAX BS Output Spectrum**

Figure 4 shows the spectrum of the Wi-Fi radio, a 5MHz (quarter bandwidth) variant of the 802.11g
technology used in the 2.4GHz ISM band. Note the radios used for test had a particularly relaxed
ACLR specification (~25dB) and the effect of the 8MHz band pass filter is quite pronounced.
An example of one of the test waveforms viewed in the time-domain is given in Figure 5. The plot is for the LTE BS idle waveform. It can be seen that this waveform exhibits a characteristic on/off pattern with a duty cycle of around 40% and around 40dB of difference in the waveform between the “on” and “off” portions.

### 3.4.3 ACLR Considerations

The protection ratio required to ensure adequate DVB-T reception is a function of the selectivity of the victim DTT receiver and the adjacent channel power emitted by the interfering WSD device. The protection ratio measurements presented in this document were made using a signal generator to emulate interference from a WSD. The adjacent channel leakage ratio (ACLR) of the signal generator was as good as 83dB for an offset of >10MHz, which is almost certainly better than the ACLR performance that would be achieved by a practical WSD. In order to develop protection ratio recommendations for practical WSDs it will be necessary to know values for the ACLR of the WSD at appropriate frequency offsets.

The final protection ratio is found in two stages; firstly, for a frequency offset $\Delta f$ the adjacent channel selectivity (ACS) of the receiver is calculated from the measured protection ratio at the offset $(PR(\Delta f))$, the co-channel protection ratio $PR_0$ and the ACLR of the signal generator:

$$ACS(\Delta f) = -10\log(10^{\frac{PR_0-PR(\Delta f)}{10}} - 10^{\frac{ACLR}{10}})$$  \hspace{1cm} (1)
Secondly, the derived value of the DTT ACS is used to determine the appropriate co-channel and adjacent channel protection ratios for WSDs that may have different ACLR characteristics. The final protection ratio, \( PR'(\Delta f) \), is a function of the ACS from Equation (1) and the ACLR of the WSD at (\( \Delta f \)), ACLR':

\[
PR'(\Delta f) = PR_0 + 10 \log(10^{-\frac{\text{ACS}}{10}} + 10^{-\frac{\text{ACLR}'}{10}})
\]  

(2)

Relaxed WSD ACLR performance will imply increased DTT protection ratios and imply lower levels of EIRP for a given level of interference.

### 3.5 Impairment Criteria

The impairment criterion determines the point at which the interfering signal source has degraded the reception to a point at which the quality is deemed unacceptable. This is generally measured by observing the displayed picture and deciding it to be unimpaired at the point where no picture break-ups are observed during the observation period (e.g., 10 seconds). For digitally encoded TV systems, the digital threshold effect means that picture break-up is accompanied by a loss of audio; it is therefore possible to detect the point at which failure occurs by measuring the audio output from the DVB-T receiver. This is achieved in these tests by using the audio measurement system (AMS) to measure the Total Harmonic Distortion (THD) of the demodulated audio. A 1dB increase in THD (compared to the case where the wanted signal is present without any interference) is used as the pass/fail decision point, although in practice the presence of WSD interference results in complete audio loss.

### 3.6 Test Formats

Two main tests have been carried out; a test to determine the variation of protection ratio with frequency for various wanted signal powers and another to investigate the precise overload characteristics of the devices for a fixed number of frequency offsets.

#### 3.6.1 C/I vs. Frequency

For the first test, the wanted signal power is fixed and the power of the interfering waveform is increased until the receiver becomes impaired. The interfering signal is then backed off until the receiver can successfully demodulate the wanted signal; the PR is recorded at this point. This is repeated for a range of frequency offsets from -80MHz to +80MHz, and for a number of wanted signal powers.

