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Interference into DTT Receivers**

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Executive Summary

This report presents the results of a measurement programme to investigate the impact of interference from 800 MHz Long Term Evolution (LTE) base station emissions to Digital Terrestrial Television (DTT) services operating below 790 MHz. The results of the study are intended to inform the Ofcom consultation on technical restrictions that may be needed for co-existence of new services in the 800 MHz band with adjacent DTT use in bands below 790 MHz [1].

Both traditional "superhet" (can) and more recent "silicon" tuners have been considered from a range of manufacturers. Receivers included integrated digital televisions, personal video recorders and set-top boxes.

The base station (BS) signals used in the testing were recorded directly from an equipment vendor's 800 MHz test network; the base station was configured for both maximum traffic loading (i.e. 100% loading) and idle conditions (i.e. no traffic on the base station, giving rise to time-discontinuous or "bursty" emissions). The recorded base station signals were replayed through a signal generator and the out-of-block emissions were adjusted to comply with the minimum requirements for Case A operation specified in ECC Dec 2010/267/EU [3]. Although base station equipment might reasonably be expected to perform better than the ECC requirement in practice, we have taken a cautious approach in this study by considering the scenario of equipment engineered to just meet the ECC out-of-block limits across DTT channel 60.

The results are presented as Carrier-to-Interference (C/I) protection ratios calculated at the point where interference results in visible degradation to viewed picture quality (the appearance of macroblock artefacts). C/I performance is a measure of receiver selectivity, defining the permitted level of interference for a given wanted signal level and frequency offset; the higher the C/I value the more sensitive the receiver is to interference.

The results show that:

- The traffic loading on the base station has a significant influence on the protection ratio results. Receivers are more susceptible to time-discontinuous emissions, when the base station is operating under idle or low traffic conditions. This is most likely due to the impact of the base station on the receivers' Automatic Gain Control behaviour;
- The wanted DTT operating mode does not appear to have a big impact on susceptibility to interference. Results using a DVB-T wanted signal are comparable to those using a DVB-T2 signal;

- Receivers become more susceptible to interference as the wanted signal level increases. This is most likely due to the receiver front-end becoming desensitised at higher signal levels (i.e. receiver overload), resulting in the interferer requiring less power to degrade the received picture quality. When the receiver is in overload the higher C/I protection ratios are driven mainly by the increase in wanted signal level. This may have implications in areas of high TV signal strength, or where an amplifier is installed between antenna and receiver to boost the received signal level. An investigation of amplifier overload effects has been undertaken by Ofcom and is published in a separate report;
- A co-channel protection ratio of 21 dB would be required to protect all but the worst performing receiver irrespective of DTT transmission mode, wanted signal level at the input to the receiver and base station operating conditions;
- Protection ratios for adjacent channel interference, with the DTT receiver tuned to channel 60 and the LTE interferer centred at 796 MHz, are in the range -17 to -37 dB for low wanted signal levels at the input to the receiver ($C = -70$ dBm), increasing to between -1 and -20 for high wanted signal levels ($C = -30$ dBm);
- Superhet tuners are susceptible to image channel interference when the interferer appears nine channels above the wanted (tuned) channel (72 MHz offset). The N+9 image channel rejection of DTT receivers based on superhet tuner designs is critical to minimising the susceptibility of these receivers to LTE base station interference. The results show that a C/I protection ratio of around -40 dB should be specified for superhet receivers. Silicon tuners have a low, or zero, intermediate frequency and do not suffer the same N+9 image problems as superhet receivers.

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Abbreviations List

AGC	Automatic Gain Control
BER	Bit Error Ratio
BEM	Block Edge Mask
BS	Base Station
C/I	Carrier-to-Interference ratio
COFDM	Coded Orthogonal Frequency Division Multiplex
DTT	Digital Terrestrial Television
DVB-T	Digital Video Broadcast - Terrestrial
FEC	Forward Error Correction
iDTV	Integrated Digital Television
IF	Intermediate Frequency
LO	Local Oscillator
LTE	Long Term Evolution
PF	Picture Failure
PVR	Personal Video Recorder
QEF	Quasi Error Free
SPF	Subjective Picture Failure
STB	Set Top Box
UCE	Un-Correctable Error

1. Introduction

1.1 Background

In March 2011 Ofcom published a consultation document setting out proposals for the award of spectrum in the 800 MHz and 2.6 GHz frequency bands [2]. The 800 MHz band is part of the digital dividend; the spectrum freed up as a result of the switchover from analogue to digital TV. Ofcom envisions this spectrum will be used to deliver the next generation of mobile broadband services using technologies such as LTE and WiMAX.

The harmonised frequency arrangements for the 800 MHz band are set out in ECC Decision 2010/267/EU [3], based on Frequency Division Duplex operation with the downlink located in the lower part of the band, from 791 – 821 MHz, an 11 MHz duplex gap between 821 – 832 MHz and then the uplink located from 832 – 862 MHz. A 1 MHz guard band, from 790 – 791 MHz, separates the edge of the broadcasting band (DTT channel 60) from the LTE downlink allocation, as illustrated in Figure 1.

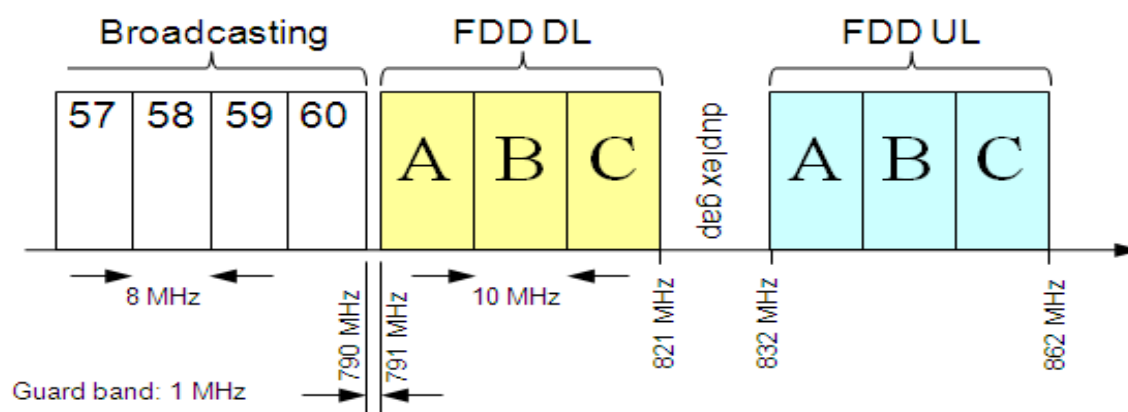


Figure 1: LTE and DTT frequency allocations

The deployment of future mobile services in the 800 MHz band introduces the risk of potential interference to DTT receiving equipment. This report considers the coexistence issue between the uppermost DTT channels (channels 51 to 60) and emissions from LTE base stations operating in the 791 – 821 MHz band. Since DTT receivers are designed to operate across UHF Band IV and V, from 470 – 862 MHz, there is the potential for base stations to cause interference to DTT reception through two principal mechanisms:

- Front end overload of the receiver: The receiver becomes overloaded if the sum of the signal powers at the receiver input exceeds a certain threshold. Since this is dependent on the cumulative effect of a number of different signal levels, the severity of the interference will vary in different geographic regions. When the

receiver is in overload the ability to discriminate against Adjacent Channel Interference falls as the RF input level rises.

- Degradation in receiver Signal-to-Noise ratio: If the ratio of wanted signal power to that of interference power at the receiver input reduces below a specific threshold then the DTT receiver will fail to operate properly. Unwanted signal power reduces as the frequency offset between the interferer and victim increases.

In this study we consider the potential for interference to ten different DTT receivers categorised as follows:

- Televisions with integrated digital TV tuners (iDTV);
- Personal video recorders (PVRs) capable of recording digital content to an internal hard drive;
- Set-top boxes capable of receiving “freeview” digital television (STBs).

Two different DTT transmission standards were considered:

- DVB-T, the most widely deployed DTT system worldwide, with more than 200 million receivers operating in over 60 countries [6]. DVB-T transmissions were first broadcast in the UK in 1998;
- DVB-T2, an evolution of the DVB-T standard offering better spectrum efficiency, robustness and flexibility. DVB-T2 uses the latest modulation and coding techniques to enable efficient use of spectrum for the delivery of video, audio and data services to fixed, portable and mobile devices. DVB-T2 transmissions were first broadcast in the UK in March 2010.

Since 800 MHz LTE technology is in the very early stages of roll-out at the time of this study, the base station emissions used as the interference source were recorded from a vendor’s test network. It should be noted that equipment from other vendors may vary in performance, which may in turn have an impact on the results.

Two base station configurations were considered:

- The base station operating under fully loaded traffic conditions (i.e. 100% loading);
- The base station operating under idle traffic conditions (i.e. no traffic loading).

The results of this study have been used to inform the Protection Clause field trial undertaken by Ofcom to test and verify the results of theoretical modelling¹.

1.2 Scope & Objectives

The objectives of the practical measurement study were to derive Carrier-to-Interference (C/I) protection ratios for a range of DTT receivers under the following operating conditions:

- DVB-T and DVB-T2 operating modes;
- Wanted signal levels at the input to the receiver of -70, -50, -30, -20 and -12 dBm;
- Interference from time variant LTE base station signals representing fully loaded and idle traffic conditions;
- Frequency offsets from co-channel to N+11 channel offsets, in 8 MHz steps.

2. Test Set-Up

2.1 Receivers Under Test

DTT receivers can be implemented using a variety of RF tuner architectures [7]. The most common are the super-heterodyne (can) receiver and the silicon receiver:

- In a superhet receiver the received RF signal is mixed with a local oscillator (LO) signal to produce a resulting intermediate frequency (IF). This type of receiver is particularly prone to image channel interference at 72 MHz above the wanted frequency ("the N+9 problem").
- Silicon receivers overcome the superhet IF image response issue by having a zero or low IF stage. The zero IF receiver directly converts the RF signal to baseband centred on 0 Hz using two mixers operating in quadrature. However, this type of architecture introduces other issues centred on the need to amplify signals near or at DC. A low IF receiver attempts to overcome the problems with zero IF receivers by choosing an IF frequency which causes the image frequency to fall into an adjacent channel. The receiver must still achieve sufficient image channel rejection to meet the required adjacent channel specification, but many radio standards require less selectivity for interfering signals occurring in adjacent channels than they do for interfering signals in other channels. Zero and low IF receiver architectures lend

¹ <http://stakeholders.ofcom.org.uk/consultations/coexistence-with-dtt/>

themselves to a high degree of integration and are hence often referred to as silicon receivers².

The 10 receivers under test in this study are shown in Table 1 below³. These consisted of a mix of iDTV, PVR and STBs with either can or silicon tuner architectures.

Table 1: Receivers Under Test

Receiver ID	DTT Transmission Mode	Receiver Type	Tuner
Receiver 1	DVB-T & T2	iDTV	Silicon
Receiver 4	DVB-T & T2	iDTV	Can
Receiver 6	DVB-T & T2	PVR	Silicon
Receiver 7	DVB-T2	iDTV	Can
Receiver 8	DVB-T & T2	STB	Silicon
Receiver 9	DVB-T2	iDTV	Can
Receiver 10	DVB-T2	PVR	Silicon
Receiver 11	DVB-T2	iDTV	Can
Receiver 12	DVB-T2	STB	Silicon
Receiver 13	DVB-T	STB	Can

2.2 Wanted Signal

The wanted DTT test signal was produced by a Rohde & Schwarz SFE signal generator configured for either DVB-T or DVB-T2 transmissions based on the appropriate parameters from ETSI standards EN 300 744 (DVB-T) [8] and EN 302 755 (DVB-T2) [9]. The key parameters are summarised in Table 2.

² For a detailed discussion on receiver architecture the reader is referred to reference [7].

³ Receivers 2, 3 and 5 were tested in a previous study by ERA [12] and are not considered further in this report.

Table 2: Wanted DVB-T/DVB-T2 system parameters

Parameter	DVB-T	DVB-T2
Multiple access	COFDM	COFDM
Modulation	64-QAM	256-QAM
Forward error correction	2/3	2/3
FFT points	8 k	32 k
Guard Interval (μ s)	7 ($1/32$)	28 ($1/128$)
Data rate (Mbit/s)	24.1	40.2
Channel bandwidth	8 MHz	8 MHz

All measurements were based on the non-critical DVB-T mask described in ETSI EN 302 296 [10] as shown in Table 3. The resulting spectral emissions of the wanted signal are compared with the ETSI non-critical mask in Figure 2 below, measured in a 5 kHz resolution bandwidth (RBW).

Table 3: DVB-T transmit masks

Offset (MHz)	Critical Mask dBc	Non-critical mask dBc	Relaxed non-critical mask dBc	Ref Bandwidth (kHz)
+/-3.8	-32.8	-32.8	-32.8	4
+/-4.2	-83	-73	-67.8	4
+/-6	-95	-85	-85	4
+/-12	-120	-110	-110	4
+/-20	-120	-110	-110	4

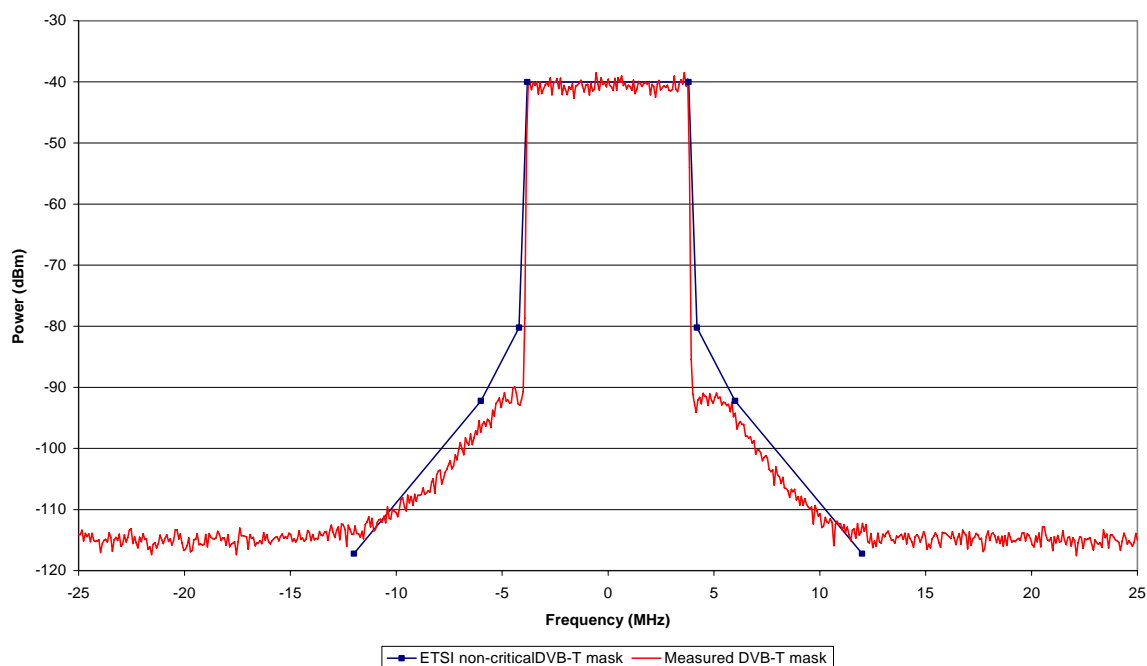


Figure 2: DVB-T wanted non-critical transmitter mask

Measurements were undertaken for wanted signal levels at the antenna input to the DTT receiver of -70, -50, -30, -20 and -12 dBm and for channel offsets from co-channel (N), channel 60 to channel 48 (in 8 MHz steps), and channel 38.

2.3 Interfering Signal

Commission Decision 2010/267/EU [3] sets out the technical parameters that apply to the use of the 800 MHz band by networks other than high-power broadcasting networks. The technical licence conditions that Ofcom proposes to adopt for the 800 MHz band are set out in a consultation document published in June 2011 [4] and are fully consistent with the ECC Decision 2010/267/EU parameters.

The base station emissions used as the interference source were recorded directly from a vendor's LTE 800 MHz test network; the base station was configured for maximum traffic loading (i.e. 100% loading) and idle conditions (i.e. no traffic on the base station). In each case the resource block allocation and sub-frame usage were adjusted automatically according to the vendor's base station scheduler. The base station was configured for QPSK modulation and 10 MHz channel bandwidth as described in Appendix A of ETSI TS 136 104 (3GPP TS 36.104) [11] and summarised in Table 5 below.

Measurements were undertaken with the base station frequency centred on 796 MHz, occupying the frequency range 791 – 801 MHz (Block A) for a 10 MHz bandwidth signal.

Table 4: LTE base station signal parameters

Parameter	Value
Multiple access method	OFDMA
Duplex	FDD
Channel bandwidth	10 MHz
Allocated resource blocks	Allocated dynamically depending on traffic
Channel modulation	QPSK
Sub-frame length	1 ms
Number of OFDM sub-carriers	12 (per resource block)
Sub-carrier bandwidth	15 kHz
Code rate	1/3

ECC Dec 2010/267/EU sets out Block Edge Masks (BEMs) as an essential requirement of the technical conditions necessary to ensure coexistence between services at a national level. These BEMs are a set of technical parameters that define the in-block and out-of-block power for the LTE base station. Three cases are defined; Case A for TV channels where broadcasting is protected, Case B for TV channels where broadcasting is subject to an intermediate level of protection and Case C for TV channels where broadcasting is not protected. Ofcom has indicated [4] that they intend to apply Case A limits at all locations and for all DTT frequencies, as summarised in Table 5.

Table 5: Base station out-of-block EIRP limits

Case	Frequency range	Condition on base station in-block EIRP, P dBm/10 MHz	Maximum mean out-of-block EIRP	Measurement bandwidth
A	470 – 790 MHz	$P \geq 59$	0 dBm	8 MHz
		$36 \leq P < 59$	(P-59) dBm	8 MHz
		$P < 36$	-23 dBm	8 MHz

Out-of-block power refers to the power radiated by a transmitter outside its channel bandwidth. Since the out-of-block performance of “real” base station equipment is not known at the time of this study we have taken a somewhat worst-case approach by assuming that base station emissions just meet the maximum mean out-of-block EIRP

requirement over DTT channel 60, given in Table 5. Although base station equipment might reasonably be expected to perform better than the ECC requirement, the scenario presented in this report does reflect the potential results of equipment engineered to just meet the ECC out-of-block limits.

The recorded base station emissions were played back through an Agilent E4438C signal generator and amplified by an overdriven amplifier to create spectral re-growth, before being filtered in order to remove any broadband noise and adjust the out-of-block emissions. The transmit power was controlled using a variable attenuator to step the entire mask up or down, thus maintaining a constant relationship between in-block and out-of-block power throughout the testing. The setup is illustrated in Figure 3.

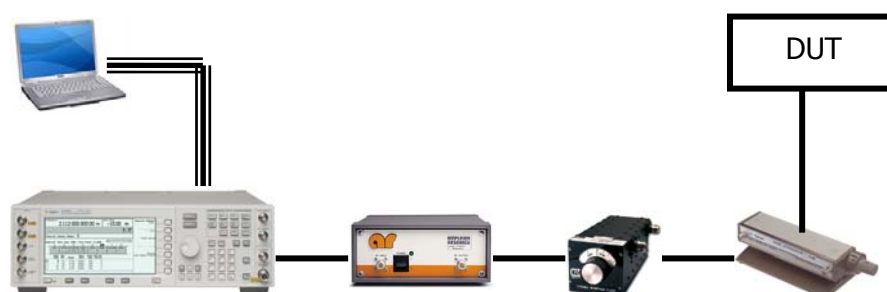


Figure 3: Generation of LTE base station interferer

The resulting spectral emissions, for the base station under fully loaded and idle conditions, are shown in Figure 4 and Figure 5 below. It can be seen from the figures that the out-of-block power in DTT channel 60, measured in an 8 MHz bandwidth, is -59 dBc (equivalent to 0 dBm assuming an in-block EIRP = 59 dBm).

Emission levels reduce with increasing frequency offset from the carrier, resulting in lower out-of-block emissions over channels 59 and below.

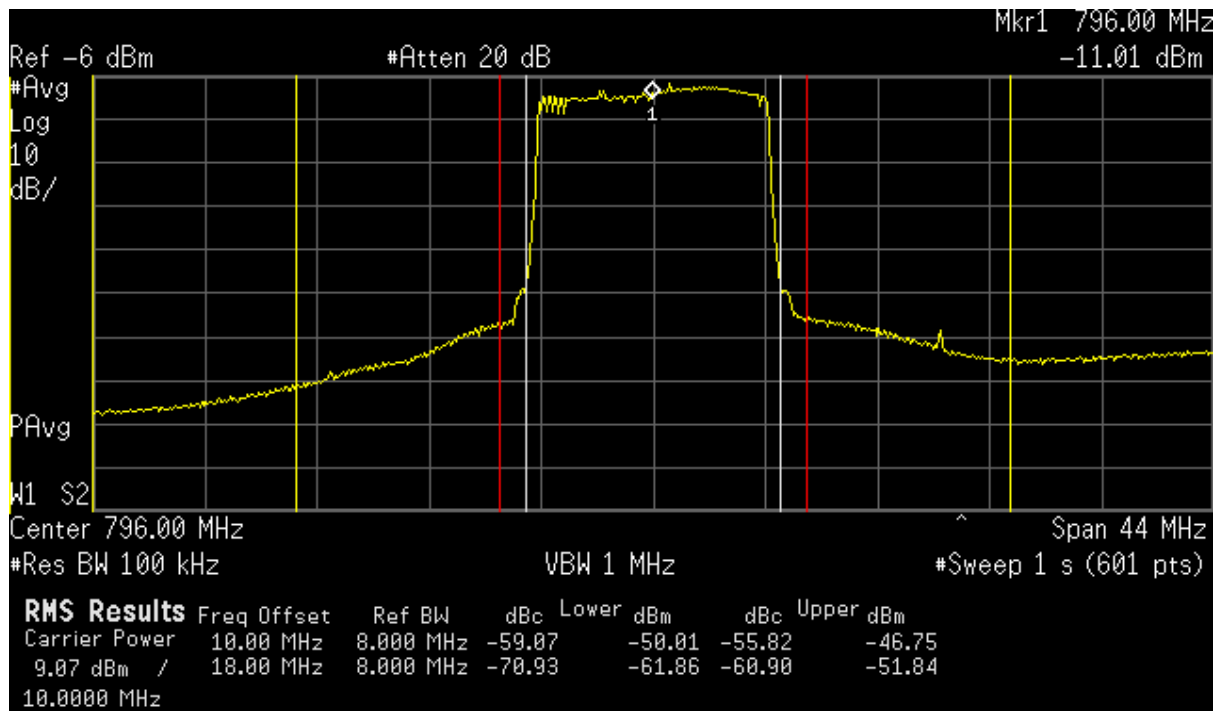


Figure 4: Spectral emissions for LTE base station under fully loaded traffic conditions

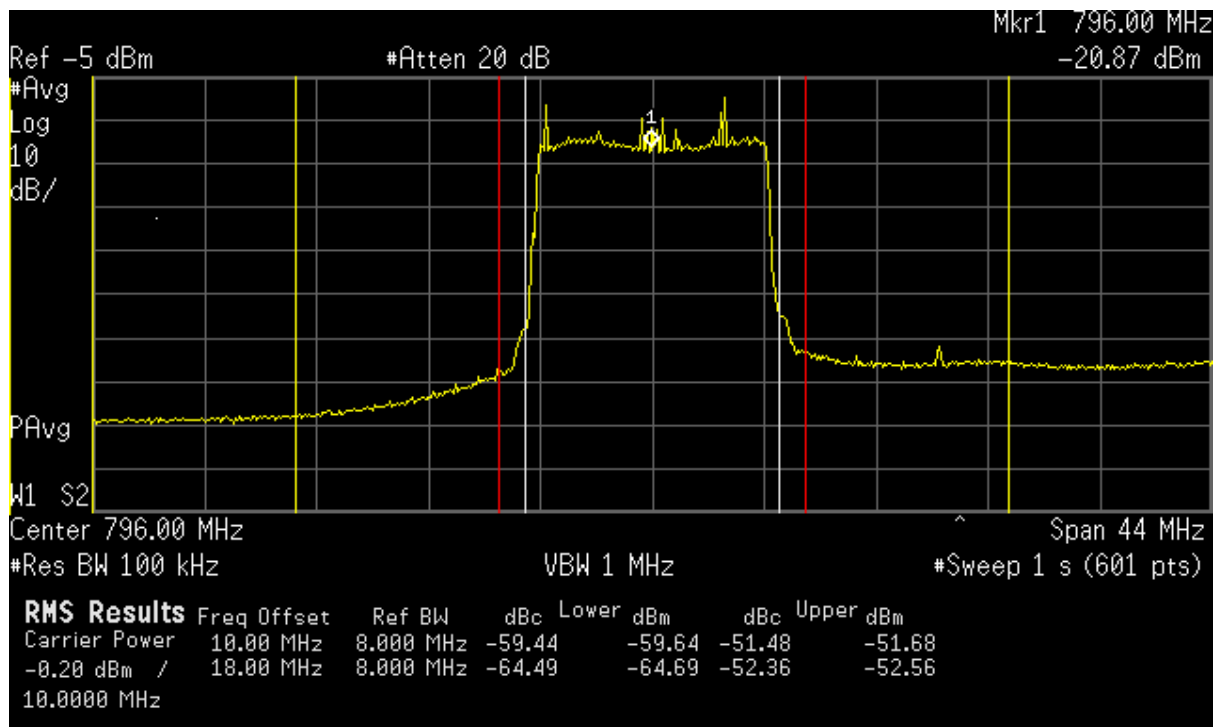


Figure 5: Spectral emissions for LTE base station under idle traffic conditions

The relative emissions for fully loaded and idle traffic conditions are compared in the figure below. It can be seen that the average power of the base station under idle conditions is lower than when the base station is fully loaded with traffic (by around 8.3 dB). Although the average power of the base station signal reduces with traffic, the peak power remains the same as for the fully loaded signal.