#### 3.6.2 Saturation Characteristics (C vs. I)

For the overload measurements, the level of the interfering signal is fixed and the power of the wanted signal is decreased until the receiver becomes impaired. The wanted signal is then increased until it can be demodulated without error by the receiver. The values of the wanted and interfering signals are then recorded. This is repeated for a number of interfering signal powers and frequency offsets.
3.7 Waveform Power Correction

In order to use the signal levels provided by these measurements for regulatory purposes, it is necessary to establish how the measured values are related to the power value that would be permitted as a licensed value $P_{\text{lic}}$.

The value provided directly by reading the signal generator output power would be the calculated RMS value of the waveform. Using the RMS value of the waveform for $P_{\text{lic}}$ is inappropriate, as some of the interfering WSD waveforms investigated are TDD based, with duty cycles as low as 2% and a high peak to average power ratio (PAPR). This would result in a high peak power for a nominally low licensed power. As it is the peak powers of the interfering waveform which cause harmful interference to the wanted DVB-T signals, it is important to capture this in the measurement.

An appropriate value for $P_{\text{lic}}$ is derived by investigating the portion of the interfering waveform that represents the transmission being active (the “On” period). The licensed power is then taken to be the RMS power value of the waveform during the “on” period.

The value of $P_{\text{lic}}$ will still be less than the peak power value (as shown in Figure 6). Protection ratio measurements made in this report use $P_{\text{lic}}$ for the value of the interfering waveform generated by the signal generator.

The characteristics of the 30 WSD waveforms used in these tests are given in Table 3. The measured PAPR of the waveform (i.e. $P_{\text{pk}} - P_{\text{RMS}}$) is given, as is the Licensed to Average Power Ratio (LAPR; i.e. $P_{\text{lic}} - P_{\text{RMS}}$). Where it is possible to observe a regular periodic structure to the waveform, such as might occur if the waveform has an uplink/downlink TDD frame structure, then the measured length of the frame is recorded in the “Frame Period” column.

Figure 6 - Licensed power
<table>
<thead>
<tr>
<th>Waveform</th>
<th>PAPR (dB)</th>
<th>LAPR (dB)</th>
<th>Frame Period (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_{pk}$</td>
<td>$P_{RMS}$</td>
<td></td>
</tr>
<tr>
<td>WSD1 BS 100%</td>
<td>4.9</td>
<td>0.8</td>
<td>20</td>
</tr>
<tr>
<td>WSD1 BS 50%</td>
<td>4.4</td>
<td>0.9</td>
<td>20</td>
</tr>
<tr>
<td>WSD1 BS IDLE</td>
<td>6.7</td>
<td>3.3</td>
<td>20</td>
</tr>
<tr>
<td>WSD1 CPE 100%</td>
<td>12.7</td>
<td>8.7</td>
<td>20</td>
</tr>
<tr>
<td>WSD1 CPE 50%</td>
<td>12.5</td>
<td>8.7</td>
<td>20</td>
</tr>
<tr>
<td>WSD1 CPE IDLE</td>
<td>15.0</td>
<td>11.0</td>
<td>20</td>
</tr>
<tr>
<td>WIMAX BS 100%</td>
<td>9.1</td>
<td>5.6</td>
<td>5</td>
</tr>
<tr>
<td>WIMAX BS 50%</td>
<td>10.9</td>
<td>7.3</td>
<td>5</td>
</tr>
<tr>
<td>WIMAX BS IDLE</td>
<td>12.7</td>
<td>9.1</td>
<td>5</td>
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<td>WIMAX CPE 100%</td>
<td>19.4</td>
<td>8.9</td>
<td>5</td>
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<td>WIMAX CPE 50%</td>
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<td>12.9</td>
<td>5</td>
</tr>
<tr>
<td>WIMAX CPE IDLE</td>
<td>31.7</td>
<td>20.4</td>
<td>5</td>
</tr>
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<td>WIFI BS 100%</td>
<td>4.9</td>
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<td>-</td>
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<tr>
<td>WIFI BS 50%</td>
<td>6.4</td>
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<td>-</td>
</tr>
<tr>
<td>WIFI BS IDLE</td>
<td>8.3</td>
<td>3.9</td>
<td>-</td>
</tr>
<tr>
<td>WIFI CPE 100%</td>
<td>5.6</td>
<td>0.9</td>
<td>-</td>
</tr>
<tr>
<td>WIFI CPE 50%</td>
<td>7.1</td>
<td>2.3</td>
<td>-</td>
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<tr>
<td>WIFI CPE IDLE</td>
<td>8.8</td>
<td>4.0</td>
<td>-</td>
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<tr>
<td>WSD2 BS 100%</td>
<td>11.3</td>
<td>2.1</td>
<td>-</td>
</tr>
<tr>
<td>WSD2 BS 50%</td>
<td>14.8</td>
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</tr>
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<td>WSD2 BS IDLE</td>
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<td>19.0</td>
<td>-</td>
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<td>WSD2 CPE 100%</td>
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<td>1.5</td>
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<td>WSD2 CPE 50%</td>
<td>14.3</td>
<td>5.4</td>
<td>-</td>
</tr>
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<td>WSD2 CPE IDLE</td>
<td>31.2</td>
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<td>-</td>
</tr>
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<td>LTE BS 100%</td>
<td>6.3</td>
<td>-0.7</td>
<td>-</td>
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<td>LTE BS 50%</td>
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<td>-0.9</td>
<td>-</td>
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<tr>
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<td>12.1</td>
<td>2.2</td>
<td>-</td>
</tr>
<tr>
<td>LTE UE 100%</td>
<td>6.3</td>
<td>-0.8</td>
<td>-</td>
</tr>
<tr>
<td>LTE UE 50%</td>
<td>8.4</td>
<td>1.1</td>
<td>-</td>
</tr>
<tr>
<td>LTE UE IDLE</td>
<td>16.3</td>
<td>8.9</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3 - WSD Waveform Characteristics