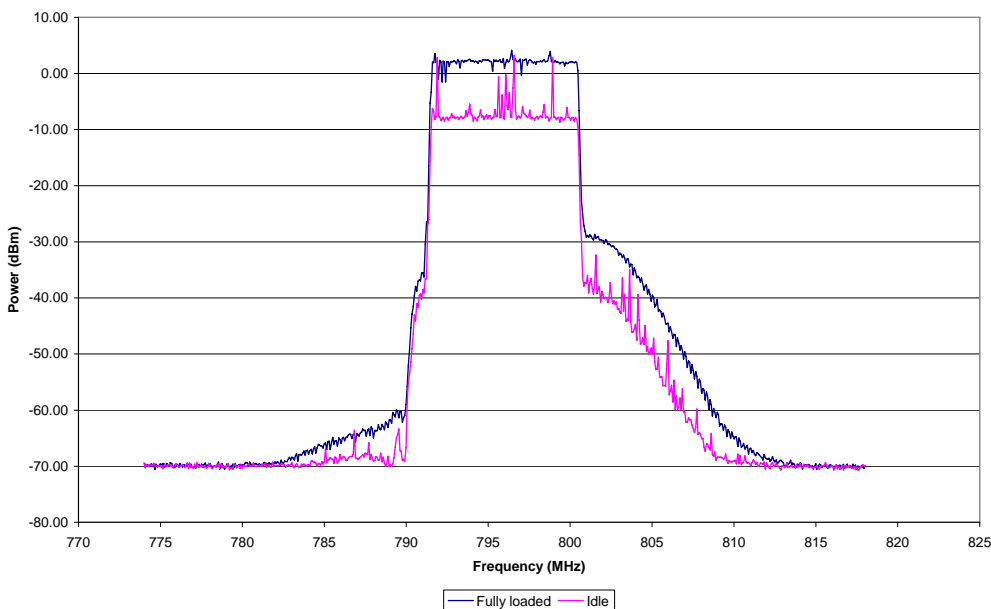


Figure 6: Comparison of fully loaded and idle base station emissions

The figure below shows the discontinuous (“bursty”) nature of the base station emissions in idle mode, captured using a fast sweep time on the spectrum analyzer.

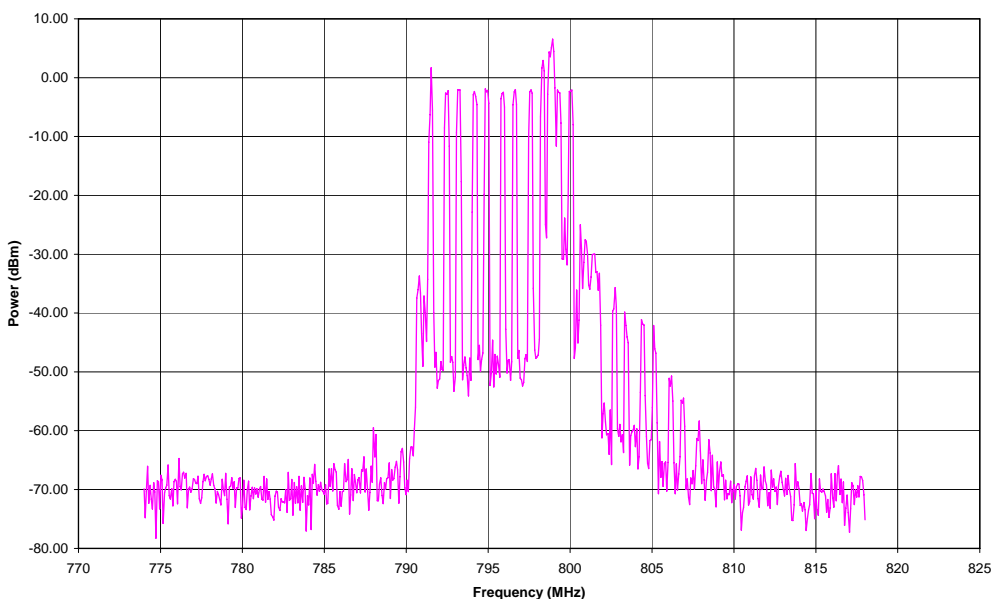


Figure 7: Bursty nature of base station emissions under idle conditions

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2.4 Failure Criterion

DVB-T/T2 systems use Coded Orthogonal Frequency Division Multiplexing (COFDM) which spreads the information over a large number of orthogonal carriers. Forward Error Correction (FEC) is then applied to improve the Bit Error Ratio (BER). In many digital systems the data to be transmitted undergoes two types of FEC coding; Reed Solomon and convolutional coding (Viterbi). At the receiver end, the pseudo-random sequence added at the transmitter by the convolutional encoder is decoded by the Viterbi decoder, followed by Reed Solomon decoding for parity checking.

The error protection employed by such digital systems usually results in an abrupt “cliff-edge” effect in the presence of interference when compared to analogue systems. The Digital TV Group⁴ publishes the D-Book, which includes degradation criteria to be used when assessing interference to digital systems. The different DVB-T receiver degradation criteria taken from the D-Book are compared in Table 6 below.

Table 6: D-Book comparison of degradation criteria

Criterion	Description	Comments
REF _{BER}	Post Viterbi BER=2x10 ⁻⁴	BER can be very erratic with some types of impairment (e.g. impulsive interference), so an accurate measure can be hard to achieve. A measure of BER is often not available (e.g. in a commercial receiver).
UCE	No un-correctable Transport Stream errors in a defined period.	Probably the most useful measure, but unfortunately this is often not available (e.g. in a commercial receiver).
UCE Rate	A measure of the number of UCE in a defined period.	Sometimes normalised to ‘Error Seconds’ (Used for ‘mobile’ applications).
PF	“Picture Failure”. No. of observed, (or detected) picture artefacts in a defined period.	This is what the consumer sees and cares about. There is always access to a ‘picture’ in a commercial receiver. However, when testing demodulators alone, MPEG decoding and picture display is not always available.
SFP	“Subjective failure point”	Essentially the same as PF

⁴ The Digital TV Group is the industry association for digital television in the UK. See <http://www.dtg.org.uk/>

The reference BER, defined as $BER = 2 \times 10^{-4}$ after Viterbi decoding, corresponds to the Quasi Error Free (QEF) criterion in the DVB-T standard, which states "less than one uncorrelated error event per hour".

However, as noted in the D-Book, there is often no direct way of identifying BER or transport stream errors for commercial receivers. In this case Picture Failure (PF) is the only means of assessing the interference effects.

The PF point was identified by visual observation as shown in Figure 8 below, which shows the onset of un-correctable errors (UCE) used to determine the failure point. The onset of a complete picture failure, i.e. no reception, could be observed with a 1 to 2 dB increase in the interfering signal from the PF point.

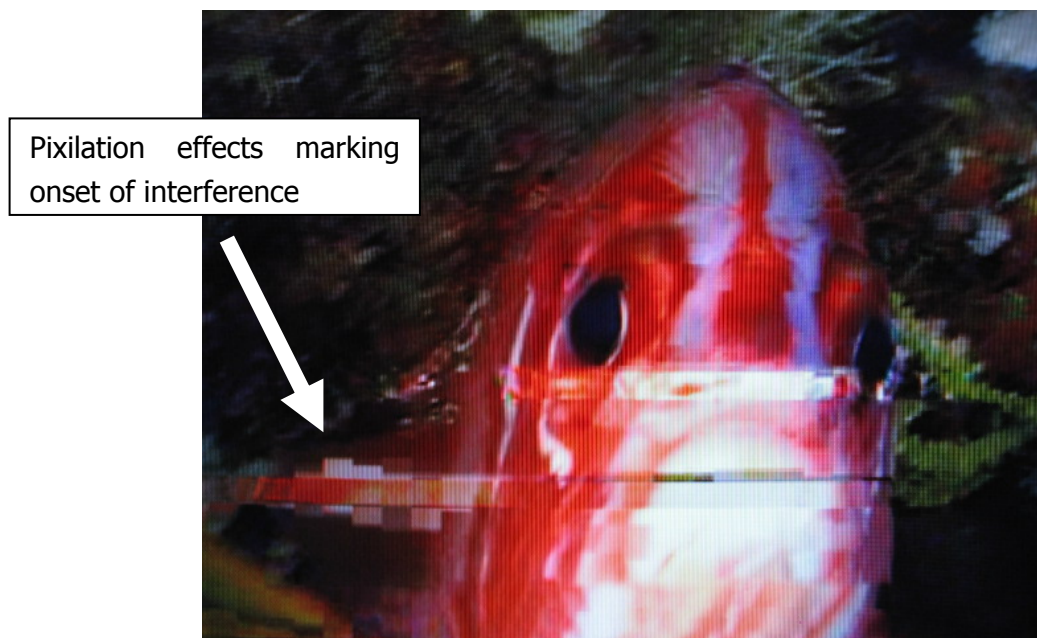


Figure 8: Received picture showing onset of interference

2.5 Measurement Set-Up

The test set-up used to perform the conducted interference measurements is shown in Figure 9 below.

The wanted DVB-T/T2 signal and unwanted LTE interferer were combined and connected to the receiver under test via an impedance matching network. A splitter was used to allow the wanted and unwanted signals to be measured on a spectrum analyzer. Cable and insertion losses have been taken into account in the results.

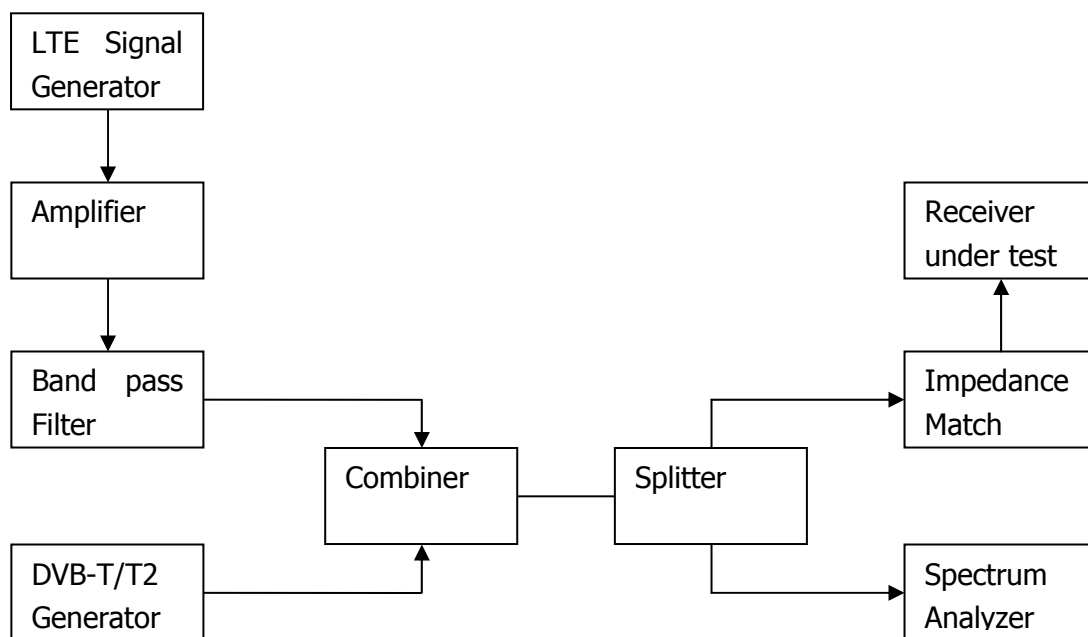


Figure 9: Equipment Test Set-Up

2.6 Test Method

The following measurement procedure was used to calculate the C/I protection ratios:

1. The receiver under test was initially tuned to 786 MHz (Ch60) and the wanted signal at the input to the antenna was set to the required power level;
2. The wanted signal channel power (C) was recorded in an 8 MHz channel bandwidth using a spectrum analyzer in channel power mode. The analyzer was set to RMS detection with a Resolution Bandwidth (RBW) of 100 kHz and a Video Bandwidth (VBW) of 1 MHz;
3. The LTE base station was set to a centre frequency of 796 MHz and the interfering signal level (I) was increased in 1 dB steps until the required failure criterion was met;
4. The interfering signal channel power (I) was recorded in a 10 MHz channel bandwidth using a spectrum analyzer in channel power mode. The analyzer was set to RMS detection with a RBW of 100 kHz and a VBW of 1 MHz;
5. The Carrier-to-Interference protection ratio was calculated from steps 2 and 4.

Steps 1 to 5 were repeated for wanted signal levels -70, -50, -30, -20 and -12 dBm and for channel offsets from co-channel (N), channel 60 to 48, and channel 38.

3. Results

In the following sections results are presented as the Carrier-to-Interference protection ratio required to protect the DTT receiver under test from LTE base station interference for the following operating scenarios:

- DVB-T and DVB-T2 signal reception;
- Wanted carrier signal levels of -70, -50 and -30 dBm;
- DTT channel offsets from co-channel⁵ to channel 38;
- LTE base station signals representing fully loaded and idle traffic conditions.

Receiver C/I performance is a measure of selectivity, defining the permitted level of interference for a given wanted signal level and frequency offset; the higher the C/I value the more sensitive the receiver is to interference.

In the following sections:

- Figure 10 to Figure 15 show the C/I protection ratio results for 5 receivers receiving DVB-T signals, for different wanted signal levels and channel offsets;
- Figure 16 to Figure 21 show the C/I protection ratio results for 9 receivers receiving DVB-T2 signals, for different wanted signal levels and channel offsets;
- Figure 22 and Figure 23 provide a comparison between DVB-T and DVB-T2 modes of operation for channel 60, for receivers 1, 4, 6 and 8;
- Figure 24 and Figure 25 provide a comparison between fully loaded and idle base station interference for channel 60, for receivers 1, 4, 6 and 8.

Appendix A provides additional results for channel 60 (the first adjacent channel to the LTE base station frequency allocation) plotted as wanted signal level (C) against interfering signal level (I).

⁵ Co-channel C/I protection ratios are included for information only; co-channel operation of DTT receivers and LTE base stations will not be possible in practice.

3.1 Carrier-to-Interference Protection Ratios

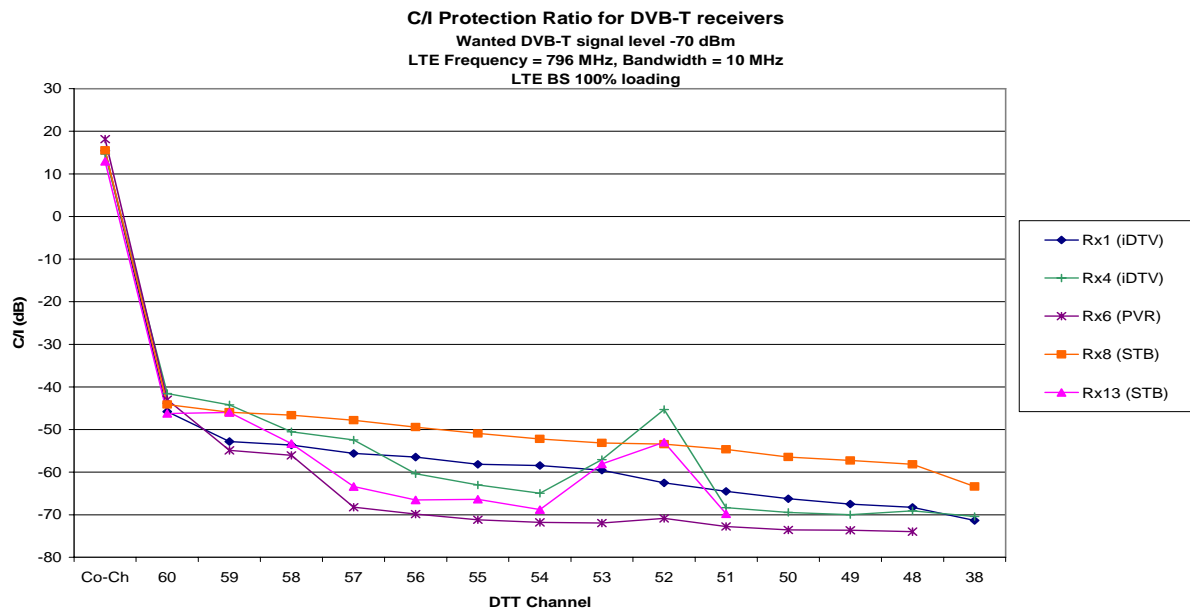


Figure 10: C/I protection ratios for DVB-T; fully loaded BS; C = -70 dBm

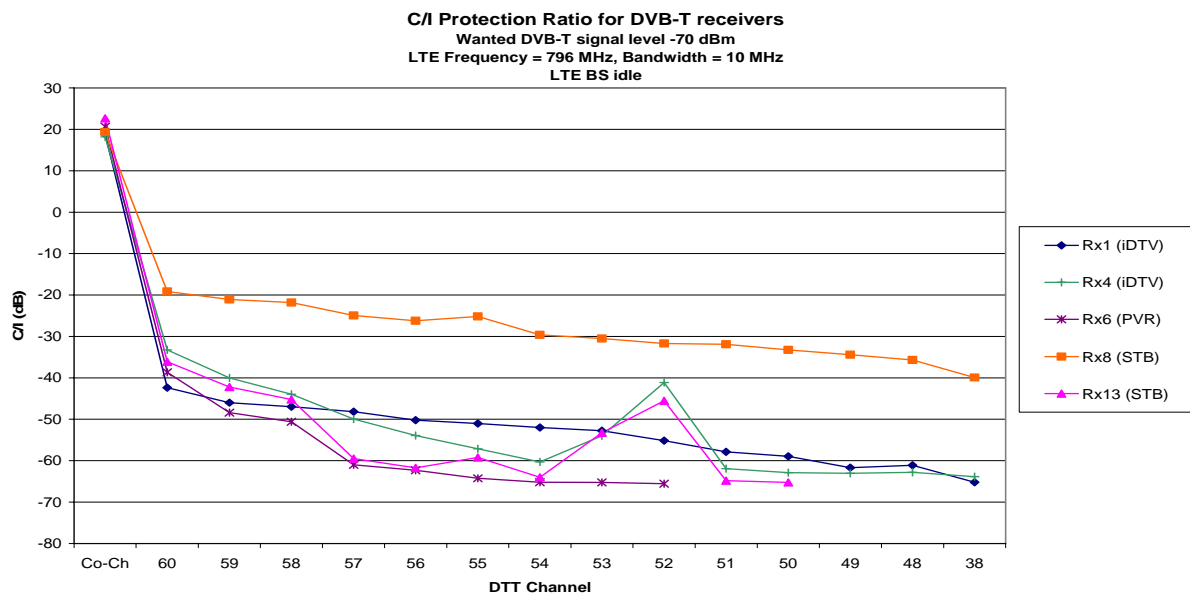


Figure 11: C/I protection ratios for DVB-T; idle BS; C = -70 dBm

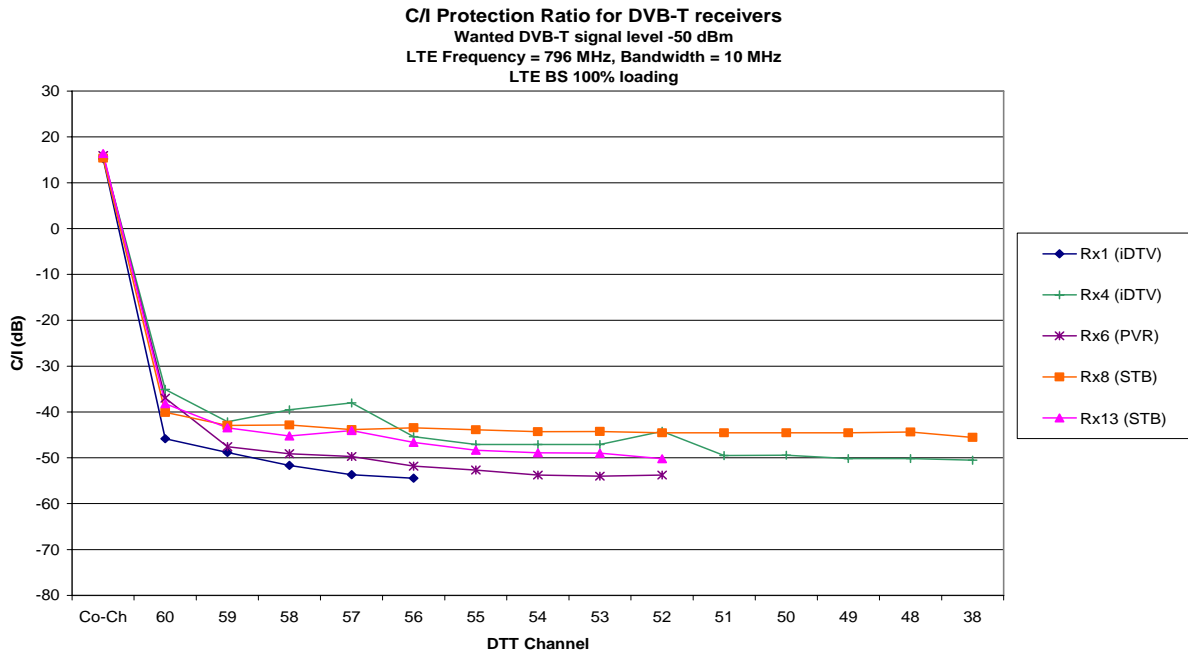


Figure 12: C/I protection ratios for DVB-T; fully loaded BS; C = -50 dBm

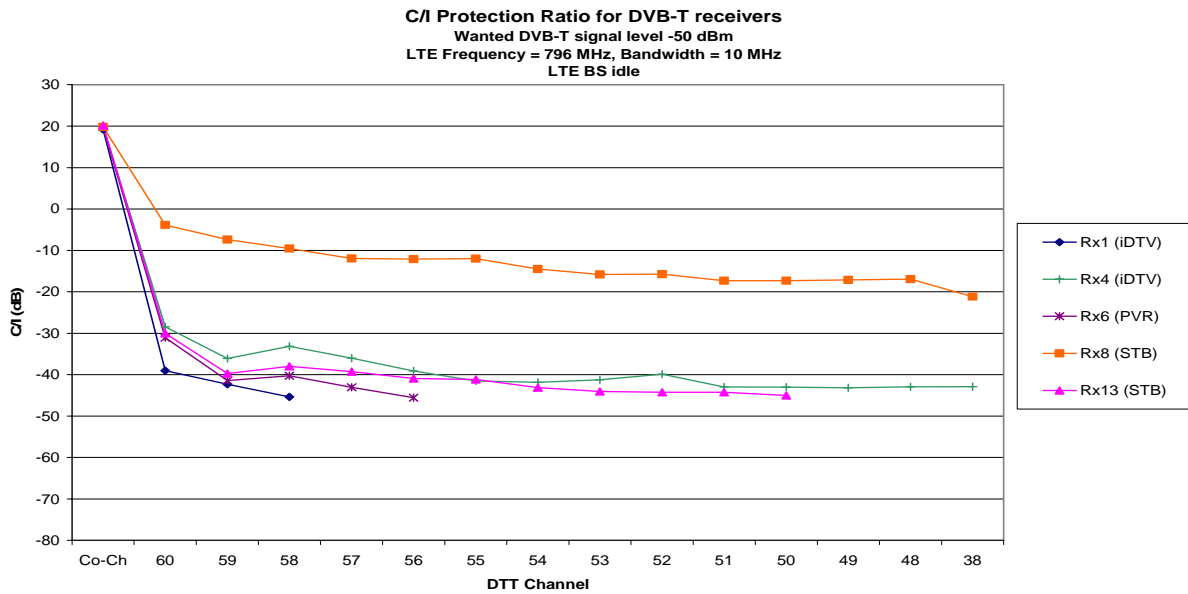


Figure 13: C/I protection ratios for DVB-T; idle BS; C = -50 dBm

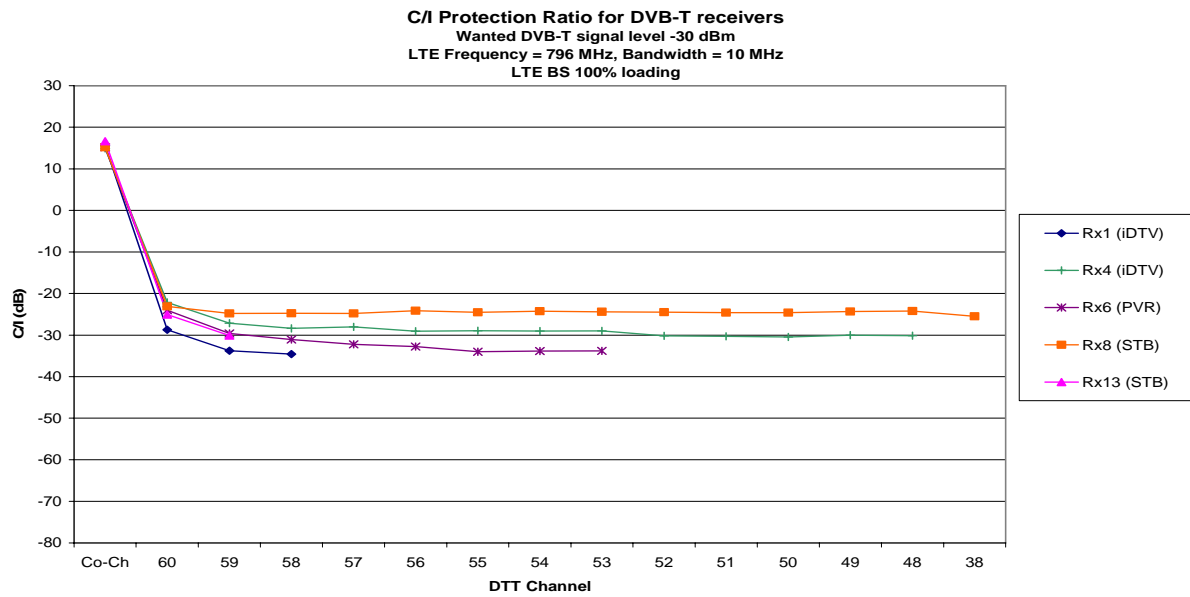


Figure 14: C/I protection ratios for DVB-T; fully loaded BS; C = -30 dBm

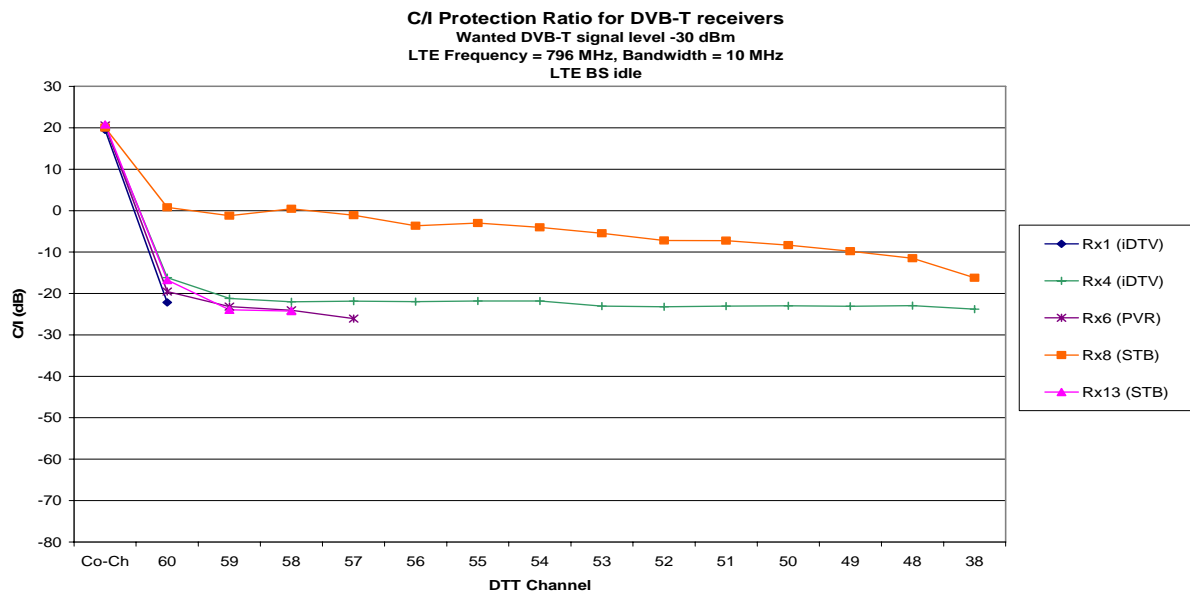


Figure 15: C/I protection ratios for DVB-T; idle BS; C = -30 dBm

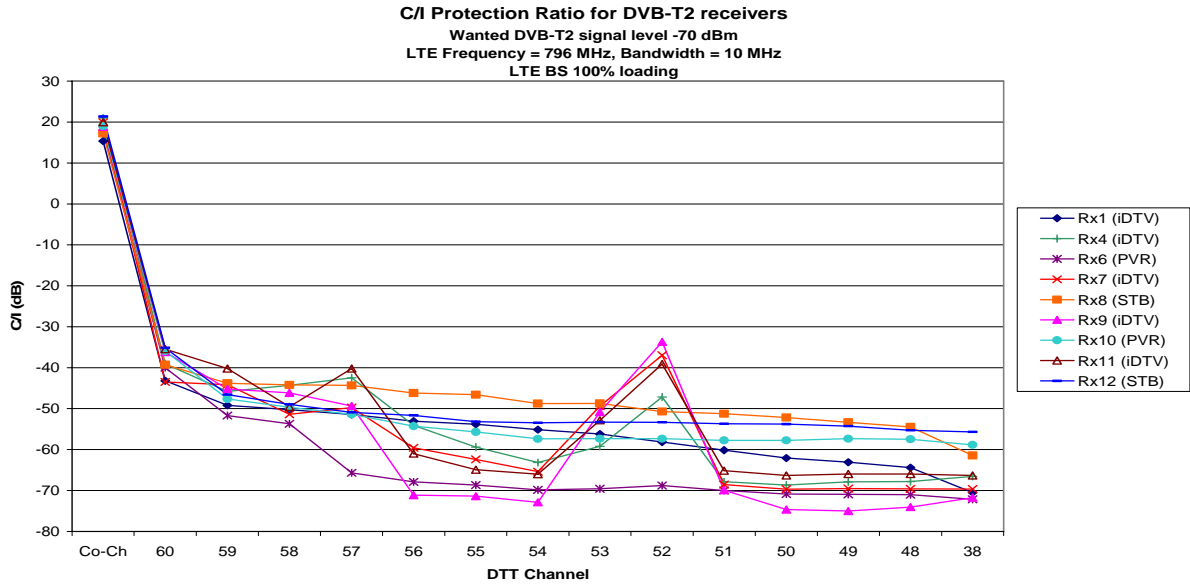


Figure 16: C/I protection ratios for DVB-T2; fully loaded BS; C = -70 dBm

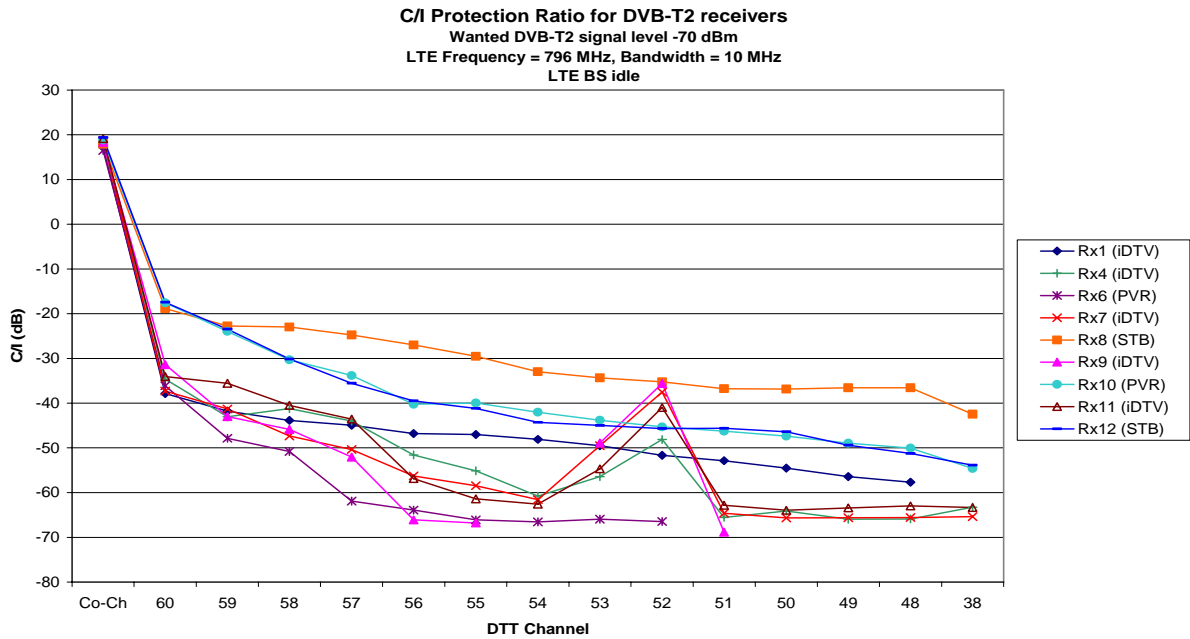