4 Results

4.1 Protection Ratio vs. Frequency

Figure 7 and Figure 8 show examples for the variation of the protection ratio with frequency for all of the receivers tested. The waveforms for the LTE base station at 100% traffic and idle are used as an example, with a wanted signal of -70dBm.

Frequency offsets between wanted and interfering signals from -80 to 80MHz were used with 8MHz spacing. Additional measurements at spacing of 1MHz were made for offsets of -5MHz to 5MHz.

In addition to the stepped frequency offset in the range -80 to 80MHz, a specific measurement was made at an offset of 72MHz. Receivers using a super-heterodyne architecture can be sensitive to signals received on offsets at twice the IF above the intended frequency, resulting in an increased protection ratio. For an intermediate frequency (IF) of 36MHz, this offset is at 72MHz. This effect is sometimes known as the "N+9" or image rejection problem.

Investigations showed that 3 receivers also suffered significant protection ratio degradation in the region of offsets between +35 and +40MHz, for this reason, additional measurements were made at these frequency offsets. This corresponds to a WSD offset by the Intermediate Frequency of the receiver’s tuner.
Figure 7 shows the spread of results for the LTE BS waveform carrying full traffic, whereas Figure 8 shows the performance where the LTE Idle BS waveform is used. The results for the full traffic waveform are similar to those found in previous work [2]. Figure 8 shows a significant increase in the required protection ratio for a number of receivers leading to the conclusion that some receivers suffer a degraded performance in the presence of the LTE Idle signal. The close grouping of performance in Figure 7 shows that the receivers are well adapted to coping with interference from broadcast-like signals. The LTE-BS 100% signal has similar characteristics to DVB-T transmissions. The spread in performance illustrated in Figure 8 shows that a significant number of receivers are ill-adapted to the bursty signals that are characteristic of the LTE-BS idle waveform. Similar results are observed for LTE-UE and WSD-TDD waveforms, and it is felt that this behaviour may be a consequence of interactions between the receiver AGC time constants and the time domain characteristics of the WSD waveforms.
4.2 Overload Characteristics