Figure 17: C/I protection ratios for DVB-T2; idle BS; C = -70 dBm

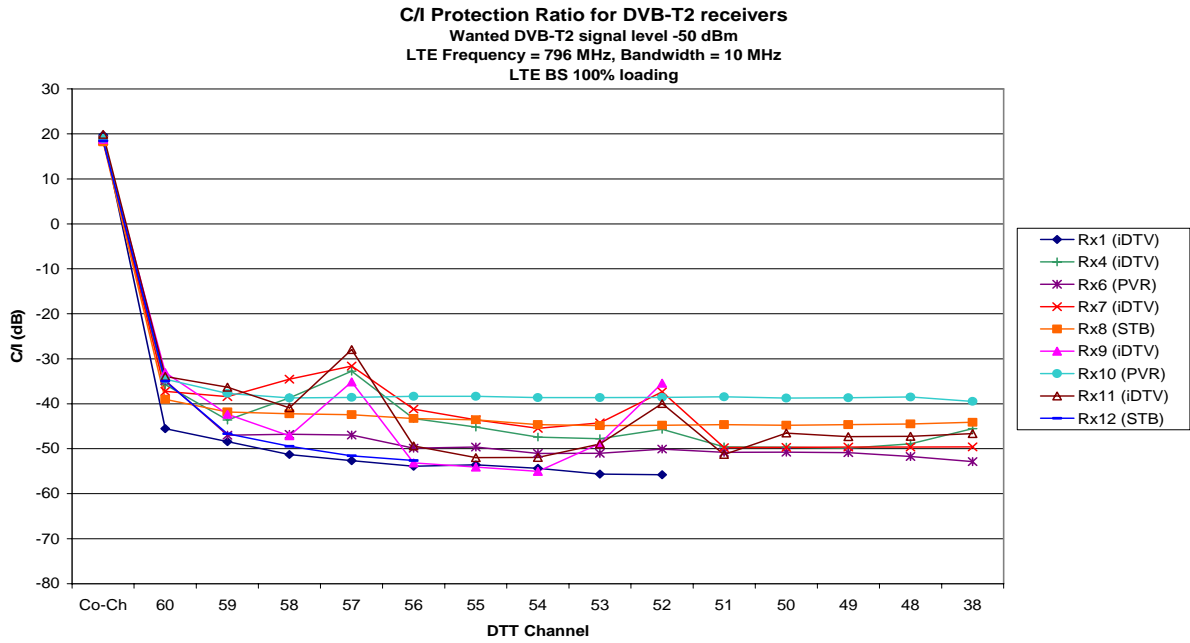


Figure 18: C/I protection ratios for DVB-T2; fully loaded BS; C = -50 dBm

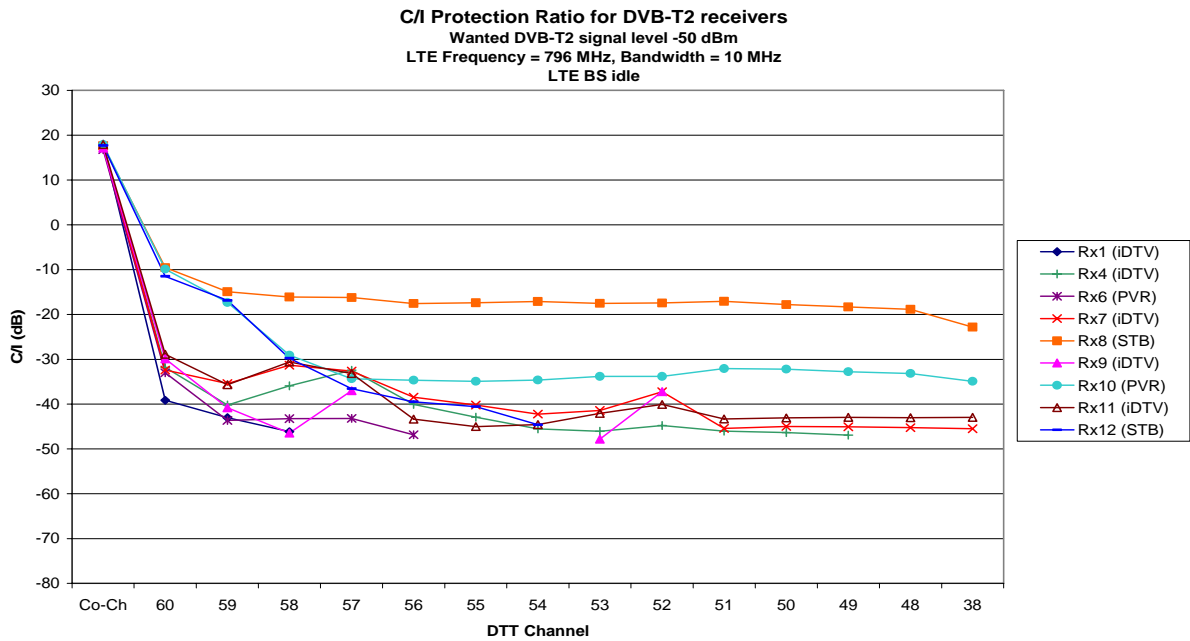


Figure 19: C/I protection ratios for DVB-T2; idle BS; C = -50 dBm

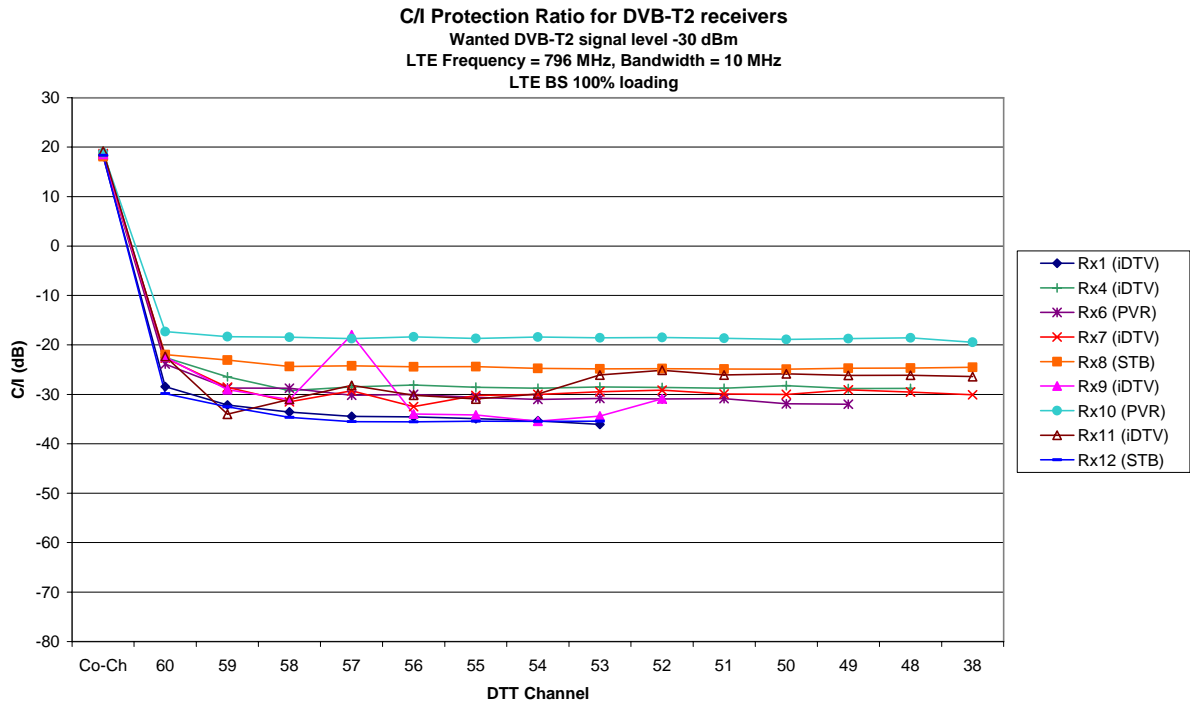


Figure 20: C/I protection ratios for DVB-T2; fully loaded BS; C = -30 dBm

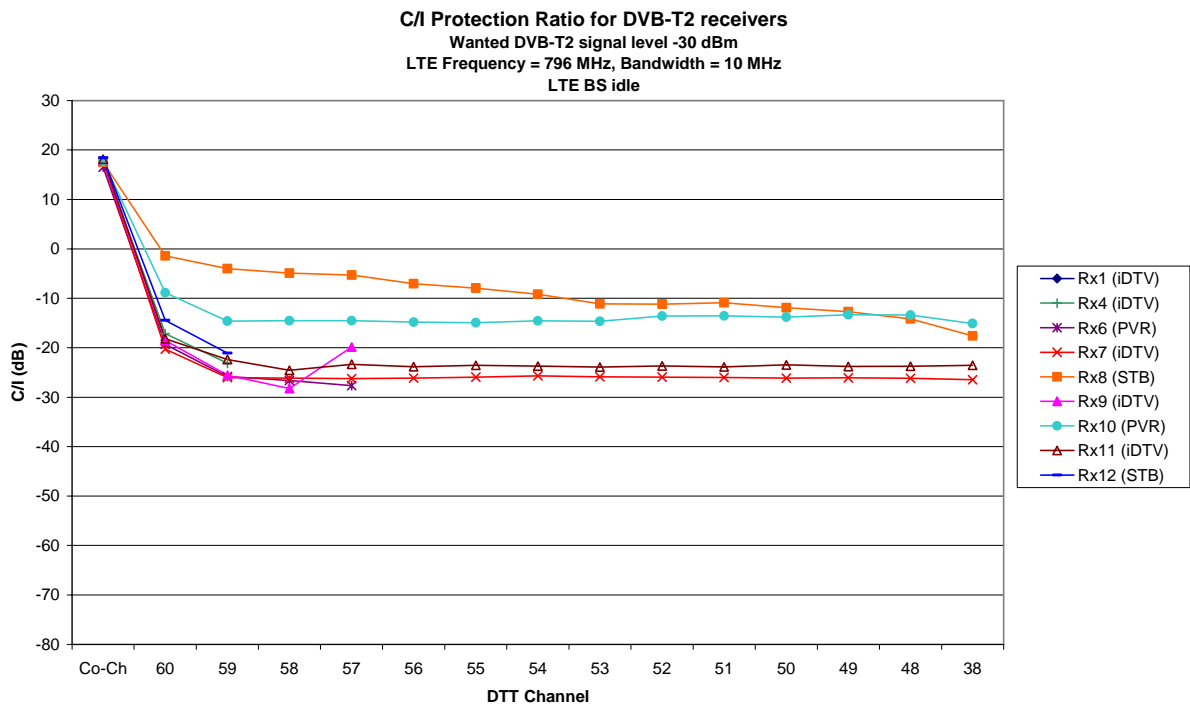


Figure 21: C/I protection ratios for DVB-T2; idle BS; C = -30 dBm

3.2 Comparison between DVB-T and DVB-T2 Reception

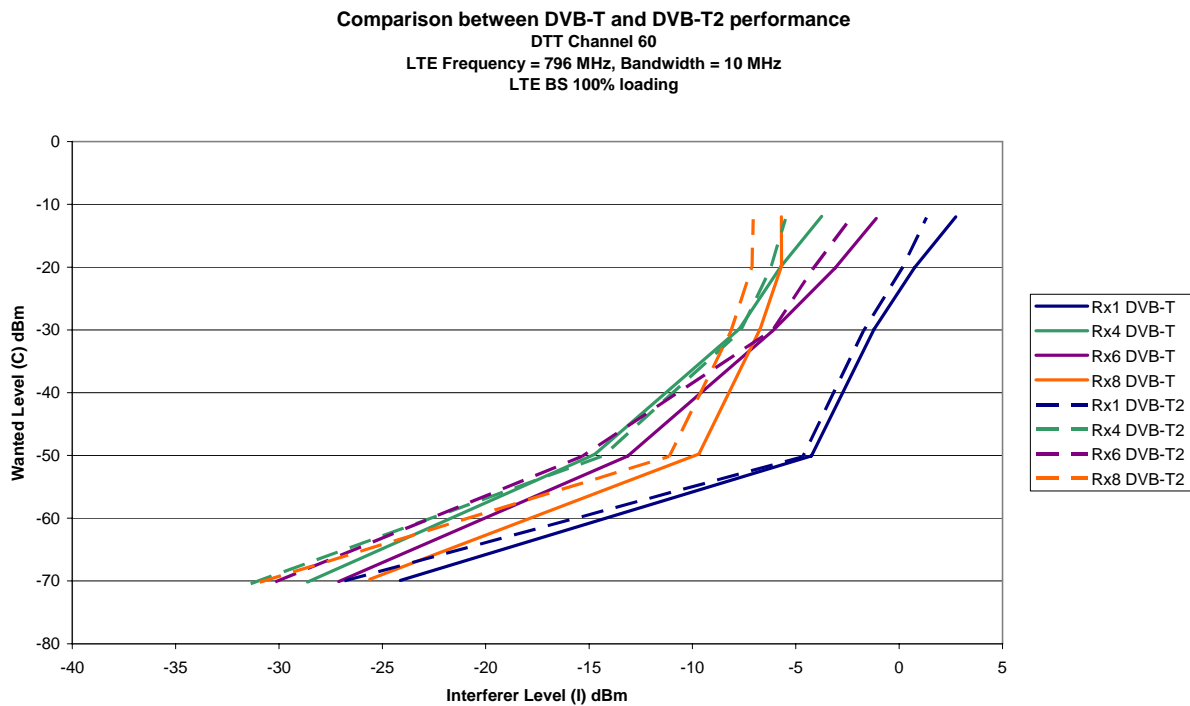


Figure 22: Comparison between DVB-T and DVB-T2; fully loaded BS

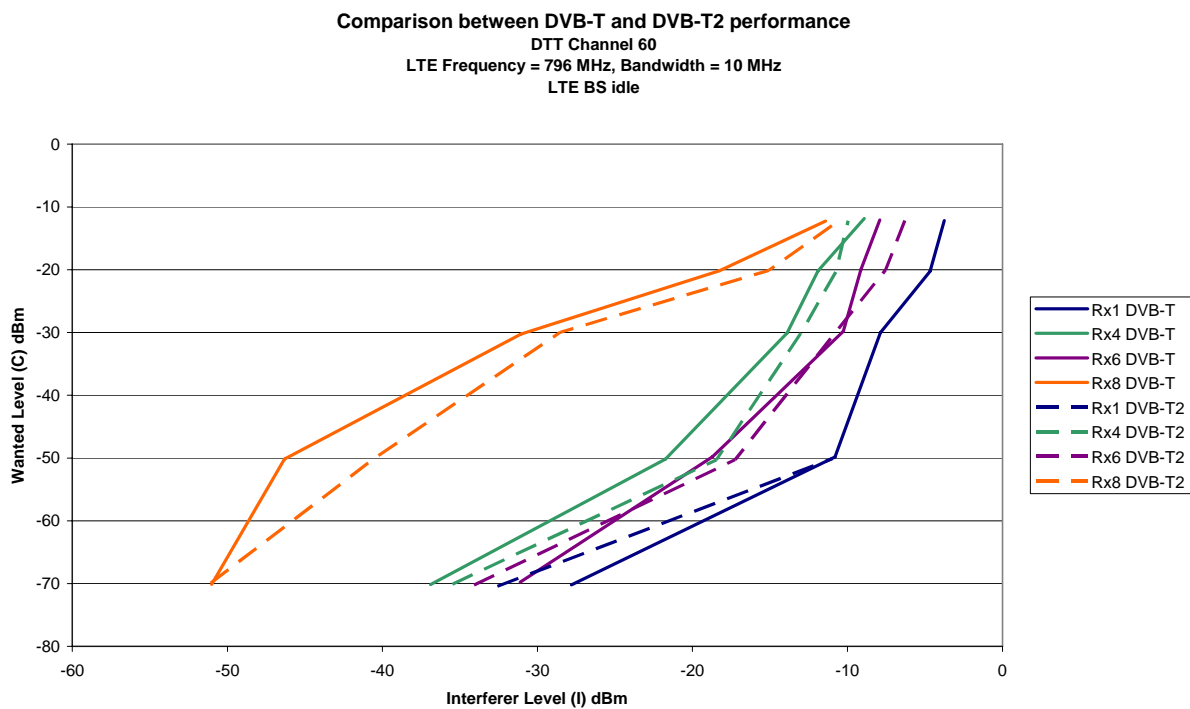


Figure 23: Comparison between DVB-T and DVB-T2; idle BS

3.3 Comparison between fully loaded and idle BS operation

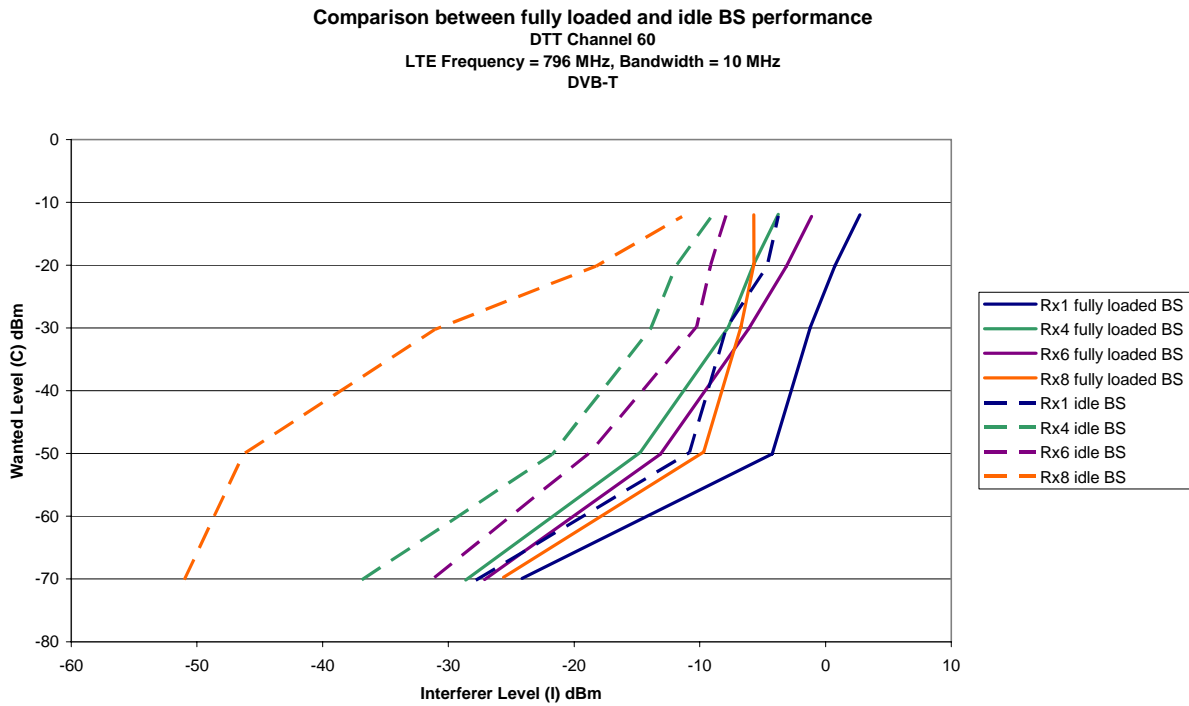


Figure 24: Comparison between fully loaded and idle BS; DVB-T transmission

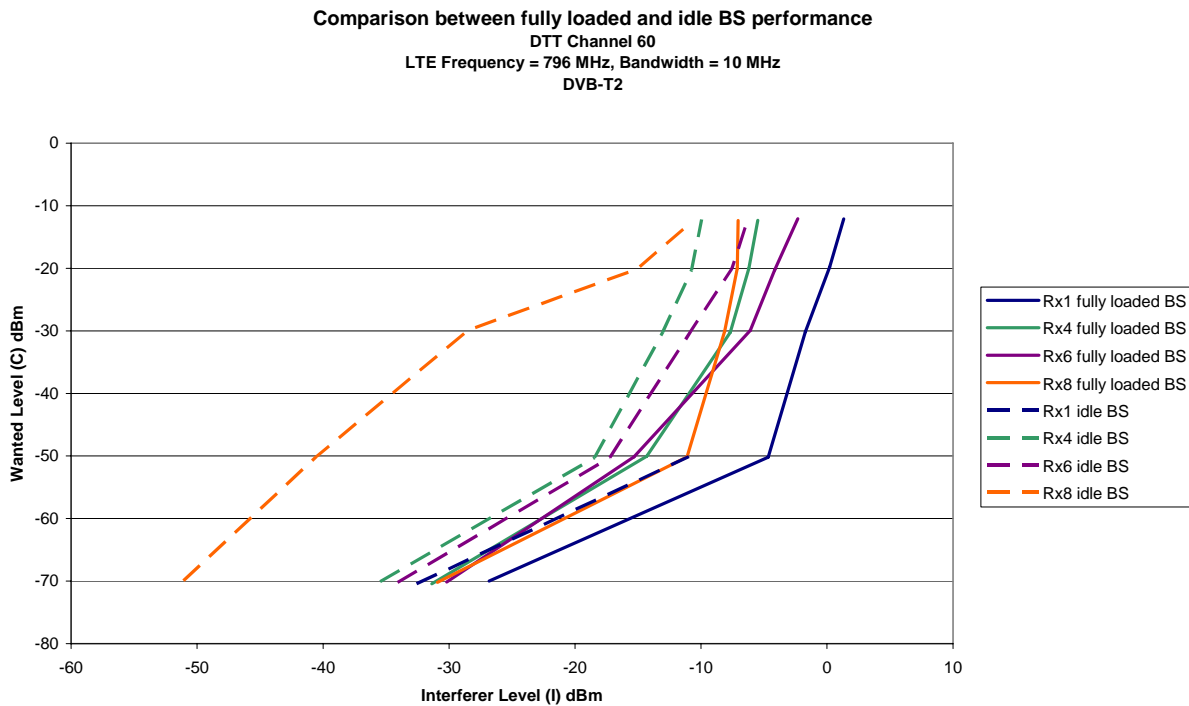


Figure 25: Comparison between fully loaded and idle BS; DVB-T2 transmission

3.4 Analysis of Results

3.4.1 Carrier-to-Interference Protection Ratios

For the DVB-T receivers operating in channel 60 (first adjacent channel to the LTE BS):

- For a base station with maximum traffic loading (i.e. 100% load), protection ratios vary between -46 and -41 dB for low wanted signal levels ($C = -70$ dBm). As the wanted signal level increases, the required protection ratios also increase, to between -28 and -22 dB for a wanted level of $C = -30$ dBm.
- For a base station operating under idle conditions (i.e. no traffic load) the receivers are more susceptible to interference, requiring higher protection ratios of between -42 and -19 dB for $C = -70$ dBm, increasing to between -22 and 0 dB for $C = -30$ dBm.