Figure 9 shows the C vs. I characteristics for one of the DTT receivers evaluated with a WSD operating in the first adjacent channel. The family of curves show the behaviour for different WSD waveforms, at different traffic loading points. The curves are generated by measuring the level of the wanted DVB-T signal required to maintain unimpaired performance for increasing levels of interfering waveform. For the first adjacent channel measurements (N+1), the frequency offset between the wanted and interfering signals is 8MHz (or 10MHz for the wider bandwidth LTE signals). The protection ratio stays constant for interfering signals of -40 to -15dBm. Beyond this, the protection ratio starts to increase as the receiver overload is approached and the receiver exhibits degraded performance.

Figure 10 shows the same information for a different receiver. As previously noted in Section 4.1, it can be seen that certain waveforms cause a degradation in the receivers performance such that the wanted signal strength must be increased by 20-30dB to maintain picture quality.

An analysis of the results was undertaken to assess which WSD waveforms were the most destructive, and which receivers were most susceptible to degraded performance. The results
show that there is no single interfering waveform can be identified that causes a problem to the vulnerable receivers. Instead each vulnerable receiver has a particular waveform that causes it particular problems, resulting in degraded (increased) protection ratios.

Three waveforms were identified which provoked the worst problems in receivers. These are:

- the idle version of WiMAX CPE waveform (WiMAX CPE IDLE)
- the idle WSD2 CPE waveform (WSD2 CPE IDLE)
- the idle LTE BS waveform (LTE BS IDLE)

C/I measurements have been made for all of the receivers in the presence of interference from all of the waveforms. A selection of the results using interference from the problematic waveforms is presented in Figures 11 to 22.
Figure 13 – C/I for LTE BS Idle, 24MHz Offset

Figure 14 – C/I for LTE BS Idle, 72MHz Offset
Figure 15 – C/I for WiMAX Idle, 8MHz Offset

Figure 16 – C/I for WiMAX Idle, 16MHz Offset
Figure 17 – C/I for WiMAX Idle, 24MHz Offset

Figure 18 – C/I for WiMAX Idle, 72MHz Offset
Figure 19 – C/I for WSD2 Idle, 8MHz Offset

Figure 20 – C/I for WSD2 Idle, 16MHz Offset
Figure 21 – C/I for WSD2 Idle, 24MHz Offset

Figure 22 – C/I for WSD2 Idle, 72MHz Offset
5 Conclusions

5.1 Summary of Receiver Performance

The results show that there are a number of WSD technology waveforms that provoke poor DTT receiver protection performance in certain receivers, when operating in their "idle" mode. The measured protection ratios are significantly degraded when compared to the corresponding waveform which carries full traffic. The cause for this deterioration is unclear, although it is believed that it is the periodic nature of the interfering signal interacting with the automatic gain control (AGC) of the tuner that results in degraded protection ratios. DTT receiver designs typically deploy a number of AGC loops to manage the level of signals into the demodulator and the degraded performance effects occur over a range of signal levels.

The degradation in receiver performance with the idle signal splits receivers into three categories (where the degradation criterion is an increase in protection ratio):

- Receivers for which the idle waveform causes no discernible change in performance.
- Receivers for which there is degradation in performance for frequency offsets less than 30MHz.
- Receivers for which there is performance degradation at all frequency offsets.

There is no single waveform that causes degraded performance in the vulnerable receivers; rather each receiver appears to have a waveform to which it is most vulnerable. The degraded performance is a function of the power level of the interfering signal; the level at which the degraded performance occurs is specific to each receiver and WSD waveform type.