For the DVB-T2 receivers operating in channel 60:

- For a base station with maximum traffic loading protection ratios vary between -43 and -35 dB for $C = -70$ dBm to between -29 and -17 dB for $C = -30$ dBm.
- For a base station operating under idle conditions the receivers are again more susceptible to interference, requiring protection ratios of between -37 and -17 dB for $C = -70$ dBm, increasing to between -20 and -1 dB for $C = -30$ dBm.

The results show that as the wanted signal level increases the receivers become more susceptible to interference from LTE base station emissions. Previous work by ERA [12] has shown that the front end of a digital receiver starts to become desensitised for wanted signal levels greater than about -50 dBm. This desensitisation results in the interferer requiring less power to degrade the received picture quality, and the increase in C/I protection ratio is driven mainly by the increase in wanted signal level.

Receiver 8 (STB with silicon tuner) was found to be most susceptible to interference overall, particularly from the base station operating in idle mode. Protection ratios as high as 0 dB are required to protect the receiver when operating in DVB-T mode at $C = -30$ dBm, and -19 dB for $C = -70$ dBm. Receivers 1 (iDTV with silicon tuner) and 6 (PVR with silicon tuner) were generally the least susceptible to interference.

Receivers 4, 7, 9, 11 and 13 are based on superhet tuners and are susceptible to image channel interference when the interferer appears nine channels above the wanted (tuned) channel (72 MHz offset). Receivers 4 and 13 (DVB-T) require C/I protection ratios of -41 and -45 dB for low wanted signal levels ($C = -70$ dBm); Receivers 7, 9 and 11 (DVB-T2) require slightly higher protection ratios, between -33 and -39 dB. Silicon tuners, although exhibiting relatively poor overload performance, are much less sensitive to interference at the N+9

image frequency. Some of these receivers also exhibit a response at N+4; this is more noticeable for a wanted signal level of C = -50 dBm, with the base station fully loaded (Figure 18). The C/I protection ratios are summarised in the tables below for co-channel (N), channel N+1, N+2 and N+9.

Table 7: Summary of C/I protection ratios (in dB) for C = -70 dBm

Wanted transmission:		DVB-T		DVB-T2	
BS operating mode:		Idle	100%	Idle	100%
Rx1	Co-channel	18.89	15.46	17.22	15.38
	N+1	-42.37	-45.79	-37.85	-43.18
	N+2	-46	-52.81	-41.8	-49.17
	N+9	-	-62.51	-51.67	-58.17
Rx4	Co-channel	18.18	14.63	17.99	20.98
	N+1	-33.27	-41.54	-34.63	-39.06
	N+2	-40.01	-44.21	-43.02	-45.78
	N+9	-39.87	-45.31	-48.13	-47.15
Rx6	Co-channel	20.64	18.17	16.49	18.28
	N+1	-38.68	-42.98	-36.13	-39.99
	N+2	-48.42	-54.87	-47.86	-51.69
	N+9	-	-70.85	-66.44	-68.78
Rx7	Co-channel			18.64	19.94
	N+1			-37.31	-43.47
	N+2			-41.31	-44.18
	N+9			-37.53	-36.96
Rx8	Co-channel	19.35	15.53	17.85	17.21
	N+1	-19.13	-44.4	-18.85	-39.28
	N+2	-21.08	-45.94	-22.73	-43.82
	N+9	-15.72	-53.44	-35.22	-50.72
Rx9	Co-channel			18.31	18.79
	N+1			-31.38	-36.19
	N+2			-43	-45.21
	N+9			-35.58	-33.71
Rx10	Co-channel			18.82	19.00
	N+1			-17.56	-35.97
	N+2			-23.95	-47.66
	N+9			-45.29	-57.35
Rx11	Co-channel			19.11	19.95
	N+1			-34.06	-35.47
	N+2			-35.54	-40.22
	N+9			-40.96	-39.11
Rx12	Co-channel			19.35	21.36
	N+1			-17.45	-35.40
	N+2			-23.47	-46.59
	N+9			-45.68	-53.34

Wanted transmission:		DVB-T		DVB-T2	
BS operating mode:		Idle	100%	Idle	100%
Rx13	Co-channel	22.67	12.93		
	N+1	-36.12	-46.25		
	N+2	-42.21	-46		
	N+9	-44.23	-52.98		

Table 8: Summary of C/I protection ratios (in dB) for C = -50 dBm

Wanted transmission:		DVB-T		DVB-T2	
BS operating mode:		Idle	100%	Idle	100%
Rx1	Co-channel	19.21	15.28	17.98	19.74
	N+1	-39.02	-45.82	-39.15	-45.54
	N+2	-42.32	-48.81	-43.03	-48.42
	N+9	-	-	-	-55.78
Rx4	Co-channel	19.78	15.76	17.73	18.55
	N+1	-28.43	-35.09	-31.84	-35.75
	N+2	-36.09	-42.16	-40.21	-43.61
	N+9	-39.87	-44.19	-44.79	-45.67
Rx6	Co-channel	19.75	15.93	16.79	18.56
	N+1	-31.08	-36.96	-33.02	-34.83
	N+2	-41.4	-47.55	-43.65	-47.00
	N+9	-	-53.77	-	-50.07
Rx7	Co-channel			17.64	18.56
	N+1			-32.41	-37.25
	N+2			-35.42	-38.42
	N+9			-37.27	-37.33
Rx8	Co-channel	19.79	15.37	17.61	18.23
	N+1	-3.84	-40.09	-9.54	-39.04
	N+2	-7.37	-42.92	-14.95	-41.83
	N+9	-15.72	-44.52	-17.44	-44.78
Rx9	Co-channel			17.12	18.79
	N+1			-29.90	-33.10
	N+2			-40.83	-42.34
	N+9			-37.2	-35.43
Rx10	Co-channel			17.89	19.02
	N+1			-9.89	-34.55
	N+2			-17.31	-37.70
	N+9			-33.82	-38.6
Rx11	Co-channel			17.89	19.88
	N+1			-28.89	-33.92
	N+2			-35.66	-36.34
	N+9			-40.07	-39.97
Rx12	Co-channel			17.72	18.43

Wanted transmission:		DVB-T		DVB-T2	
BS operating mode:		Idle	100%	Idle	100%
	N+1			-11.51	-34.97
	N+2			-16.89	-46.66
	N+9			-	-
Rx13	Co-channel	20.17	16.39		
	N+1	-30.00	-38.19		
	N+2	-39.71	-43.43		
	N+9	-44.23	-50.21		

Table 9: Summary of C/I protection ratios (in dB) for C = -30 dBm

Wanted transmission:		DVB-T		DVB-T2	
BS operating mode:		Idle	100%	Idle	100%
Rx1	Co-channel	19.50	15.56	17.53	18.15
	N+1	-22.16	-28.71	-	-28.45
	N+2	-	-33.76	-	-32.16
	N+9	-	-	-	-
Rx4	Co-channel	20.19	14.92	17.88	19.25
	N+1	-16.17	-22.13	-17.16	-22.55
	N+2	-21.18	-27.15	-23.12	-26.45
	N+9	-23.23	-30.17	-	-28.58
Rx6	Co-channel	20.56	15.14	16.53	18.38
	N+1	-19.55	-24.03	-19.28	-23.86
	N+2	-23.20	-29.63	-25.81	-28.71
	N+9	-	-	-	-30.93
Rx7	Co-channel			17.62	18.67
	N+1			-20.26	-22.67
	N+2			-26.04	-28.57
	N+9			-25.92	-29.15
Rx8	Co-channel	20.05	15.14	17.54	18.07
	N+1	0.80	-23.08	-1.44	-21.95
	N+2	-1.23	-24.78	-4.03	-23.05
	N+9	-7.19	-24.46	-11.17	-24.79
Rx9	Co-channel			17.84	18.57
	N+1			-18.51	-22.46
	N+2			-25.55	-29.05
	N+9			-	-30.89
Rx10	Co-channel			17.76	18.88
	N+1			-8.87	-17.31
	N+2			-14.60	-18.31
	N+9			-13.59	-18.49
Rx11	Co-channel			18.14	19.16
	N+1			-18.18	-22.34

Wanted transmission:		DVB-T		DVB-T2	
BS operating mode:		Idle	100%	Idle	100%
	N+2			-22.37	-34.00
	N+9			-23.65	-25.13
Rx12	Co-channel			18.42	18.35
	N+1			-14.44	-29.87
	N+2			-21.07	-32.54
	N+9			-	-
Rx13	Co-channel	20.80	16.61		
	N+1	-16.77	-25.09		
	N+2	-23.94	-30.10		
	N+9	-	-		

3.4.2 DTT Transmission Mode

Receivers 1, 4, 6 and 8 are capable of operating in either DVB-T or DVB-T2 reception modes. Figure 22 and Figure 23 show the difference in results for DVB-T and DVB-T2 wanted signals under fully loaded and idle base station operating conditions for channel 60.

The results show that the susceptibility of DVB-T and DVB-T2 signals to LTE base station interference is very similar; DVB-T2 signals appear to be slightly more susceptible to interference when the base station is fully loaded with traffic and DVB-T signals are slightly more susceptible when the base station is in idle mode.

Receiver 1 was more susceptible to interference when receiving DVB-T2 signals regardless of base station operating mode.

3.4.3 Base Station Operating Mode

Figure 24 and Figure 25 show the difference in receiver performance when subjected to interference from fully loaded and idle base station emissions.

The results show that receivers are more susceptible to emissions when the base station is operating under idle conditions, most likely due to the time domain variation of the signal envelope affecting the receivers' AGC behaviour. This is particularly evident for Receivers 8, 10 and 12 which are all based on silicon tuner architectures.

Receiver 8 requires an additional 25 dB of protection from idle base station emissions in channel 60, compared to fully loaded base station emissions.

4. Conclusions

A measurements programme has been undertaken to derive Carrier-to-Interference protection ratios for a selection of DVB-T and DVB-T2 capable receivers when subjected to interference from LTE 800 MHz Base Stations. Both traditional “superhet” (can) and more recent “silicon” tuners have been considered from a range of manufacturers. Receivers included integrated digital televisions, personal video recorders and set-top boxes.

The base station signals used in the testing were recorded directly from a vendor’s 800 MHz test network; the base station was configured for maximum traffic loading (i.e. 100% loading) and idle conditions (i.e. no traffic on the base station resulting in time-discontinuous, or “bursty” emissions). The recorded base station signals were replayed through a signal generator and the out-of-block emissions were adjusted to comply with the minimum requirements for Case A operation specified in ECC Dec 2010/267/EU. Although base station equipment might reasonably be expected to perform better than the ECC requirement in practice, we have taken a cautious approach in this study by considering the scenario of equipment engineered to just meet the ECC out-of-block limits across DTT channel 60.

The results show that:

- The traffic loading on the base station has a significant influence on the protection ratio results. Receivers are more susceptible to time-discontinuous emissions, when the base station is operating under idle or low traffic conditions. This is most likely due to the impact of the base station on the receivers’ Automatic Gain Control behaviour;
- From the limited number of receivers tested, silicon tuners appear to be more susceptible to interference when the base station is operating under idle conditions;
- Results for DVB-T and DVB-T2 reception modes are similar; DVB-T receivers appear to be slightly more susceptible to idle base station conditions while DVB-T2 receivers appear to be more susceptible to fully loaded base station conditions;
- Receivers become more susceptible to interference as the wanted signal level increases. This is most likely due to the receiver front-end becoming desensitised (overloaded) at higher signal levels, resulting in the interferer requiring less power to degrade the received picture quality. When the receiver is overloaded, the higher C/I protection ratios are driven mainly by the increase in wanted signal level. This may have implications in areas of high TV signal strength, or where an amplifier is installed between antenna and receiver to boost the received signal level;

- A co-channel protection ratio of 21 dB would be required to protect all but the worst performing receiver irrespective of DTT transmission mode, wanted signal level at the input to the receiver and base station operating conditions;
- Protection ratios for adjacent channel interference, with the DTT receiver tuned to channel 60 and the LTE interferer centred at 796 MHz, are in the range -17 to -37 dB for low wanted signal levels at the input to the receiver (C = -70 dBm), increasing to between -1 and -20 for high wanted signal levels (C = -30 dBm);
- Superhet tuners are susceptible to image channel interference when the interferer appears nine channels above the wanted (tuned) channel (72 MHz offset). Receivers 4 and 13 (DVB-T) require C/I protection ratios of -41 and -45 dB for low wanted signal levels (C = -70 dBm); Receivers 7, 9 and 11 (DVB-T2) require slightly higher protection ratios, between -33 and -39 dB. Silicon tuners, although exhibiting relatively poor overload performance, are much less sensitive to interference at the N+9 image frequency.

5. References

- [1] Coexistence of new services in the 800 MHz band with digital terrestrial television, Ofcom consultation, 2nd June 2011.
(<http://stakeholders.ofcom.org.uk/consultations/coexistence-with-dtt/>)
- [2] Consultation on assessment of future mobile competition and proposals for the award of 800 MHz and 2.6 GHz spectrum and related issues, Ofcom consultation, 22nd March 2011 (<http://stakeholders.ofcom.org.uk/consultations/combined-award/>)
- [3] European Commission Decision of 6 May 2010 on harmonised technical conditions of use in the 790 – 862 MHz frequency band for terrestrial systems capable of providing electronic communications services in the European Union (2010/267/EU) <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010D0267:EN:NOT>
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- [8] ETSI EN 300 744: Digital Video Broadcasting; Framing structure, channel coding and modulation for digital terrestrial television, v1.5.1 November 2004.
 - [9] ETSI EN 302 755: Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2), v1.2.1 (2010-10).
 - [10] ETSI EN 302 296: Transmitting equipment for the digital television broadcast service, terrestrial (DVB-T), v1.1.1 January 2005.
 - [11] ETSI TS 136 104 V8.5.0 (2009-04): LTE; Evolved Universal Terrestrial Radio Access (EUTRA); Base Station radio transmission and reception (FDD) (3GPP TS 36.104 version 8.5.0 Release 8).
 - [12] Characterising DVB-T interference into iDTV and PVR equipment, ERA Technology, September 2008.

Appendix A

Carrier against Interference Results

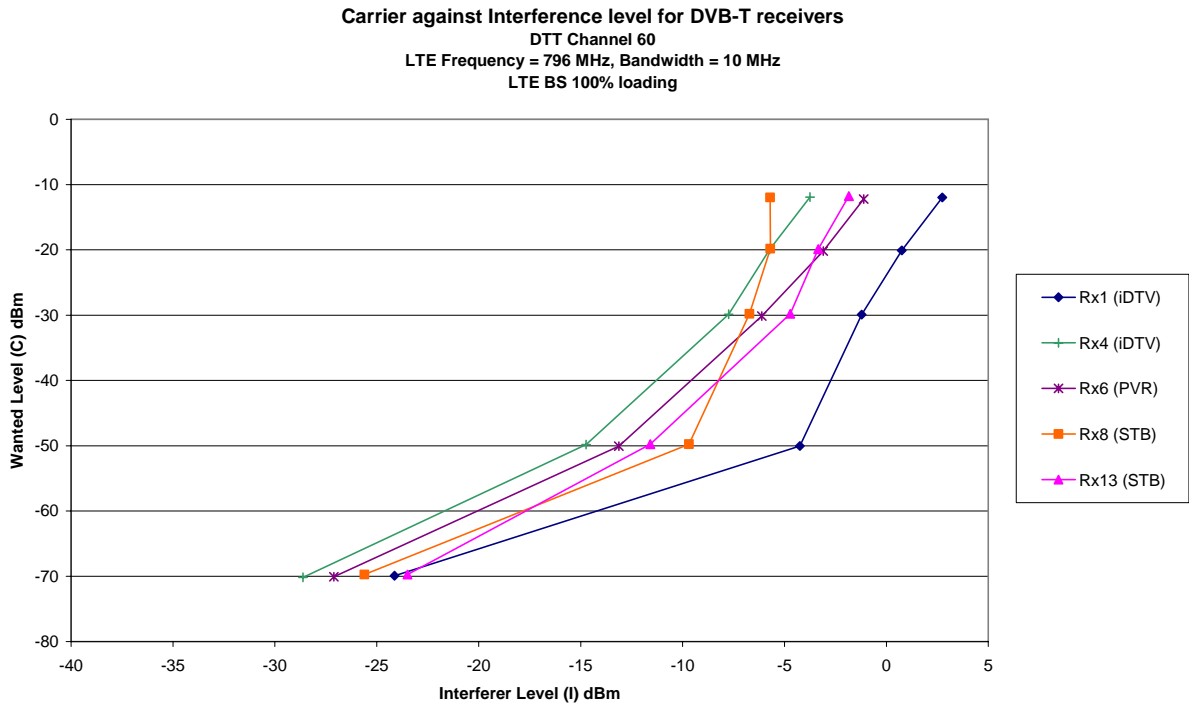


Figure 26: C against I for channel 60, DVB-T transmission, fully loaded BS

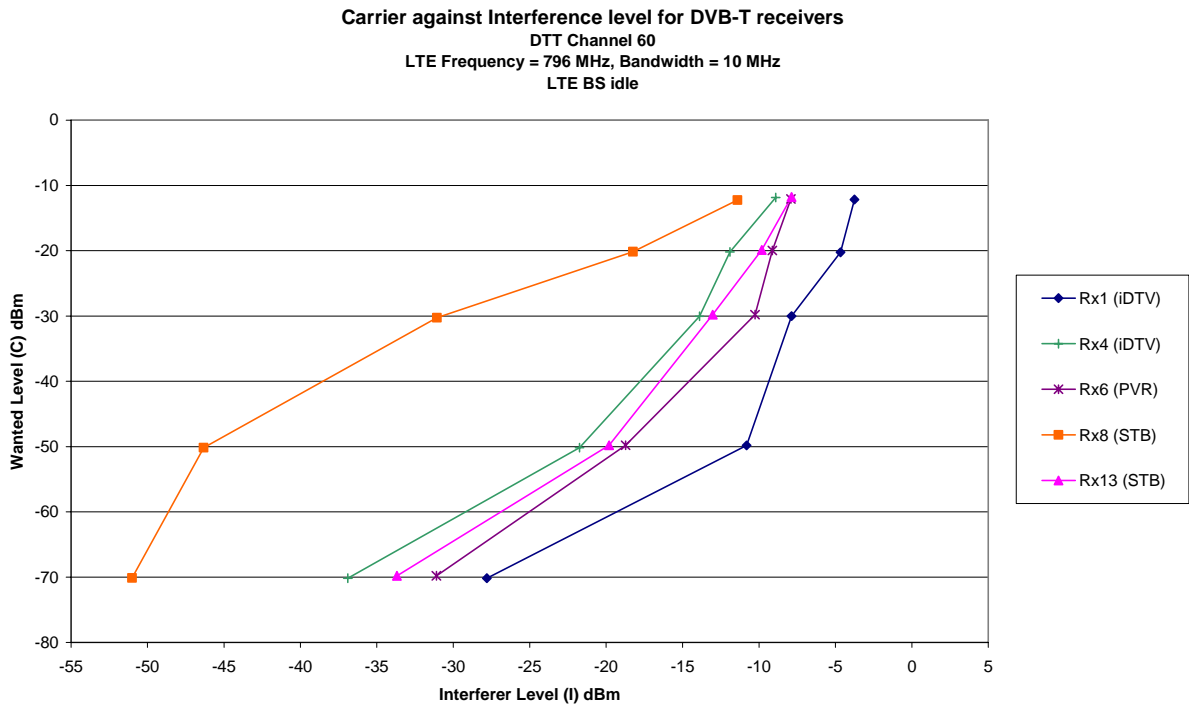


Figure 27: C against I for channel 60, DVB-T transmission, idle BS

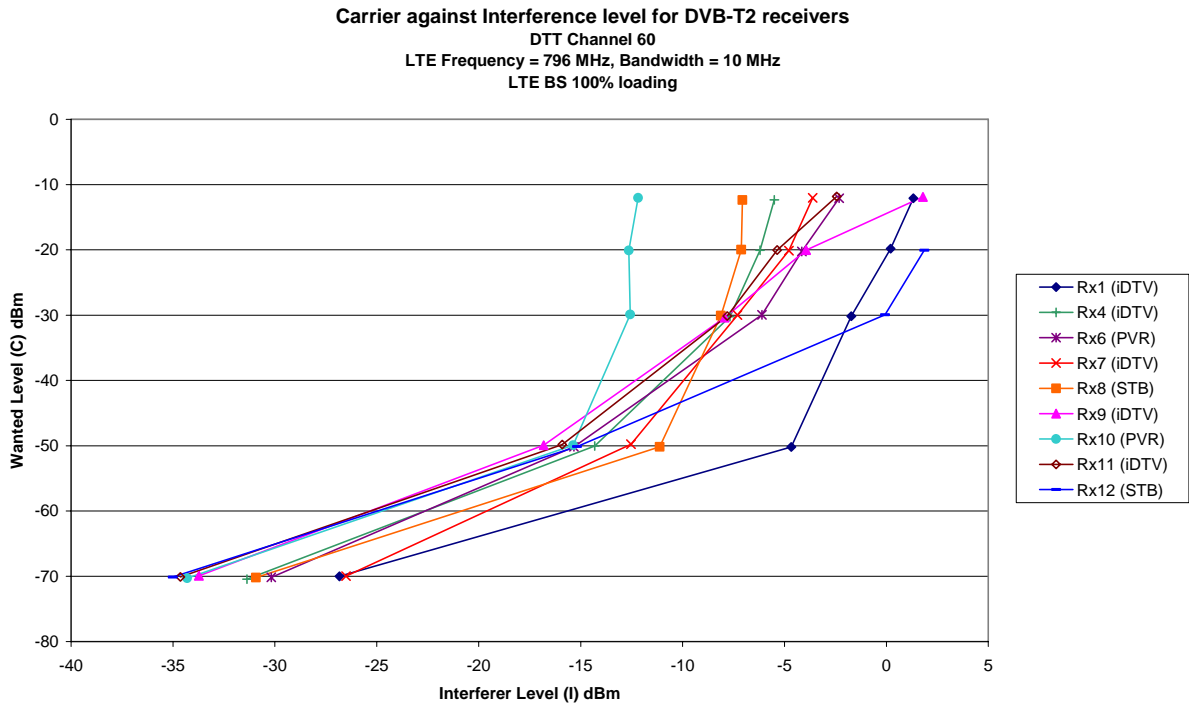


Figure 28: C against I for channel 60, DVB-T2 transmission, fully loaded BS

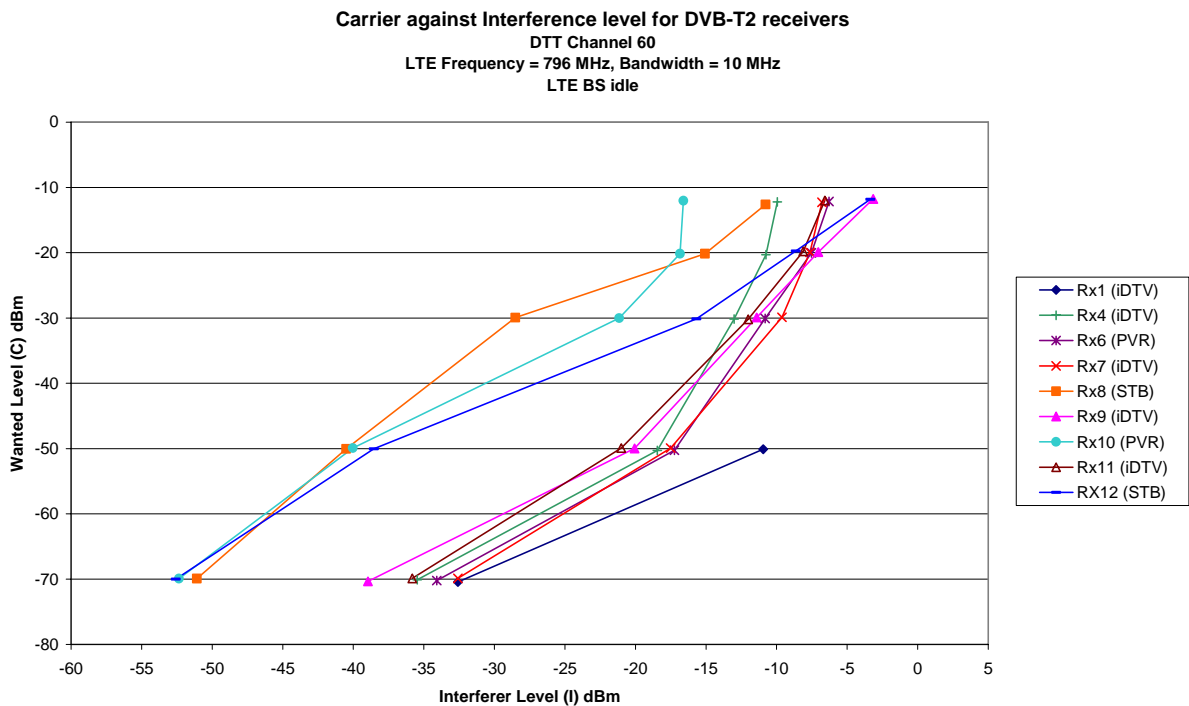


Figure 29: C against I for channel 60, DVB-T2 transmission, idle BS