5.2 Protection Ratio Recommendations

The increased protection ratio required for particular combinations of receiver and waveform has the potential to reduce considerably the value obtainable from TVWS. In the long term it would be highly desirable for the issues concerning DVB-T performance in the presence of WSD interference to be fully investigated and resolved. In the near-term, there are a number of possible approaches to deploy WSD whilst maintaining DTT protection. The UK regulator has initially suggested the following protection ratio values [1], with no variation suggested for different levels of signal power:

<table>
<thead>
<tr>
<th>Offset (8MHz channel)</th>
<th>Protection Ratio (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-9</td>
<td>-43</td>
</tr>
<tr>
<td>n-8</td>
<td>-65</td>
</tr>
<tr>
<td>n-7</td>
<td>-65</td>
</tr>
<tr>
<td>n-6</td>
<td>-65</td>
</tr>
<tr>
<td>n-5</td>
<td>-65</td>
</tr>
<tr>
<td>n-4</td>
<td>-65</td>
</tr>
<tr>
<td>n-3</td>
<td>-49</td>
</tr>
<tr>
<td>n-2</td>
<td>-47</td>
</tr>
<tr>
<td>n-1</td>
<td>-30</td>
</tr>
<tr>
<td>Co-channel</td>
<td>20</td>
</tr>
<tr>
<td>n+1</td>
<td>-30</td>
</tr>
<tr>
<td>n+2</td>
<td>-47</td>
</tr>
<tr>
<td>n+3</td>
<td>-49</td>
</tr>
<tr>
<td>n+4</td>
<td>-65</td>
</tr>
<tr>
<td>n+5</td>
<td>-65</td>
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<tr>
<td>n+6</td>
<td>-65</td>
</tr>
<tr>
<td>n+7</td>
<td>-65</td>
</tr>
<tr>
<td>n+8</td>
<td>-65</td>
</tr>
<tr>
<td>n+9</td>
<td>-43</td>
</tr>
</tbody>
</table>
Based on the measurements reported in this document, these values appear somewhat optimistic (i.e., too low), and significantly higher protection ratios will be required to protect the worst performing receivers, particularly in the presence of bursty idle-mode interference from white space devices.

Three options for protecting DTT performance are considered:

- Protect for the worst WSD interference to the most susceptible receiver
- Incorporate information about the susceptibility of receivers to different types and levels of interference into the geolocation database
- Regulate to prohibit particular WSDs

It is assumed that regulators will adopt a technology neutral approach to white space deployments (rather than seeking to prevent certain WSDs being deployed), and so the first two options are considered.

### 5.2.1 Worst Case Protection Ratios

From the measurements made in this report, the protection ratio required to ensure adequate performance for each receiver in the presence of the waveform which degrades its respective performance by the greatest amount is shown in Figure 23 for frequency offsets of 8MHz, 16MHz, 24MHz and 72MHz. As noted in Section 3.4.3, these protection ratios have been measured using a signal generator with a high ACLR.

![Figure 23 - Summary of Protection Ratio Values](image)

Figure 23 shows that in order to guarantee adequate DTT receiver performance in the presence of all types of WSD interference, it would be necessary to increase the protection ratio values by 30-40dB compared to those suggested in [1].

### 5.2.2 Enhanced Database

The findings of this report include that the degradation in performance of the DTT receivers is highly dependent on the class of WSD waveform, the receiver type, and the signal level at which the interfering signal is received. The geolocation database algorithms could be expected to take account of the particular technology class and the predicted interference signal strength, when returning a set of possible channels and permissible powers in response to a query from a WSD. Further protection ratio measurements would need to be carried out on a large number of receivers in order to ensure that the database algorithms are based on statistically significant data.
Finally, it should be noted that the protection ratio values used for geolocation database are a function of the device ACLR characteristics. For these measurements, care has been taken to filter the WSD waveforms and use a signal generator with good ACLR (typically 60 -80dB). The FCC have specified an ACLR of 55dB for devices in the US, and ETSI are currently considering what values might be appropriate for devices for use in Europe. Certain manufacturers are proposing relaxed ACLR specifications, and such proposals will require increased protection ratios.

6 References
